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# OREGON GEOTHERMAL ENVIRONMENTAL

# OVERVIEW STUDY

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# PREFACE

The following report on environmental issues related to the development of geothermal energy in the State of Oregon is part of the U. S. Department of Energy's Geothermal Overview Project which is administered by the University of California Lawrence Livermore Laboratory. The purpose of the Geothermal Overview Project is to provide the U. S. Department of Energy with information on existing environmental data and major environmental issues, and to make recommendations for resolving these issues. Information in this report is intended for use in planning and decision making. Although this report has been prepared for the Assistant Secretary for Environment, U. S. Department of Energy, it is expected that the contents will also be of use to others in the public and private sectors who are concerned with developing geothermal resources in an environmentally sound manner.

One of the keys to an effective overview study is the early involvement of all interested parties, including representatives of local, state and federal governments, industry, research organizations, consultants, universities, land owners, public interest groups, and local citizens.

We sincerely thank all of the individuals, organizations and agencies that have helped with the many phases of the overview study. Without their cooperation and contributions, this report would not have been possible. We especially thank Paul Phelps, Neil Crow, the Geothermal Overview Project Staff of the Lawrence Livermore Laboratory, Philip Leitner of St. Mary's College of California, Debra Justus of the Oregon Institute of Technology, our advisory committee members and the workshop speakers, discussion leaders and participants.

Finally, we gratefully acknowledge the invaluable contributions of Dorothy Malek, who coordinated the workshop activities and typed the final report.

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# EXECUTIVE SUMMARY

## Background

The purpose of this report is to present an assessment of the key environmental issues which may influence the development of geothermal resources in Oregon. The report is intended to provide the Assistant Secretary for Environment, U.S. Department of Energy, with site-specific and regional data on environmental aspects of geothermal energy development in Oregon. The information and recommendations are intended for planning relevant research and for making policy decisions.

An advisory committee composed of representatives from environmental interest groups, land management agencies, universities, developers, regulatory agencies, etc. was formed to assist in setting the direction of the study. It was recommended by the advisory committee early in the study that efforts should not focus just on Known Geothermal Resource Areas (KGRA's) because of the minimal amount of information known about the state's geothermal resources and the widespread belief that there was as much likelihood of finding and developing geothermal energy outside KGRA's as within them. Thus, the state was divided into seven high geothermal potential regions or provinces which included the Western Cascades, High Cascades, High Lava Plains, Basin and Range, Alvord Valley, Vale and LaGrande. These larger geographic areas were studied and KGRA's within each were used as specific features for examples.

Major issues and concerns relating to geothermal development in these provinces were identified and assessed in six general categories of potential environmental impacts: Geological and Subsidence, Air Quality, Water Quality, Ecosystems, Socioeconomics and Noise. In addition, the existing data base for each of these areas was defined and evaluated and recommendations made where additional data and research are required to ensure environmentally sound development of geothermal energy in Oregon.

A vital part of this study was a free flow of information with early involvement of all interested parties and a workshop where everyone had an opportunity to contribute to the identification and prioritization of issues. Almost 150 people attended the two day workshop which included representatives from local, state and federal governments, industry, research organizations, consultants, universities, land owners, public interest groups and local citizens. Their participation provided support for developing a consensus on the major environmental issues and their ideas and recommendations form an integral part of the report.

Details of the study are discussed in the following sections of the report. The more important general observations and high priority issues and recommendations are emphasized in this summary. A detailed ranking of the high priority issues was not possible because of the need for more precise definition of resources and the strong dependence of priority on site specific local issues. Although it was generally felt that most environmental issues could be resolved, it was also recognized that any one of many issues could be used as a barrier to impede the development of geothermal energy in Oregon. The development moratorium on Newberry Crater is an example of the State's resolve to protect Oregon's environment and natural resources.

## Geothermal Environmental Issues In Oregon

### Geological

Will withdrawal of geothermal fluids increase subsidence activity in the region? This was the only issue within the geological impact category that was identified as potentially a high priority issue and then only for local areas within the Brothers Fault Zone, Basin and Range and Alvord Desert provinces. The most significant geological issues for each region are:

- Western Cascades - - - - - - - - Slope Stability
- High Cascades - - - - - - - - - Accidental Mixing of Water
- Other Provinces - - - - - - - - Subsidence

Given suitable subsurface reservoirs, injection of fluids appears from the experience in the oil industry, as an attractive possibility for disposing of geothermal wastes and mitigating subsidence. It is imperative, however, that site specific information on Oregon's potential sites be collected for modeling of subsidence associated with groundwater extraction. The most significant data gaps required include:

- Baseline leveling surveys to establish background subsidence due to other natural and anthropogenic sources
- Baseline monitoring of seismic activity
- Topographic and geologic maps

Air Quality

Air quality issues were strongly dependent on the resource utilization method, i.e. electrical (flash or binary) or direct. High priority issues included:

- Western Cascades - - - - - - - Visibility reduction and $H_2S$ odor
- High Cascades - - - - - - - - Visibility reduction and $H_2S$ odor
- Alvord Desert - - - - - - - - Fugitive dust and visibility reduction

- Vale - - - - - - - - - - - - - - Fog, Icing of roads and powerlines
- Brothers Fault Zone - - - - - Fugitive dust and visibility reduction

Substantial data gaps exist for:

- Emission characteristics for potential geothermal sources in Oregon. Improved emission characterization is the most immediate need and it is suggested that future analyses such as those done by the U.S. Geological Survey include all constituents historically found in geothermal fluids.
- Meteorological data on elevated winds, thermal stratification, turbulence characteristics and fog frequency. A meteorological data acquisition program should be initiated in those regions having high potential for geothermal resource development.
- Air quality data on TSP, $SO_2$, $CO_2$ and $H_2S$ and other constituents identified by geothermal source analysis is lacking. Air quality monitoring sites should be established in high potential areas.

Water Quality

Water quality issues of high concern included:

- Thermal degredation of surface waters
- Drawdown and degredation of ground water and hot springs
- Chemical degredation of surface water.

All of these issues were of high concern in the High and Western Cascades, and Klamath Falls, while they were considered of less importance in other regions. Substantial data gaps exist in the characteristics and amounts of geothermal water associated with potential resources. Precise environmental impacts cannot be defined without this information, and hydrological and water quality baseline studies of streamflow, springs and groundwater of prospective geothermal fields are recommended.

Ecosystems

Can biological resources, including sensitive plant and animal species and their habitats, be adequately protected in the Alvord Valley? Will geothermal development alter the unique ecological communities which have developed around hot springs and elsewhere in the valley? Major concerns were expressed for the ability to preserve rare and endangered plant and animal species, unusual ecosystems and critical wildlife habitat in the Alvord Valley with the development of geothermal energy. The Alvord Valley was clearly the geographic area of most concern. Several hot springs have been identified as having particular biological and scientific value and two rare fish species occur in Alvord Valley hot springs. A large number of rare and endangered plant species have also been located in the Alvord. The east base of the Steens is an important big game wintering range for deer, antelope and big horn sheep. It was recommended that the highest priority be given to a survey of the Alvord Valley ecosystems to define sensitive species and habitats, and define areas unsuitable for geothermal development. Careful facility siting on the basis of thorough baseline surveys may preclude impacts to sensitive ecosystems.

Socioeconomics

Will geothermal development stimulate additional growth and change the economic base of a region? Will it cause population changes in isolated rural areas? What level of geothermal development is compatible with current land use patterns and what would be the effect on aesthetics?

The following specific high priority statewide socioeconomic issues were identified:

- "Boom-bust" cycle
- Oregon's energy self-sufficiency
- Tax and royalty payments to local governments
- Conflicts with agricultural uses
- Aesthetic and historical land use values
- Community planning capabilities
- Cultural identity
- Public uncertainties

Underlying these issues is the fundamental question of public perceptions of potential "trade-offs" involved where geothermal development occurs in sparsely populated, undeveloped or primarily agricultural areas. Unknown (in the mind of the public) geothermal impacts are weighed against known agricultural and recreational uses of rural lands, especially those unique areas which contribute to the "Oregon image".

The issue of aesthetics or visual pollution was considered in several sections of this report even though it was considered inappropriate. In every case, however, it was considered a substantial issue which could be the basis for opposing geothermal developments in such sensitive areas as the Alvord Valley, High Cascades and Western Cascades.

## Noise

Will noise from construction or operation of geothermal facilities become a nuisance, infringe on existing land use patterns or be detrimental to wildlife? Although this issue was not generally expected to be a primary issue restricting the development of geothermal energy in the state, a significant deficiency in the data base was identified which limits the precision of the impact projection. The deficiency identified was in the timing of information gathering. Noise baseline data should be phased in at an earlier time than presently required, i.e., at full - field development state - which may be after considerable exploratory activity. Early identification of noise receptors was considered essential.

## Conclusions

A general underlying feature impacting most of the environmental issues raised in this study was the lack of basic information on the

- nature and characteristics of the potential resources,
- method of utilization, and
- existing environmental conditions.

This information void substantially reduces the precision and accuracy with which high priority issues can be identified because of their strong site specific nature and dependence on local issues. Lack of information on how geothermal developments are likely to proceed in Oregon and specific regions of the state leads to public misperceptions. Baseline data on the resource and its local environment needs to be improved substantially and collected in advance of development.

Although it is difficult to rank the issues raised because of their site specific nature, several generalizations regarding issue types and regions can be made based on the importance of the reservoir, likelihood of impact, and severity of potential impact. For example, it is clear that the following three issues must be addressed if geothermal energy is to develop rapidly in the areas noted.

- Can geothermal energy be developed in an aesthetically acceptable manner in the state and in particular, in the Alvord Valley, High Cascades and Western Cascades?
- Can water quality and quantity be maintained with the development of geothermal energy?
- Can the ecosystems of the Alvord Valley be preserved with the development of geothermal energy?

Although these issues may not be given the highest priority ranking in any specific development, the Alvord Valley, water quality, aesthetics and ecosystems themes were considered in more than one section and ranked as being of substantial concern.

# INTRODUCTION

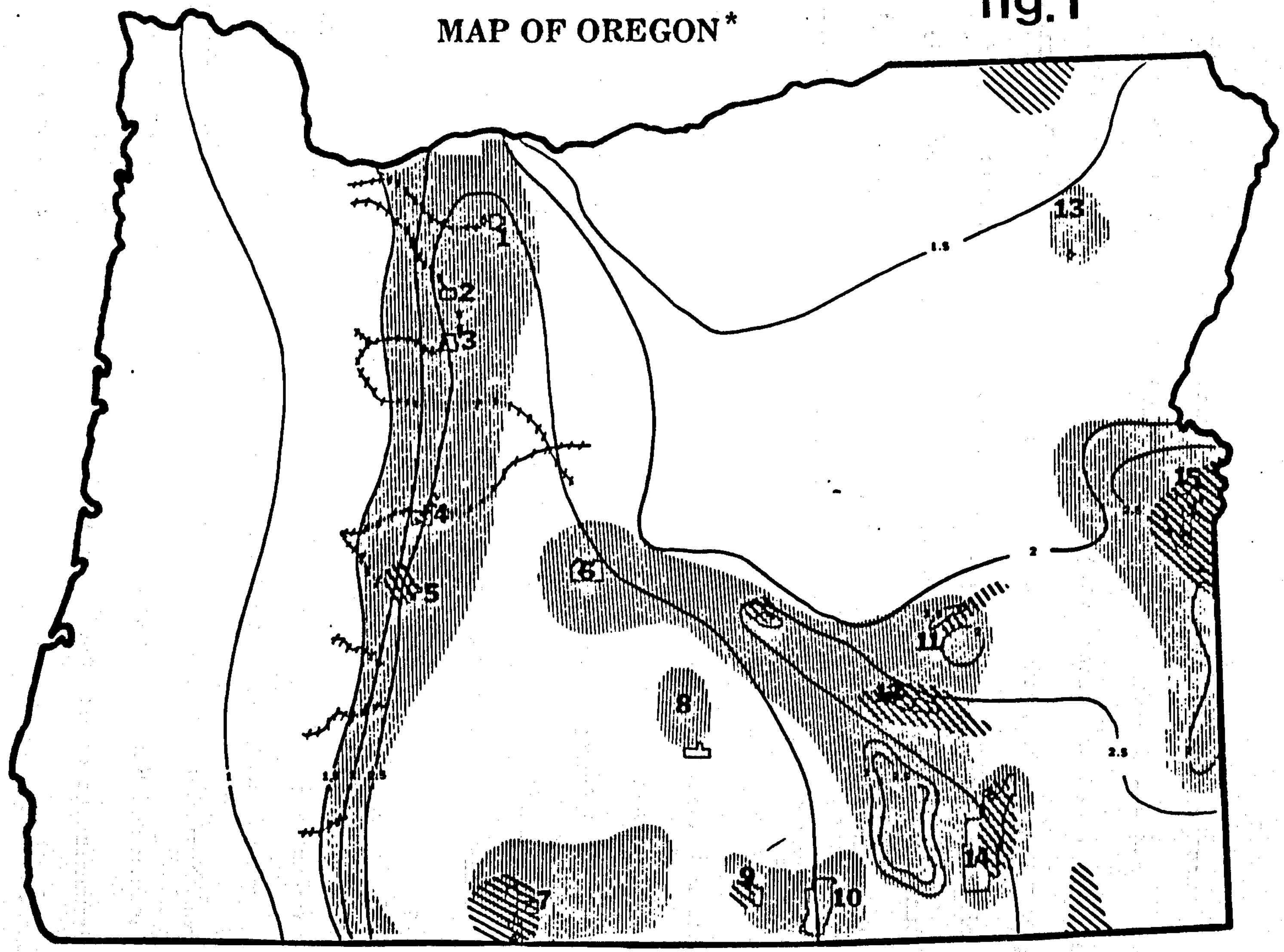
Geothermal resources appear to be widespread in Oregon from the Western Cascades and eastward to the Idaho border (Figure 1, Table 1). Oregon's known and potential geothermal resource areas are some of the most promising in the nation and have the potential of annually displacing seven million barrels of fuel oil. Although there are indications that both high and low temperature geothermal resources exist in Oregon, only a single geothermal reservoir, Klamath Falls, has been extensively tested. Elsewhere, knowledge of the extent of reservoirs is based on indirect information, and scattered shallow wells and hotsprings. Utilization has been minimal and the production has been too erratic or small in scale to define the potential of any given area.

The geographic areas in Oregon generally considered to have geothermal potential and included in this study, are the Western Cascades, High Cascades, High Lava Plains, Basin and Range, Alvord Valley, Vale and La Grande.

The Western Cascades province is a north-south trending, highly dissected belt of tertiary volcanic rocks on the western flank of the Cascades. There are numerous faults and lineaments, including a major fault zone which extends along nearly the entire length of the boundary between the Western and High Cascades. In addition to a promising geologic setting, its proximity to major population centers within the Willamette Valley makes it an attractive geothermal prospect. Regional heat flow values are substantial in the eastern third of the province where there is a belt of hot springs oriented parallel to the regional structure. Unfortunately, relatively

# GEOTHERMAL RESOURCE MAP OF OREGON*

fig.1




Legend

Low Temperature Geothermal Resource Areas

Suggested Areas for Exploration

Heat Flow Contours
HFU = $10^{-6}$ cal cm²/sec or $4.19\times10^{-2}$ W/M²

KGRA

Geothermal Exploratory Well

Fluid Transport Corridor

*From the Geothermal Task Force Report to the Alternate Energy Development Commission for the State of Oregon, 1980.

TABLE 1

Identification of Resources in Figure 1*

| Identified on Map # | Name | Reservoir Temp (°C) | Mean Reservoir Volume ($Mi^3$) | Wellhead Thermal Energy ($x10^{15}$ BTU) | Wellhead Thermal Power ($x10^6$ BTU) | Resource to Load Distance (Mile) | LOC |
|---|---|---|---|---|---|---|---|
| 1 | Mt. Hood KGRA | 125 | 0.79 | 0.24 | 913 | 20-47 | Portland |
| 2 | Carey/ Austin KGRA | 105 | 0.79 | 0.20 | 761 | 17-42 | Oregon City Portland |
| 3 | Breitenbush KGRA | 125 | 0.79 | 0.25 | 951 | 33-53 | Salem/Albany Corvallis |
| 4 | Belknap-Foley KGRA | 113 | 1.58 | 0.41 | 1,560 | 33-42 | Springfield Eugene |
| 5 | McCredie KGRA | 91 | 0.79 | 0.17 | 647 | 25-38 | Springfield Eugene |
| 6 | Newberry Crater KGRA | 230 | 11.28 | 6.9 | 26,300 | 16-25 | Bend/ Electric |
| 7 | Klamath & Klamath Hills KGRA | 130 | 29.9 | 8.18 | 31,100 | 0-10 | Klamath Falls |
| 8 | Summer Lake KGRA | 118 | 1.87 | 0.54 | 2,050 | | |
| 9 | Lakeview KGRA | 150 | 3.67 | 1.39 | 5,290 | 0-5 | Lakeview |
| 10 | Crump KGRA | 167 | 1.73 | 0.74 | 2,820 | | Electric |
| 11 | Northern Harney | 117 | 1.58 | 0.45 | 1,710 | 0-8 | Burns |
| 12 | Southern Harney | 116 | 0.79 | 0.23 | 875 | | |
| 13 | La Grande | 120 | | | | 8-13 | La Grande |
| 14 | Alvord KGRA | 192 | 7.05 | 3.49 | 13,300 | | Electric |
| 15 | Vale KGRA | 157 | 28.07 | 11.2 | 42,600 | 0-10 | Vale/Ontario |
| | | 188 | 0.79 | 0.39 | 1,190 | | Electric |

*From the Geothermal Task Force Report to the Alternate Energy Development Commission for the State of Oregon, 1980.

little is known about the geologic setting of the geothermal resource. Population density is low and there are no major population centers. Land use is centered on forestry and recreation. There are designated wilderness areas, a number of major dams, and power transmission lines near known or potential geothermal resource areas.

The High Cascades, an elongated north-south trending belt of lower Pliocene to Recent extrusives, is dominated by composite volcanic cones dating from the Late Pleistocene. Though currently dormant, the High Cascade volcanoes in Oregon have been active until recently (e.g. pumice on Mt. Hood dated at ca. 200 ± 150 yrs. B.P., increasing fumarolic activity as recently as 1908, etc.). The current activity of Mt. St. Helens attests to the potential for renewed volcanism. Though no large hydrothermal convection systems have been identified in the High Cascades, it is widely believed that Mt. Hood and other volcanic cones have significant geothermal potential. Warm springs and fumaroles are the major geothermal manifestations in the High Cascades. Population is very low with much of the area being uninhabited forest lands and wilderness areas. Recreation and forestry are the dominant land use.

The High Lava Plains, a dry, largely undissected, poorly drained plateau of low relief, is transected by the northwest-striking Brothers Fault Zone. The Brothers Fault Zone, a segment of the Oregon-Nevada lineament, is the northern boundary of the Basin and Range Province in Oregon. This zone of faulting apparently marks the thermal as well as tectonic boundary of the Province. Though little detailed information is available, geothermal resources are likely associated with residual magmatic heat underlying recently formed rhyolitic and rhyodacitic volcanic vent complexes (e.g. Glass Buttes) and mafic vent complexes and basalt flows (e.g. Newberry and Diamond Craters). "Blind" geothermal anomalies, that is, those without obvious surface expressions may be awaiting discovery. Population density is very low with only two towns of significant size, Bend in the west and Burns in the east. A particularly sensitive area is the Malheur Wildlife Refuge, an area of extremely low relief (i.e. 125 sq. mi. with only 15 ft. relief) and many miles of irrigation canals.

The Basin and Range province is a tectonically active area with generally north-trending horsts, tilted fault blocks, and grabens typically forming basins with interior drainage. Though heat flow within the province significantly exceeds the world average, relatively little is known about specific geothermal prospects. An exception is the Klamath Falls KGRA. Due to similar structural and lithologic settings, a geothermal model developed for the Klamath Falls area, may be applicable to other grabens within the province. Klamath Falls has the most widespread use of geothermal energy for direct applications in the United States and includes commercial greenhouses, pool heating, residential and industrial space heating, pavement de-icing, aquaculture, accelerated curing of concrete, milk pasteurization and hog raising. There are only two sizable population-commercial-transportation centers within the Basin and Range province of southern Oregon, Klamath Falls and Lakeview. Both are located near Known Geothermal Resource Areas. Irrigation and watering of livestock are local activities, scattered throughout the Basin and Range.

The Alvord Valley, a graben bound on the west by the Steens Mountain fault, lies in the easternmost Basin and Range region of Oregon. The valley is filled with various unconsolidated or poorly consolidated sediments.

Depth to bedrock is generally unknown with the exception of a single well east of Fields that encountered bedrock at 600 ft. Although very little is known about the subsurface geology of the Alvord Valley, it is considered a resource with electricity-generating potential. A model has been proposed wherein meteoric water from adjacent mountains circulates into an area of high geothermal gradient. The Steens Basalt and Steens Mountains Volcanic Series are likely functional geothermal aquifers. There are only three small settlements in this largely unpopulated area. Land use is devoted mainly to stock grazing, recreation and restricted areas under irrigation. During the turn of the century borax was produced south of Alvord Lake. In wet years Alvord Lake expands northward over a surface of extremely low relief to flood the Alvord Desert playa.

The Vale-Ontario area is on the western flank of a large structual trough, the Snake River downwarp, which extends across Idaho into eastern Oregon. A geothermal model proposed for the nearby Cow Hollow anomaly may apply to others in the area, that is, faulting has vertically moved reservoirs against impermeable strata to form traps for geothermal fluids. Upward leakage along fault planes is manifested by hot springs. Reservoir rocks are probably the Grassy Mountain Basalt (ca. 2,500 ft.) and the Owyhee Basalt (ca. 6600 ft.). The basalts are recharged near the margins of the Snake River Basin. Vale and Ontario, the two main population centers in the area, are closeby known or suspected geothermal areas. The economy is based largely on irrigated agriculture and food processing. Some irrigation canals run near KGRA's.

LaGrande lies within the Grande Ronde Valley, a graben within an area of block faulting. The valley is a unit of the Grande Ronde River Basin.

Land use is devoted almost exclusively to agriculture, lumber and recreation related industries. Although there are positive indicators of geothermal potential, very little about the resource has been published. Any development would likely be concentrated near Hot Lake Spring (180°F). The association of a hot spring boundary fault zone and Columbia River Basalt at depth, suggests a geothermal model in which heat may be transferred to meteoric waters within the basalt and circulated via various channels back to the surface.

These provinces are large areas and have been only generally delineated in terms of the occurrence of geothermal resources. There has been no commercial development of the geothermal resources for electrical use in Oregon and as yet there is little certainty as to where within each area development may occur.

A recent study by Battelle-Northwest identified five geothermal systems in Oregon which could begin producing electricity in the 1980's on an economically competitive basis (at > 50 mwe for 30 years). These systems are the Newberry Caldera (Brothers Fault Zone/High Cascades), Vale Hot Springs (Vale), Mickey Hot Springs (Alvord Valley), Borax Lake (Alvord Valley) and Crump's Hot Springs (Basin and Range Province). Of these, Newberry Caldera appears to be the best candidate for early development in terms of economics. Newberry Crater, however, has been designated as unsuitable for siting of geothermal electric generating facilities by the Oregon Energy Facility Siting Council. According to current regulations, geothermal power plants greater than 25 mw may not be licensed in the Newberry Crater area.

Although sites with high resource potential can be identified, the existence of legal, economic, and in some cases, the types of environmental constraints discussed in this report may limit actual development. In addition, the nature of the geothermal resource in terms of the generating capacity is largely unknown for large areas of Oregon; presently undiscovered resources may be the ones to be developed.

Environmental impacts will differ widely and depend on the type of geothermal resource, location, stage of development and ultimate end use. Table 2 lists the environmental setting and possible types of development prevalent at some of the known geothermal areas in Oregon.

The purpose of this report is to present an assessment of the key environmental issues which may influence the development of geothermal resources in Oregon. The report is intended to provide the Assistant Secretary for Environment, U. S. Department of Energy, with site-specific and regional data on environmental aspects of geothermal energy development in Oregon. The information and recommendations are intended for planning relevant research and for making policy decisions.

An advisory committee composed of representatives from environmental interest groups, land management agencies, universities, developers, regulatory agencies, etc. was formed to assist in setting the direction of the study. Major issues and concerns relating to geothermal development were identified and assessed in six general categories of potential environmental impacts: Geological and Subsidence, Air Quality, Water Quality, Ecosystems, Socioeconomics and Noise. In addition, the existing data base for each of these areas was defined and evaluated and recommendations made where additional data and research is required to ensure environmentally sound development of geothermal energy in Oregon.

A vital part of this study was a free flow of information with

TABLE 2

ENVIRONMENTAL FACTORS IN FOUR MAJOR GEOTHERMAL AREAS*

| | Klamath Falls | Vale | Alvord Desert | Breitenbush |
|---|---|---|---|---|
| Location & Description | In South-Central Oregon, the resource is well developed, heating more than 500 structures. The Klamath Basin is between the Cascades and the high desert in the Basin & Range Province. | East-Central Oregon. Low, bad-lands topography. Direct use of the resource will continue, but power generation is a possibility. The area is associated with the Snake River Plain Basin. | In SW Oregon. Graben associated with northern Nevada drift zone in Basin & Range Province. Resource associated with high angle normal faults. Ecosystem: high, cold desert in rain shadow, fragile. High aesthetic value, sparcely populated. Geothermal power likely. | In the West-Central Cascades, the area consists of steep east-west trending forested ridges. Development is probable for direct use, and speculative for power generation. |
| Air Quality | Air quality good. Fogging and icing possible, but continued direct use should have little impact. | Air quality good. Continued direct use should have little impact. Use by industry may increase construction, degrade air. | Air quality good. Noxious gas content low. Higher levels of particulates due to gusty winds, lack of vegetation. Potential high impact from development. | Air quality excellent. Impact could be moderate from development depending upon type. |
| Water Quality | Groundwater excellent. Surface water variable. Thermal water is generally potable and mildly basic. | Malheur River water quality low due to irrigation. High phosphorous and nitrogen content. Algal blooms present. Geothermal fluid is alkaline. | Irrigation water fair to alkaline, contaminated near hot springs, as fluid is high in boron and lithium and very basic, with TDS of 1400 ppm. Ephemeral streams and playas. | Water quality of North Santiam and Breitenbush Rivers excellent. Geothermal fluid anomalously high in chloride, and slightly alkaline. |
| Plant | Diverse ecology. | Proposed endangered species present: Hackelia congruistii Collamia macrocalyx | Big sagebrush--desert shrub, ecosystems present--desert shrub considered fragile. | Aster gormanii is a threatened species native to the area. |
| Animal | Endangered species: Peregrine Falcon, Brown Pelican. Oregon threatened list: Northern Bald Eagle. Protected: Western Spotted Frog. | Endangered species present: Peregrine Falcon. Threatened: Norhtern Bald Eagle. | Fish of limited distribution: Alvord Chub, Alvord Cutthroat Protected species: leopard lizard, Borax Lake Chub. | Threatened: Northern Bald Eagle. Protected: Wolverine. |
| Geologic Concerns | Low seismic risk, moderate subsidence risk. | Low seismic risk, low subsidence risk. | Definite landslide and rockfall hazard. Flash flooding is also a typical hazard in such an ecosystem. Moderate seismic risk. Moderate subsidence risk. | Low seismic risk, low subsidence risk. Moderate groundwater contamination risk, moderate slope stability risk. |
| Noise Control | Not a major concern to animal populations. | Of concern to human population only. | Some animals are disrupted from nesting patterns, etc., by excess noise. Noise control necessary due to carrying distance. | Small carrying distance, but high wildlife density makes mitigation necessary. |
| Historical/ Archeological Significance | Known archeological site is located in the KGRA. Two historical places, two historical trails. Indian artifacts & dwellings found near the city. | Approximately 14 Km of historic Oregon Trail parallels present day Lytle Blvd. in Vale, and Vale Hot Springs has been used for over 100 years. | 17 cultural sites identified, primarily rock shelters & open sites with artifacts. One significant area nominated to National Register of Historic Places. | 11 archeological sites located and are not to be disturbed (from five percent survey). Other sites may be discovered during development. |
| Aesthetics | Lakes and marshes provide important waterfowl habitat, EAR classifies the area as having intermediate scenic value. | Low to intermediate scenic value. | The desert with the abrupt Steens Mtns. adjacent provide unique contrast and high aesthetic value. Man-made structures are visible for great distances on the flat desert floor. | High aesthetic value. Near several wilderness areas, roadless areas, and scenic areas. |
| Other Concerns | Long history of geothermal use, reinjection being considered. | High concentration of food processors in the area makes geothermal energy attractive for that purpose. | Environmentally sensitive area. | Watershed area, environmentally sensitive. |

*From the Geothermal Task Force Report to the Alternate Energy Development Commission for the State of Oregon, 1980.

early involvement of all interested parties and a workshop where everyone had an opportunity to contribute to the identification and prioritization of issues. Almost 150 people attended the two day workshop which included representatives from local, state and federal governments, industry, research organizations, consultants, universities, land owners, public interest groups and local citizens. Their participation provided support for developing a consensus on the major environmental issues and their ideas and recommendations form an integral part of the report. Details of the study are discussed in the following sections of the report.

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SECTION A

of the

OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW STUDY[*,†]

# GEOLOGICAL AND SUBSIDENCE ISSUES RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

by

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# GEOLOGICAL AND SUBSIDENCE ISSUES RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

## SUMMARY

The objective of the geologic analysis was, on a region by region basis, to identify potential geologic hazards relating to geothermal resource development. Based on existing geological/geophysical data the hazards identified were evaluated in terms of their potential environmental impact. Significant data gaps and areas of needed research were determined.

Of the potential geologic hazards considered particular attention was given to seismicity and subsidence. Geologic risk for each region was estimated according to the following criteria:

Seismic risk

LOW: Historical record indicates relatively low intensity and frequency of earthquakes. Little or no known evidence of Holocene active faulting.

MODERATE: Historical record indicates fairly intense and frequent earthquakes and/or considerable evidence of known or strongly suspected active faulting during the Holocene.

HIGH: Historical record indicates frequent, high intensity earthquakes associated with numerous known active faults.

Subsidence risk

Estimates were made using Table 5-1 of DOE report [SAN/1269-1], "Evaluation of Geothermal energy exploration and resource assessment -- final report," Vol. 1: A review of geothermal subsidence modeling (1977). For example:

LOW: Geothermal production zone is within competent basement rock; primarily from fracture porosity; greater than 1.5 km. deep. Overburden contains an aggregate of > 500 m. of competent rock (basalt, andesite, welded tuff, etc.); deep water table (> 400 m. below surface); small fraction (∿ 10% by volume) of mudstone, claystone, or weak shales; apparent lateral compression > overburden.

HIGH: Geothermal production zone is above competent basement rock; from sediments $<1.0 \times 10^6$ yrs. B.P. (Pliocene-Holocene); primarily from matrix porosity; less 1.5 km. deep.

Overburden is entirely clastic sediments (alluvium, sands, silts, clays); shallow water table (< 200 m. below surface); a large fraction (> 25% by volume) of mudstone, claystone or weak shales; apparent lateral compression < overburden.

The results of seismic/subsidence-risk evaluations, based on existing geologic information and environmental considerations, are summarized in Figure 1.

For each region the most significant geologic consideration is believed to be:

1. Western Cascades . . . . . . . . . . . . . Slope stability.
2. High Cascades . . . . . . Accidental mixing of geothermal waters and shallow groundwater.
3. Brothers Fault Zone . . . Effect of geothermal production on flow/quality of mixed (geothermal and groundwater) waters at shallow depth in Harney Basin.
4. Basin and Range . . . . . . . . . Subsidence associated with shallow production.
5. Alvord Desert . . . . . . . . . . "
6. Western Snake River Basin . . . "
7. LaGrande . . . . . . . . . . . . . "

Data/information gaps believed to be significant are:

1. Topographic maps. Extensive areas within the Brothers Fault Zone, Basin and Range and Alvord Desert require more detailed topographic coverage than currently exists. Specifically, U.S. Geological Survey quadrangles, 7½ min. or at least 15 min., are essential as a base for detailed geologic mapping and geophysical surveys.
2. Geologic maps. Geologic mapping in more detail than the reconnaissance-geology maps now available is needed in order to evaluate geologic risks as well as to further define the geologic setting of known or suspected geothermal resource areas.
3. Baseline leveling surveys. Apparently such data does not exist for any of the areas under consideration. In order to differentiate any subsidence re. geothermal exploitation from other causes (natural or man-induced) leveling data should be collected regularly and for a significant interval (preferably several years) prior to production.
4. Seismic monitoring. Baseline data should be obtained during the pre-impact phase of geothermal development. Seismic and microseismic monitoring of potential sites is recommended.

5. <u>Environmental geology studies</u>. An important element of sound land-use planning is geologic mapping for the delineation of geologic hazards (e.g. landslides, liquefaction and differential settling, etc.). For example, a slope stability map should be compiled as part of a broader environmental geology investigation of the Western Cascades.

Based on considerable experience, particularly in the oil industry, there is no evidence of significant seismic activity due to fluids injected at low pressure. This experience includes low-pressure injection of very large quantities in complexly faulted and seismically active terrains. The oft-cited experiments at Rangely and Rocky Flats, Colorado were conducted at high pressures, well above those contemplated for low-pressure injection of spent geothermal fluids. In fact, fluid injection that keeps pressures well below the local fracture pressure of rocks will likely avoid serious induced seismicity. Therefore, given suitable subsurface reservoirs, injection appears attractive for disposing of geothermal wastes and mitigating subsidence.

Considerable data and experience with modelling of subsidence associated with groundwater and petroleum extraction provide a foundation for subsidence assessment in geothermal areas. However, Oregon is a region of highly varied volcanic and sedimentary rocks with a wide range of engineering properties. Moreover, there is insufficient knowledge of the detailed structural geology, layering geophysics and material behavior in the known or potential geothermal resource areas. It is imperative in evaluating subsidence potential that this information be collected.

Figure 1. Subsidence and Seismicity-risk Evaluation

| REGION | SUBSIDENCE | | SEISMICITY | |
|---|---|---|---|---|
| | GEOLOGY | IMPACT | GEOLOGY | IMPACT |
| WESTERN CASCADES | LOW | LOW | LOW | LOW |
| HIGH CASCADES | LOW to MODERATE | LOW | LOW | LOW |
| BROTHERS FAULT ZONE | LOW to HIGH (local) | LOW to MODERATE (local) | LOW | LOW to MODERATE (local) |
| BASIN & RANGE | LOW to HIGH (local) | LOW to MODERATE (local) | MODERATE | LOW to MODERATE (local) |
| ALVORD DESERT | LOW to HIGH (local) | LOW | MODERATE | LOW |
| WESTERN SNAKE RIVER PLAIN | LOW to MODERATE | LOW to MODERATE | LOW | LOW to MODERATE (local) |
| LAGRANDE | LOW to MODERATE | LOW | LOW | LOW |

Notes:

For the Basin and Range, Brothers Fault Zone, Western Snake River Plain, Alvord Desert and LaGrande, subsidence is generally considered to be low for deep drilling (> 2,000 ft.) with production from competent rock (e.g. basalt); moderate, perhaps high locally, where shallow production may be from incompetent reservoir rocks (e.g. breccias, gravel, etc.) with an overburden mainly of unconsolidated to semiconsolidated sediments.

"Low to moderate (locally)" means that in general environmental impact would be low throughout the region, but locally significant (e.g. near population centers, irrigation canals, etc.)

No shallow production is currently foreseen for the Alvord Desert.

# GEOLOGIC SETTING AND RISK EVALUATION

Western Cascades:

The Western Cascades province is a north-south trending, highly dissected belt of Tertiary volcanic and volcanoclastic rocks on the western flank of the Cascades. In general, thick assemblages of competent volcanics predominate (Table I). There are numerous faults and lineaments, including a major fault or fault zone which extends along nearly the entire length of the boundary between the Western and High Cascades. There are few, if any known structural indicators of high compression (i.e. overthrusts, reverse faults, recumbent folds, etc.).

Population density is low and there are no major population centers. Land use is concentrated on forestry and recreation. However, there are designated wilderness areas, a number of major dams, and power transmission lines near known or potential geothermal resource areas.

Since 1841, the beginning of recorded seismic activity in Oregon, the Western Cascades has been a region of low intensity and frequency compared to events reported elsewhere in Oregon. The historical record, though brief, is corroborated by the fact that there are few, if any, known faults that may be active at the present time. Moreover, there are ample reservoirs for low pressure injection of spent geothermal waters. Given the above considerations seismic risk is judged to be low.

In addition to a promising geologic setting, its proximity to major population centers within the Willamette Valley makes the Western Cascades an attractive geothermal prospect. Regional heat flow values vary regularly from 1.0 HFU in the west to 3.0 HFU in the eastern third of the province where there is a belt of hot springs oriented parallel to the regional structure. In fact, these figures may be conservative indicators of geothermal potential because of the masking effect of unusually high precipitation and an abundance of cold shallow water. Unfortunately, relatively little is known about the geologic setting of the geothermal resource. For example, the source of heat in the eastern third of the province may be due to localized heat source(s), deep circulation of geothermal fluids from the High Cascades, or lateral effects of crustal heating associated with volcanism in the High Cascades.

Though subsidence potential is site specific, it is judged to be generally low for the Western Cascades. The expected production zone(s) are likely to be in or above competent basement rock and/or within competent volcanic rocks, primarily from fracture porosity in a region of relatively high recharge. Overburden would likely contain more than 500 meters of competent volcanics (basalt, andesite, etc.) and about 10% by volume, or greater than 10%, but less than 25% by volume, of relatively incompetent rock. The water table is shallow. Geostatic pressure apparently exceeds horizontal tectonic stress which is essentially tensional.

A major consideration in the Western Cascades is slope stability. Mass earth movements (i.e. landslides, block slumping, earth flows, etc.) are potential hazards in areas overlain by glacial till or underlain by weathered or hydrothermally altered volcanoclastic sediments. In particular, weathered tuffs and breccias, mainly in the Little Butte Volcanic Series and Sardine Formation, form highly unstable soils containing concentrations of expandable clays. The hazard is especially acute where these conditions obtain in conjunction with steep slopes. Geologic engineering studies in the Western Cascades are recommended to delineate bedrock hazard areas.

High Cascades:

The High Cascades, an elongate north-south trending belt of lower Pliocene to Recent extrusives, is dominated by composite volcanic cones dating from the Late Pleistocene. These volcanos, typified by alternating layers of competent andesitic flows and incompetent units of ash, pumice, tuff and cinder, are built on a platform of mafic volcanics. The mafic extrusives apparently filled a gradually subsiding graben-like depression defined by flanking faults. Locally, thick glacial deposits are the product of a period of extensive Alpine glaciation during the Pleistocene. Though currently dormant, High Cascade volcanoes in Oregon have been active until recently (e.g. pumice on Mt. Hood dated at ca. 220 ± 150 yrs. B.P. increasing fumarolic activity as recently as 1908, etc.). The current activity of Mt. St. Helens attests to the potential for renewed volcanism.

Population is very low; much of the area being uninhabited forest lands and wilderness areas. Recreation and forestry are the dominant land use.

Though the peaks are seismically active, intensity levels are low. In fact, the entire Cascades is historically an area of low intensity seismic activity. No major faults known to be active have been reported in the literature. Earthquake risk is considered low.

Though no large hydrothermal convection systems have been identified in the High Cascades, it is widely believed that Mt. Hood and other volcanic cones have significant geothermal potential. Associated near surface magmas are likely to provide sufficient residual heat to drive geothermal systems. However, there is no consensus regarding several models that have been suggested. Warm springs and fumaroles are the major geothermal manifestations in the High Cascades.

Environmental risk due to subsidence may vary from low to moderate. Expected production zones would probably be above competent basement rock; from fractures in competent volcanic flows or matrix porosity within weak volcanic units (i.e. cinder beds, breccias, ash, etc.). Overburden would have at least an aggregate of from about 100 m. to more than 500 m. of competent rock and greater than 10%, but less than 25% by volume of ash and/or other clayey weathering products. The water table is shallow, recharge high, and geostatic stress greater than lateral compression. In general, development on the flanks of the volcanoes would entail greater risks from subsidence than drilling sites at lower elevations within the High Cascades.

A major geologic consideration is the potential for accidental mixing of geothermal fluids and shallow groundwater. This consideration is related to a characteristic alternation of competent units (e.g. lava flows) and incompetent units (e.g. ash, debris flows), particularly at high elevations within the High Cascades. The incompetent units tend to be highly permeable and may be direct conduits to springs and/or laterally to the shallow groundwater system. Drilling under these conditions is difficult at best and the potential for accidental mixing, therefore, a significant hazard. Groundwater is used locally for drinking (e.g. well water at Timberline Lodge.)

Other considerations concerning development at high elevations are the potential for landslides, avalanches and mudflows due to rapid spring and summer melting of snow. Thawing and water saturation of underlying soils and intensely fractured rock occur. There are stable zones of unaltered lava flows and unstable zones of weathered and otherwise altered sedimentary rocks composed of volcanoclastics, which, due to the high precipitation and generally extreme relief, pose problems of slope stability. The load-bearing capacity of locally thick beds of loose ash, pumice and cinders, is low.

High Lava Plains:

The High Lava Plains, a dry, largely undissected, poorly drained plateau of low relief, is transected by the northwest-striking Brothers Fault Zone. Miocene to Holocene volcanics and continental sediments predominate (Table II). Sedimentary deposits are mainly poorly indurated tuffaceous sandstones, siltstones and claystones of lacustrine and fluviatile origin. With these are interbedded basalts and andesite flows, including widespread sheets of massive welded tuffs. Thick assemblages of volcanics - basic or silicic flows - occur throughout the province. Silicic volcanic domes, which decrease in age from east to west are widely and irregularly spaced along the Brothers Fault Zone. Pleistocene and Holocene deposits are dominantly unconsolidated sediments and basalts, the former consisting of alluvium, aeolian, lacustrine and playa deposits, terrace gravels, landslide debris, etc., which are almost exclusively restricted to depressions (e.g. Harney Basin) and stream valleys (e.g. Donner and Blitzen River). Quaternary basalts are widespread; some of them are very recent (e.g. Diamond Craters, Lava Mountain.

Population density is very low with only two towns of significant size, Bend in the west and Burns in the east. A particularly sensitive area is the Malheur Wildlife Refuge, an area of extremely low relief (i.e. 125 $mi.^2$ with only 15 ft. relief) and many miles of irrigation canals.

The Brothers Fault Zone, a segment of the Oregon-Nevada lineament, is the northern boundary of the Basin and Range Province in Oregon. This zone of faulting apparently marks the thermal as well as tectonic boundary of the province. Though the historical record is poor, the area is apparently one of low seismic activity (i.e. a single intensity III earthquake that occurred near Bend in 1943). Only one possibly active fault is known. Given the geologic evidence and the low population density, the Brothers Fault Zone is believed to be an area of low seismic risk.

The geologic setting (i.e. recent volcanism, scattered hot springs and wells, etc.) and extensive heat-flow studies indicate a positive correlation between the Brothers Fault Zone and potential geothermal resources.

Though little detailed information is available, geothermal resources are likely associated with residual magmatic heat underlying recently formed rhyolitic and rhyodacitic volcanic vent complexes (e.g. Glass Buttes) and mafic vent complexes and basalt flows (e.g. Newberry Crater, Diamond Craters). "Blind" anomalies, that is, those without obvious surface expression may be awaiting discovery.

Environmental risk due to subsidence is generally low. No major problems are anticipated from deep production (>2,000 ft.) from potential deep-seated geothermal aquifers of thick, competent volcanic assemblages (e.g. Steens Basalt). These are typically overlain by impermeable "caprock" of tuffaceous sediments and tuffs. However, production of shallow, intermediate temperature geothermal waters from aquifers within semiconsolidated and unconsolidated sediments in depressions such as the Harney Basin may have a moderate, perhaps locally high probability of induced subsidence.

A primary concern is the effect of geothermal production on flow and quality of mixed waters (geothermal and groundwater) at shallow depth in the Harney Basin. As a rule, over much of the central plain there are few permeable conduits that connect deep and shallow water-bearing units. However, locally a certain fraction of ascending geothermal fluids escapes from fault-plane conduits and percolates laterally into wall rocks at relatively shallow depths. For example, geothermal water migrates northward through permeable facies of bedrock and valley fill in Warm Spring Valley where it ultimately mingles with cold groundwater or slightly thermal water from the north and west. Slightly thermal waters, apparently due to such admixing, are tapped by municipal and irrigation wells near Burns. Slightly thermal waters and, indeed, hot springs, are used for irrigation elsewhere in the Basin (e.g. Warm Spring Valley). A particularly sensitive resource is Sodhouse Spring which supplies slightly thermal water to Malheur Lake, in fact, 8-12% of the total inflow to the lake. On the other hand, the possibility should not be ignored that geothermal production may improve the potability of mixed, slightly thermal waters by removing the more highly mineralized geothermal fluids.

Basin and Range:

The Basin and Range province is a tectonically active area with generally north-trending horsts, tilted fault blocks, and grabens typically forming basins with interior drainage. In gross aspect, the Basin and Range province in Oregon consists of thick assemblages of Cenozoic volcanics and sedimentary deposits of volcanic provenance (Table III). Complex facies relationships, scattered intrusives and eruptive volcanic centers are characteristic. Extrusives ranging from mafic to silicic occur as flows, tuffs, breccias, pyroclastics, maars and tuff rings. Sediments are mainly incompetent lacustrine or fluviatile deposits, typically tuffaceous and interfingered with flows. Diatomaceous sediments, welded tuffs, and palagonitic tuffs are widespread in some units (e.g. "Yonna" Fm., Fort Rock Fm.). During much of the Pleistocene and Holocene unconsolidated fluvial, pluvial, and alluvial sediments were deposited in topographic lows. In general, thicknesses are unknown, but at least 1,300 ft. have been reported near Summer Lake and 1,000 ft. near Lakeview.

There are only two sizeable population-commercial-transportation centers within the Basin and Range province of southern Oregon, Klamath Falls and Lakeview. Both are located near Known Geothermal Resource Areas. Irrigation and watering of livestock are local activities, scattered throughout the Basin and Range.

Although the historical record is poor, recurrence of an average magnitude 5.2 (intensity V-VI) earthquake per 20 years has been calculated for the Basin and Range of Oregon. In fact, recent seismic activity seems to be concentrated south of the Eugene-Denio fault zone, one of two major northwest-striking lineaments recognized in southern Oregon. An example is the Warner Valley earthquake swarm of 1968 with maximum magnitude 5.1. It has been suggested that a greater regional strain rate obtains south of the Eugene-Denio line than to the north. It should also be noted that southern Oregon is adjacent to areas outside the state that have experienced more frequent and intense earthquakes. A history of considerable tectonic activity is corroborated by many faults of Pleistocene and Holocene age. Given the above, the Basin and Range province of southern Oregon is judged to be an area of moderate seismic risk.

Though heat flow within the Basin and Range significantly exceeds the world average, relatively little is known about specific geothermal prospects. An exception is the Klamath Falls KGRA. Due to similar structural and lithologic settings a geothermal model developed for the Klamath Falls area may be applicable to other grabens within the province. The model for the Klamath Falls area includes deep circulation of meteoric waters, perhaps to a depth of 15,000 ft. with convective transportation of heat in a cyclical system. Widespread volcanic sequences are potentially major geothermal aquifers (e.g. Steens Basalt). Essentially impermeable, volcanically derived sediments that occupy the valley bottoms are in effect a caprock that acts as a thermal insulator as well as a hydraulic seal. Geothermal waters rise along major fault-plane conduits and spread laterally via permeable distribution channels (e.g. fractured basalt flows) within alluvial and lacustrine sediments and associated pyroclastics.

Though simple in concept, actual operating systems are extremely complex in detail. Geophysical surveys in the Klamath Falls area outline a subsurface model that is unexpected beneath the featureless floor of the graben valley. A quilt-like pattern of tilted blocks arranged at various depths and bounded by intersecting faults is further complicated by buried basalt flows in the valley fill. The high degree of compartmentalization has obviously important ramifications for the distribution of geothermal fluids, their chemistry, and recharge of the thermal reservoir.

Given the above model, subsidence risk is directly related to depth of production. That is, relatively deep wells producing from such units as the "lower lava rocks" or pre-"lower lava rocks" of the Klamath Falls area are unlikely to induce subsidence because production would be from or above competent basement rock, within competent volcanic rock sequences, and primarily from fracture porosity. Though the overburden would be predominantly clastic sediments, it is assumed that an aggregate of at least 100 m. of competent rock would be present. Furthermore, it is generally true that the water table would be shallow, overburden content more than 10% but less than 25% by volume of mudstone, claystone or weak shales, and lateral compression would be significantly less than the weight of overlying rocks.

In contrast, subsidence potential is at least moderate where production would be from shallow permeable units within unconsolidated to semi-consolidated sediments. In some areas, for example, the Lakeview area where shallow gravels and deltaic deposits may contain geothermal reservoirs of economic value, subsidence could be locally large. The production zone would consist of Pliocene or younger unconsolidated sediments yielding geothermal water from matrix porosity. The sediments overlying the reservoir may contain relatively little competent rock. However, geothermal prospects in the Basin and Range province of Oregon tend to be elongate along faults bordering grabens where valley fill is relatively thin, thereby reducing subsidence potential.

It is possible that intensive exploitation of geothermal waters on a large scale could draw down shallow producing hot wells (e.g. for heating, watering livestock, etc.) in the Klamath Falls area. In fact, over the last 50 years formerly flowing hot springs below the hot-well area of Klamath Falls have disappeared. Hydraulic heads of existing hot wells have also declined in past years. It has been suggested that heavy use of water from shallow hot wells is the cause. The problem is particularly evident in the Klamath Falls area because of its long history of geothermal exploitation. Environmental impact of additional production could, therefore, be serious.

Alvord Valley:

The Alvord Valley, a graben bounded on the west by the Steens Mountain fault, lies in the eastermost Basin and Range region of Oregon. The Pueblo Mountains and Steens Mountain are immediately adjacent to the west. Steens Mountain, a massive fault block tilted to the west, forms a bold escarpment overlooking the valley. The basement complex of Paleozoic metamorphics and Late Jurassic plutonic rocks, is overlain by thick assemblages of flows and volcanic-derived sediments ranging in age from Oligocene (?) to the present (Table IV). The stratigraphic section, well exposed along the face of Steens Mountain, is noted for the great thickness (7,500+ ft.) of basaltic and andesitic flows and flow breccias which comprise the Steens Basalt and Steens Mountain Volcanic Series of Miocene age. Above are generally fine-grained, tuffaceous, sedimentary rocks interbedded with flows and tuffs of Miocene and Pliocene age. Prominent basalt flows date from the Late Miocene and Early Pliocene. The valley is filled with various unconsolidated or poorly consolidated sediments (i.e. lacustrine, fluviatile, aeolian, landslide debris, playa deposits, etc.) ranging in age from Pliocene to Holocene. With the exception of a single well that encountered bedrock at 600 ft. east of Fields, depth to bedrock is generally unknown.

Dominant structural features are the major north-trending boundary faults and subsidiary faults on either side of the valley (total vertical displacement: 5,000 ft. min.; 10,000 ft. max.) Transverse faults striking to the northwest, the alignment of hot springs and orientation of mafic dikes and dike swarms suggest that the Brothers Fault Zone extends beneath the valley as part of the Oregon-Nevada lineament. Given the pattern of faulting and unconformities exposed adjacent to the valley, the structure beneath the valley floor is presumed to be complex.

There are only three small settlements in this largely unpopulated area. Land use is devoted mainly to stock grazing, recreation and restricted areas under irrigation. During the turn of the century borax was produced south of Alvord Lake. In wet years Alvord Lake expands northward over a surface of extremely low relief to flood the Alvord Desert playa.

Though the historical record is very poor, Alvord Valley is not known to be near areas of high magnitude and/or frequent earthquakes. However, earthquakes felt locally in 1928 were associated with exceptional activity in hot springs. There is also considerable indirect evidence of recent tectonic activity. For example, fresh displacements were reported in 1884 and there are raised graded valley floors with entrenched streams, scarplets on newly formed alluvial fans, faceted alluvial fans and youthful gullies entrenched in pediments. Therefore, earthquake risk is rated moderate, although overall environmental impact must be rated low.

Though very little is known about the subsurface geology of the Alvord Valley, it is considered a resource with electricity-generating potential. A model has been proposed wherein meteoric water from adjacent mountains circulates into an area of high geothermal gradient. The Steens Basalt and Steens Mountains Volcanic Series are likely functional geothermal aquifers. Both are largely brittle, extensively jointed and faulted flows. They also contain scoriaceous and fragmental zones, some interbeds of basaltic sandstone and siltstone, and at least one major unconformity. Overlying tuffaceous sediments are largely aquicludes and aquitards with good thermal insulating qualities.

The likelihood of significant subsidence associated with deep production is probably low. Geothermal fluids would be extracted primarily from fracture perosity within thick assemblages of competent volcanics or basement rock. Overburden would likely contain 100 m. or more of competent rock (e.g. basalts, welded tuffs) and sediments would contain a small to moderate amount (<25% by volume) of mudstone, claystone, weak shales and the like. Shallow production from permeable units within unconsolidated Pliocene to Holocene sediments would certainly entail greater risk, perhaps locally high. However, shallow production is currently not contemplated for the Alvord Valley. In any case, the environmental impact of subsidence would be low. An exception may be in the central valley where the gradient is very low and drainage patterns could be locally altered by subsidence.

Concern has been expressed regarding the effect of production on hot springs, which support a rather unique fauna and flora. Though this matter may deserve further attention, disruption due to deep production is unlikely.

Along the lower reaches of the eastern scarp of Steens Mountain, landslides are a potential geologic hazard. Areas of particular concern are identified by a hummocky topography caused by reverse rotation landslides. Sliding is associated with incompetent tuffaceous beds.

Vale:

The Vale-Ontario area is on the western flank of a large structural trough, the Snake River downwarp, which extends across Idaho into eastern Oregon. Recent studies along the western margin have revealed a complex zone of nearly vertical northwest-striking faults downthrown to the northeast. The extrusion of lavas and deposition of fluvial-lacustrine sediments contemporaneously with downwarping and faulting, resulted in thick accumulations of Tertiary rock (Table V). Where exposed, the Sucker Creek Formation of upper Miocene age consists of unindurated, clayey lake bed deposit with high volcanic tuff content. Silicic rocks within the formation may be potential geothermal reservoirs. Superjacent is the Owyhee Basalt, a thick unit of great lateral extent, believed to be the best potential geothermal reservoir. The Deer Butte Formation which overlies the Owyhee Basalt is a competent unit of fine grained, tuffaceous beds grading upward into well cemented arkoses and conglomerates.

The Pliocene is represented by the Idaho Group which in the Vale area consists of the Kern Basin Formation, Grassy Mountain Basalt and Chalk Butte Formation. The Kern Basin Formation consists of minor basalt flows and sills associated with loosely consolidated beds of fluvio-lacustrine origin that weather into "hoodoo" forms in outcrop. The Grassy Mountain Basalt is a possible geothermal reservoir. It is overlain by the Chalk Butte Formation, a very poorly consolidated fluvial-lacustrine unit of low porosity and permeability with interbeds of thin basalt flows. The Chalk Butte Formation crops out throughout much of the area where it has a "healing" effect on faults. Silt content apparently exceeds clay content in near surface sediments in that there is no evidence of slope instability.

Holocene alluvial deposits are confined mainly to the flood plains of the Malheur and Snake rivers. Adjacent to these are eroded remnants of Pleistocene terrace gravels up to 30 feet thick.

Vale and Ontario, the two main population centers in the area, are close by known or suspected geothermal areas. The economy is based largely on irrigated agriculture and food processing. Some irrigation canals run near KGRA's.

There is no record of major earthquakes in the Vale-Ontario area. Until recently no faults or fault-related structures were even known. However, a zone of right-lateral tear-faulting, the Vale zone, is now recognized.

In fact, numerous steeply dipping faults with displacements of only a few hundred feet or so may in aggregate total several thousand feet of displacement. In addition, concealed faults apparently exist beneath the Idaho Group sediments and volcanics. None of the faults in the Vale-Ontario area are known to be active. Given the above history of relative quiescence and currently inactive faults, the Western Snake River Plain in Oregon is believed to have low earthquake potential.

There is a close association between the location of the Cow Hollow geothermal anomaly and pattern of faulting near Vale. Two parallel faults about 6 miles apart, the Willow Creek fault and Bully Creek fault, delineate a northwest-trending graben just south and west of Vale. The Cow Hollow anomaly lies along the Willow Creek fault. Perpendicular to the graben is a third fault, the Malheur River fault. The Willow Creek fault and Malheur River fault intersect in Vale at the site of Vale Hot Springs.

A geothermal model proposed for the Cow Hollow anomaly may apply to others in the area, that is, faulting has vertically moved reservoirs against impermeable strata to form traps for geothermal fluids. Upward leakage along fault planes is manifested by hot springs. Reservoir rocks are probably the Grassy Mountain Basalt (ca. 2,500 ft.) and the Owyhee Basalt (ca. 6,600 ft.) The basalts are recharged near the margins of the Snake River Basin where they crop out and are intersected by high angle faults.

Subsidence associated with deep production (i.e. Owyhee Basalt) is unlikely. Expected production zones would be above basement rock but within competent volcanics, from fracture porosity, and at depths greater than 1.5 km. Overburden would contain about 100 m. of competent rock (e.g. Grassy Mountain Basalt) and probably more than 10%, but less than 25% of mudstone, claystone or weak shales. Static water level is shallow (<200 m.) and lateral compression would be less a force than overburden pressure. A moderate subsidence potential may be associated with shallow production (e.g. Grassy Mountain Basalt) primarily because of the general incompetency of the overlying Chalk Butte Formation and alluvial fill within the Snake and Malheur River valleys. Environmental impact is considered low except where subsidence may locally breach irrigation canals.

Where overlain by rhyolite or Owyhee basalt there is a tendency for the Sucker Creek formation to break away from erosion scarps and slump downhill in blocks ranging in size from a few feet to a square mile. This behavior of the Sucker Creek formation should be a consideration in siting geothermal facilities.

<u>LaGrande</u>:

LaGrande lies within the Grande Ronde Valley, a graben within an area of block faulting. The valley is a unit of the Grande Ronde River Basin, a compound structural depression within the Blue Mountain section of the Columbia Plateaus physiographic province. The basement complex is composed of virtually impermeable metasediments and volcanics with dioritic and granodioritic intrusions of pre-Tertiary age (Table VI). The most important and widespread lithologic unit is the Columbia River Basalt which consists of at least 3,000 ft. of basalt (Miocene) and overlying andesitic flows (Pliocene?). Interflow zones of fluvio-lacustrine sediments may yield large quantities of water, though communication between these water-bearing zones is discontinuous and erratic. Extensive joints and fissures allow vertical movement of groundwater through flows that act as confining layers. Overlying the Columbia River Basalt are fanglomerates interfingered with lacustrine deposits of Plio-Pleistocene age. In some places within the valley their thickness exceeds 2,000 ft. The lake deposits are increasingly impermeable with depth so that little groundwater is extracted below 300 ft. Holocene deposits include alluvium, colluvium, welded tuff and a light gray volcanic ash up to 10 ft. thick. The topography within the valley interior is very subdued with gradients as gentle as one foot per mile. The water table is near or slightly above the major drainage.

Land use is devoted almost exclusively to agriculture, lumber and recreation related industries.

The Grande Ronde graben is part of a northwest striking fault system. The faults display relatively young, uneroded scarps that apparently cut and displace basalts beneath the valley fill. Latest deformation, folding followed by faulting, is middle to late Pleistocene. Because the LaGrande area is relatively aseismic and no post-Pleistocene deformation has been reported, seismic risk is believed to be low.

Although there are positive indicators of geothermal potential, very little about the resource has been published. Any development would likely be concentrated near Hot Lake Spring (180°F). The association of a hot spring, boundary fault zone and Columbia River Basalt at depth, suggest a geothermal model. That is, heat may be transferred to meteoric waters within the Columbia River Basalt and circulated via various channels back to the surface.

Because little is known about the resource, the potential for subsidence may range anywhere from low to moderate. Expected production zones would probably be above basement rock, from competent volcanics at depths perhaps less, perhaps greater, than 1.5 km. Production would be primarily from fracture porosity and/or matrix porosity within interflow units. Overburden would be clastic sediments with a small amount (ca. 10% by volume) to moderate amount (>10%, <25% by volume) of mudstone, claystone or weak shales. There may be some interbedded welded tuffs. Geostatic pressure would be more significant than lateral compression. However, production would likely be along the side of the valley where the overburden is relatively thin and there is no major land development.

TABLE I

Western Cascades: Generalized Geologic Column[1]

| | | |
|---|---|---|
| QUATERNARY | Alluvium. Gravel, sand, silt, locally thick layers of till. | 0-500' |
| PLIOCENE & QUATERNARY | Volcanic rocks of High Cascades and Boring Lava. Flows, mainly basaltic andesite and olivine basalt assoc. with lesser amounts of pyroclastic rocks. | 0>3,000' |
| PLIOCENE | Troutdale Fm.. Poorly indurated stream deposits: cgl., ss. and siltst. | 0-400 (>1,000 near Portland |
| MIDDLE & LATE MIOCENE | Sardine Fm.. Flows, mainly andesitic, tuff breccia, lapilla tuff and tuff. In northern Oregon: lower pyroclastic unit and upper unit of flows. Massive tuff breccia locally abundant. | 0-10,000' (ave. ca. 3,000') |
| MIDDLE MIOCENE | Columbia River Basalt. Tholeiitic basalt and andesite flows. | 0-1,500' |
| | Marine tuff and ss.. Interfingers eastward with Little Butte Volcanic Series. | |
| OLIGOCENE & EARLY MIOCENE | Little Butte Volcanic Series. Dacitic and andesitic tuff with lesser amounts of flows and breccias of basalt, andesite, dacite, rhyodacite and rhyodacite tuff. Massive pumice lapilli vitric tuff is most abundant rock type. | 3,000-15,000' (ave. 5,000-10,000) |
| LATE EOCENE | Colestin Fm.. Andesitic volcanics and volcanic-wacke ss., cgl., etc. | 0-3,000' |

[1]Modified from Peck, et. al., 1964.

TABLE II

High Lava Plains: Generalized Geologic Column[1]

| | |
|---|---|
| QUATERNARY | Unconsolidated sediments and basalts: Alluvium, aeolian, lacustrine, playa, terrace gravels, landslide debris, etc. almost exclusively restricted to depressions (e.g. Harney Basin, Fort Rock Valley) and stream valleys (e.g. Donner und Blitzen River, Silver Creek). Quaternary basalts widespread, some very recent (e.g. Diamond Craters, Lava Mountain); also mafic vent complexes and pyroclastics. |
| PLIOCENE-PLEISTOCENE | Widespread basalt flows (includes early shield-forming basalt flows of Newberry Volcano) and sedimentary rocks. |
| PLIOCENE | Tuffaceous sedimentary rocks, tuffs and interbedded basalts and andesite flows: Sediments well to semi-consolidated lacustrine ss. and siltsts.; massive sheets of welded tuff (e.g. Welded tuff of Double O Ranch). Complex interbedding and interfingering of sediments and volcanics. |
| MIOCENE & PLIOCENE | Basalt flows. |
| | Tuffaceous sedimentary rocks, mostly fine-grained of lacustrine and fluviatile origin. |
| MIOCENE | Widespread, thick assemblages of basalts, basaltic andesites and andesites, >2,000' max. (e.g. Steens Basalt in SE; part of Columbia River Grp. in NW) with interbeds of tuffaceous sedimentary rocks. Underlain by up to 2,000' of silicic extrusives in SE; tuffaceous sediments in NW. |

[1]Modified from Greene, Walker and Corcoran, 1972; Walker, Peterson and Greene, 1967.

TABLE III

Basin and Range: Generalized Geologic Column[1]

WESTERN

| | | |
|---|---|---|
| PLEISTOCENE-HOLOCENE | Fluvial, terrace & lacustrine deposits; landslide debris; basaltic tuffs & assoc. maars; pumice; alluvium. | 0> 3,000'+ |
| PLEISTOCENE? | Basalt flows. | 50-200'+ |
| LATE PLEISTOCENE or EARLY PLEISTOCENE | Andesitic flows.<br>Rhyolitic ash-flow tuff. | 0-500' |
| PLIOCENE | Tuffaceous & diatomaceous seds. & basalt tuffs, breccias & flows; maars, tuff rings & welded tuffs (includes "Yonna" Fm. & Fort Rock Fm.) | 800-1,000' |
| PLIOCENE | Basalt flows. | 20-600' |
| EARLY PLIOCENE MIDDLE MIOCENE ? | Rhyolitic & dacitic tuff, tuffaceous seds., subordinate basalt & andesite flows & palagonitic tuffs. | locally 13,000'+ |
| OLIGOCENE-EARLY MIOCENE | Andesite & basalt flows, pyroclastics & seds. of volcanic provenance. | 2,500'+ |
| OLIGOCENE or PRE-OLIGOCENE | Dacite flows. | 3,000'+ |

EASTERN

| | |
|---|---|
| PLIOCENE-HOLOCENE | Lacustrine, fluviatile & aeolian seds.; landslide debris; basalt & andesite flows; alluvium & playa deposits. |
| PLIOCENE | Tuffaceous seds., tuffs, basaltic & andesitic flows. |
| EARLY PLIOCENE & LATE MIOCENE | Basalt flows. |
| MIOCENE | Rhyolitic & dacitic tuffs, tuffaceous seds., silicic flows. |
| | Basalt & andesite flows & flow breccias (includes Steens Basalt, Steens Mountain Volcanic Series, etc.). Several thousand feet thick. |
| OLIGOCENE? & MIOCENE | Mainly lithified & altered silicic, tuffaceous sed. rocks (Pike Creek Fm.). |

[1]Compiled from several sources, including Walker, 1963; Walker and Repenning, 1965; Peterson & McIntyre, 1970.

## TABLE IV

### Alvord Valley: Generalized Geologic Column[1]

| | | |
|---|---|---|
| PLIOCENE-HOLOCENE | Lacustrine, fluviatile and aeolian sediments; landslide debris; playa deposits; alluvium. | "Older-alluvium" 200-800' |
| PLIOCENE | Tuffaceous sedimentary rocks, including semiconsolidated lacustrine tuffaceous ss. and siltst.; tuffs and interbedded basaltic and andesitic flows (includes Alvord Creek Fm.). | 800'+ |
| LATE MIOCENE & EARLY PLIOCENE | Basalt flows. | |
| MIOCENE | Tuffaceous sedimentary rocks; silicic tuffs, including some partly to density welded tuffs; rhyolite and dacite flows. | |
| | Basalt and andesite flows and flow breccias (includes Steens Basalt and Steens Mountain Volcanic Series.) | 7,500'+ |
| OLIGOCENE ? & MIOCENE | Pike Creek Fm.. Lithified and altered silicic, tuffaceous sedimentary rocks, including tuffs and extrusive/intrusive rhyolite. | 2,500'+ |
| PRE-TERTIARY | Basement complex. Metamorphic rocks (Paleozoic) and plutonic rocks (Late Jurassic). | |

[1]Modified from Walker and Repenning, 1965.

TABLE V

Vale: Generalized Geologic Column[1]

| | | |
|---|---|---|
| RECENT | Mainly sand and silt in flood plains of Snake and Malheur Rivers. | |
| PLEISTOCENE | Eroded and terraced unconsolidated gravel, sand, silt and clay. On benches above present flood plains of Snake and Malheur Rivers. | 50'+ |
| PLIOCENE | Chalk Butte Fm.. Generally incompetent unit of relatively unconsolidated tuffaceous conglomerate, sandstone and siltstone of lacustrine and fluviatile origin; lesser amounts of ash and fresh-water limestone; occasional interbeds of basalt. | 2,500-3,500' |
| | Grassy Mountain Basalt. Thin flows of olivine basalt. | 500-1,000' |
| | Kern Basin Fm.. Tuffaceous ss. and siltst. with bedded tuffs, ash deposits and massive tuff breccias. Cgl. beds common in basal part of section. | 750' |
| MIOCENE | Deer Butte Fm.. Fine-grained tuffaceous sediments grading upward into massive silicified arkoses and rhyolite-granite conglomerates. | 1,250' |
| | Owyhee Basalt. Massive, scoriaceous basalt flows with tuffs and ash deposits. | |
| | Sucker Creek Fm.. Bedded, massive tuffs and tuffaceous shs. with minor siltst. and ss.. Includes massive flows and intrusions of rhyolite; also basalt in lower part. | |

[1]Modified from Corcoran, et. al., 1962.

TABLE VI

LaGrande: Generalized Geologic Column[1]

| | | |
|---|---|---|
| RECENT | Alluvium, colluvium, welded tuff; also light gray volcanic ash up to 10' thick. | |
| PLIOCENE & PLEISTOCENE | Fanglomerate and lacustrine deposits. Lake deposits of fine sand, silt and clay interfinger with alluvial fans of unconsolidated boulders and clay. | 0>2,000' |
| PLIOCENE ? & MIOCENE | Columbia River Basalt. Sequence of basalt lava flows constituting the thickest and most widespread part of unit overlain by platy andesite flows. | ≥3,000' |
| MIOCENE | Tuff-breccia, welded and silicified tuff, andesite and dacite flows. | |
| PRE-TERTIARY | Basement complex of metasediments and volcanics with diorite and granodiorite intrusions. | |

[1]Modified from Hampton and Brown, 1964.

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SECTION B

of the

# OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW STUDY*†

## AIR QUALITY IMPACTS RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

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## I. SUMMARY

This chapter communicates an effort to identify air quality issues associated with the development of geothermal resources in Oregon. The chapter's objectives are to:

- inventory presently available data,
- assess the available data to determine their adequacy for making air quality impact estimates,
- identify data needs which must be met to make realistic air quality impact estimates, and
- identify key air quality issues which may hinder or obstruct development of the resource.

Thus, the purpose of the chapter is to provide information needed to make decisions pertaining to future atmospheric/environmental effects of geothermal energy development in Oregon.

The first portion of the chapter (sections II through IV) examines generic air quality issues encountered in previous developments such as The Geysers field in California and Wairakei, New Zealand, and summarizes the kinds of data necessary to identify and quantify potential air quality impacts.

Section V focuses on specific areas of Oregon identified as having high geothermal development potential. Topics addressed include: climate; topography; available source, meteorological and air quality data; and factors which may enhance air quality impacts locally.

Section VI summarizes those issues and impacts, real and perceived, that appear to be most significant for geothermal energy development in Oregon. The main issues were judged to be broad issues relating to public attitudes, and include general environmental concerns such as aesthetics. Specific air quality issues include:

- visibility reduction,
- fogging and icing from cooling tower emissions,
- cooling tower plume visibility,
- odor nuisance of hydrogen sulfide ($H_2S$), and
- increased air concentrations of other substances found in geothermal fluids.

Finally, section VII summarizes conclusions and outlines needs for additional data and research. It was concluded that presently available data are insufficient for making realistic air quality impact assessments. Recommendations are given for acquiring additional data which will allow more realistic assessments. Other suggestions include:

- research on the oxidation of $H_2S$ to $SO_2$ in moist plumes,
- establishment of a state-wide ambient $H_2S$ standard,
- research on the effects of geothermal effluents on native and cultivated plant species,
- research in complex terrain meteorology,
- refining the state-of-the-art of regional-scale visibility and complex terrain modeling, and
- research and development for $H_2S$-abatement technology and on-site testing of energy-conversion systems.

## II. INTRODUCTION

Oregonians have a broad reputation for being "environmentally conscious." It is also widely suspected that Oregon has substantial geothermal resources. A moot question, then, is whether or not geothermal resources in Oregon can be developed in a manner that is acceptable to environmentally conscious Oregonians. In particular, in this chapter, the question addressed is: what are the key *air quality issues* related to geothermal energy development in Oregon?

Air quality issues have been, and continue to be, of major importance to geothermal development in other regions of the world. For example, the problem of the "rotten-egg" smell of hydrogen sulfide ($H_2S$) in the Geysers area of California is well summarized by the following quotation from report DOE/ERD-0005 (1978):

> Large scale utilization of vapor-dominated reservoirs has been demonstrated at the Geysers area of California. However, further expansion and even continued operation of the present power plants is contingent upon the successful demonstration of an operational abatement system to limit $H_2S$ emissions to acceptable levels.

As another example, air quality issues related to inadvertent weather modification (fogging, icing, cloud stimulation, etc.) can be raised if releases are similar to those at the liquid-dominated electrical generating plants at Wairakei, New Zealand:

> The Wairakei plant discharges approximately 6.5 times as much heat, 5.5 times as much water vapor, and 0.5 times as much sulfur, per unit of power produced, as would a modern coal plant in New Zealand.
> (Axtmann, 1975).

Or, as a final example, the issue of contributing to potential, world-wide, climate modification can be raised if large scale use of geothermal energy released carbon dioxide ($CO_2$) to the atmosphere at a rate commensurate with the Monte Amiata field in Italy: there, the $CO_2$ discharge rate (on a per megawatt-day basis) could be ten times that of a fossil-fueled plant (Axtmann, 1975). And, for those readers who think that such issues would not impede geothermal development in Oregon, they might study the plume visibility arguments that helped delay geothermal development at Breitenbush, Oregon and study the current arguments in Oregon to delay nuclear reactor construction until the national problem of long-term storage of nuclear wastes is solved. In other words, the significance of air quality issues to future geothermal development in Oregon should not be underestimated.

Unfortunately, though, it is difficult (if not impossible or even useless) to attempt to generalize about effects from emissions to the atmosphere associated with the use of geothermal energy. The reasons why generalizations are so difficult include: (1) each geothermal field has a unique chemical (and thermal) characterization and (2) there are many different ways to use the available energy. As an example of different chemical characterizations, mercury concentrations in non-condensible gases have been measured to range from 0.03 micrograms per liter ($\mu g\ \ell^{-1}$) at Heber, California to 5.8 $\mu g\ \ell^{-1}$ at the Geysers Unit 3 (Robertson *et al.*, 1978). And, though few generalizations can be made about utilization, one fairly safe generalization is that more deleterious effects can be expected from electrical power generation at a once-through, vapor-dominated field and fewer air quality impacts should result from the direct use of geothermal heat such as for district heating with reinjection or when a secondary working fluid is used. Thus, given the existence of so many potential variables, it is difficult to make realistic speculations of effects.

To circumvent these difficulties, it might be thought better to approach air quality issues of geothermal energy development from a regulatory viewpoint. Unfortunately, though, neither the states nor the U.S. Environmental Protection Agency (EPA) have established firm, realistic regulations. Consequently, developers are frequently faced with changing, nonuniform and/or unrealistic regulations. For example, there is no federal $H_2S$ emission standard (although in an EPA report by Hartley, 1978, it is recommended that "$H_2S$ emissions . . . should be limited to an average of not more than 10% of the loading in the raw fluid"--which varies dramatically from field to field!) yet California has a statewide, 1-hr average standard of 30 parts per billion by volume (ppbv), New Mexico has a 3 ppbv standard, and Oregon has yet to establish an $H_2S$ standard. Further, as shown in Figure 1, there are substantial variations among what different observers define as the odor threshold for $H_2S$--and there are not yet sufficient data available to specify firmly which of the many sulfur compounds is/are typically responsible for the pungent odor associated with most geothermal fields. Thus, attempts to regulate for only one issue (*viz.*, the odor nuisance) can be seen to be fraught with serious problems.

Similar problems, uncertainties, and confrontations could arise because of other air pollutants such as mercury, arsenic, boron, and even particulates. For example, as an illustration of uncertainties about particulates, the following relevant question is essentially unanswered: what amount of $H_2S$ can be released in areas of mountainous terrain so that the resulting visibility reduction, caused by particulates generated from the oxidation of $H_2S$, will not violate the prevention of significant deterioration (PSD) regulations in a nearby, Class I, national park or wilderness area? Unanswered

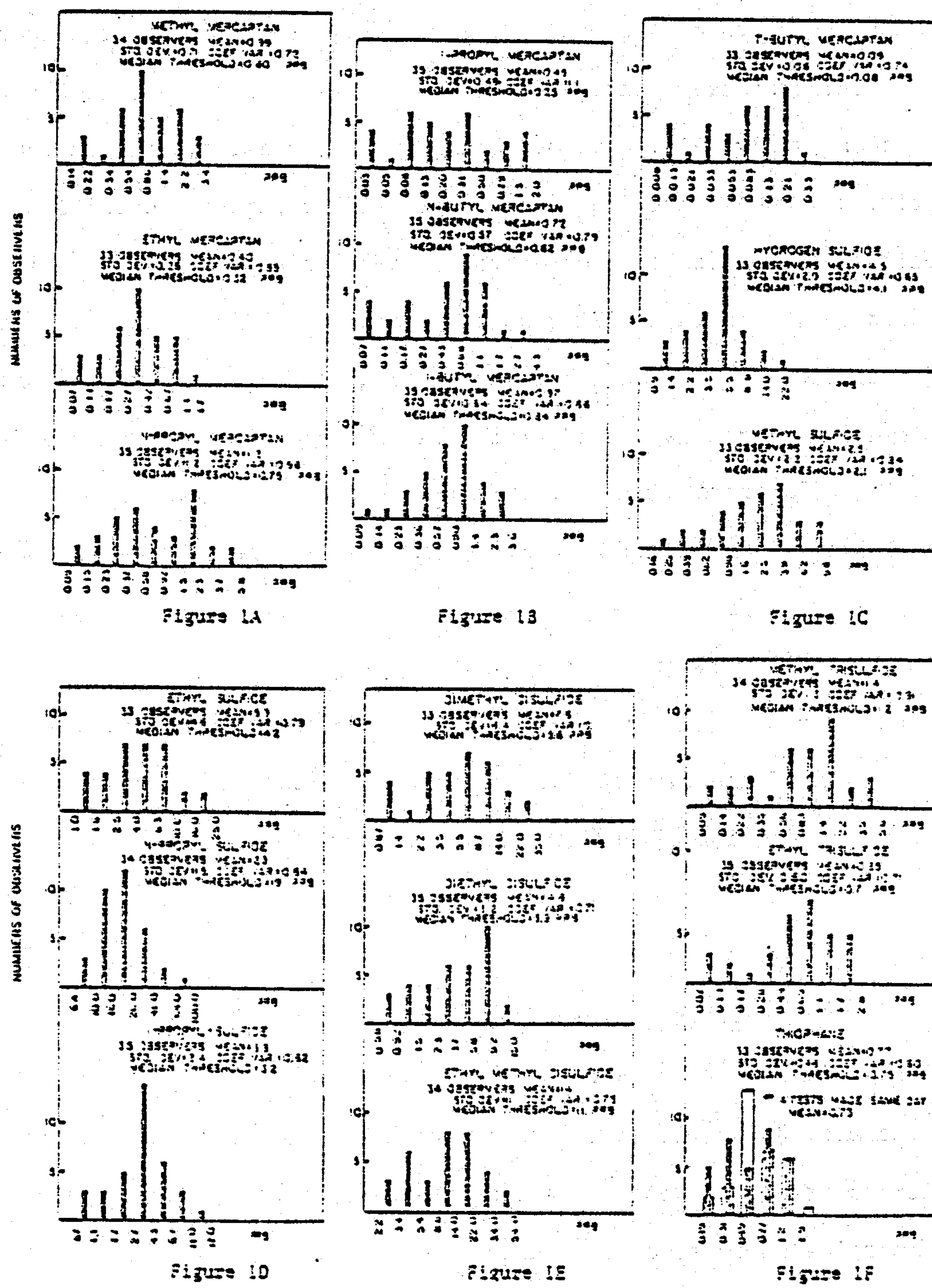

Figure 1. Odor thresholds of a number of sulfur compounds.
Figure reproduced from Wilby (1969).

questions such as these result in great uncertainties and dissatisfactions with approaching the environmentally acceptable development of geothermal energy from the regulatory viewpoint.

Nevertheless, such difficulties and uncertainties have not significantly impeded lawmakers from creating a legal framework for air quality regulations. For example, on federal lands (and approximately one-half of Oregon is federal lands) the U.S. Geological Survey (USGS) supervises geothermal operations and issues operational permits. To obtain these permits, developers must determine baseline meteorological and air quality data and submit environmental impact analyses of the proposed development. However, the realism of the predicted impacts can be (and later in this chapter will be) severely questioned. In addition, the EPA has statutory authority and responsibility to establish emission levels *via* the New Source Performance Standards (NSPS) in Section 111 of the Clean Air Act and Section 109 of the Clean Air Act Amendments of 1977. Further, the Oregon State Legislature can set more stringent air quality regulation if desired. However, as will be repeatedly stated and emphasized in this report, seriously deficient gaps in knowledge mock many if not most of these regulations.

In general, then, the legal (if not the scientific and technological) framework is in place for environmentally acceptable development of geothermal energy in Oregon. However, there is also a legal framework that has been effectively used in the past, for "environmentally" active Oregonians to block development of geothermal and other energy resources. This seemingly contradictory situation is derived, in part, from the lack of firm scientific technological knowledge about geothermal energy use. Thus, without doubt, a major contribution to environmentally acceptable geothermal energy development can be made by the U.S. Department of Energy (DOE) if this agency would help remove scientific and technological uncertainties.

In this chapter, some of the air quality issues will be described that require scientific and/or technological resolution to assist in the environmentally acceptable development of geothermal energy in Oregon. In the next section, some generic issues will be described for each of the identified phases of geothermal development and then summarized for all phases. Following these generic issues, data needs, site specific issues, and data deficiencies will be addressed.

There are a number of objectives for this chapter. One is simply the desire to provide interested Oregonians with background information for air quality aspects of geothermal energy development. A second objective, more relevant to the sponsor (the U.S. DOE), is to provide information needed to make decisions on future funding for atmospheric studies that will result in environmentally acceptable development of geothermal energy in Oregon and elsewhere. Toward accomplishing this objective, the chapter will contain: (1) an inventory of available data; (2) an assessment of this data; (3) identification of data gaps; and (4) identification of what is perceived to be important air quality issues.

## III. GENERAL CONSIDERATIONS

Air quality and climate effects of geothermal electrical power generation depend on various factors such as chemical composition of the working fluid, plant design and operating characteristics, and local meteorology. This section will discuss these factors and identify potential effects in a general sense.

These generic effects can first be categorized by two stages of the development process: resource development and resource utilization.

A. RESOURCE DEVELOPMENT (EXPLORATION/CONSTRUCTION): In the resource development phase, air quality will be affected by an increase in fugitive dust suspension caused by construction of roads, road travel by heavy equipment, drill pad construction, power plant construction, etc. Although it is difficult to estimate the degree of impact from these sources, similar impacts occur in other types of construction activities and are temporary in nature. With care, e.g. periodic watering down of roads, impacts from fugitive dust emissions can be minimized.

Heavy equipment operation will also increase fugitive emissions from engine exhaust gases. However, this impact should be minimal for construction activities of this scale and is also temporary in nature.

During the exploration/construction phase, test holes must be drilled to delineate reservoir boundaries and obtain samples of the geothermal fluid to determine its flow rate, chemical composition, temperature, etc. If results are favorable, production holes would need to be drilled. These operations create the most serious potential for air pollution during this phase because of well blowouts. A well blowout occurs when the bottom-hole pressure overcomes the well's hydrostatic weight. Blowouts can result in an uncontrolled release of contaminants. However, improved drilling technology has made blowouts rare occurrences.

Release of $H_2S$ and other non-condensable gases can also occur when wells into vapor-dominated reservoirs are blown for cleanout. However, this type of release is temporary and unique to vapor-dominated (dry-steam) fields. (A dry-steam field, as opposed to a liquid-dominated, or hot water, field, is a geothermal reservoir from which the fluid emerges at the earth's surface as steam.)

In summary, atmospheric impacts during the exploration/construction phases of geothermal development should be temporary and local, and hence minimal, barring accidental blowouts which have a low probability of occurrence. Further discussion will be limited to the plant operation phase.

B. RESOURCE UTILIZATION (PLANT OPERATION): It is during the actual utilization phase that air quality-climate effects are most significant. The degree and nature of these impacts are dependent on four major factors:

1. Type of utilization.
2. Type of energy conversion cycle used for electrical power generation.
3. Chemical characteristics of the working fluid.
4. Types of waste heat rejection systems (cooling towers).

Each of these four major factors will now be considered.

1. *Types of Utilization:* Economics dictate that the working fluid have a temperature in excess of 150°C (about 300°F) to make electrical power generation (i.e., indirect utilization) feasible. At temperatures >150°C, utilization must be direct; that is, the heat energy must be used directly rather than converted, for example, to electrical energy. Examples of direct utilization are district space heating, greenhouse heating, and for certain industrial processes such as that planned for the Ore-Ida food processing plant at Ontario, Oregon (*Geothermal Energy Magazine,* Jan. 1979).

In direct utilization systems, the fluid is passed through heat exchangers of some kind and discharged in toto (Figure 2). In this case, since there is very little interaction of the fluid with the atmosphere, air quality impacts are essentially negligible. Pipeline networks may be more extensive than with indirect utilization systems and,

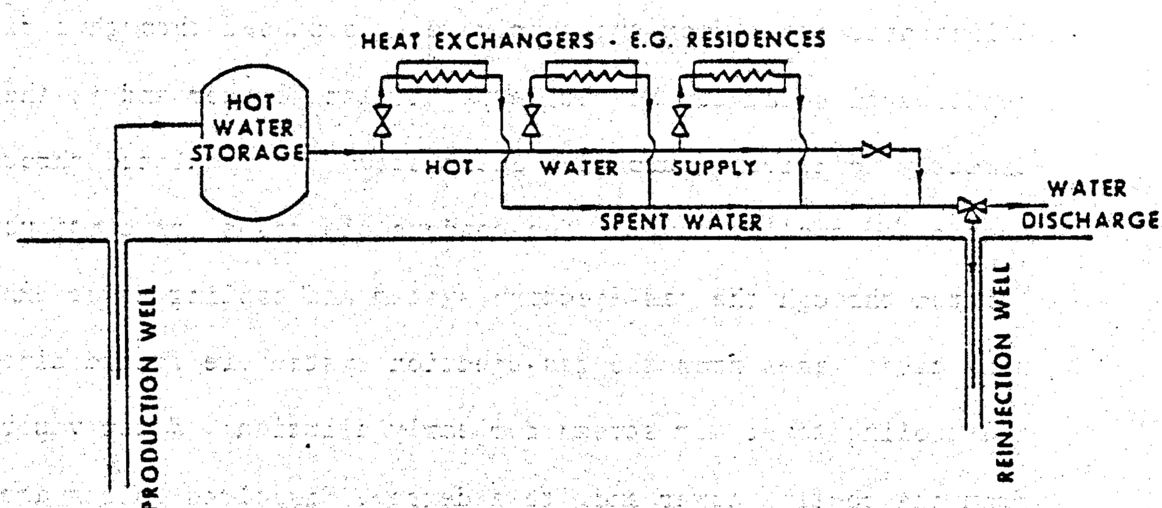


Figure 2. Simplified schematic diagram of non-electric use (space heating) of geothermal energy. Spent fluids either can be injected or discharged to surface waters. Figure reproduced from Hartley (1978).

in some cases, there may be need for a waste heat rejection system. However, these factors are common to both direct and power-generation utilization systems. Further discussion will be limited to electrical power generation.

2. *Energy Conversion Cycles:* The major sources of air pollutants emitted during electrical power production are direct releases during all stages of development (e.g. well blowouts, steam line vents, etc.) and releases of heat, water vapor, and contaminants during plant operation. The latter source, because of its continuous nature, is most important in terms of air pollution and climate modification potential. However, the significance of these releases depends upon the type of energy conversion cycle used.

(a) *Dry-Steam Cycle:* This type of system is illustrated in Figure 3. In this process, unique to dry-steam fields such as The Geysers, California, steam from the supply well is passed through a filter or centrifugal separator to remove particulate matter and is then used directly to drive a turbine. Spent steam is circulated through a condenser and cooling tower. Non-condensable gases are continuously emitted through the gas-ejection system and cooling tower exhaust. In many cases gases from the gas-ejection system are vented directly into the cooling tower air stream for early dilution. Water vapor is emitted from the cooling tower and, to a degree, dissolved solids are emitted from the cooling tower in drift droplets. Drift droplets are small droplets that are caught in the air stream and exit through the cooling tower exhaust.

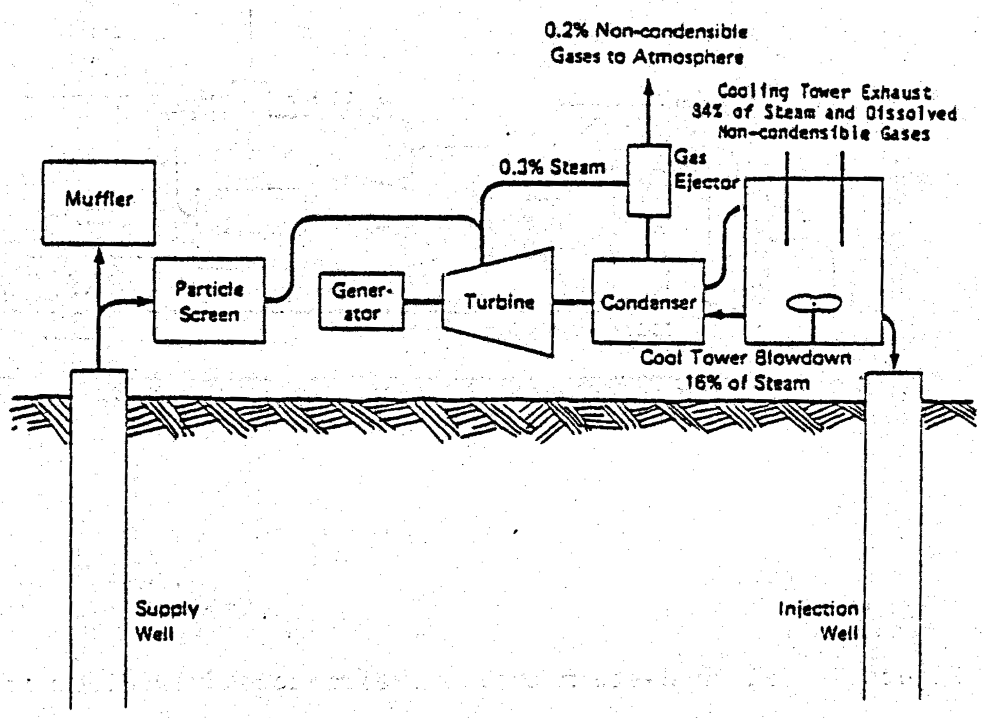


Figure 3. Dry-Steam Cycle. Figure reproduced from Wimer *et al.* (1977).

It is unlikely that a system based on a dry-steam cycle will have any applicability in Oregon since there are no identified dry-steam reservoirs in the state.

(b) *Flashed-Steam Cycle:* In this system, geothermal water that is under great pressure at depth is withdrawn. As the water nears the surface, pressure decreases sufficiently so that a portion (which depends upon the design characteristics but is typically near 20%) boils and "flashes" to steam. This system has a low efficiency and results in more waste fluid to be disposed of through re-injection or other means. Also, the system requires high (>175°C) temperatures. Its effects on the environment are similar to the dry-steam cycle. The flashed-steam cycle is illustrated in Figure 4.

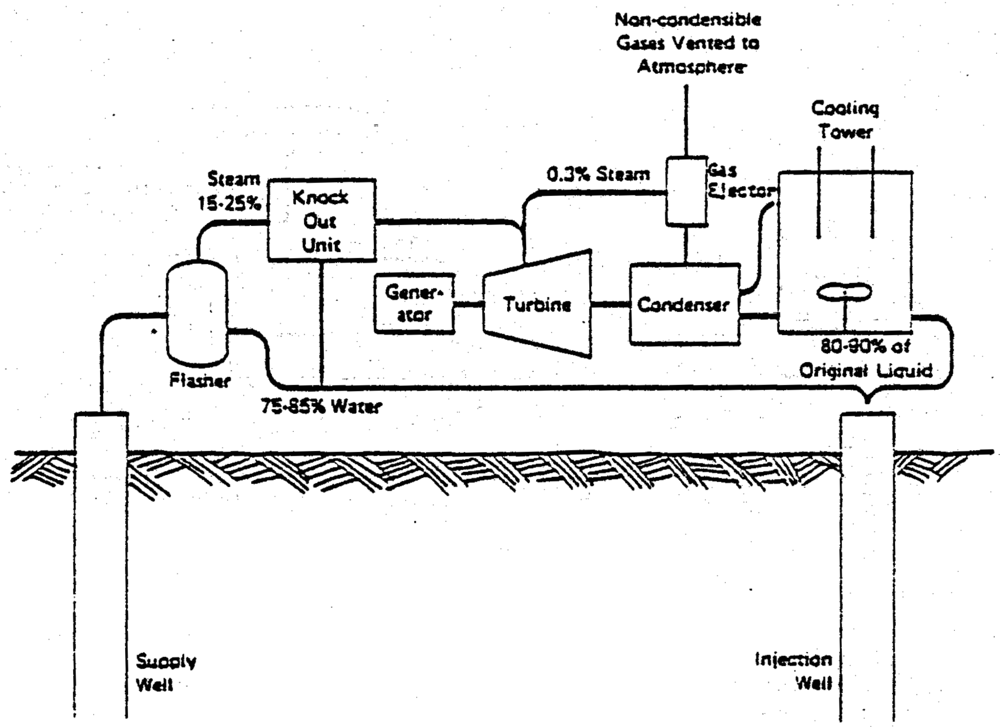


Figure 4. Flashed-steam cycle. Reproduced from Wimer *et al.* (1977).

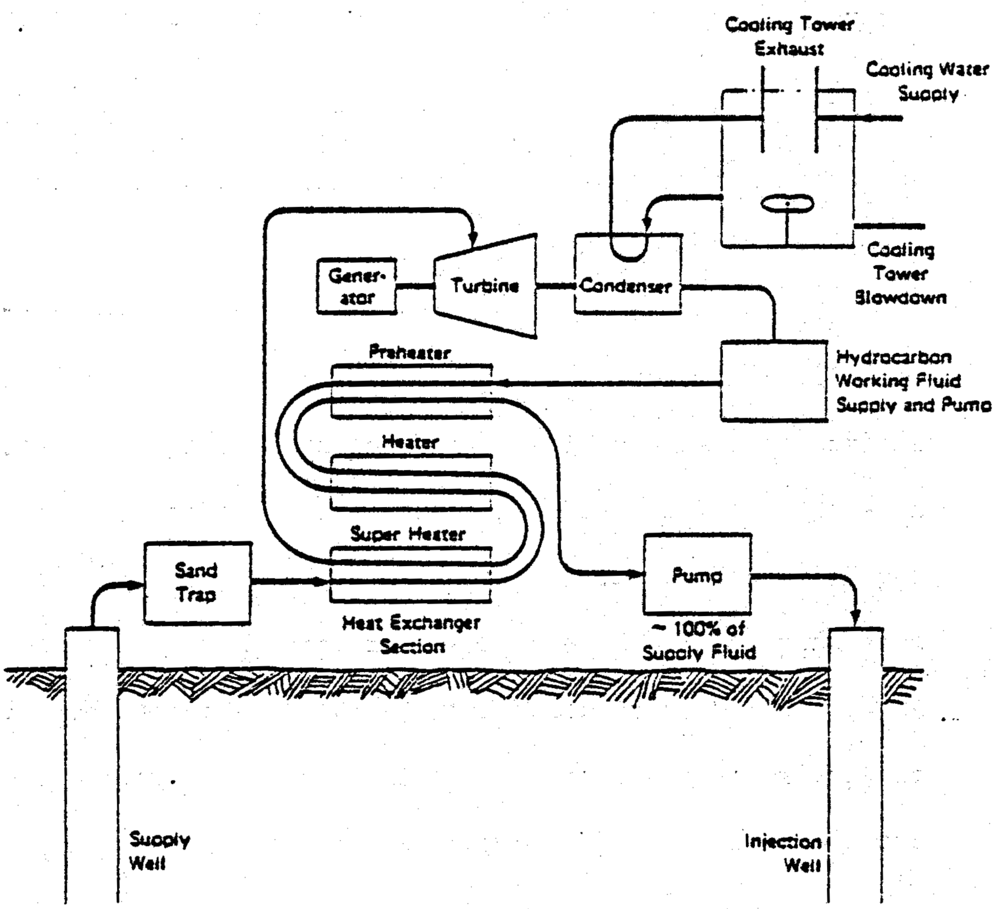


Figure 5. Binary system. Reproduced from Wimer *et al.* (1977).

(c) *Binary Cycle:* This is a process in which hot water from the reservoir is used to heat a secondary fluid (e.g., freon or isobutane) with a lower boiling point, generating a vapor that is used to drive the turbine (Figure 5). This vapor is then condensed and recirculated in a closed system. The geothermal fluid is also maintained in a closed loop and, if re-injection is used, there is no interaction of the fluid with the atmosphere; hence, the only emissions from this system are heat and moisture. This system extracts energy from the total fluid and is thus more efficient than the flashed-steam system.

The binary system eliminates potential emissions of pollutants found in the geothermal fluid but raises the problem of containment of the highly volatile secondary fluids. The method is applicable to regions with reservoir temperatures of 150° to 175°C and is the most likely type of conversion process for most parts of Oregon (Wimer *et al.*, 1977). However, because of the low operating efficiency of geothermal electrical generation systems, their cooling water requirements are high, some four to six times as much as for fossil fuel power plants with equivalent electrical capacity. Because the geothermal fluid in a binary system usually remains enclosed and is not available for cooling water, this system may require large amounts of supplemental cooling water. Ermak (1978) has estimated cooling water requirements for power plants in the Imperial Valley of California to be 3000 to 4500 acre-feet per year for a 50 MW unit (1 acre-foot ≈ 1,234 $m^3$, or $1.24 \times 10^6$ kg $H_2O$). Consequently, the suitability of binary systems for the more arid regions in Oregon will probably depend largely on water availability.

(d) *Total Flow System:* This process is still in the design and testing stage but holds promise for better efficiency than the flash or binary systems. In this method, both the steam and water are used in one generating process that combines a steam turbine and waterwheel. The system proposed by Austin *et al.* (1973) allows for re-injection of the spent fluid, with non-condensable gases injected by aspirator into the disposal wells, so that there would be no atmospheric emissions of contaminants. Cooling would be accomplished via cooling towers or spray pond.

3. *Chemical Characteristics of the Working Fluid:* At a given site with a given type of power plant, the kinds and quantities of emissions to the atmosphere depend, first, upon the kinds and quantities of constituents present in the geothermal fluid. In turn, this depends on the geochemistry of the underground reservoir. The chemical composition of the geothermal fluid can vary substantially from reservoir to reservoir and even at different sites within the same reservoir. Table 1 makes an illustrative comparison of gases in steam from wells at The Geysers, California and Wairakei, New Zealand. Figure 6 shows ranges of historical measurements of constituents on a logarithmic scale that also shows some of the wide variations possible.

Some of those constituents listed in Figure 6 pose potential health or environmental hazards. Emission levels historically associated with geothermal power plants have not been high enough to become health hazards, but because of the variability from site to site, serious effects could occur at new sites. Some of the constituents that have

Table 1. Comparison of Noncondensable Gases in Steam from Wells at Two Geothermal Power Plants. Reproduced from U.S. EPA Publication EPA-600/9-77-010 (1977).

| Gas | Range of Concentrations Measured (ppm) | | | |
|---|---|---|---|---|
| | Geysers | | | Wairakei |
| | Low | High | Average | Average |
| Hydrogen sulfide | 5 | 1,600 | 222 | 40 |
| Carbon dioxide | 290 | 30,600 | 3,260 | 600 |
| Methane | 13 | 1,447 | 194 | 5 |
| Ethane | 3 | 19 | – | 1 |
| Ammonia | 9 | 1,060 | 104 | 8 |
| Nitrogen | 6 | 638 | 52 | 3 |
| Hydrogen | 11 | 213 | 56 | 10 |

SOURCES: Reed, M.J., and G. Campbell 1975. Axtmann, R.C., 1976.

been of most concern at other geothermal resource areas will now be considered.

*Hydrogen Sulfide* ($H_2S$) has been most frequently associated with geothermal fluids, primarily as a nuisance because of its "rotten egg" odor. It is emitted as a non-condensable gas through cooling tower exhaust and gas ejection systems. Concentrations of $H_2S$ in emissions from existing geothermal electrical generating plants are near the odor threshold of this gas.

$H_2S$ is chemically reactive and, in the presence of ozone ($O_3$), is oxidized to sulfur dioxide ($SO_2$). This reaction is quite slow in the gas phase; in the presence of airborne particles with a concentration of 200 particles per $cm^3$ the lifetime of one ppb $H_2S$ is estimated to be about 28 hours (Seinfeld, 1975). However, $H_2S$ and $O_3$ are soluble in water and the oxidation rate of $H_2S$ in a moist plume may be very fast.

$SO_2$ is in turn removed from the atmosphere through deposition processes and through chemical transformations, mainly oxidation to sulfates.

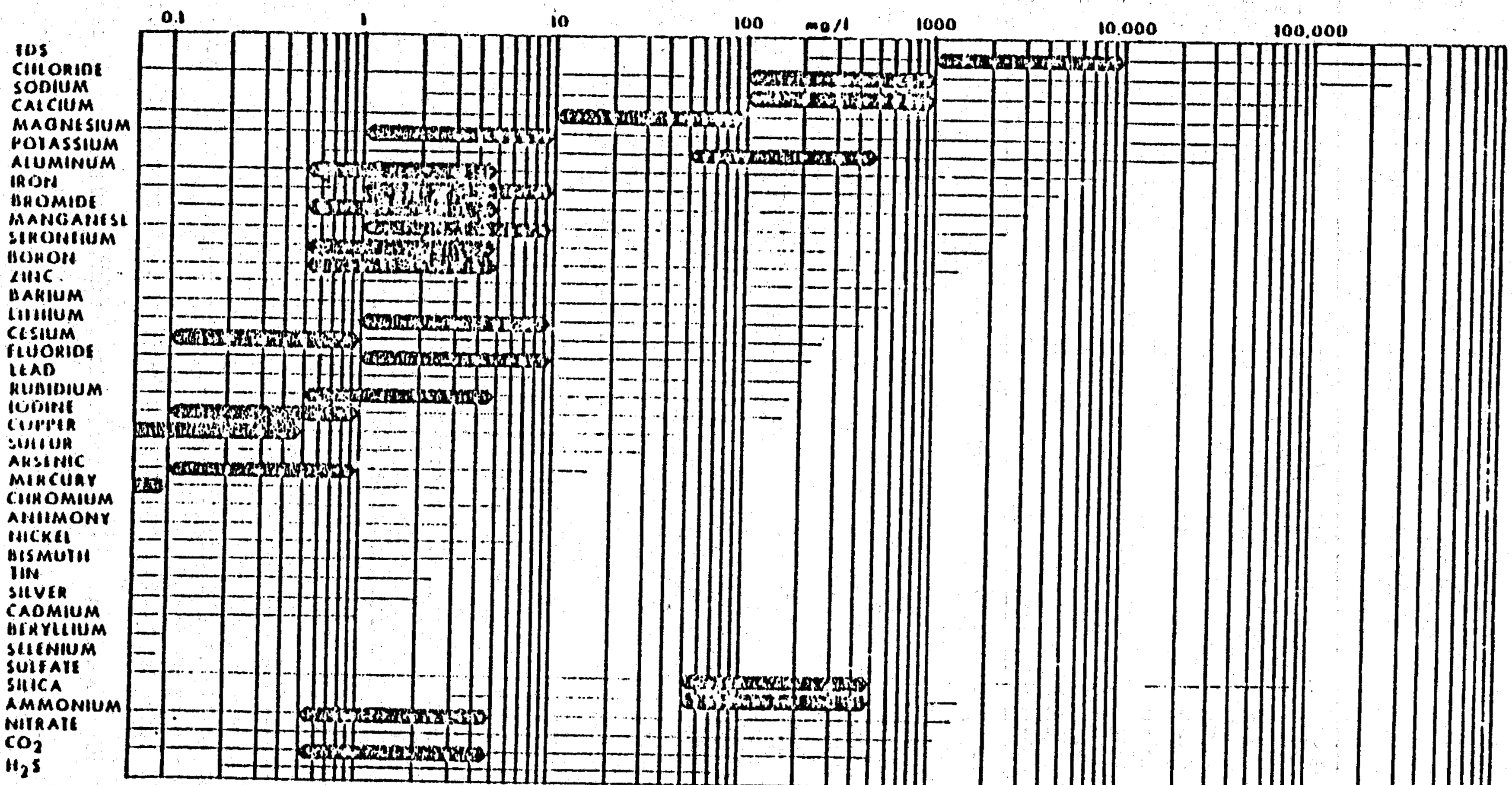


Figure 6. Ranges of chemical constituent concentrations in geothermal fluids - mg $\ell^{-1}$ bars show measured ranges. Wide bars show ranges within which the majority of measurements will probably fall. Where no wide bar is shown, data are insufficient to make a judgment. Figure reproduced from Hartley (1978).

These sulfate particles can, through coagulation, produce larger particles that can scatter and absorb light and cause visibility reduction. In addition, $SO_2$ in the presence of water vapor can produce sulfuric acid ($H_2SO_4$) aerosol, which can cause acid rain at large distances downwind. In view of the time required for this whole process, these effects (visibility reduction and acid rain) are most likely to occur on a regional basis as a result of large-scale geothermal development.

*Boron* (B), dissolved in drift droplets, is emitted from cooling towers. At sufficient concentrations boron, deposited on vegetative surfaces, is believed to have detrimental effects on vegetation. Sensitive trees in the immediate vicinity of cooling towers in The Geysers field have suffered leaf burn from boron deposition (Rosen and Molenkamp, 1978).

*Arsenic* (As) and *mercury* (Hg) are of concern because of their toxicity at low concentrations. Because of its high vapor pressure, Hg can be emitted in a gaseous form (through cooling tower exhaust) as well as in the form of Hg compounds dissolved in drift droplets. Arsenic is emitted primarily in drift droplets (Rosen and Molenkamp, 1978).

*Ammonia* ($NH_3$) is a volatile compound emitted through cooling tower exhausts. Although inhalation of sufficient amounts (1000 ppm) can cause serious harm, concentrations found in most geothermal steam are too low to pose a direct health hazard. However, $NH_3$ can act as a catalyst for oxidation of $SO_2$ to ammonium sulfate. In addition to its visibility reduction effects (see preceding section on $H_2S$), this substance may have harmful effects on human health and some plant and animal species (see Sheiler, 1975).

*Carbon Dioxide* ($CO_2$) is a normal component of the atmosphere. Impacts upon the climate caused by increased atmospheric $CO_2$ are significant in a global context; a significant increase of $CO_2$ in the earth's atmosphere could cause an increase of the earth's mean temperature.

*Radon* ($^{222}Rn$), a radioactive noble gas, is produced by the decay of uranium in rocks at geothermal reservoir depths and is normally diffused through the earth's surface. $^{222}Rn$ and its short-lived daughter products have been found in trace amounts in the non-condensable gas portion of geothermal steam at The Geysers, but within the range of concentrations measured at background locations (Serpa *et al.*, 1977).

4. *Waste Heat Rejection Systems (Cooling Towers)*: The nature of the effect on the atmosphere of geothermal resource development can also be categorized into:

(i) Air quality degradation through release of contaminants not normally present in the atmosphere in significant amounts (e.g. $H_2S$, B).

(ii) Local climate or weather modification through releases of heat and water vapor.

The first category includes all of those contaminants discussed earlier; in what follows, some comments will be made about the second category.

As a preliminary to considering inadvertent weather modification effects, it is noted that, characteristically, geothermal power plants have low thermal efficiencies. Thermal efficiency can be defined as

$$\frac{E_E}{E_H} \times 100(\%) \qquad (1)$$

where $E_H$ = heat contained in geothermal fluid, and

$E_E$ = electrical energy output.

Thermal efficiencies for geothermal power plants range from 8 to 18%, compared with 30 to 40% for fossil fuel and nuclear power plants. Consequently, geothermal power plants emit larger amounts of waste heat per unit of electrical power generation than more conventional power plants, by a factor of 4 to 5. Table 2 makes an illustrative comparison of waste heat output for different types of power plants in the 1000 MWe range.

Table 2. Expected Waste Heat Emissions During Power Plant Operation for Alternative Electrical Generating Processes, 1000 MWe Plant (kilowatt-hours/year). Reproduced from U.S. EPA Document EPA-600/9-77-010 (1977).

| Process | Total Waste Heat ($\times 10^{10}$) |
|---|---|
| Nuclear (light-water reactor) | 1.86 |
| Coal | 1.2 |
| Residual fuel oil | 1.2 |
| Natural gas | 1.2 |
| Low Btu synthetic natural gas (from coal) | 1.2 |
| Geothermal: The Geysers | 4.5[a] |
| Wairakei | 9.7[b] |

SOURCES: Teknekron, Inc., 1975; Axtmann, R.C., 1975.

a. Discharged to air.

b. $4.3 \times 10^{10}$ is discharged to air.
$5.4 \times 10^{10}$ is discharged to water.

The potentials for inadvertent weather modification (*viz.*, fogging, icing, cloud stimulation, etc.) are directly dependent upon the type of waste heat rejection system used. Environmental concerns over the availability and adequacy of cooling-water supplies and potential biological effects of warming natural bodies of water have led to the use of air as a coolant because of air's substantial capacity for dispersing waste heat. The most common air cooling method is the cooling tower.

Since the cooling tower is the focal point of atmospheric emissions during plant operation (the non-condensable gases are frequently injected into the cooling tower), the cooling tower's design is a determining factor in the ultimate dispersion of emissions. Relevant design characteristics are:

(a) *Methods to Induce Air Movement Through the Tower: Natural draft* cooling towers use a chimney effect (*viz.*, hot air's buoyancy) to create air movement. Typically, these towers are high (100 to 150 m) and create density differences sufficient to maintain a large updraft velocity. *Mechanical draft* cooling towers rely on fans to move ambient air through the system, usually are lower (15 to 25 m) and are grouped into rows of about ten cells.

(b) *Method of Heat Transfer: Wet-type* or evaporative cooling towers are those in which the fluid is broken into fine droplets and brought into direct contact with the air stream. Heat is dissipated mainly by evaporation, so that the efficiency of this method may vary with climate and season. Wet-type cooling towers may be either mechanical draft or natural draft. In this type, contaminants in the fluid are released along with the heat and water vapor; the contaminants may be gases, particulates, or contained in drift droplets.

*Dry-type* cooling towers circulate the fluid being cooled in a closed system and cool it by conduction and convection, the same processes used by the radiator of an automobile. Since there is no direct interaction of the fluid with the air, only the heat is transferred to the atmosphere. Consequently, dry-type cooling towers may cause less environmental impact than the wet-type. (See, however, section 5e.) Also, since there is no evaporative loss to the atmosphere, dry-type cooling towers do not require a continuous water supply; this has obvious attractions for arid areas. However, dry-type towers are expensive to construct and may lower the overall plant efficiency.

Because of economic considerations, wet-type, mechanical draft towers have been used for geothermal power plants to date. Wet, mechanical cooling towers cause the greatest local impact because of their low level exhaust and release of water vapor and pollutants. Figure 7 illustrates this type of cooling tower complex.

5. *Weather/Climate Modification from Cooling Towers:* Local weather and climate modification effects can occur as a result of cooling tower emissions of heat and water vapor.

(a) *Visible Plume Formation:* As hot saturated air is emitted into the atmosphere, it comes into contact with ambient air that is cooler and has a smaller capacity for water vapor. As mixing occurs, the amount of water vapor may exceed the saturation capacity of the mixed air. Some of the water vapor will condense creating a visible plume of fine water

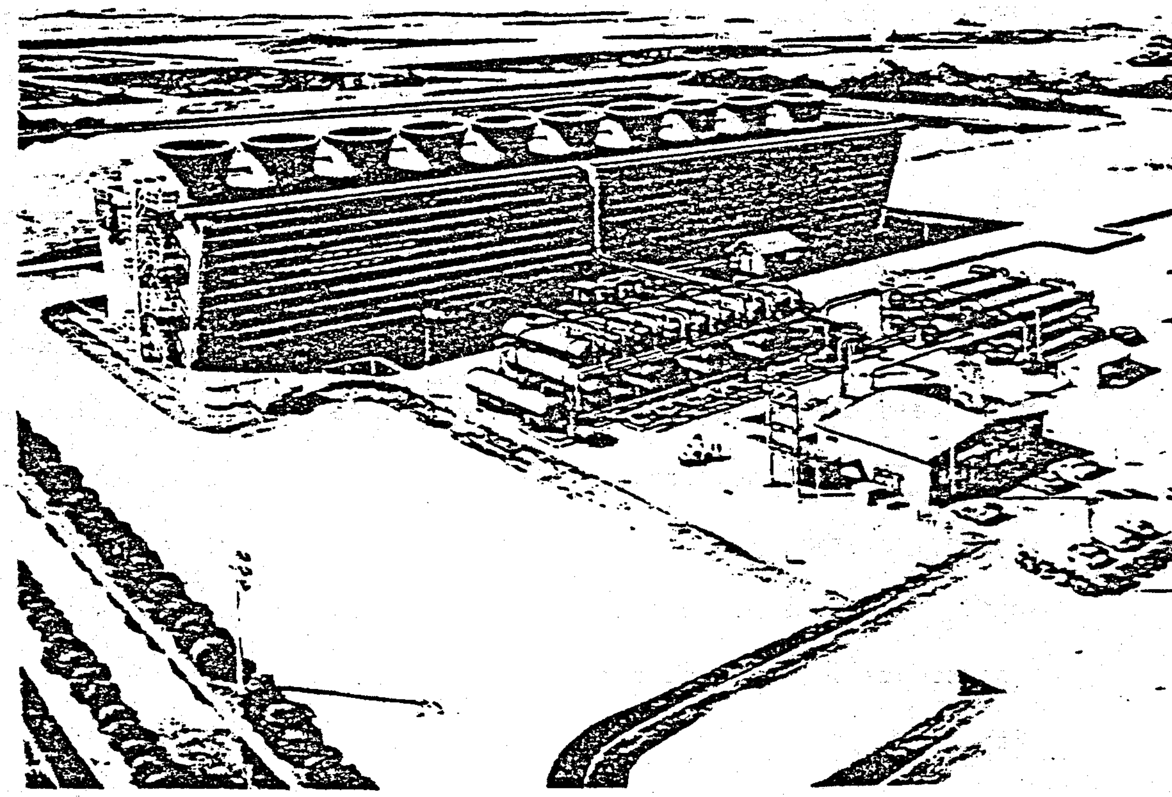

Figure 7. Artist's conception of a 50 MWe binary cycle geothermal power plant with wet-type, mechanical draft cooling tower complex. Reproduced from Wimer *et al.* (1977).

droplets. The presence of this visible plume can cause ground shadowing and may be objectionable to many people for aesthetic reasons.

(b) *Fogging and Icing:* If the saturated plume contacts the ground, local ground fog will occur. Under freezing conditions, this fog can also cause icing of surfaces within the saturated plume. These conditions will persist until mixing reduces the amount of liquid water to a concentration below the saturation amount and all of the added water re-evaporates.

(c) *Drift Deposition:* As air is passed through a wet-type cooling tower, water droplets may be caught in the flow and carried out with the exhaust air as unevaporated or partially evaporated drops which may contain dissolved contaminants. These droplets, typically amounting to 0.001 to 0.01% of the water flow, have settling speeds that depend on their size but which are of the order of 0.1 to 1.0 m $sec^{-1}$, large enough that they break away from the plume and are deposited on the ground. The impact from drift deposition occurs primarily within a few hundred meters of the cooling tower and can contribute to icing of roads, trees, and powerlines, as well as deposition of moisture and chemical residue.

(d) *Precipitation Augmentation:* Precipitation could conceivably be augmented by (i) condensation and fallout of water vapor in the plume, (ii) induced convection and subsequent cumulus cloud formation, (iii) precipitation scavenging of plume droplets, or "washout," or (iv) moisture deposited from drift droplets. However, as Overcamp and Hoult (1971) have shown, the residence time of a droplet in a typical cooling tower plume has been shown to be less than the time required for natural formation of raindrops; consequently, raindrops probably could not be formed in a plume by water vapor condensation alone. Also, except at very large power stations, air and moisture fluxes from cooling towers are small compared with those associated with naturally occurring thunderstorms and it is unlikely that heat release alone could generate thunderstorm clouds except through a dynamic triggering action at the base of an existing cloud. Since the mechanical draft towers typical of geothermal power plants release their effluents at very low levels, these towers are not likely to intensify clouds with bases a few thousand feet above the ground (Huff, 1972).

An estimate of the maximum surface rainfall enhancement that could result from precipitation scavenging of plume droplets can be made by considering the amounts of water involved. Mechanical draft towers at a 100 MW geothermal power plant would emit about $10^5$ g $sec^{-1}$, or about $3.15 \times 10^6$ $m^3$ $yr^{-1}$ of moisture. Areas of geothermal potential in Oregon typically have annual precipitation frequencies of 5 to 15%. With a maximum annual precipitation frequency of 15%, the amount of moisture emitted during periods of precipitation would be about $4.7 \times 10^5$ $m^3$ $yr^{-1}$. If all of this moisture were captured by precipitation and deposited over a circle of radius two km around the site, the resulting addition to annual rainfall would be, at most, 3.7 cm $yr^{-1}$. (Here, we have not considered rainfall intensity or the collection efficiency of falling drops. Consideration of either of these factors will decrease the preceding estimate. Studies made by Dana and Wolf (1977) have indicated that rainfall enhancement resulting from precipitation scavenging of plume droplets can be significant, even in light rains.) Annual precipitation in even the driest parts of Oregon is at least 18 cm. Consequently, precipitation augmentation by this process, though perhaps not insignificant, should be confined locally and may be beneficial in dry, irrigated areas.

Additional precipitation from drift droplets could be significant within a few hundred meters of the tower; this depends upon cooling tower water flow and drift rate.

(e) *Cloud Development:* Although heat and water vapor emissions from mechanical draft cooling towers at a 100 MW geothermal power plant would probably not be large enough to initiate significant cumulus or stratus cloud development, a generating station of 500 MW using the total flow method would have a thermal output of 2300 to 2400 MW, using emission rates calculated by Quong (1977). This is in the same range as mechanical draft cooling towers at Oak Ridge, Tennessee described in a study by Hanna (1974b). In this study, cloud development initiated by a cooling tower complex with a thermal output of 2000 MW was estimated to occur 10% of the time. This included occurrence of a cumulus cloud 0.5 km in depth with base at a height of 0.5 km, and stratus clouds extending to the horizon on rainy days (Hanna, 1974b). So although cloud development is probably insignificant for plants of the 100 MW size range, it could become significant for 500 MW or larger plants in humid conditions.

Koenig *et al.* (1978) tentatively concluded, on the basis of a numerical simulation experiment, that the potential for cloud initiation is larger for dry cooling towers than for wet towers, and therefore that it would be unwise to assume that the more expensive dry towers would prove to be more acceptable from all environmental viewpoints.

(f) *Snow Augmentation:* Little information is available concerning augmentation of snow by cooling towers. Its occurrence would be mainly from droplets being captured by snow crystals falling through the plume (Huff, 1972). There have been observations of snowfall induced from natural draft towers at a 2900 MW nuclear generating station (Kramer *et al.*, 1976) and from mechanical draft towers at Oak Ridge, Tennessee having a thermal output of 2000 MW (Culkowski, 1962).

## IV. DATA REQUIREMENTS

To assess potential impacts of geothermal resource development, an adequate baseline data set must be established. By "baseline" is meant: conditions before development. The required data falls into three general categories:

A. Source data;
B. Meteorological data; and
C. Air quality data.

In what follows, comments about data needs in each of these three categories will be made.

A. SOURCE DATA: Required source data includes information on the various substances that could be released into the atmosphere (emissions), and operating characteristics of the power plant (plant design).

1. *Emissions*: The first requisite in determining severity of atmospheric emissions from a power plant is identification of the kinds and quantities of substances that may be emitted. This entails:

(a) Analysis of the geothermal fluids as they will ultimately be used in power production (i.e. at reservoir depths). Analysis should initially be done for all constituents historically found in geothermal fluids. The U.S. Department of Interior has published a guide (Crittenden, 1977) that lists the following substances: $CO_2$, $H_2S$, $SO_2$, $NH_3$, As, Ag, B, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Mo, $NH_4$, Pb, Se, Sr, and Zn. These constituents should be quantified by accepted laboratory methods as outlined in Presser and Barnes (1974) and Brown, *et al.* (1970);

(b) Analysis of geothermal gases and water at places where they are released naturally into the atmosphere as gas or gas-liquid mixtures, i.e. at naturally occurring hot springs or fumaroles;

(c) Determination of the radioactivity of geothermal fluids; and

(d) Analysis of naturally occurring aerosols, such as dust particles, for those properties that determine impacts on visibility. For a detailed analysis, these properties include size distribution, shape, surface characteristics, refractive index, and homogeneity (Fenn, 1976). However, an estimate of local visibility effects can be measured by a dichotomous particulate sampler and/or nephelometer.

These analyses should be the first goal of a baseline data acquisition project so that subsequent ambient air quality measurements include relevant constituents and properties.

2. *Plant Design*: Besides the composition of the fluid used as input to the power plant, emission characteristics depend on the operating characteristics of the power plant and include:

(a) type of energy conversion cycle used;

(b) cooling tower operation characteristics (including exhaust height, drift droplet size distribution and emission rate, exhaust velocity and volume, etc.); and

(c) type and effectiveness of air pollution control technology used.

The type of power plant may ultimately depend on its cooling water requirements, especially in the more arid regions of eastern Oregon. Hence a hydrological survey of those portions of the state having geothermal potential with the purpose of determining cooling water availability is desirable.

B. METEOROLOGICAL DATA: To assess air quality impacts at a given location (receptor) from a geothermal power plant (source) it is necessary to know (i) the meteorological conditions that govern the movement of emissions from source to receptor and the pollutants' dilution, transformation and removal en route and (ii) climatological conditions that may enhance or mitigate impacts at the receptor.

Since potential pollutants are emitted and transported at different levels above the surface, knowledge of wind flow patterns within the boundary layer, and their seasonal and annual frequency distributions are necessary. Since most plume models require data at plume height (which is dependent upon thermal stratification) diurnal patterns of vertical temperature structure, including inversion heights and their seasonal variation, are also necessary. Hence a baseline data acquisition plan should include:

1. *Atmospheric soundings*, taken over a period of two weeks each season. These may be made using radiosondes, tethersondes, acoustic radar, pibals, or aircraft flights. Whatever method used should be capable of penetrating at least 1 km into the atmosphere and should measure wind speed and direction, temperature, and relative humidity at discrete intervals. To determine diurnal variations, soundings should be made at least twice daily, preferably once in the early morning (just before sunrise) and once at mid to late afternoon, when inversion heights are, respectively, minimum and maximum. If possible, soundings should be made at the point of emissions, i.e. at the expected power plant site. Soundings at other points may be desirable to define upper level flow patterns.

Wind flow patterns at and near the surface are modified by local terrain and diurnal drainage patterns created by differential heating of the surface. Dispersion models capable of handling complex terrain require data at topographically significant points. Hence a second baseline data requirement is:

2. *A Surface Meteorological Recording Network*: The number of stations will be determined by the topographic complexity of the area. Each station should be capable of producing hourly averages of meteorological parameters within the following constraints (Crittenden, 1977): (i) relative humidity or

dew point with an accuracy of ±2°F, (ii) temperature range of -20°F to +130°F, (iii) wind speed starting threshold of 1 mph and an accuracy of 0.5 mph, or 1% of the wind speed, whichever is greater, (iv) precipitation accurate within ±0.01 inch, and (v) data recovery over at least 75% of the base period. If possible, one station should be placed 50 to 200 feet above the ground at the point of projected emissions.

Potential impacts previously mentioned include fogging, icing, and cloud development. To determine the severity of these impacts, it is necessary to know their natural occurrence in the absence of geothermal development. A third baseline data requirement is therefore:

3. *Natural Frequency of Occurrence of Fog and Cloudiness* (cloud type and 1/10's of sky cover): The meteorological data should be gathered over a period of at least one year, as required by the Geothermal Steam Act of 1970. This is necessary to determine the annual and seasonal distribution of parameters.

C. AIR QUALITY DATA: The objectives of an air quality monitoring network are:

1. Characterize the ambient air quality prior to significant changes associated with geothermal development through a baseline data acquisition project.

2. Continue monitoring during development and operation to assess the impact on air quality from power plant operations, and to test models that can subsequently be used to predict impacts from new sources.

Objective 1 implies that the constituents to be monitored should be those which are expected to be released into the atmosphere as a result of geothermal resource utilization. Since these potential pollutants depend on reservoir geochemistry which can vary considerably from site to site, the most effective approach would be to conduct source tests before deciding which constituents to monitor. This is the suggested approach. However, any list of substances to be monitored should include particulates, $SO_x$, $NH_3$, $NO_x$, CO, $H_2S$, and hydrocarbons (Crittenden, 1977), as well as $SO_2$, $CH_4$, B, the trace elements As and Hg, and $^{222}Rn$. $H_2S$ analytical equipment should have a minimum detectable sensitivity of 1 ppbv, with a precision of 10% of full scale. It is also recommended that fine particles be monitored, since it is highly likely that fine-particle, ambient-air-quality standards will soon be set.

In addition, chemical reactions in the atmosphere may produce new constituents. The most prominent example is the oxidation of $H_2S$ to $SO_2$ and sulfate particulate matter, which may degrade visibility. Visibility data should be obtained using a long-path method such as camera or telephotometer for adequate representation of overall visual range (White, 1978), and should be obtained in a manner compatible with EPA PSD (prevention of significant deterioration) criteria, when they become available.

Since there is some uncertainty as tc what substances should be monitored and much uncertainty as to what ambient standards should be imposed for most of the potential pollutants identified, little can be said about methodologies or minimum detectabilities. EPA's Environmental Monitoring and Support Laboratory - Las Vegas is currently engaged in methodology development (Hartley, 1978). A collection of papers relating to sampling methods for geothermal effluents can be found in EPA-600/7-78-121.

In view of the relative infancy of the geothermal industry, especially in Oregon, initial continuous monitoring network designs will be subject to revisions. However, the networks should be designed to conform as closely as possible with local meteorological and topographical conditions and should ultimately indicate concentrations climatologically upwind and downwind of projected or actual emissions. Sampling sites should be in accordance with EPA's standard Air Monitoring Work Group requirements.

Sampling should be done within 5 m of ground level and concentrations should be averaged over small enough time periods that diurnal variations will be evident.

Initial (baseline) monitoring should extend over a period of at least one year to represent seasonal weather variations.

## V. SPECIFIC REGIONS OF OREGON

In this section, we will consider the specific areas of Oregon identified in the planning stages of the Oregon Geothermal Environmental Overview Project and discussed at the Geothermal Workshop held at Portland, 27-28 March 1979. In particular, we will consider the climatology, topography, present air quality, available source and meteorological data, and any unique issues related to geothermal development in each area.

A summary of climatological characteristics of each area is shown in Table 3. The parameter values listed are long-term trends over wide areas and could be different at any particular site. Data from National Weather Service stations mentioned in the text is compiled in two publications: *Climatological Handbook of the Columbia Basin States* (1968 and 1975) and *Climatic Summary of the U.S.* (1930).

The U.S. Geological Survey has done chemical analyses on gases and waters from hot springs scattered throughout the state of Oregon (Mariner, *et al.*, 1974 and Mariner, *et al.*, 1975). Although these analyses were not done for the purpose of characterizing geothermal fluids for impact assessments and omit analysis for some relevant substances (e.g. $H_2S$), they do provide an idea of the wide variety of chemical constituents found in hot spring waters across the state; therefore, the data will be referred to in the present report. A summary of results from these analyses, arranged by areas, is presented in Tables 4, 5, and 6. An open file report on these and more recent analyses including all work done in the state of Oregon by the U.S. Geological Survey is in preparation and will be available during 1979.

## Table 3. Climatological Data[1]

| Area | Temperature (°F) January Mean | Temperature (°F) January Diurnal Range | Temperature (°F) July Mean | Temperature (°F) July Diurnal Range | Temperature (°F) Historical Extremes | Relative Humidity (%)[2] January AM | Relative Humidity (%)[2] January PM | Relative Humidity (%)[2] July AM | Relative Humidity (%)[2] July PM | Precipitation (Inches) Annual | Precipitation (Inches) Snow |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alvord KGRA (Andrews) | 28 | 20-25 | 72 | 40-45 | -30° to 100°+ | 83[3] | 68 | 54 | 21 | 7 | 23 |
| Southern Basin and Range[4] | 30 | 20 | 65-70 | 30-35 | -30° to 105° | 75-80[5] | 60-65 | 75-80 | 25-30 | 10-12 | 25-50 |
| Brothers Fault Zone[6] | 26 | 15-20 | 61-68 | 40 | -30° to 100°+ | 83[3] | 68 | 54 | 21 | 10-12 | 30-50 |
| Newberry Caldera KGRA[7] | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 30 | n.d. |
| Vale Hot Spring KGRA (Ontario) | 25-30 | 20 | 65-70 | 40 | -5° to 107° | 84 | 78 | 52 | 22 | 10 | 18 |
| La Grande (Baker, La Grande) | 26-31 | 15 | 70 | 35 | -20° to 100°+ | 80 | 75-80 | 70 | 30-35 | 10-20[8] | 30-35[8] |
| West Cascades[9] | 35-40[10] | 12-15 | 62-69 | 30-35 | -2° to +105° | 80-90 | 75-80 | 80-90 | 35-45 | 45-80[10] | 20-100[10] |
| High Cascades[10,11] | | | | | | | | | | | |
| East Side | 25-30 | 25 | 60 | 40-45 | -25° to +100° | n.d. | n.d. | n.d. | n.d. | 60-70 | 200-500 |
| West Side | 30-35 | 15 | 60 | 25-35 | 0° to 90° | n.d. | n.d. | n.d. | n.d. | 70-80 | 300-500+ |

1. Data compiled from: *Climatological Handbook of the Columbia Basin States*, Pacific NW River Basins Commission, 1968 and 1975; and *Climatic Summary of the U.S.*, U.S. Weather Bureau, 1930.
2. R.H. at 4:00 A.M. and 4:00 P.M.
3. R.H. data from Burns.
4. Includes Summer Lake, Crump Geyser, Lakeview, and Klamath Falls KGRA's.
5. R.H. data from Klamath Falls. R.H. in S.B.&R. shows eastwardly decreasing pattern. Crump Geyser, Lakeview, and Summer Lake KGRA R.H.'s fall somewhere between Klamath Falls and Burns R.H.'s.
6. Includes Burns Butte KGRA, Glass Buttes area, and Harney Basin.
7. Precipitation data only.
8. Precipitation will be higher at higher elevations. Annual snowfall at Cornucopia is 267 in.
9. Includes Breitenbush, Carey, Belknap-Foley, and McRedie KGRA's. Data compiled from several stations in the area.
10. Due to wide range of elevations in Cascades temperature and precipitation can vary widely over a short distance.
11. Includes Mt. Hood KGRA.

n.d. No data.

Table 4. Surface Temperature (°C), Major Element Composition (mg/l) and Estimated Aquifer Temperature (°C) of Hot Springs in Oregon*

| Spring Name | Temperature (°C) | pH | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Lithium (Li) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Boron (B) | Best Estimate of Aquifer Temp. (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vale KGRA** | | | | | | Malheur County | | | | | | | | | |
| Beulah H.S. | 60 | 7.56 | 170 | 24 | .2 | 200 | 6.0 | .24 | 161 | 1 | 290 | 55 | 4.7 | 4.7 | 86 |
| Neal H.S. | 87 | 7.32 | 180 | 8.8 | .2 | 190 | 16 | .3 | 198 | <1 | 120 | 120 | 9.4 | 4.1 | 173-181 |
| Unnamed H.S. (near Little Valley) | 70 | 8.71 | 115 | 3.2 | <.05 | 160 | 3.2 | .11 | 127 | 1 | 110 | 74 | 6.8 | 4.7 | 119-145 |
| Mitchell Butte H.S. | 62 | 8.69 | 94 | 4.6 | <.1 | 110 | 1.6 | .03 | 72 | 3 | 130 | 28 | 10.4 | .49 | 72 |
| Vale H.S. | 73 | 7.47 | 130 | 19 | .8 | 310 | 16 | .28 | 143 | -- | 100 | 360 | 6.1 | 9.4 | |
| **Alvord KGRA** | | | | | | Harney County | | | | | | | | | |
| Unnamed H.S. (Trout Creek) | 52 | 6.77 | 105 | 18 | .8 | 270 | 10.8 | .68 | 439 | 1 | 204 | 24 | 12.8 | .89 | 144 |
| Hot Lake | 36 | 7.28 | 190 | 16 | .3 | 500 | 31 | .65 | 420 | <1 | 350 | 300 | 9.0 | 16.6 | 165-176 |
| Unnamed H.S. (near Hot Lake) | 96 | 7.30 | 160 | 14 | .3 | 450 | 28 | .51 | 374 | 4 | 434 | 250 | 7.2 | 15 | 165-176 |
| Alvord Springs (Indian Springs) | 76 | 6.73 | 120 | 13 | 2.2 | 960 | 69 | 2.1 | 1,196 | 1 | 220 | 780 | 10.2 | 30 | 150-200 |
| Mickey Springs | 73 | 8.05 | 200 | .9 | .1 | 550 | 35 | 1.1 | 774 | 11 | 230 | 240 | 16 | 10.5 | 179-207 |
| | | | | | | Malheur County | | | | | | | | | |
| Unnamed H.S. (near McDermitt) | 52 | 8.79 | 72 | .6 | <.1 | 130 | 1.0 | .06 | 237 | 13 | 52 | 14 | 6.6 | 1.1 | 105-118 |
| **Breitenbush H.S. KGRA and Carey H.S. KGRA** | | | | | | Clackamas County | | | | | | | | | |
| Austin H.S. | 86 | 7.63 | 81 | 35 | .1 | 300 | 7.1 | .4 | 56 | <1 | 140 | 430 | 1.4 | 2.6 | 88 |
| | | | | | | Marion County | | | | | | | | | |
| Breitenbush H.S. | 92 | 7.31 | 83 | 100 | 1.3 | 720 | 31 | 1.8 | 142 | <1 | 140 | 1,300 | 3.4 | 4.1 | 127-149 |
| **Crump Geyser KGRA** | | | | | | Lake County | | | | | | | | | |
| Fisher H.S. | 68 | 7.93 | 77 | 8.4 | 1.0 | 92 | 7.9 | 0.4 | 105 | 1 | 59 | 56 | 3.5 | 2.2 | 123 |
| Crump (Charles Crump's Spring) | 78 | 7.26 | 180 | 16 | .2 | 280 | 11 | .4 | 153 | <1 | 200 | 240 | 4.9 | 13.6 | 144 |

*Compiled from Data in Mariner, et al., "Chemical Composition and Estimated Thermal Reservoir Temperatures of Selected Hot Springs in Oregon," USGS Open File Report, 1974.

Table 4. - Continued (Page 2)

| Spring Name | Temperature (°C) | pH | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Lithium (Li) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Boron (B) | Best Estimate of Aquifer Temp. (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lakeview KGRA | | | | | | Lake County | | | | | | | | | |
| Barry Ranch H.S. | 88 | 7.76 | 130 | 8.8 | .1 | 280 | 9.0 | .15 | 232 | 2 | 240 | 170 | 5.4 | 11.2 | 140-153 |
| Hunter's H.S. | 96 | 7.77 | 140 | 13 | <.1 | 210 | 8.5 | .15 | 79 | <1 | 260 | 120 | 4.4 | 6.9 | 149 |
| Summer Lake KGRA | | | | | | | | | | | | | | | |
| Summer Lake H.S. | 43 | 8.43 | 94 | 2.1 | .1 | 390 | 4.6 | .15 | 406 | 10 | 120 | 280 | 2.2 | 6.9 | 112-134 |
| Klamath KGRA | | | | | | Klamath County | | | | | | | | | |
| Olene Gap H.S. | 74 | 7.68 | 98 | 40 | .2 | 190 | 7.2 | .15 | 53 | <1 | 400 | 59 | 1.2 | 1.0 | 80 |
| Belknap-Foley H.S. KGRA | | | | | | Lane County | | | | | | | | | |
| Belknap H.S. | 71 | 7.62 | 96 | 210 | .2 | 690 | 15 | .95 | 17 | <1 | 170 | 1,300 | 1.2 | 6.4 | 82 |
| Cougar Reservoir H.S. | 44 | 7.76 | 50 | 225 | .1 | 392 | 6.3 | .52 | 19 | <1 | 260 | 788 | .8 | 5.1 | 49 |
| McRedie H.S. KGRA | | | | | | | | | | | | | | | |
| McRedie Springs | 73 | 7.29 | 79 | 460 | .9 | 1,000 | 22 | 1.4 | 21 | -- | 240 | 2,200 | 2.7 | 18 | |
| Newberry Caldera KGRA | | | | | | Deschutes County | | | | | | | | | |
| East Lake H.S. | 62 | 6.49 | 36 | 38 | 16 | 32 | 3.8 | 0.1 | 184 | -- | 58 | 0.4 | 0.2 | .93 | |
| La Grande | | | | | | Baker County | | | | | | | | | |
| Radium H.S. | 58 | 9.56 | 78 | 1.5 | 0.1 | 58 | 1.1 | 0.01 | 86 | 27 | 34 | 17 | 1.3 | 0.42 | 77 |
| | | | | | | Union County | | | | | | | | | |
| Medical H.S. | 60 | 8.23 | 80 | 72 | .2 | 190 | 7.0 | .05 | 26 | <1 | 400 | 77 | 1.2 | 2.2 | 67 |
| Hot Lake | 80 | 9.21 | 48 | 4.9 | <.1 | 130 | 2.7 | .03 | 75 | 12 | 56 | 140 | 1.7 | 2.9 | 90 |

Table 4. - Continued (Page 3)

| Spring Name | Temperature (°C) | pH | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Lithium (Li) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Boron (B) | Best Estimate of Aquifer Temp. (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Harney Basin** | | | | | | | Harney County | | | | | | | | |
| Unnamed H.S. (near Harney Lake) | 68 | 7.26 | 92 | 12 | 1.8 | 630 | 13 | .45 | 566 | 1 | 140 | 590 | 3.3 | 11.3 | 130 |
| Crane H.S. | 78 | 8.10 | 83 | 3.7 | .1 | 170 | 3.9 | .09 | 202 | 3 | 86 | 79 | 9.0 | 7.9 | 127 |
| **Others** | | | | | | | Wasco County | | | | | | | | |
| Kahneeta H.S. | 52 | 8.32 | 104 | 3.2 | <.05 | 325 | 3.4 | .52 | 493 | 9 | 34 | 155 | 21 | 2.6 | 103-139 |
| | | | | | | | Umatilla County | | | | | | | | |
| Lehman Springs | 61 | 9.18 | 44 | .9 | .1 | 53 | .7 | .03 | 101 | 13 | 23 | 5.4 | 2.1 | .12 | 73 |
| | | | | | | | Grant County | | | | | | | | |
| Weberg H.S. | 46 | 6.53 | 82 | 38 | 7.8 | 610 | 36 | .7 | 1,710 | 1 | 13 | 50 | 3.9 | 15 | 130 |
| Blue Mountain H.S. | 58 | 7.96 | 47 | 2.2 | .2 | 140 | 3.3 | .07 | 323 | 3 | 11 | 15 | 10.6 | 1.6 | 99-126 |
| Ritter H.S. | 41 | 9.68 | 70 | 1.4 | <.05 | 72 | .82 | .01 | 86 | 28 | 9 | 29 | 4.0 | 2.6 | 71 |
| | | | | | | | Malheur County | | | | | | | | |
| Unnamed H.S. (at Three Forks) | 34 | 8.11 | 40 | 10.5 | .7 | 61 | 1.2 | .04 | 108 | 1 | 34 | 18 | 4.2 | .11 | 44 |
| Unnamed H.S. (near Riverside) | 63 | 7.43 | 110 | 34 | .5 | 240 | 9.7 | .27 | 160 | <1 | 290 | 140 | 4.8 | 6.6 | 138-142 |

Table 5. Chemical Composition of Gases Escaping from Hot Springs in Oregon (volume percent)

Compiled from Data in Mariner, et al., "Minor and Trace Elements, Gas, and Isotope Compositions of the Principal Hot Springs of Nevada and Oregon," USGS Open File Report, 1975.

| Spring Name | | Oxygen ($O_2$) + Argon (Ar) | Nitrogen ($N_2$) | Methane ($CH_4$) | Carbon dioxide ($CO_2$) |
|---|---|---|---|---|---|
| Vale Hot Springs KGRA | | | | | |
| Neal H.S. | Malheur County | 12 | 62 | 6 | --[1] |
| Alvord KGRA | | | | | |
| Mickey Springs | Harney County | 18 | 60 | 1 | 23 |
| Crump Geyser KGRA | | | | | |
| Crump (Charles Crump's Spring) | Lake County | 5 | 75 | 6 | 14 |
| Lakeview KGRA | | | | | |
| Barry Ranch H.S. | Lake County | 2 | 54 | 42 | 2 |
| McRedie Hot Springs KGRA | | | | | |
| McRedie Springs | Lane County | 1 | 98 | <1 | <1 |
| Newberry Caldera KGRA | | | | | |
| East Lake H.S. | Deschutes County | 6 | 30 | 9 | 56 |
| La Grande | | | | | |
| Hot Lake | Union County | 2 | 90 | 9 | <1 |
| Harney Basin | | | | | |
| Unnamed H.S. (near Harney L.) | Harney County | 1 | 91 | 1 | 9 |
| Others | | | | | |
| Lehman Springs | Umatilla County | 4 | 94 | <1 | <1 |
| Weberg H.S. | Grant County | 1 | 1 | 2 | 95 |

1/ Insufficient sample for analysis.

Table 6. Minor and Trace Elements for Hot Springs Sampled in Oregon (mg/l)*

| Spring Name | Aluminum (Al) | Ammonia (as N) | Phosphate (as P) | Arsenic (as As) | Bromide (Br) | Iodine (I) | Rubidium (Rb) | Cesium (Cs) | Strontium (Sr) | Iron (Fe) | Manganese (Mn) | Copper (Cu) | Mercury (Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <u>Vale H.S. KGRA</u> | | | | | | Malheur County | | | | | | | |
| Beulah H.S. | .006 | .20 | .06 | .21 | .1 | .03 | <.02 | <.1 | .17 | <.02 | .03 | .01 | .0001 |
| Neal H.S. | .008 | .80 | .07 | .02 | .5 | .06 | .09 | .1 | .16 | <.02 | .06 | .02 | .0001 |
| Unnamed H.S. (near Little Valley) | -- | -- | -- | -- | -- | -- | .02 | <.1 | <.05 | <.02 | <.02 | <.01 | .0007 |
| Mitchell Butte H.S. | .015 | .30 | .04 | <.01 | .2 | .01 | <.02 | <.1 | <.05 | <.02 | <.02 | <.01 | .0001 |
| Vale H.S. | .017 | .80 | -- | -- | -- | -- | .09 | <.1 | -- | <.02 | .04 | <.01 | -- |
| <u>Alvord KGRA</u> | | | | | | Harney County | | | | | | | |
| Unnamed H.S. (Trout Creek) | 0.002 | 0.02 | .02 | -- | -- | -- | .10 | .1 | .30 | .08 | <.02 | .03 | .0003 |
| Hot Lake | -- | -- | .29 | .01 | 2 | .2 | .23 | .1 | .42 | <.02 | .03 | .03 | .0004 |
| Unnamed H.S. (near Hot Lake) | .020 | .13 | .39 | -- | -- | -- | .18 | .1 | .60 | <.02 | .04 | .01 | .0008 |
| Alvord Springs (Indian S.) | .003 | .70 | .14 | .04 | 2 | .09 | .33 | .2 | .92 | .12 | .02 | .05 | .0001 |
| Mickey Springs | .058 | .30 | .24 | .01 | 1 | .09 | .20 | .1 | .15 | <.02 | <.02 | .05 | .0001 |
| | | | | | | Malheur County | | | | | | | |
| Unnamed H.S. (near McDermitt) | 0.013 | 0.08 | 0.02 | 0.05 | 0.4 | 0.008 | <0.02 | <0.1 | <0.05 | <0.02 | <0.02 | <0.01 | 0.001 |
| <u>Breitenbush H.S. KGRA and Carey H.S. KGRA</u> | | | | | | Clackamas County | | | | | | | |
| Austin H.S. | -- | -- | .02 | .59 | 2 | .03 | .03 | <.1 | .33 | <.02 | <.02 | <.01 | .0002 |
| | | | | | | Marion County | | | | | | | |
| Breitenbush H.S. | -- | -- | .08 | .51 | 5 | .1 | .18 | .1 | .73 | .02 | .22 | .01 | .0002 |
| <u>Crump Geyser KGRA</u> | | | | | | Lake County | | | | | | | |
| Fisher H.S. | .011 | .14 | .06 | .10 | .4 | .03 | .02 | <.1 | .05 | <.02 | <.02 | <.01 | <.0001 |
| Crump (Charles Crump's Spring) | .017 | .47 | .19 | .46 | .4 | .1 | .07 | .1 | .12 | <.02 | .03 | <.01 | .0004 |

*Compiled from Data in Mariner, et al., "Minor and Trace Elements, Gas, and Isotope Compositions of the Principal Hot Springs of Nevada and Oregon," USGS Open File Report, 1975.

Table 6. - Continued (Page 2)

| Spring Name | Aluminum (Al) | Ammonia (as N) | Phosphate (as P) | Arsenic (as As) | Bromide (Br) | Iodine (I) | Rubidium (Rb) | Cesium (Cs) | Strontium (Sr) | Iron (Fe) | Manganese (Mn) | Copper (Cu) | Mercury (Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lakeview KGRA | | | | | | Lake County | | | | | | | |
| Barry Ranch H.S. | .014 | 1.4 | .06 | .07 | 1 | .1 | .04 | <.1 | .17 | <.02 | <.02 | <.01 | .0017 |
| Hunter's H.S. | .034 | .24 | .08 | .06 | .4 | .08 | .04 | <.1 | .32 | <.02 | <.02 | <.01 | .0004 |
| Summer Lake KGRA | | | | | | | | | | | | | |
| Summer Lake H.S. | -- | -- | .06 | .02 | 1 | -- | <.02 | <.1 | .07 | <.02 | <.02 | .02 | -- |
| Klamath KGRA | | | | | | Klamath County | | | | | | | |
| Olene Gap H.S. | -- | -- | .06 | .09 | .08 | .01 | .02 | <.1 | .58 | <.02 | <.02 | .01 | -- |
| Belknap-Foley H.S. KGRA | | | | | | Lane County | | | | | | | |
| Belknap H.S. | -- | -- | .07 | .35 | 33 | .2 | .05 | <.1 | 1.4 | .02 | .02 | .01 | <.0001 |
| Cougar Reservoir H.S. | -- | -- | -- | -- | -- | -- | .03 | <.1 | 2.0 | <.02 | <.02 | <.01 | .0005 |
| McRedie H.S. KGRA | | | | | | | | | | | | | |
| McRedie Springs | .010 | .20 | .20 | -- | -- | -- | .11 | .1 | -- | .02 | .10 | .02 | -- |
| Newberry Caldera KGRA | | | | | | Deschutes County | | | | | | | |
| East Lake H.S. | -- | -- | -- | -- | -- | -- | <.02 | <.1 | .14 | <.02 | .10 | .01 | .0003 |
| La Grande | | | | | | Baker County | | | | | | | |
| Radium H.S. | -- | -- | 0.03 | <0.01 | 0.01 | 0.007 | <0.02 | <0.1 | <0.05 | <0.02 | <0.02 | <0.01 | 0.0005 |
| | | | | | | Union County | | | | | | | |
| Medical H.S. | -- | -- | -- | -- | -- | -- | .02 | <.1 | .80 | <.02 | <.02 | <.01 | .0004 |
| Hot Lake | -- | -- | .03 | .01 | .4 | .08 | <.02 | <.1 | <.05 | <.02 | <.02 | .01 | .0032 |

Table 6. - Continued (Page 3)

| Spring Name | Aluminum (Al) | Ammonia (as N) | Phosphate (as P) | Arsenic (as As) | Bromide (Br) | Iodine (I) | Rubidium (Rb) | Cesium (Cs) | Strontium (Sr) | Iron (Fe) | Manganese (Mn) | Copper (Cu) | Mercury (Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Harney Basin** | | | | | | | | | | | | | |
| | | | | | | Harney County | | | | | | | |
| Unnamed H.S. (near Harney Lake) | .005 | 1.4 | .07 | .60 | 29 | .2 | .08 | <.1 | .11 | .05 | .04 | .02 | .0001 |
| Crane H.S. | .022 | 2.5 | .03 | .09 | .1 | .02 | .03 | <.1 | .06 | <.02 | <.02 | .01 | .0005 |
| **Others** | | | | | | | | | | | | | |
| | | | | | | Wasco County | | | | | | | |
| Kahneeta H.S. | -- | -- | -- | -- | -- | -- | .02 | <.1 | <.05 | <.02 | <.02 | <.01 | .0003 |
| | | | | | | Umatilla County | | | | | | | |
| Lehman Springs | -- | -- | .04 | .02 | .006 | .001 | <.02 | <.1 | <.05 | <.02 | <.02 | <.01 | .0003 |
| | | | | | | Grant County | | | | | | | |
| Weberg H.S. | -- | -- | .04 | .04 | .1 | .1 | .09 | <.1 | 2.10 | .24 | .06 | .18 | .0003 |
| Blue Mountain H.S. | -- | -- | .04 | <.01 | .04 | .01 | <.02 | <.1 | <.05 | <.02 | <.02 | <.01 | .0004 |
| Ritter H.S. | -- | -- | -- | -- | -- | -- | <.02 | <.1 | <.05 | <.02 | <.02 | .01 | .0005 |
| | | | | | | Malheur County | | | | | | | |
| Unnamed H.S. (at Three Forks) | -- | -- | -- | -- | -- | -- | <.02 | <.1 | .06 | <.02 | <.02 | <.01 | -- |
| Unnamed H.S. (at Riverside) | -- | .40 | .07 | .04 | .5 | .03 | .04 | <.1 | .42 | <.02 | .04 | .01 | .0001 |

A. ALVORD DESERT: This area consists mainly of the Alvord Desert Known Geothermal Resource Area (KGRA), an area of 176,835 acres in the remote SE corner of Oregon.

1. *Topography*: The Alvord Desert KGRA consists of the Alvord Desert Basin (elevation 4100 ft) oriented roughly NNE-SSW, bounded on the west by the Steens Mountains which rise to 9100 ft at their highest point, and on the east by a plateau area with elevations near 4300 ft and cut by small intermittent streams and drainages. Dimensions of the basin are roughly 30 to 35 miles long by 10 miles wide.

2. *Climate*: Eastward moving maritime air masses from the Pacific Ocean, which have already lost much of their moisture ascending the Cascades, are further reduced in moisture content by the Steens Mountain Range. Consequently the area's climate is generally arid. Mean annual precipitation is about seven inches at Andrews, most of which occurs in the months of November to March with very little during the summer. Snowfall accounts for much of the precipitation. During the summer the major source of precipitation is from occasional thunderstorms.

Large-scale (synoptic) flow patterns produce generally westerly winds at upper levels, but topographical features tend to channel these winds at the surface into a more N-S oriented direction. Occasionally, there are intrusions of dry continental air from western Canada that produce more northerly, light winds and periods of extreme cold that may last for days or weeks at a time. Warm, Santa Ana type winds are common in the winter and spring, with strongest winds occurring during March to June. During the summer, high surface temperatures create turbulent updrafts which can carry large quantities of dust aloft, producing dust clouds and dust storms. Dust devils occur frequently during the summer.

3. *Available Data*

(a) *Source Data*: The only available source data are chemical analyses done by Mariner, *et al.*, (1974, 1975) on water from hot springs in and around the Alvord Desert KGRA. These analyses showed relatively high amounts of boron at four of the six hot springs sampled and a relatively high amount of mercury at an unnamed hot spring near Hot Lake.

(b) *Air Quality Data*: No records of air quality for the area exist. However, essentially the only source of particulate matter at present is dust from occasional high wind storms and the only local source of noxious gases is from infrequent vehicular traffic. Consequently, at present, the air is generally pristine.

(c) *Meteorological Data*: Meteorological data are sparse and consist almost exclusively of surface temperature and precipitation data from National Weather Service climatological stations in the area. These stations include Andrews within the KGRA, and Juniper Lake, approximately 10 miles north of the KGRA. The nearest stations that have data on winds aloft are Burns and Winnemucca. The Winnemucca station also makes routine observations of vertical temperature structure. There is no surface wind data for the KGRA except for 11 years of monthly average, prevailing wind direction at Andrews; these data do not include any data on speed frequencies or distributions. The Physics Department at the University of Oregon maintains instruments to record solar radiation and energy at Whitehorse Ranch, a few miles east of the KGRA. These instruments will be supplemented in the near future by wind recording equipment from the Atmospheric Sciences Department at Oregon State University, to be used in wind power studies (Hewson and Baker, 1978).

4. *Potential Issues and Special Considerations:* Geological and sample evidence indicate a large geothermal reservoir with temperatures >350°F. This evidence makes utilization of geothermal energy for electrical production the most likely type of development. Therefore, consideration of environmental impacts should include all aspects of exploration, construction, and operation of a power plant. Because of the remoteness and sparse population, any direct utilization will probably be on a small scale.

Several climatological and meteorological features of the Alvord KGRA may tend to enhance certain aspects of environmental impact, particularly on air quality:

(a) Because of the extreme cold temperatures that sometimes persist for long periods of time, there are potentials for enhanced fog and cloud conditions and for icing through release of water vapor from wet cooling towers. These releases would lead to degradation of visibility locally, and could also increase the humidity of the region if large-scale development occurs.

(b) Because of the aridity of the region, strong radiational cooling could establish strong surface temperature inversions. With the semi-enclosed nature of the basin and periodic cold spells, temperature inversions could lead to pollutant buildups and visibility degradation.

(c) Dryness of the region implies dry soil conditions as evidenced by frequent dust storms. Visibility and air quality could be degraded through increased particulate loading of the atmosphere derived from vehicle traffic and construction activities.

(d) Decreased visibility is of special consideration because of aesthetic and philosophical viewpoints about polluting one of the few areas in Oregon that possesses pristine air quality. These aesthetic and philosophical viewpoints could create other issues of confrontation concerned, for example, with the subjective "visual pollution" of power plants in an otherwise primitive landscape.

(e) Because of the aridity of the region, there is uncertainty about the feasibility of using a binary system or any system that requires supplemental cooling water. Dry-type cooling towers may be necessary.

B. BROTHERS FAULT ZONE: This region extends from the foothills of the Cascade Mountain Range near Bend, eastward to the Burns area and the northern tip of the Steens Mountains. It is defined by the Brothers Fault Zone, a major structural lineament (Hull, *et al.*, 1977a). Areas of geothermal interest within this region are Burns Butte and Newberry Caldera KGRA's, the Glass Buttes heat flow anomaly, and Harney Basin.

1. *Topography*: The Burns Butte KGRA consists of one square mile in the foothills WNW of Burns, at its highest point an elevation of 4900 ft, surrounded by irregular foothill terrain to the north and flatland to the south. The Glass Buttes area consists of a low range of hills about 2900 ft above the surrounding land with an elevation of 6400 ft at its highest point. Locally, the terrain in the Glass Buttes area varies from high rocky outcroppings to relatively flat terraces. These two areas have similar irregular and complex topography, which may cause difficulty in developing realistic air quality models.

The Harney Basin area lies at the extreme east portion of the Brothers Fault Zone and consists of a large enclosed basin containing Harney and Malheur Lakes at an elevation of about 4100 ft. The land is fairly level with occasional low hills.

Newberry Caldera KGRA comprises Newberry Crater near Bend, a collapsed volcano with elevations at the rim over 7000 ft and containing two very cold lakes, Paulina Lake and East Lake, at elevations near 6000 ft. The outer slopes taper down to about 4000 to 4500 ft within 10 to 20 miles.

2. *Climate*: Lying in the rain shadow of the Cascades, the Brothers Fault Zone's major climatic characteristics are aridity, wide temperature ranges, short, warm summers and cold winters.

Except at Newberry Crater, annual precipitation is 10 to 12 inches, mostly occurring during November to March with a secondary maximum in May and June, probably caused by convectionally-produced rainfall associated with increased land heating. July and August are usually dry as the North Pacific High Pressure Zone becomes dominant. Much of the winter precipitation occurs as snow. The water budget shows marked seasonality, with eastward increasing deficits in summer and westward increasing surpluses in winter. Cold, dry periods occasionally occur during periods of continental high pressure buildup in Canada and overflow into this area.

Four year windroses at Burns for January show W to SW winds 15 to 20% of the time with 58% calm conditions (speed <3 mph). For July, winds are NW to N 40% with 22% calm. Annual windroses show NW 25 to 30% with 37% calm. Local windstorms with speeds >60 mph occasionally occur, especially during spring. Warm SW winds in winter and spring can melt accumulated snow and create rapid runoff. Air movement in areas of broken topography is often gusty and can trigger severe dust storms.

Newberry Caldera KGRA was included in the Brothers Fault Zone area because it lies at the westernmost end of that fault; however, it is climatologically different. The Newberry Caldera KGRA receives about three times the precipitation of other geothermal areas in the zone and temperatures should be lower though no long-term temperature data are available for the immediate vicinity. An annual-mean precipitation map of Deschutes National Forest shows a singularity in the vicinity of Paulina Lake of about 30 inches annually. The very cold temperature of the lakes, with the enclosed nature of the rim, make this area susceptible to strong temperature inversions. However, the consequences of strong inversions are difficult to assess because ventilation conditions are unknown.

3. *Available Data*

(a) *Source Data*: Apparently, there are no data available concerning chemical composition of geothermal fluids or natural emissions in the Glass Buttes area. Nevertheless, the area has geothermal potential based on geological evidence, mainly temperature gradient data from the drilling of a water well (Hull, *et al.*, 1977a). The principal economic mineralization of the area is mercury, so its presence in geothermal fluids in high concentrations is a reasonably good possibility. There are no known hot springs in the Glass Buttes area and the uninhabited nature of the area makes it likely that any development in the area would be for power generation using either binary or flash systems.

Similarly, no geochemical data appear to exist for Burns Butte KGRA. Several "warm" springs are present but the authors have found no estimates of aquifer temperatures in the area. Proximity to the communities of Burns and Hines suggests that both direct and indirect utilizations would be economically viable.

Two wells located NE of Burns, 15 to 20 miles from Burns Butte KGRA, have been found to contain abnormally high amounts of boron and arsenic (Leonard, 1970). Further information on water resources can be found in Appendix A of EAR No. 1* (1977).

Two springs in the Harney Basin area were included in studies by Mariner, *et al.* (1974 and 1975). One of them, an unnamed hot spring near Harney Lake, indicated relatively high amounts of boron and arsenic (see Tables 4 and 5). Similar analyses were done by Leonard (1970) on several springs in the area. Lynch Spring, on the west side of Harney Basin, has been noted to smell of $H_2S$ (EAR No. 1, 1977).

Results of analyses mentioned above indicate geothermal reservoir temperatures of about 260°F (see Table 4), not hot enough for electrical power generation. Present and past uses in the area include a natatorium (heated swimming pool) at Crane Hot Spring, and greenhouse heating.

East Lake Hot Spring in Newberry Crater was included in analyses done by Mariner *et al.* (1974 and 1975). This analysis showed a high amount of $CO_2$ gas (see Table 5). Though no direct evidence is available, geological evidence suggests that Newberry Caldera KGRA may have a geothermal reservoir with temperatures >300°F (Hull, *et al.*, 1977a), making it a candidate for geothermal electrical power production.

(b) *Meteorological Data*: No climatological data stations are located within the Glass Buttes area; however, long-term data from nearby stations should be representative. Nearby stations are at Brothers (30 mi NW), and

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*EAR (Environmental Analysis Record) refers to studies done by the U.S. Bureau of Land Management District Offices. These are numbered independently in the Reference section.

Suntex and Squaw Butte (20 mi E). The nearest first-order climatological station is at Burns (60 mi E). This station routinely records surface meteorological data and has historical records of winds aloft, although it no longer makes routine soundings.

Burns Butte KGRA is located adjacent to the Burns National Weather Service station and is therefore well-represented for most meteorological parameters except for vertical temperature structure. However, the complexity of the terrain requires that development in this area be preceded by a more extensive data acquisition program, particularly wind flow at surface points and vertical temperature structure.

In addition to the National Weather Station at Burns, the Atmospheric Sciences Department at Oregon State University maintains a windrun anemometer on Burns Butte for wind power studies. This instrument is at an elevation of 8307 ft, 35 ft above local ground level. It began operation in December 1976 and provides monthly average wind speeds (Hewson and Baker, 1978). However, the windpower site is at a location of expected high winds, rather than "typical" winds.

Climatological stations in the Harney Basin area for which there are long-term surface temperature and precipitation data include Malheur Refuge Headquarters, Buena Vista Station, and 00 Ranch. The nearest first-order climatological station is at Burns, which borders Harney Basin on the north side.

The only available data within the Newberry Caldera KGRA is precipitation data at Paulina Lake. These data show an annual precipitation of 30 inches. Nearby surface climatological data can be obtained from stations at Brothers (35 to 40 mi E) and Bend (20 mi N). However, these sites may not be representative of conditions at Newberry Crater, especially within the rim. The nearest first-order climatological station is at Burns (100+ mi E).

(c) *Air Quality Data:* Air quality is not monitored anywhere within the region but should generally be very good with two exceptions:

(i) During periods of high winds and dry conditions, mainly during the late spring and summer, dust storms contribute to the particulate loading of the atmosphere.

(ii) In the vicinity of Burns, effluents from the Hines Mill can degrade the air quality in that area under inversion conditions. Low traffic volume, absence of large population centers, and small numbers of polluting industries in the region make other contaminant sources nearly negligible.

4. *Potential Issues and Special Considerations:* There are features of the Brothers Fault Zone that may influence the severity of air quality impacts of geothermal energy development. These features include those previously mentioned for the Alvord Desert, including the region's aridity and periods of cold that may lead to local climate modification and visibility degradation (see Alvord Desert section).

In addition:

(a) Because of the area's pristine nature, uniqueness, and scenic attractiveness, development at Newberry Crater may be opposed on general principles. Specific objections may include all objections associated with any type of development in the area. For example, a citizen's group in Bend has effectively halted consideration of development inside the crater rim. However, development could still occur on the outer slopes. Primary issues would include decreased visibility and visual pollution.

(b) Newberry Crater within the rim is an area of relatively simple terrain. However, because of its uniqueness, two further characteristics should be considered:

(i) It appears that the inner rim could be susceptible to strong surface temperature inversions. Hence, emphasis should be placed on determining strengths, frequencies, and heights of inversions and stable layers. These data could probably most readily be acquired with a tethersonde with penetrative capabilities of at least 1500 ft.

(ii) Because of the elevation of Newberry Crater above the surrounding landscape, some data on vertical wind speeds might be desirable in addition to thermal structure. These data could be used to determine the degree of impact at receptors at lower elevations. This is speculative. Also, wind data should be taken at points around the outside slopes to provide a detailed picture of air flow around the crater.

(c) Glass Buttes and Burns Butte KGRA are areas of relatively complex terrain. Modeling requirements will be more stringent.

(d) The Harney Basin area includes a large part of the Malheur Wildlife Refuge and Diamond Crater's proposed Natural Resource Area. Though current knowledge indicates this area's potential is for direct utilization, it is not conclusive. Air quality issues here would include those factors that affect local wildlife, such as cooling tower emissions of $H_2S$.

C. SOUTHERN BASIN AND RANGE: This region consists of much of the northern part of the vast Great Basin that covers parts of Oregon, Nevada, California, Arizona, and New Mexico. The region includes Crump Geyser, Lakeview, Klamath Falls and Summer Lake KGRA's.

1. *Topography*: The land generally comprises several enclosed undrained basins at elevations of 4000 to 4500 ft, separated by largely N-S oriented highlands or plateaus. These basins are characteristically steep

on one side and gently sloped on the other as a result of block faulting and tilting, with dimensions typically 25 to 50 miles N-S and 10 to 25 miles E-W. Many of them contain remnants of ancient pluvial lakes such as Summer Lake (in Summer Lake KGRA), Lake Abert, and Crump Lake (Crump Geyser KGRA).

Klamath Falls KGRA lies near the southern extremity of Upper Klamath Lake near the center of the Greater Klamath Basin, whose western edge is formed by the Cascade Mountain Range. This KGRA also includes some of the more complex terrain (foothills and broken plateau lands) of the perimeter of the Southern Basin and Range province, as well as the city of Klamath Falls.

The Lakeview KGRA includes the city of Lakeview.

2. *Climate*: The region is situated in the lee of the Cascade Mountains and is thus removed from the moderating influence of the Pacific Ocean. The climate is similar to that of the Brothers Fault Zone and is characterized by small amounts of precipitation, clear dry air, maximum solar radiation, and extreme diurnal temperature ranges (see Table 3). The basins are characterized by slightly higher average temperatures than the highlands, moderately channeled winds, and susceptibility to temperature inversions, especially during wintertime continental air penetration from western Canada.

Most of the annual precipitation occurs in the winter months with a secondary maximum during May and June. Summers are dry, with most precipitation from thunderstorms. A substantial part of the winter precipitation is snow, with annual amounts variable depending on elevation but generally 25 to 50 inches per year. Typically, the snow occurs during isolated storms over a several-months period. The ground typically has ample time to clear between storms; consequently, snow accumulations are usually small on the open ground of the basin floors.

Surface windroses for Klamath Falls show SW to SE winds 30 to 40% of the time with 42% calms (speed ≤3 mph). July windroses show northwesterly winds 40 to 50% with 46% calms. Throughout the region, the prevailing (synoptic scale) winds are generally westerly but with more southerly flow during the winter and northerly during the summer. Strongest winds occur during the months of November to June; lighter winds, steered by local topography and diurnal drainage, can vary from site to site.

3. *Available Data*

(a) *Source Data*: Spring waters analyzed by Mariner *et al.* (1974 and 1975) have indicated relatively high concentrations of boron and arsenic in Crump Spring (Crump Geyser KGRA) and high concentrations of boron, mercury, and methane gas in waters from Barry Ranch Hot Springs (Lakeview KGRA) (see Tables 4-6). Adel Hot Spring and Fisher Hot Spring (Crump Geyser KGRA) have also been noted to "smell of $H_2S$" (EAR No. 6, 1975).

Chemical analyses of 57 wells and hot springs in the vicinity of Klamath Falls KGRA have been reported by Sammel (1976). These include analyses for the constituents Na, $SO_4$, Ca, $HCO_3$, Cl, B, K, $CO_3$, Silica ($SiO_2$) and As, but not $H_2S$, $NH_3$ or Hg. It should be noted that some of the conclusions reported in Sammel (1976) have been modified based on new information and changes will be reported in a scientific publication in preparation (Sammel, 1979).

Temperature gradient data from various wells and pre-drilled holes in the area have been tabulated in publications by the Oregon Department of Geology and Mineral Industries (Bowen, *et al.*, 1975; Hull, *et al.*, 1978). Surface temperatures and flow rates have also been reported for five springs in the Summer Lake KGRA (EAR No. 7, 1976) and 15 springs and wells in the vicinity of Klamath Falls KGRA (EAR No. 4). However, none of these data or any other presently available is sufficient to characterize geothermal fluids adequately for the purpose of estimating potential air quality impacts of geothermal development in the area.

(b) *Meteorological Data*: There are several National Weather Service climatological stations in the region. These include: Paisley, in the Summer Lake KGRA; Adel, Plush, and Hart Mountain National Antelope Refuge in and near Crump Geyser KGRA; Lakeview in Lakeview KGRA; and Klamath Falls in Klamath KGRA. Records from Klamath Falls include long-term annual, monthly, and hourly means of surface wet- and dry-bulb temperatures, cloud cover, ceiling height, and relative humidity. The nearest first-order station is at Burns, near the extreme NE portion of the region. There are no long-term data on vertical temperature structure or stability class frequencies anywhere in the region. The OSU Atmospheric Sciences Department maintains windrun Anemometers at Adel and in the Coyote Hills, near Crump Geyser KGRA, for wind power studies (Hewson and Baker, 1978). However, these data show only monthly average wind speeds and are located at high points not representative of orographically steered winds in the basins.

(c) *Air Quality Data*: The only station in the region that is regularly monitored for air quality is Klamath Falls where total suspended particulate (TSP) and $SO_2$ have been monitored since 1970 and 1974, respectively. Annual geometric means for TSP have been about 70 μg $m^{-3}$ with some downward trend. Annual means of $SO_2$ have been consistently lower than 13.1 μg $m^{-3}$ (Oregon Air Quality Report 1977, 1978). (13.1 μg $m^{-3}$ is the concentration at the lowest limit of detection for the methods used.)

Except near the larger communities of Klamath Falls and Lakeview, air quality should be good. The only main sources of particulates are nature and agriculture. Dry winds during the summer create local dust storms and increase dust and hay pollen concentrations. Other sources of air contaminants are smoke from burning garbage dumps, sawmills, and dust from numerous unsurfaced roads. Near the larger communities, additional sources of air pollutants are automobile exhausts, smoke from home heating units, heating fuels, and slash- and mill-waste burning.

No quantitative data is available for specific contaminants of interest, e.g. $H_2S$. It has been noted that some hot springs in the area smell of $H_2S$ and concentrations of .002 to .03 ppm have been reported. These concentrations encompass typical thresholds of odor detection.

4. *Potential Issues and Special Considerations*

(a) Aridity and wide temperature ranges imply the same potential impacts already discussed for the Alvord Desert and Brothers Fault Zone: decreased visibility and icing and fogging potential. Availability of supplemental cooling water may not be large a question because of the presence of many pluvial lakes in the basins; however, this depends on the exact siting.

(b) The enclosed basins in the region may be susceptible to temperature inversions that will trap pollutants. During periods of stagnation, air pollution buildups could occur. Also, since many of the enclosed basins contain lakes, there could be natural occurrences of low level fog when cold air settles over the water. This phenomenon could be enhanced by water vapor emissions from cooling towers.

(c) This region includes the Summer Lake Game Management area, an important waterfowl habitat, and the Hart Mountain Natural Antelope Refuge in the highlands east of Warner Valley in Crump Geyser KGRA. Consequently, any eventual impact assessment should include a study of the effect of geothermal effluents on biological receptors.

(d) At the southern end of Summer Lake, along the Chewaucan River, is an area heavily used for recreation. Here, issues relating to air quality such as odor nuisance and visibility impairment may be particularly controversial.

(e) This region includes the Gearhart Mountains Wilderness Area, located 20 to 30 miles NE of Klamath KGRA and 20 to 30 miles NW of Lakeview KGRA. As an automatically-designated Federal Class 1 area, it is protected by the Clean Air Act Amendments of 1977 from any degradation of visibility.

D. WESTERN SNAKE RIVER PLAIN: This region is located in extreme eastern Oregon and forms the westernmost portion of the Snake River Plain. It includes the enlarged Vale KGRA, comprising about 23,000 acres around the city of Vale.

1. *Topography*: In the general area, the terrain varies from flat or gently sloping near Vale and Ontario at an elevation of 2000 ft, to gently sloping, rising gradually to 5000 ft, in the western portions of the area 40 to 50 miles west. At the southern edge of the region, the land comprises many high ridges and deep canyons. In the north, the region is bordered by the southern portion of the Blue Mountains.

Vale KGRA lies mostly just SSE of Vale and includes the city of Vale. The Vale KGRA topography consists of Rhinehart Buttes, a series of buttes with elevations up to 3200 ft, broken by intermittent drainages. The KGRA is bounded on the north and west by the Malheur River, which flows through the town of Vale at the base of the buttes. Near Vale the river makes a sharp bend from N-S to E-W and is joined by Willow Creek from the NW. Thus, depending on the precise plant location, cooling tower emissions could have a significant impact on the town of Vale, especially if the cooling towers were located near the Malheur River where low level winds could be channeled by the river basin into the town. In general, it can be expected that requirements for complex-terrain, air-quality models will be moderate to severe.

2. *Climate*: The climate of the area is typical of eastern Oregon, with hot, dry summers and cold winters. The climate is influenced by both the Cascade and Blue Mountains, which serve to remove moisture from eastward moving air masses. Consequently, as it reaches this area, the air is more typically continental in nature.

In general, annual temperature means show little variation in the area, ranging from 48.8°F at Beulah (elevation 3000 ft in the western portion of the area) to 52.5°F at Owyhee Dam (elevation 2400 ft, at the southern perimeter). For further details, see Table 3.

The area is subject to periodic intrusions of continental air masses from inland western Canada or the Great Basin to the southeast. This leads to periodic extreme cold spells with resulting persistent stable or inversion conditions. Although there are no long-term records of vertical temperature in the immediate area, long-term records from Boise, Idaho (approximately 50 miles east and also located in the Snake River Plain in a similar environment) may be representative. Boise data indicate that the probabilities of occurrence of a stable layer or temperature inversion with base below 1640 ft (500 m) in January are 61% and 43%, respectively, for 1200 Greenwich Mean Time (GMT) (0400 Local Mean Time (LMT)) and 38% and 22%, respectively, for 0000 GMT (1600 LMT). The probabilities of a stable layer or inversion with base below 500 m that persists for longer than five days are 5 to 8% and 1 to 2%, respectively. These figures are probably more representative of flat-land areas around Vale than near Ontario, because of the similarity of the Boise Airport and Vale sites. Stability episodes are probably more frequent and severe in the canyons and basins around the perimeter of the general area.

Much of the precipitation (40%) occurs during the winter with small amounts (10%) during the summer, primarily from convective thunderstorms.

Surface data for Ontario show predominantly W to SW winds in January with strongest winds (10.5 mph) from the SSE. Calms (<3 mph) occur about 58% of the time. In July the prevailing direction is NW to NNW, strongest winds (12.5 mph hourly average) are from the NNW, and calms occur 23% of the time. These figures may not accurately represent conditions at Vale as the Snake River valley may channel the winds at Ontario.

3. *Available Data*

(a) *Source Data:* Several hot springs in the region were included in chemical analyses done by the U.S. Geological Survey, including Vale Hot Springs (in the town of Vale), Neal Hot Springs, Mitchell Butte Hot Spring, and an unnamed hot spring near Little Valley, 5 to 10 miles west of Vale. Analysis of Vale Hot Springs water showed a concentration of boron generally higher than that for most other waters analyzed.

Three heat flow anomalies have been identified within and near the Vale KGRA, at Cow Hollow, Willow Creek, and Jacobsen Gulch (Bowen, *et al.*, 1975; Bowen and Blackwell, 1975). These anomalies may indicate a large reservoir with temperatures >300°F, making this area a prime candidate for electrical power production. In fact, this is the largest presently identified such reservoir in Oregon, and may have a potential of 870 MW over a period of 30 years (Bowen, 1979).

No deep well data is available, and there has been no analysis of $H_2S$ concentrations in any waters in the area.

(b) *Meteorological Data*: Long-term surface records of temperature and precipitation are available for several climatological stations in the area, including Beulah, Juntura, Nyssa, Ontario, Owyhee Dam, and Vale. Records for Ontario include: long-term hourly means by month of wet-bulb temperature, dry-bulb temperature, and relative humidity; monthly frequency of occurrence of wind speed and direction; joint distributions of temperature/wind speed/ relative humidity by months; and frequency of cloud cover in tenths by months.

No upper-level wind or stability data are available within the region. The nearest station regularly recording these data is the NWS station at Boise Airport, 50 miles east of Ontario. Data from this station may at best approximate conditions at Vale but orographic effects probably lead to significant differences.

(c) *Air Quality*: Air quality is not presently being monitored on a continuous basis anywhere within the region; however, the quality of the air should be generally good except in the immediate vicinity of the communities of Ontario and, to a lesser extent, Vale and Nyssa, though more data are needed to test this hypothesis. Particulate matter is primarily from dust storms during the non-irrigating season, when winds stir up dust from dry fields. Other sources of particulate matter are smoke from range fires, trash burning, and home heating. There could also be an industrial contribution from potato processing plants in Ontario and Nyssa as well as from traffic along I-80 and near the population centers of Vale, Ontario, and Nyssa. No conclusive statements can be made without further air quality monitoring.

4. *Potential Issues and Special Considerations*: Geological and sample evidence indicate that Vale and vicinity may be above a large geothermal reservoir with temperatures adequate for electrical generation, and in fact may be the most likely such site in Oregon. Certain aspects of the region may tend to enhance the air quality impact of such development.

(a) Because of the periodic extreme cold spells characteristic of eastern Oregon, there may be potential for increased fogging and icing from water vapor emissions from a plant utilizing a wet cooling tower(s).

(b) Because of the agricultural nature of the region, special emphasis should be placed on the effects of potential emissions on sugar beet, onion, and potato crops. Some studies have been done on these subjects (Bennett, 1977; Shinn, *et al.*, 1976; Thompson and Kats, 1978).

(c) Dryness of the region implies dry soil conditions. This could enhance the local air quality impact of construction and road-building activities through increased particulate loading of the atmosphere.

(d) It should also be noted that plans are in effect for direct utilization of geothermal fluid at the Ore-Ida Potato Processing plant in Ontario. However, because of the closed nature of the proposed system, air quality impacts should be negligible.

E. LA GRANDE: The La Grande geothermal interest area includes parts of Baker and Union counties in northeast Oregon. In particular, it comprises the Grande Ronde and Baker Valleys. There are no KGRA's in the area.

1. *Topography*: The terrain of the area generally shows high relief, varying from high rugged mountains to deep valleys and rolling hills. The region includes the two large valleys Grande Ronde and Baker, drained by the Grande Ronde and Powder Rivers, respectively.

The Grande Ronde Valley is roughly diamond-shaped with its largest axis about 20 miles long, oriented SSE-NNW. The city of La Grande lies at its westernmost apex. Baker Valley is an oval-shaped basin some 17 miles in length NW-SE, with the city of Baker at its south end. The two valleys are separated by foothills of about 5500 ft in elevation and it is in this general area that geothermal interest is centered because of the presence of numerous known hot springs and the Craig Mountain Fault Zone.

This area is further bounded by more foothills rising 600 to 1200 ft above the Baker Valley floor and 2500 to 3500 ft above the Grande Ronde Valley, and which lead eventually to the high peaks of the Blue Mountains to the north and west, and the Wallowa Mountains to the east, with elevations up to 10,000 ft.

2. *Climate*: In general, the climate of the area is dry with high summer temperatures and low winter temperatures and is influenced by the Cascade and Blue Mountain Ranges. Because of the wide range of elevations and exposures, local climates within the area are diverse.

Because of the enclosed nature of the Grande Ronde and Baker Valleys, they are subject to periodic inversion conditions which may sometimes last for days. Primarily for this reason, the Oregon Energy Facility Siting Council has classified them as less than suitable for nuclear and coal-fired power plants (Huggins, *et al.*, 1978).

Annual precipitation varies widely: 23.4 inches at Elgin, 20.3 inches at La Grande, and 11.3 inches at Baker at the southernmost point of the region. Most of the precipitation occurs in the winter with about 75% as snow. Annual snowfall amounts vary from 31.3 inches at Baker to 267.3 inches at Cornucopia (elevation 4700 ft).

Prevailing wind directions follow the orientation of the valleys, roughly SE to NW. In winter, winds are generally S to SE with average speeds of 7 mph at Baker and 13.9 mph at La Grande airport. In the summer, surface flow is reversed to NW with average speeds of 6 to 7 mph in both cities.

Windroses for January and July show calms (speed ≤3 mph) 16% and 37% of the time at La Grande and Baker, respectively, for January, and 22% and 41% at La Grande and Baker, respectively, for July. Under calm conditions, flow patterns are more influenced by orographic and diurnal effects and hence are more site specific. It might be anticipated that greatest air pollution potential would be under light northerly wind and stable conditions, when effluents would tend to drift toward Baker at the extreme south end of Baker Valley.

3. *Available Data*

(a) *Source Data*: Hot springs for which chemical analyses were done by the U.S. Geological Survey (Mariner, *et al.*, 1974 and 1975) include Medical Hot Springs, Hot Lake, and Radium Hot Springs in the La Grande area. Geothermal reservoir temperatures estimated from these analyses are about 160 to 190°F, insufficient for electrical power generation. A high mercury concentration was found in the waters of Hot Lake (see Table 6).

Additional information on the composition of water from warm springs and wells in the area is tabulated in Huggins, *et al.* (1978). The objective of this survey was to identify the location, ownership, surface temperature, and composition of 27 springs and wells in the area. Consequently, the results are inadequate for making an assessment of the composition of deep fluids that would be used for energy applications.

A well 236 ft deep was drilled near Baker by the Oregon Department of Geology and Mineral Industries. The purpose was to compare solar radiation versus geothermal heat for heating near-surface waters. A description of this and other monitor wells in the state can be found in Bowen, *et al.* (1975).

(b) *Meteorological Data*: Long-term records of surface temperature and precipitation are available from numerous National Weather Service stations in the area, including Baker, La Grande, Elgin, Cove, and Union. In addition, stations at Baker and La Grande also routinely record surface wind, relative humidity, and sky cover.

The nearest station from which data on winds aloft are available is Pendleton, 50 miles west, across the Blue Mountains and in a different climatic regime. There are no long-term data on vertical temperature structure or inversion frequencies for the area.

The Atmospheric Sciences Department at Oregon State University has been collecting wind data in the area for windpower analysis since October 1977. Instruments at Haines and La Grande record monthly average wind speeds from windrun anemometers at 30 to 50 ft in height. In addition, an hourly strip chart recorder is being maintained at the La Grande elevator, connected to an instrument at 136 ft in height, which gives hourly wind velocities, including direction (Hewson and Baker, 1978).

(c) *Air Quality Data*: The only air contaminant currently being monitored in this area is TSP, which has been monitored since 1970 in La Grande and Baker. There have been numerous violations of the air quality standards for this area but since most violations can be attributed to naturally entrained dust, these areas are considered to have met the particulate standards (Oregon Air Quality Report 1977, 1978). No records exist for other, more relevant, contaminants but as Baker and La Grande are cities of some 10,000 population, contributions from nonindustrial sources could be significant. At points at higher elevations outside the valleys, air quality should be excellent.

4. *Special Issues and Considerations*

(a) Geological and sample evidence presently available indicates reservoir temperatures below that necessary for electrical power generation; hence, any development here is likely to be through direct utilization, e.g. district space heating. Unless this assessment changes with further study, air quality impacts will be minimal and characteristic of direct utilization, e.g. pipeline leaks, emissions encountered in well drilling, dust suspension during construction, etc.

(b) In the event of development of larger scale than is anticipated (for example, electrical power generation) air quality impacts in this area probably will be heightened. In particular, it is noted that the closed-in nature of the terrain and the area's susceptibility to inversions could serve to trap effluents at low levels.

(c) In general, this is an area of steep terrain with high relief. This could have a pronounced effect on local flow patterns and could make modeling efforts difficult, depending on the particular site.

(d) This area is heavily used for recreational purposes. Consequently, impacts that would be tolerable in more urban environments may be intolerable here. In particular, the Eagle Cap Wilderness area, located in the Wallowa Mountains to the northeast, is a designated Federal Class 1 area and is thus protected from visibility degradation by the Clean Air Act Amendments of 1977.

F. WESTERN CASCADES: This region includes the Cascade Mountains west of the crest with elevations roughly 1500 to 4000 ft. It includes four KGRA's: Breitenbush, McRedie Hot Springs, Belknap-Foley Hot Springs, and Carey Hot Spring.

1. *Topography*: The terrain of the region is characterized by steep, generally E-W oriented ridges, which are divided by valleys and canyons cut by the Clackamas, Santiam, and McKenzie Rivers, and smaller drainages. These canyons and valleys are subject to frequent temperature inversions and stability episodes from nighttime, cold-air drainage. The situation is further complicated by the rugged and complex terrain that steers low level winds and will make modeling attempts extremely difficult.

2. *Climate*: The most significant climatological factor of the Cascade Range is its presence as a barrier to incoming maritime air masses from the Pacific Ocean. When these air masses are orographically lifted by the mountains they are cooled adiabatically, and almost always result in condensation and copious amounts of precipitation. Because of the great local relief, precipitation can vary significantly over short distances, especially in

snowfall amounts. In general, the amounts vary with proximity to the crest of the range, with largest amounts falling near the crest on the west side.

Annual amounts of precipitation near the KGRA's range from 70 to 80 inches near Breitenbush and Carey Hot Springs and 70 inches near Belknap-Foley Hot Springs, to 45 to 55 inches near McRedie Hot Springs. Most of the precipitation occurs from November to February with very little during July and August.

A large part of the winter precipitation occurs as snowfall, varying greatly with elevation. Annual mean snowfall ranges from 20 inches at Oakridge (elevation 1300 ft, near McRedie Hot Springs KGRA) to 151 inches at Marion Forks Fish Hatchery (elevation 2475 ft, near Breitenbush KGRA). As an example of the local variation, at Wicopee (elevation 2877 ft) snow data for 23 years between 1931 and 1965 show an annual mean of 92.5 inches. At Oakridge Salmon Hatchery, data for roughly the same period show an annual mean of 20.6 inches. Yet these stations are only 7 to 8 miles apart (both near McRedie Hot Springs KGRA).

During the summer, most of the precipitation is associated with convective thunderstorms.

Temperatures, represented by data at stations at elevations of 1300 to 2500 ft, average 48 to 52°F annually, with January means 35 to 40°F and July means 62 to 69°F. Because of the variety of elevations, temperatures may vary over short distances. Diurnal ranges average 12 to 15°F in winter and 30 to 35°F in summer. Occasionally, there are periods of continental air penetration from east of the Cascades, especially through the Columbia River Gorge. This situation produces the most extreme temperatures, driest conditions, and strongest thermal stability.

Wind data are sparse but the strongest winds, associated with eastward moving storm systems, are west to southwesterly and occur during the winter months. Summertime strong winds are northwesterly and are associated with the subtropical high pressure zone which is usually established over the Pacific during these months. Summer winds are generally not so strong as winter winds.

Light winds occur more frequently than high winds and are more significant with respect to air pollution. Flow patterns under these conditions are more dependent on local topography and diurnal drainage patterns than synoptic weather patterns, and consequently may vary from drainage to drainage.

3. *Available Data*

(a) *Source Data*: Studies by Mariner, *et al.* (1974, 1975) included chemical analyses of surface water from several hot springs in the West Cascades (see Tables 4 and 5). These analyses showed relatively high concentrations of arsenic in Austin Hot Springs and Breitenbush Hot Spring (Breitenbush and Carey KGRA's) and in Belknap Hot Spring (Belknap-Foley KGRA), and a high boron concentration in McRedie Hot Spring (McRedie KGRA).

These analyses also indicated that Breitenbush KGRA is the only presently identified KGRA in the region with geothermal fluids hot enough to support electrical power generation. Nevertheless, because data is so sparse, the West Cascades could still have potential as a geothermal electrical power source. It has been postulated, in fact, that this region could eventually prove to be one of the biggest fields with electrical power generation potential in the world (Bowen, 1979). Its importance as a potential energy source is further enhanced by its proximity to major population centers and energy markets in the Willamette Valley.

(b) *Meteorological Data*: Meteorological data are also sparse and consist almost solely of long-term monthly and annual means and extremes of surface temperature and precipitation from National Weather Service climatological stations. These include Marion Forks Fish Hatchery, Detroit, and Three Lynx (in and near Breitenbush and Carey Hot Springs KGRA's), McKenzie Bridge and Belknap Springs 8N (Belknap-Foley Hot Springs KGRA), and Wicopee and Oakridge Salmon Hatchery (McRedie Hot Spring KGRA).

The only first-order NWS station close to the areas of interest that regularly records hourly and upper level data is at Salem (elevation 200 ft), 30 to 40 miles west of Breitenbush KGRA and at a lower elevation in the Willamette Valley. It is doubtful that data from Salem would be applicable to sites in the West Cascades, except for synoptic scale winds.

NWS stations at Medford (elevation 1315 ft) and Sexton Summit (elevation 3836 ft) in southern Oregon routinely record hourly surface data. The Medford station also makes upper air observations daily, but these stations are remote from the KGRA's, lying some 100 to 150 miles south of McRedie Hot Spring KGRA, the southernmost of the KGRA's.

The Department of Atmospheric Sciences at Oregon State University maintained a windrun anemometer on Snow Peak (elevation 4200 ft) near Breitenbush KGRA from June 1976 to February 1977. Data from this site consist only of monthly average wind speeds used in a study of windpower potential in Oregon (Hewson and Baker, 1978), and are not representative of orographically steered winds at lower elevations.

Various studies and reports on meteorology and air quality in the Willamette Valley are available from Oregon Department of Environmental Quality (DEQ) and OSU Atmospheric Sciences Department but the applicability of these studies to regions of the West Cascades is questionable.

(c) *Air Quality Data*: No air quality data are available anywhere in the region but air quality is generally very good because of remoteness from industrial activity and heavy vehicle traffic. At present, the only major contributors of TSP are smoke from slash burning and field burning in the Willamette Valley. Logging operations and lumber mills may contribute to local concentrations of particulate matter.

4. *Potential Issues and Special Considerations*

(a) The nature of the terrain of the West Cascades could lead to local, severe stagnation conditions. This emphasizes the necessity for long-term monitoring of the vertical structure of the atmosphere *locally* as part of any baseline studies. This should include data on the vertical structure of temperature, wind, and moisture fields that shows their diurnal variations. Also necessary are continuous monitoring of temperature, relative humidity, wind speed and direction at surface locations in the local area of interest.

(b) The rugged terrain characteristic of the area will serve to steer low level winds, and ventilation conditions will be uncertain. Any modeling undertaken for this area will have to utilize models capable of handling complex three-dimensional flow fields.

(c) High relative humidity and periodic low temperatures of the area would serve to heighten the occurrence of visible cooling tower plume and fogging/icing episodes.

(d) The West Cascades region is an area noted for its scenic beauty and recreational opportunities. Hence, the biggest obstructions to geothermal development would probably be those factors that degrade the pristine nature of the area. In terms of air quality, these would include visibility degradation, presence of visible plumes, and $H_2S$ odors. The degree of impact of these factors cannot be estimated on the basis of available data.

(e) Some of the areas of the West Cascades adjoin pristine wilderness areas, most notably Breitenbush KGRA, which adjoins the Mt. Jefferson wilderness area (USDA-FS-R6-FES(ADM)-77-3, 1978). This and other wilderness areas in the Cascades are automatically designated Federal Class 1 areas, protected from visibility degradation by the Clean Air Act Amendments of 1977. Air quality and visibility preservation requirements will be especially severe in these areas.

(f) In view of the large amounts of snowfall in the region, consideration should be given to the effects of deposition and accumulation of geothermal effluents on the snowpack and their flushing with the spring thaws.

G. HIGH CASCADES: The High Cascades region comprises the higher elevations and crest of the Cascade Range, with elevations above 5000 ft and including several peaks with elevations around 10,000 ft. It includes Mt. Hood KGRA in the northernmost portion of the region.

1. *Topography*: The terrain of sites in the High Cascades may be typified by Mt. Hood KGRA. This KGRA includes the tip of Mt. Hood (elevation 11,235 ft) and its slopes down to 6000 to 7000 ft. These slopes have wide-open exposure and are largely covered by glacial ice. Though the probability of large-scale utilization of geothermal energy in this KGRA is small, the ventilation effect of these slopes is obvious.

Sites within the High Cascades at slightly lower elevations may have less exposure and more limited ventilation conditions depending on the specific location. Such sites would have conditions similar to those described in the West Cascades section.

2. *Climate*: The climate of the High Cascades is governed by the same factors as the West Cascades. The major difference is that with the higher elevations most of the wintertime precipitation is snow. This region has recorded some of the largest snowfall amounts in the United States.

Annual precipitation varies significantly on a west to east traverse of the Cascade crest. Amounts range from 85 inches at Musick (elevation 5530 ft, west of crest), 69 inches at Crater Lake (elevation 6475 ft, just east of crest), to 46 inches at Fish Lake (elevation 4839 ft, in southern Cascades) and about 20 inches at Chemult (4760 ft, east side of Cascades near foothills).

Annual snowfall amounts at selected stations include 430 inches at Musick, 541 inches at Crater Lake, 500 inches at Mt. Hood Ski Meadows (bordering Mt. Hood KGRA), 324 inches at Odell Lake, 183 inches at Fish Lake, and 167 inches at Chemult. This snow remains on the higher peaks year-round.

January mean temperature, represented by stations at 4500 to 6500 ft, are near 25 to 30°F on the east side and 30 to 35°F on the west. July means are near 60°F at all points in this elevation range. Temperatures at higher elevations such as Mt. Hood KGRA should be significantly lower. January daily ranges are about 15°F on the west side of the crest and 25°F at the higher elevations east of the crest. July daily ranges are 25 to 35°F on the west and 40 to 45°F on the east.

Little information on relative humidity is available for elevations representative of this region but is expected to be near 80 to 90% in January and 20 to 30% in July. This should show considerable variation east to west and values will be lower during periods of continental dry air penetration from east of the Cascades.

Wind data are nearly nonexistent. Prevailing directions on the west side are westerly, with tendencies to SW in winter and NW in summer. Near the crest there are periods of easterly flow, especially during the winter when the continental high pressure system is established. Winter wind data from a 30 ft high anemometer at Mt. Hood Ski Meadows (elevation 6600 ft, bordering Mt. Hood KGRA) show mean monthly speeds of 15 to 18 mph, predominantly SSW but with occasional lighter east winds. Data for 29 years at Government Camp (elevation 3900 ft, near Mt. Hood KGRA) show prevailing SW winds during every month except December and January when the prevailing direction is east.

During periods of calm or light winds, the rugged terrain of the area should have a significant effect on air-flow patterns at lower elevations.

3. *Available Data*

(a) *Source Data*: There is virtually no useful source data in the High Cascades. The only chemically analyzed hot springs waters are from Kahneeta Hot Springs on the lower east side of the range. This data suggests reservoir temperatures of 210 to 280°F (Mariner, *et al.*, 1974 and 1975).

At elevations representative of this province, the only known geothermal manifestations are warm springs and fumaroles on Mt. Hood and this is the basis for its designation as a KGRA. Nevertheless, the areas surrounding the High Cascade volcanos are some of the most promising geothermal resource areas of the state (Hull, *et al.*, 1977).

Northwest Natural Gas of Portland is in the process of doing exploratory drilling near Mt. Hood KGRA and plans to do chemical analyses of subsurface water in the near future. This utility may provide a source of data in the future.

(b) *Meteorological Data*: Long-term climate data, consisting of monthly and annual means of surface temperature and precipitation are available at several stations at elevations representative of the High Cascades, including those mentioned previously. Data from Government Camp include prevailing direction, and maximum total precipitation for 1 to 12 consecutive hour periods.

No data for upper level wind, temperature, or relative humidity distributions are available at sites representative of the High Cascades. The nearest such station is Salem, in a much different climatic regime.

The U.S. Forest Service collects meteorological data at Mt. Hood Ski Meadows for avalanche forecasts. These data are available for winter months since 1975 and include wind speed and direction from a 30 ft anemometer, snow depth, water equivalent, and maximum, minimum and mean daily temperatures. These data are available from the Rocky Mountain Forest and Range Experiment Station in Denver, Colorado.

The Atmospheric Sciences Department, Oregon State University, maintained a windrun anemometer on Snow Peak from June 1976 to February 1977 (see Meteorological Data, West Cascades). This department also maintains a wind spectrum analyzer at Tygh Ridge (elevation 3083 ft) just east of the Cascades in northern Oregon, which may have wind data locally representative of the east portion of the northern High Cascades (Hewson and Baker, 1978).

(c) *Air Quality Data*: No long-term data on air quality exist for the High Cascades. The air quality should be generally near pristine at these elevations with the excellent ventilation conditions and absence of contaminant sources. The only major source is smoke from slash burning and occasional forest fires. The extent of Willamette Valley field-burning smoke penetration to these areas is unknown.

4. *Potential Issues and Special Considerations*

(a) Evidence of geothermal resources in the High Cascades is geological and nothing conclusive can be said of its potential for direct utilization. Any near-term utilization is likely to be direct (see item b). However, the area has been estimated to be potentially one of the biggest fields in the world with temperatures sufficient for electrical power production and should be so considered.

(b) Mt. Hood KGRA is a wilderness designated area and under Forest Service regulations is unavailable for development. However, plans are underway for geothermal heating of Timberline Lodge and Northwest Natural Gas Co. of Portland is investigating the potential for piping geothermal heat to the urban areas of the Willamette Valley. Immediate emphasis should be placed on determining the impact of long distance transport of heated fluids, e.g. microclimate modification in the immediate vicinity of a hot pipeline, (buried or above surface), and the probability and nature of potential leaks and resultant emissions into the immediate atmosphere.

(c) The most obvious climatic characteristic of this province is its snowfall. Research is necessary into the question of deposition of contaminants onto the snowpack, i.e., what will be the effect on water resources quality of a season-long accumulation of a pollutant (e.g. boron) and its subsequent flushing in the spring?

(d) The High Cascades region, like the West Cascades, is an area of scenic beauty and recreation; hence the biggest obstacle for geothermal development in this area is the possibility of compromising its pristine nature. The Mt. Hood wilderness area is an automatically designated Federal Class 1 area. In this connection, emphasis should be placed on determining the degree of impact of geothermal development in terms of visibility degradation, as well as the presence and persistence of visible cooling tower plumes, and $H_2S$ odors. Data necessary for such determination are insufficient in all categories.

## VI. SUMMARY OF KEY ISSUES

On 28-29 March 1979 a Geothermal Workshop was held at Portland, Oregon to identify and discuss environmental issues associated with geothermal energy development in Oregon. Table 7 presents potential *air quality* issues identified by the Air Quality subgroup of that meeting. However, it was evident from discussions that:

1. The paucity of available data prevents any firm identification and prioritization of potential issues that are specifically air quality related. Additional data requirements will be discussed in the next section. Until these data needs are satisfied, air quality issues must remain conjectural.

2. The main issues that may impede or obstruct geothermal development in the state are probably broad issues that are not easily categorized but which are fundamental and relate to public attitudes. For this reason, key issues here are divided into general issues and air quality issues.

### A. GENERAL ISSUES

1. *Environmental Concern*. Because of the relative infancy of the geothermal industry and lack of a suitable example typical of the type of development that may ultimately occur in Oregon, public awareness is confused by uncertainties. As an example, much has been said of the $H_2S$ problem at The Geysers, but The Geysers is a vapor-dominated field, the first of its kind to be developed. Much of the $H_2S$ problem arose from inefficiency of $H_2S$ abatement systems retrofitted to existing units. These iron catalyst $H_2S$ control systems have been only 40 to 70% effective (Joyce and Fontes, 1978). In contrast, geothermal fields in Oregon are probably of the liquid-dominated type

Table 7. Potential Air Quality Issues

| | FLASH | BINARY | DIRECT |
|---|---|---|---|
| GENERIC ISSUES | Fugitive dust from construction activities<br>Cooling towers<br>Geothermal fluid emissions | Fugitive dust from construction activities<br>Cooling towers<br>Accidental releases of binary fluid | Fugitive dust from construction activities<br>--<br>Population growth and associated effects on air quality |
| | | SITE SPECIFIC ISSUES | |
| La Grande | N.A.(1) | N.A. | Resuspension-L(2) |
| Vale | $H_2S$-Odor, Crops-H(2)<br>Trace Elements, Crops-M(2)<br>Fog, Ice, etc.-L/H(3)<br>Plume Visibility-L<br>Resuspension-L | Fog, Ice, etc.-L/H(3)<br>Plume Visibility-L<br>Resuspension-L | Population Growth-M<br>Resuspension-L |
| Alvord | Visibility-H(6)<br>Plume Visibility-M<br>Fugitive Dust-L/H(5)<br>Trace Elements-L/M(4) | Plume Visibility-M<br>Fugitive Dust-L/H(5) | Population Growth-M/H<br>Fugitive Dust-L/H(5) |
| Brothers | " | " | " |
| Southern Basin | " and $H_2S$-M | " | " |
| High Cascades | Visibility-H(6)<br>$H_2S$ Odor-H(6)<br>Trace Elements-L/M<br>Resuspension-L | Visibility-H(6)<br>Resuspension-L | Resuspension-L |
| Western Cascades | " | " | " |

Notes

(1) N.A. = Not applicable (based on the development forecasts suggested).

(2) Severity of the issue was judged qualitatively as low (L), medium (M), or high (H). This "severity" generally reflects our estimate of the public's perception of the severity of the issue or, in some cases, the actual severity if no abatement procedures were followed. However, for example for the case of $H_2S$ in the Vale area, state standards could be set (e.g., 10 ppb $H_2S$) so that the issue probably could be avoided.

(3) Our lack of agreement about the severity of inadvertent weather modification effects reflects both scientific uncertainties and the lack of information about specific site locations in relation, for example, to highways or airports.

(4) We have hedged on the severity of trace element emissions until information is supplied about the sensitivity of biological receptors.

(5) The severity of fugitive dust (resuspension) in the Alvord desert will depend on the care taken during construction activities.

(6) Visibility and odor problems in the High and Western Cascades and Alvord Desert were judged to be highly significant not so much because of enhancement of the effects compared with effects in other areas but because of the high aesthetic value placed on these areas by some Oregonians.

liquid-dominated type and can be developed using more up-to-date methods, including the more promising EIC upstream scrubbing process, which may have an efficiency of over 97% (Hartley, 1978). Research is currently being conducted on the applicability of this process to the flashed-steam system (see p. 91). It is also possible that binary systems will be used, in which case emissions other than heat and water vapor will be eliminated.

There is also a degree of mistrust in the public's attitude, a "guilty until proven innocent" philosophy. No doubt, this philosophy has gained more followers since recent events at Three Mile Island.

Perhaps the best solution to the problem of public distrust of new technologies would be the construction of a small (50-100 MW) demonstration plant at a promising site such as Vale, Oregon. Such a demonstration plant could be sponsored by state and federal agencies and could serve as an example of environmentally sound development of geothermal resources in Oregon.

2. *Aesthetics*: It will probably be a source of confrontation that many of the most promising geothermal resource sites in Oregon are located in areas noted for their scenic beauty or pristine nature, such as the Cascades or the Alvord Desert. Even given that development can proceed in an environmentally sound manner, many people will oppose development on the grounds that the few pristine areas left should remain untouched and that we should "cinch up" rather than keep looking for new energy sources. However, although there are issues arising from basic philosophical viewpoints, problems may also be eased with the construction of a demonstration plant that would "show the people of Oregon what a geothermal electrical power generating plant really looks like."

## B. AIR QUALITY ISSUES

One of the purposes of this study was to identify and prioritize those air quality issues, *real or imagined*, which may impede geothermal energy development in Oregon. It is difficult if not impossible to estimate the probability, let alone the severity, of potential air quality impacts on the basis of information presently available. Also, the degree to which specific issues might obstruct development depends partially upon public opinion (which may be based on past experience rather than future events), future state, national, and international events (e.g., another OPEC oil boycott), and upon many other factors such as the occurrence of another incident similar to the one at Three Mile Island. As an example, geothermal energy development is associated in the minds of many people with $H_2S$ odor nuisance from experiences at The Geysers; however, with the use of binary systems in which geothermal fluids are completely enclosed and reinjected, there should be no odor problem at all. Thus, the following prioritized list (with priorities set only to the degree possible) should be considered to be conjectural. Recommendations for additional data and research that will further refine and prioritize these issues are presented in the next section.

1. *Visibility Reduction*: This effect can arise from two sources:

(a) Particulate loading of the atmosphere from dust suspension during construction. The degree of this impact depends on soil conditions and dryness, as well as the care taken during construction to minimize soil disturbance.

(b) $H_2S$ emissions and atmospheric oxidation processes. $H_2S$ is slowly oxidized to $SO_2$ and $SO_4^=$ in the unperturbed atmosphere (DOE/EDP-0014,

1978) but the reaction may be rapid (minutes to hours) in a moist, polluted plume. Though $SO_2$ removal rates from wet and dry deposition are uncertain and are highly dependent on atmospheric conditions, it is possible that much of the $SO_2$ would remain in the atmosphere and oxidize to sulfate particles. These sulfate particles can, through condensation and coagulation, produce particles in the 0.1 to 1.0 μm diameter range (White, 1978; Liu and Durran, 1976). These particles can scatter and absorb light and cause visibility reduction. In view of the time required for this whole process, visibility reductions from this effect are most likely to occur on a regional scale.

The impact of visibility reductions will be most significant in areas of southeastern Oregon where arid conditions can lead to buildups of sulfate particles, and in parts of the Cascades that are designated class 1 areas are thus protected by the Clean Air Act Amendments of 1977 from any impairment of visibility.

2. *Fogging and Icing of Roads and Powerlines*: The severity of this impact is highly dependent on the exact siting of the generating plant relative to roads and powerlines, as well as local meteorology, i.e. predominant wind direction, temperature, and relative humidity. Southeastern Oregon, with its high elevations and periodic extremely low temperatures is particularly sensitive to this impact, even with small releases of water vapor. Major highways through KGRA's in the Cascades can also be susceptible to periodic obstruction of vision from fogging unless care is taken in plant siting.

3. *Plume Visibility*: Because it is caused by releases of water vapor into the atmosphere, plume visibility is regarded as an air quality issue

even though it may be objectionable only for aesthetic reasons. Plume visibility and visible length are determined by wind speed and dispersion characteristics as well as ambient temperature and relative humidity; consequently, more knowledge of local meteorology is necessary to quantify its impact.

4. *Odor Nuisance of $H_2S$*: This is regarded as a potential issue because of its association in the minds of many people with geothermal energy. With up-to-date technology in abatement systems or the use of the binary conversion cycle, the true impact of $H_2S$ may be minimal. However, its actual status as a real issue cannot be estimated without more knowledge of the type of development that may occur in Oregon and the amount of $H_2S$ present in geothermal fluids.

5. *Increased Ambient Concentrations of $H_2S$, Boron (B), Methane ($CH_4$), Ammonia ($NH_3$), Mercury (Hg), Arsenic (As), Carbon Dioxide ($CO_2$), and Other Constituents*: This issue is the most difficult to judge because of lack of information on:

(a) Kinds and quantities of constituents present in geothermal fluids;

(b) Type of energy conversion cycle to be used;

(c) Effects on biological receptors such as crops, vegetation, and wildlife, and concentrations that can cause deleterious effects;

(d) Plant siting.

With the use of closed cycle energy conversion systems, there may be no significant issue concerned with air pollutants. Even if effluents are not completely contained, their effects may be minimized by selective plant siting based on local meteorology to achieve optimum ventilation and dispersion conditions. Presumably, too, appropriate abatement systems will be applied.

The impact of effluent emissions is likely to be most severe in areas where inversion conditions occur frequently, such as enclosed basins of the Cascades or in eastern Oregon under conditions of dry continental air penetration and resulting stagnation.

6. *Accidental Release of Secondary Fluids Used in Binary Systems*: The use of volatile fluids such as isobutane or propane in binary loops carries a potential for accidental releases if system leaks should occur (DOE/EDP-0014, 1978). Data from field experience in binary systems does not exist, but hazards could be considerable with heat exchangers using high temperature fluids. However, this may be more of a system-safety issue than an air quality issue. The main threat from such releases is their potentially explosive nature.

## VII. CONCLUSIONS/RECOMMENDATIONS

The primary factor hindering any useful predictions of air quality impacts from geothermal resource development in Oregon is the absence of adequate source, meteorological, and baseline air quality data. In this final section of the chapter, therefore, we will include a brief recapitulation of available data and data gaps. Following this recapitulation, suggestions will be made for acquiring additional data and undertaking relevant research.

### A. RECAPITULATION

1. Available source data are limited mainly to analyses of waters from hot springs and shallow wells throughout the state. These measurements were made for the most part with the purpose of estimating geothermal reservoir temperatures (e.g. on the basis of silica concentrations as outlined in Fournier and Rowe, 1966). Consequently, these measurements omitted analysis for many constituents that may be environmentally hazardous. In addition, concentrations of those constituents that were measured may have changed during ascent of geothermal waters to the surface. Therefore, the measured concentrations may not be representative of geothermal fluids as they occur at greater depths and as they are used as input to energy extraction systems. Further, projections as to the type of development that may occur in Oregon are speculative and there is no information as to the nature or amount of eventual emissions from geothermal electrical generating plants. In fact, some of the proposed energy conversion systems have not even been tested. Finally, natural emissions from hot springs and fumaroles have not been analyzed for many constituents relevant to air quality, although many have been described as having a "rotten egg" odor. Thus, in summary, available source data are extremely meager.

2. Meteorological data in areas of Oregon having geothermal potential are limited almost exclusively to long-term averages of surface temperature and precipitation taken at isolated stations and, occasionally, to near-surface-level, average wind speeds. Exceptions are National Weather Service stations at Klamath Falls, Burns, and Ontario, but these stations are only marginally representative of conditions at remote sites in southeastern Oregon and the Cascades. Consequently, realistic air quality impact estimates will require more extensive data on elevated winds, thermal stratification, turbulence characteristics, and fog frequency.

3. Useful air quality data for areas of geothermal potential in Oregon are essentially nonexistent. The Oregon Department of Environmental Quality (DEQ) presently monitors the following constituents at the sites listed: TSP - La Grande, Baker, Klamath Falls, Bend, and Medford; $SO_2$ - Klamath Falls; total hydrocarbons (THC), photochemical oxidants, and CO at Medford. This list does not include relevant constituents commonly found in geothermal fluids (most notably, $H_2S$) and includes only sites which are, at best, peripheral to geothermal resource areas. As shown in Figure 7, large areas of southeastern Oregon are in counties that have no air quality monitoring data at all.

B. DATA REQUIREMENTS: To fill obvious data gaps, we have formulated and put in priority specific data collection tasks. In addition, we offer the following response to the expected question: Who should be responsible for meeting these data requirements? Normally, it would be expected that the developer of a specific geothermal resource would undertake programs to obtain the necessary data at the developer's site, and under PSD regulations, the developer is responsible for collecting air quality data and for monitoring pollutants that are expected to be emitted. However, because of uncertainties

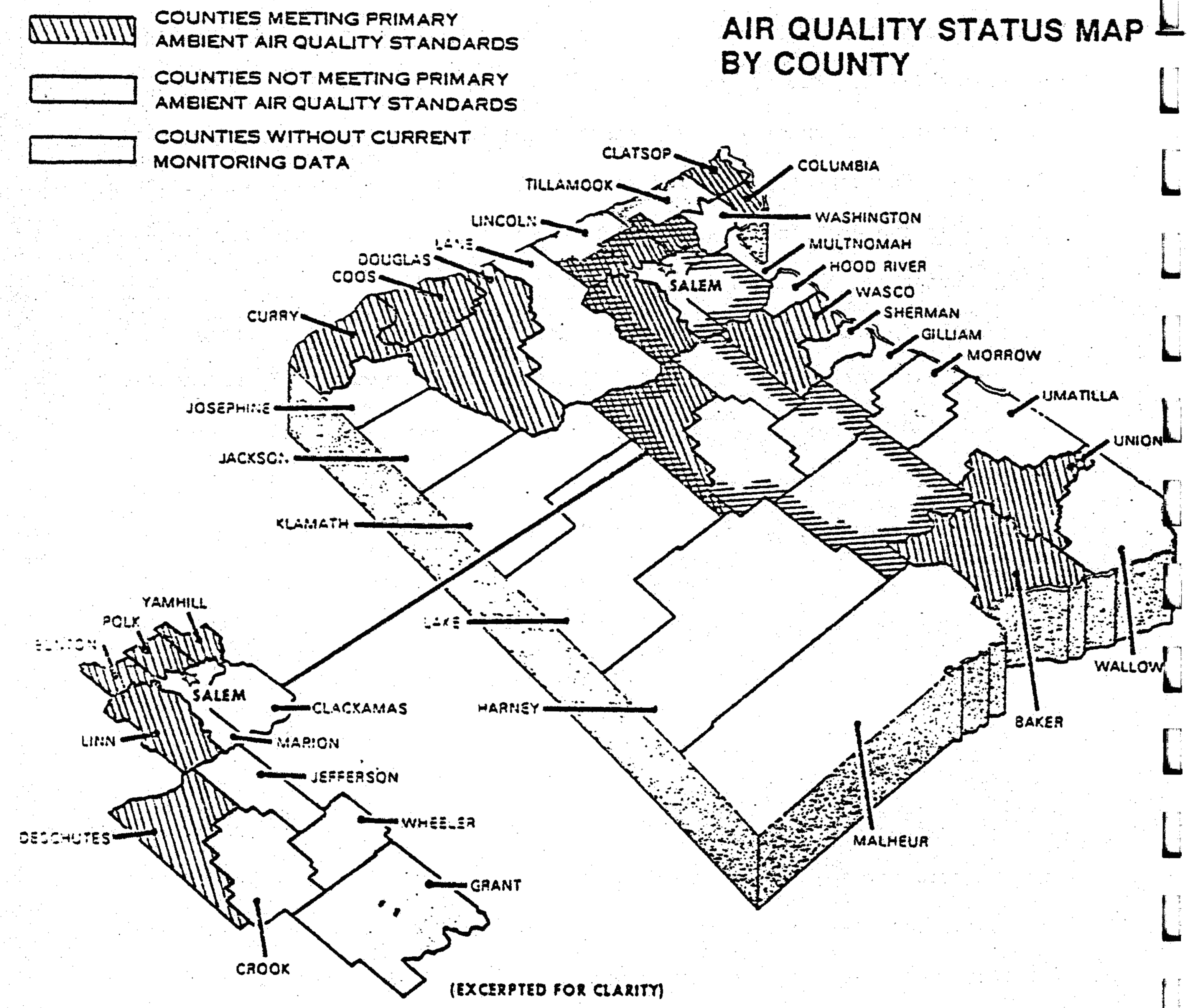


Figure 8. From "Oregon Environmental Quality Profile 1978," EPA publication EPA 910/9-78-049C, 1978.

1. *Fate of $H_2S$ in the Atmosphere*: The most important oxidizing reaction for $H_2S$ appears to be

$$H_2S + O_3 \rightarrow H_2O + SO_2$$

This reaction is quite slow in the gas phase; in the presence of airborne particles with a concentration of 200 particles/$cm^3$ the lifetime of 1 ppb $H_2S$ is estimated to be about 28 hours (Seinfeld, 1975). However, $H_2S$ and $O_3$ are soluble in water and the oxidation rate of $H_2S$ in a moist plume may be very fast. More information is needed on the behavior of $H_2S$ and $SO_2$ in a moist plume.

$SO_2$ is removed from the atmosphere primarily through deposition processes (wet and dry), and through chemical transformations, mainly oxidation to sulfates. Dry deposition rates depend on the type of surface and more information is needed on the rate of uptake of $SO_2$ by the types of soil and vegetation present in geothermal resource areas of Oregon. The rate of $SO_2$ oxidation depends on conditions of relative humidity and sunshine, and the presence of foreign substances as catalysts (e.g. $NH_3$). A wide range of $SO_2$ oxidation rates have been deduced from field experiments, from 0 to 50% per hour (Koch, *et al.*, 1977). Improved information on the dominant $SO_2$ conversion mechanisms and reaction rates for conditions typical of the various regions of Oregon are necessary for realistic depiction of the effects of $SO_2$ and its reaction products; e.g., the effects of submicron sulfate particles on visibility. In addition, dry deposition rates for submicron aerosol particles' depositing on vegetation are essentially unknown.

2. *Establishment of Emission Standards for $H_2S$*: At present there are no Oregon or U.S. standards for ambient $H_2S$ concentrations, although it was recommended in the EPA report by Hartley (1978) that $H_2S$ emissions be limited to 10% of the loading in the raw fluid. New Mexico has a 3 ppbv standard and California has a 30 ppbv standard (1 hour average), although the California standard is under review and may be lowered. The Occupational Health and Safety Act standard for $H_2S$ is 20 ppm, applicable inside buildings. To provide developers with a target for controlling $H_2S$ emissions it is essential that the state of Oregon establish an ambient $H_2S$ standard. A standard of 10 ppbv would fall below the median threshold of detection established by most studies of $H_2S$ effects (e.g., see Figure 1C).

3. *Effects of Geothermal Effluents on Vegetation*: Research is necessary to determine the effects of pollutants found in geothermal fluids, on native and cultivated plant species; in particular:

(a) the effect of *long-term low-level* exposure of $H_2S$ on cultivated species (hay, grain, sugar beets, potatoes) in terms of injury, growth reduction, and yield; and

(b) the effect of deposition of substances found in cooling tower plumes and drift droplets (e.g. boron, $SO_2$) on cultivated species such as those mentioned above, and on native species such as Douglas Fir and Ponderosa Pine.

4. *Complex Terrain Meteorology*: Much research is needed concerning meteorology in complex terrain. Specific areas in which more information is needed include (Koch, *et al.*, 1977; Barr, *et al.*, 1976):

(a) Upslope/downslope, thermally driven winds and their coupling/decoupling with synoptic scale flows;

(b) Turbulence generation by thermally driven drainage and upslope flows and waves in the lee of ridges;

(c) Amplification of horizontal plume spread caused by plume separation processes and plume meandering when high terrain elevations are confronted by a plume;

(d) Definition of the manner in which plume impingement occurs in complex terrain, and how this is affected by atmospheric stability;

(e) Initiation of moist convection as a result of differential heating of sloped surfaces, which could in turn result in injection of pollutants into upper-level winds;

(f) Flow separation and reattachment on the lee side of a ridge, which can result in high concentrations of contaminants at the point of reattachment;

(g) Effects of forest canopies on plumes, i.e., plume scrubbing and subsequent wash off onto the soil and uptake by plants.

5. *Modeling*

(a) *Regional Scale Modeling*: The fate of $H_2S$ is, in large part, oxidation to $SO_2$ and subsequent conversion to sulfates, with a time scale on the order of days (Seinfeld, 1975). Though it might be expected that concentrations of sulfate particles would be low at large downwind distances, even low concentrations could produce visibility effects on a regional scale. Consequently, it is vital to develop realistic models capable of handling long-range transport, conversion of reactive species such as $H_2S$ and $SO_2$, and visibility. A survey of long-range transport models was made by Nuber, *et al.* (1978), and includes several models which allow for $SO_2$ transformation processes and which may be applicable to areas in Oregon. A model which assesses the impact, at large distances, of $SO_2$ emissions from multiple point sources is described in Liu and Durran (1977). However, these models were developed for $SO_2$ emitting sources and neglect the initial transformation of $H_2S$ to $SO_2$ typical of geothermal power plants using, for example, the flashed-steam conversion cycle. Further, few regional scale models have been developed for complex terrain and even fewer have had experimental verification. Therefore, clearly, much additional research is needed.

(b) *Complex Terrain Modeling*: Although presently available models such as the EPA "Valley" model, may be applicable to many of the areas discussed in section V, the terrain of some areas, such as the Cascades, is so complex that ground-level concentrations predicted by these models may be totally unrealistic. In general, currently available air quality models for complex terrain have only order-of-magnitude predictive capability (e.g., see Barr *et al.*, 1976 and references therein). Consequently, there is a need for models which can more adequately handle three-dimensional flow fields in complex terrain, especially under stable conditions.

(c) *Drift Deposition Modeling*: There is an abundance of models which describe plumes and drift deposition from cooling towers. These are summarized and compared in publications by McVehil and Heikes (1975) and Chen and Hanna (1978). However, it was concluded by these and other investigators that what is needed in this area is more data with which to test these models under different meteorological conditions. This data, obtained under a variety of meteorological conditions and at various sites, should consist of simultaneous measurements of contaminant concentrations in cooling tower water, droplet distribution at the tower exit, drift rate, ground deposition rate distribution, and on-site weather conditions.

6. *Research and On-Site Testing of $H_2S$ Abatement Technologies and Energy-Conversion Systems*: The EIC upstream scrubbing process (described by Hartley, 1978) is effective in removing $H_2S$ from raw *steam* before the steam enters the plant. This eliminates $H_2S$ emissions even during shut-downs of plants using the dry-steam cycle. However, there is a need for development of a process similar to the EIC process that would be applicable to the flashed-steam cycle and with which $H_2S$ can be removed from the fluid *prior* to flashing. The U.S. EPA Industrial Environmental Research Laboratory (IERL) is currently supporting research in this area.

There is also a need for more on-site testing of plants using the various energy conversion cycles to determine operating characteristics more accurately. In this connection, it should be noted that construction is nearing completion of a 10 MWe binary cycle power plant near East Mesa, California, by the Magma Power Company of Los Angeles. Testing is scheduled to begin in July, 1979. This plant will provide much-needed information on the operating characteristics of a power plant using the binary cycle.

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# APPENDIX A

# HYPOTHETICAL CASE STUDY

## APPENDIX A

## HYPOTHETICAL CASE STUDY

This section will present an analysis, based on limited available data, of potential air quality impacts from a 100 MW geothermal electrical power generating plant. The site selected for study is near the eastern Oregon community of Vale (see Figure A-1). It should be noted at the outset that, to the author's knowledge, no plans for construction of such a power plant at this or any nearby site exist. This site was chosen because of the high geothermal potential of the area, its proximity to a populated area where impacts will be most significant, and because it is representative of the climate in eastern Oregon.

In particular, analyses will be made of the meteorological consequences of heat, moisture, and drift emissions from a wet-type mechanical draft cooling tower typically used at such a plant. Results will be in terms of visible plume length, increased fogging, and drift deposition. Because of certain assumptions and approximations, which will be discussed, the results should be considered highly tentative. Approximations to be made will be conservative; that is, they are made with the intention of presenting an upper limit to predicted effects.

A. SOURCE PARAMETERS: The type of plant considered will use a flashed-steam energy conversion cycle, as the worst possible case, though it is likely that development in eastern Oregon will use the binary cycle (Wimer et al., 1977). In the flashed-steam cycle, steam flashed from the geothermal fluid drives a turbine and is then re-condensed and passed through a cooling tower to reject excess heat to the atmosphere. In a binary system with re-injection of the geothermal

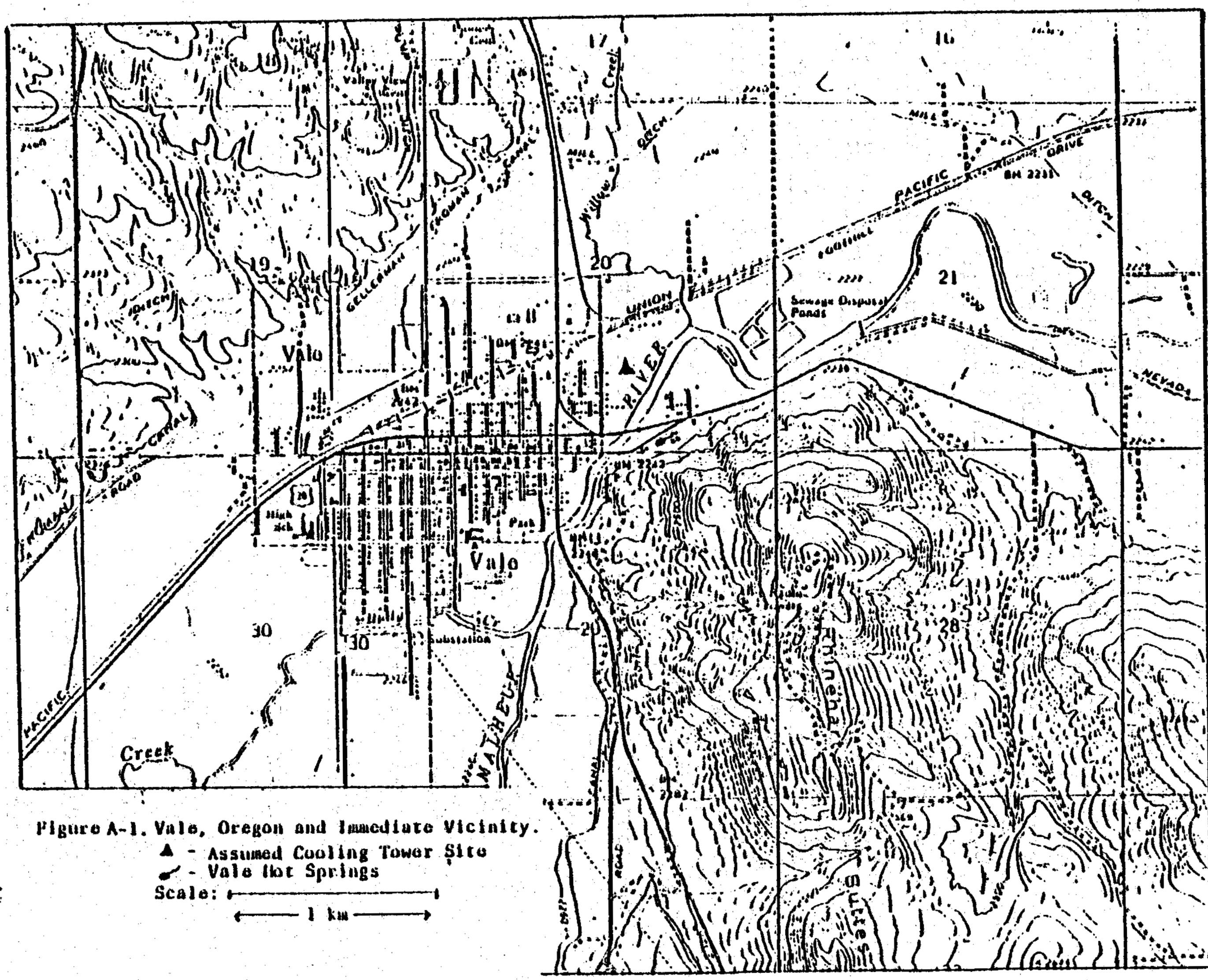



Figure A-1. Vale, Oregon and Immediate Vicinity.
▲ - Assumed Cooling Tower Site
- Vale Hot Springs
Scale:
← 1 km →

fluid, the fluid is isolated from the environment, and cooling water comes from an exterior source, e.g., river water. Both types of systems inject heat and moisture into the atmosphere, but with the flashed-steam system, dissolved solids and non-condensable gases present in the geothermal water may also be emitted.

The assumed cooling tower complex is a rectangular structure, 100 m long by 25 m wide, and consists of ten individual cooling cells, as illustrated in Figure 7 of the main body of this chapter. Based on descriptions of similar-type plants (Paquin, 1979; Rosen and Molenkamp, 1978; Quong, 1974; Wood, 1973), the values shown in Table A-1 were chosen for the source parameters.

Table A-1. Numerical Values Chosen for Hypothetical Case Study

| Symbol | Value | Parameter |
|---|---|---|
| $h_s$ | 25 m | source height |
| $R_o$ | 4.6 m | individual cell radius |
| $W_o$ | 7.5 m $sec^{-1}$ | vertical velocity at cell exit |
| L | 6.3 x $10^5$ g $sec^{-1}$ $cell^{-1}$ | water flow rate |
| $Q_w$ | $10^4$ g $sec^{-1}$ $cell^{-1}$ | moisture emission |
| $Q_h$ | $10^7$ cal $sec^{-1}$ $cell^{-1}$ (approximately 50 MW $cell^{-1}$) | heat emission |
| DR | 0.01% | drift rate |

From the values chosen in Table A-1, two additional parameters can be evaluated. The volume flux of stack-exit air, V, is defined by Briggs (1969) as:

$$V \equiv W_o R^2 = 150 \text{ m}^3 \text{ sec}^{-1} \text{ cell}^{-1} \qquad (2)$$

Also, the buoyancy flux F, is (Briggs, 1969):

$$F \equiv \frac{g}{T_p} V (T_p - T_a) = gV \left(1 - \frac{T_a}{T_p}\right) \text{ m}^4 \text{ sec}^{-3} \qquad (3)$$

where g is the acceleration of gravity (9.8 m $\text{sec}^{-2}$) and $T_p$ and $T_a$ (°K) are the plume initial temperature and ambient temperature, respectively. The buoyancy flux parameter is used in plume rise estimations, discussed later in this section.

B. METEOROLOGICAL DATA: Meteorological data used in this analysis are long-term trends at the Ontario airport, Ontario, Oregon, taken from the Climatological Handbook of the Columbia Basin States (1968). The data include:

(i) Annual joint probability frequencies of surface temperature T and relative humidity f, for windspeed classes $U < 2.0$ m $\text{sec}^{-1}$, $2.0 \leq U < 6.5$ m $\text{sec}^{-1}$, $6.5 \leq U < 11.0$ m $\text{sec}^{-1}$, and $U > 11.0$ m $\text{sec}^{-1}$.

(ii) Monthly means of T, f, U, and cloud cover at four times each day (0500, 1100, 1700, 2300 MST).

(iii) Annual and monthly windroses.

These data are summarized in Appendix B.

Figure A-2 shows the relative locations of the Ontario Airport and Vale. It is assumed that temperature and relative humidity trends at Vale are well represented by the Ontario airport data, since the two locations are separated by 19 km with no intervening topographic obstructions and about 30 m difference in elevation.

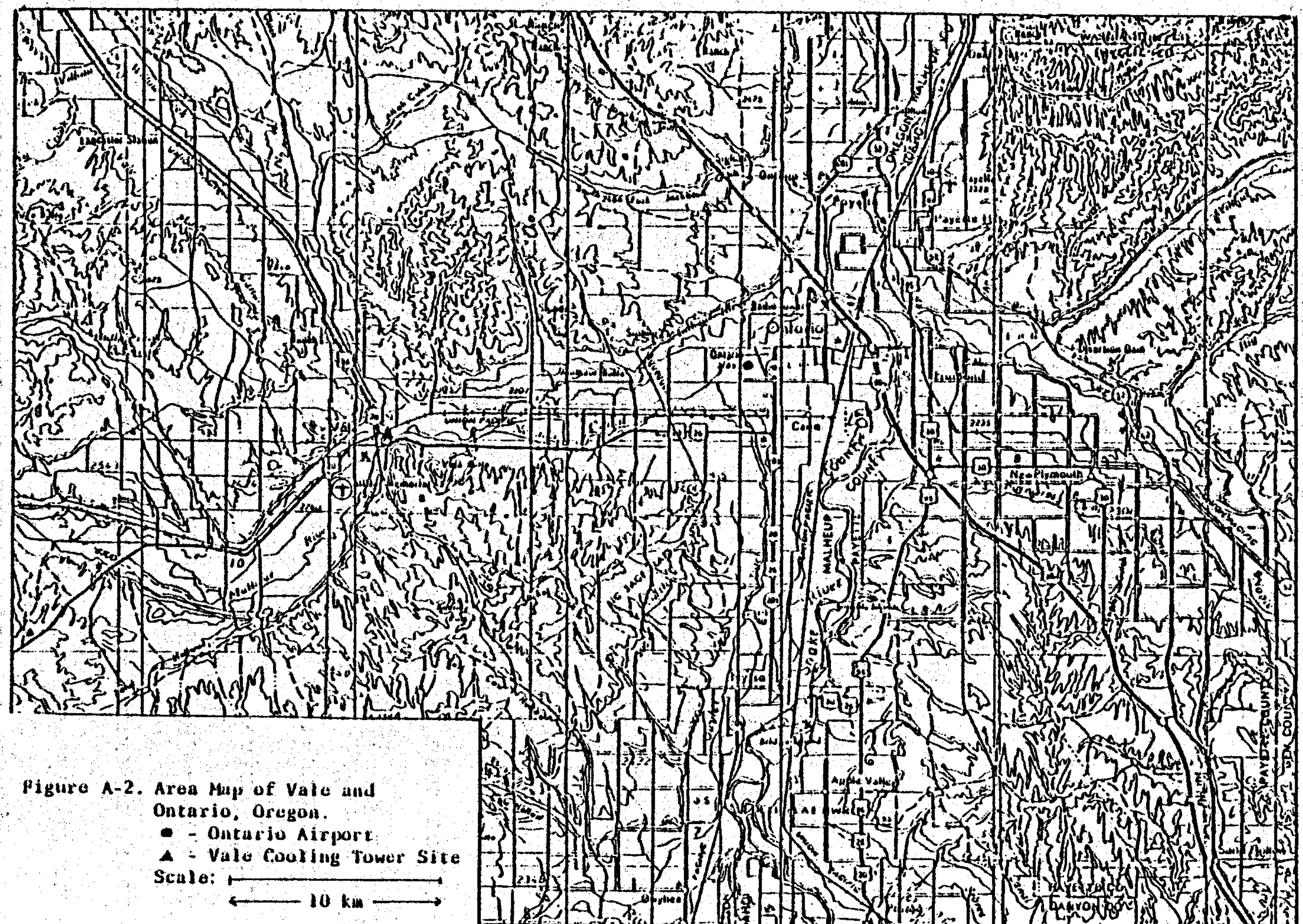



Figure A-2. Area Map of Vale and Ontario, Oregon.
● - Ontario Airport
▲ - Vale Cooling Tower Site
Scale: ←—— 10 km ——→

Because of the sensitivity of wind to local topography, near-surface wind data from Ontario Airport may not represent conditions at Vale. To estimate annual drift deposition and fog frequency in the vicinity of the Vale site a knowledge of wind flow around the site is necessary. This is discussed in the following paragraphs.

Figures A-2 and A-3 show the topographical setting around the Ontario Airport and Figure A-4 is the annual windrose constructed from Ontario Airport data. (This windrose is tabulated in Appendix B.) The major topographical features are the Snake River valley, which runs south to north near the site, and the Malheur River valley to the west-southwest. The latter is bounded on the north by a range of hills to the west and northwest, running from Malheur Butte to a point north of the airport.

From Figure A-4 it is seen that the strongest winds are from the northwest and north-northwest sector, which indicates that these hills do not pose a large obstacle to high winds. Mid-scale winds (1.6 to 5.6 m $sec^{-1}$) occur most frequently from the west-southwest, indicating some channeling of westerly winds by the Malheur River valley. Light winds, driven in part by diurnal variations in the pressure gradient resulting from differential surface heating (drainage winds) show a trend to south-southwest and northeast flow, following the course of the valley and hills.

Figures A-1 and A-2 show the topographical setting around the suggested site at Vale. For the purpose of extrapolating Ontario Airport data to the Vale site, several observations can be made:

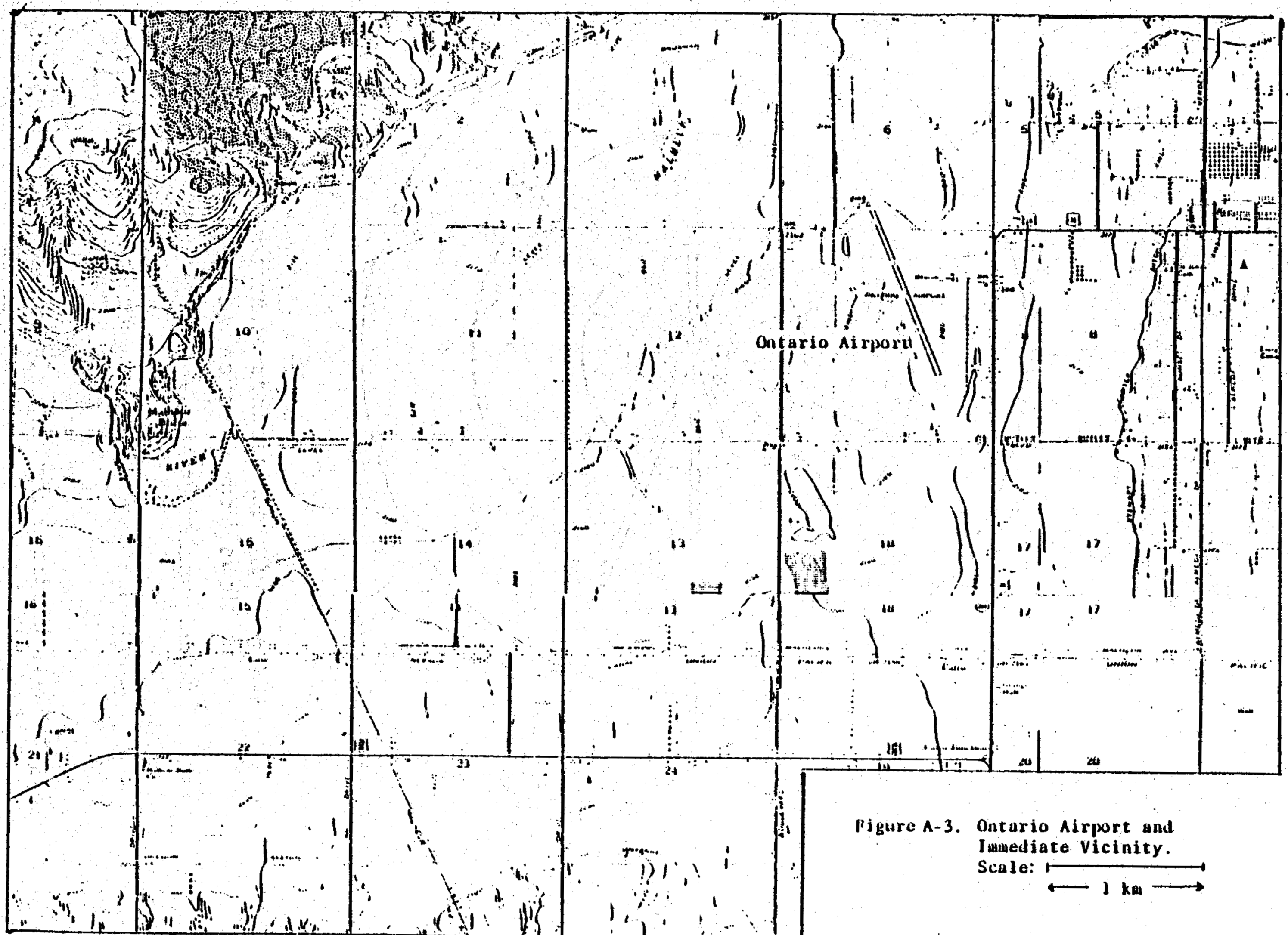
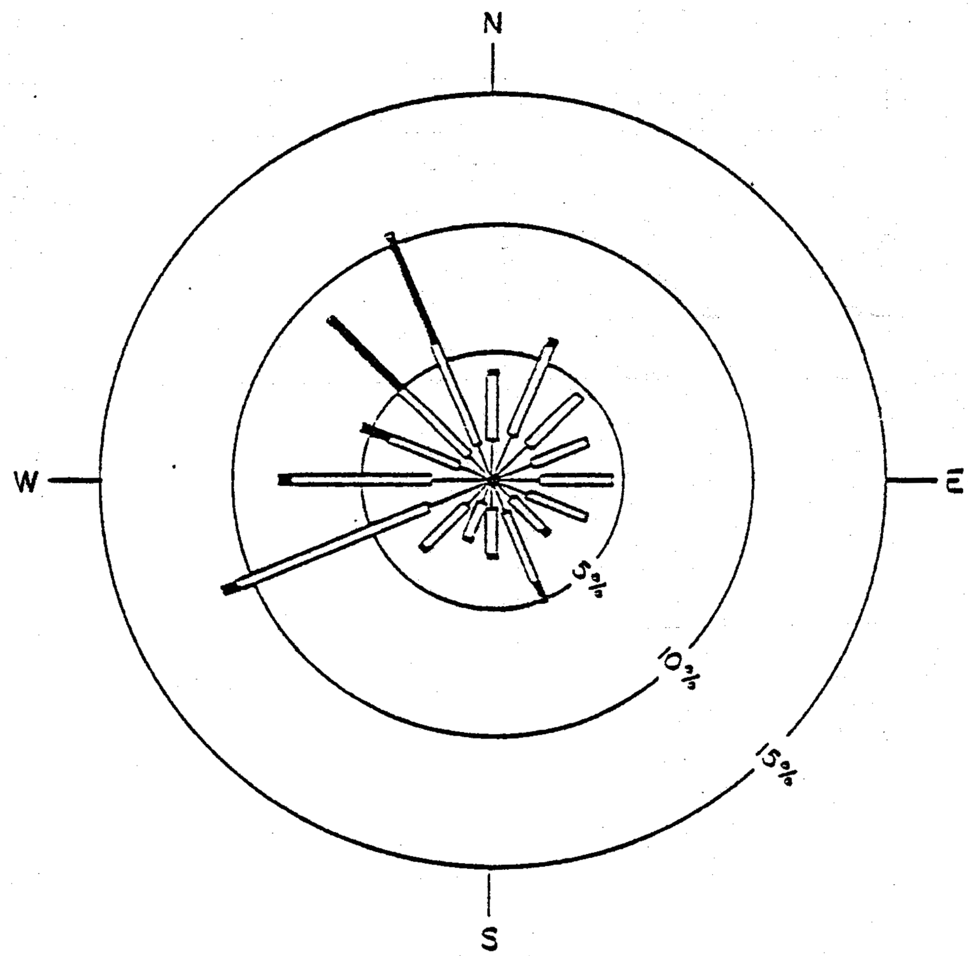



Figure A-3. Ontario Airport and Immediate Vicinity.
Scale: 1 km




Line length corresponds to percent of year that wind blows from direction indicated.

Speed classes (meters/second): 0.5–1.6, 1.6–5.6, 5.6–11.4, 11.4+

Calm (speed <0.5 m/sec) occurs 11% of the year.

Figure A-4. Windrose for Ontario Airport - 1948 to 1954. Constructed from Data in Climatological Hand-Book of the Columbia Basin States (1968).

1. The major topographical feature near the Vale site is the Rhinehart Buttes area, immediately south and east and rising steeply to 120 to 150 m above the site. This highland area will probably eliminate most winds from the southeast quadrant, channeling them into easterly or southwesterly directions. Winds from the northwest sector will probably be steered to a more westerly direction.

2. To the north, the terrain rises more gently to some 100 m above the site at a distance of six to seven km. The terrain is broken by the Willow Creek drainage, which could provide some channeling for northerly winds and drainage flows.

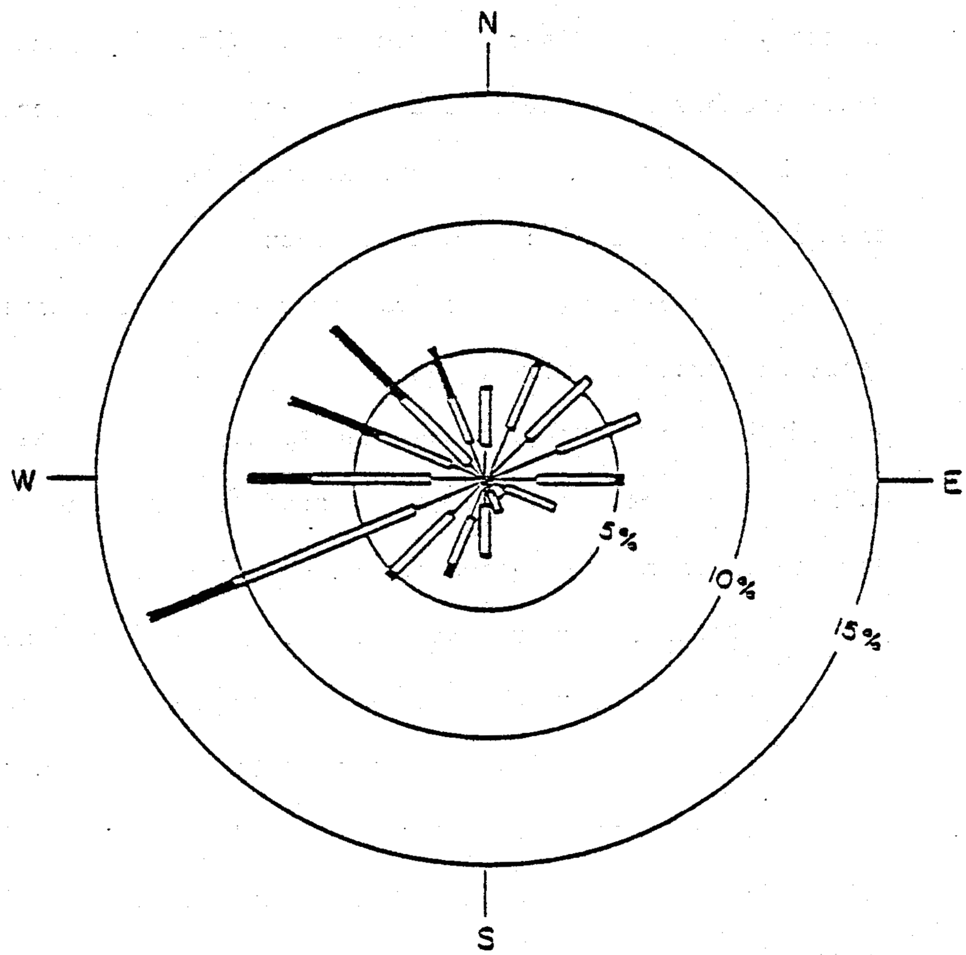
3. To the west-southwest and to the east-northeast along the Malheur River valley as far as Ontario Airport, the exposure is unobstructed. Therefore, winds from these directions should be similar to those at Ontario Airport, with the addition of components: (i) as a result of steering by the buttes area to the southeast, and (ii) some acceleration, as the flow is constricted by these buttes.

Based on these observations, a windrose was constructed for the Vale site. This windrose is depicted in Figure A-5 and tabulated in Appendix B. The following postulated features are noted:

1. Light winds follow a tighter west-southwest to north-northeast pattern, from channeling and steering by the Rhinehart Buttes highlands;

2. Mid-scale winds show small southeast components because of this channeling;

3. High winds are shifted to a more westerly direction as they impinge on the Buttes area;




Line length corresponds to percent of year that wind blows from direction indicated.

Speed classes (meters/second): 0.5–1.6, 1.6–5.6, 5.6–11.4, 11.4+

Calm (speed < 0.5 m/sec) occurs 11% of the year.

Figure A-5. Windrose for Hypothetical Site at Vale, Oregon, Extrapolated from Data for Ontario Airport.

4. Westerly flows show a somewhat higher percentage in the high speed range, because of acceleration mentioned previously.

It should be noted that there may be additional topographic effects not accounted for in the preceding discussion. For example:

(i) Under some conditions of southeast flow, a lee eddy could be established near the base of the buttes, which could capture emissions in a circular flow pattern. Such conditions include strong southeast winds and neutral or unstable temperature stratification.

(ii) With conditions of low windspeed, low sun angle, and resulting shadowing at the base of the buttes, excess heating of the valley floor could establish downslope and valley-ward flow from the buttes area. This flow would be the reverse of that in (i).

(iii) During unstable conditions, air could more easily flow up and over the buttes rather than around, resulting in less directional diversion.

(iv) Near these hills, mechanically-generated turbulence could be enhanced, resulting in more efficient dispersion than would occur in simple terrain.

Consequently, this windrose is a coarse extrapolation of remote data. However, recognizing that the purpose of this study is a gross estimate of potential impacts in a hypothetical case, it is used in subsequent analyses to fulfill the need for quantified data.

C. VISIBLE PLUME LENGTH

1. Psychrometric Chart: The psychrometric chart presented in Figure A-6 shows the amount of water vapor that air can contain as

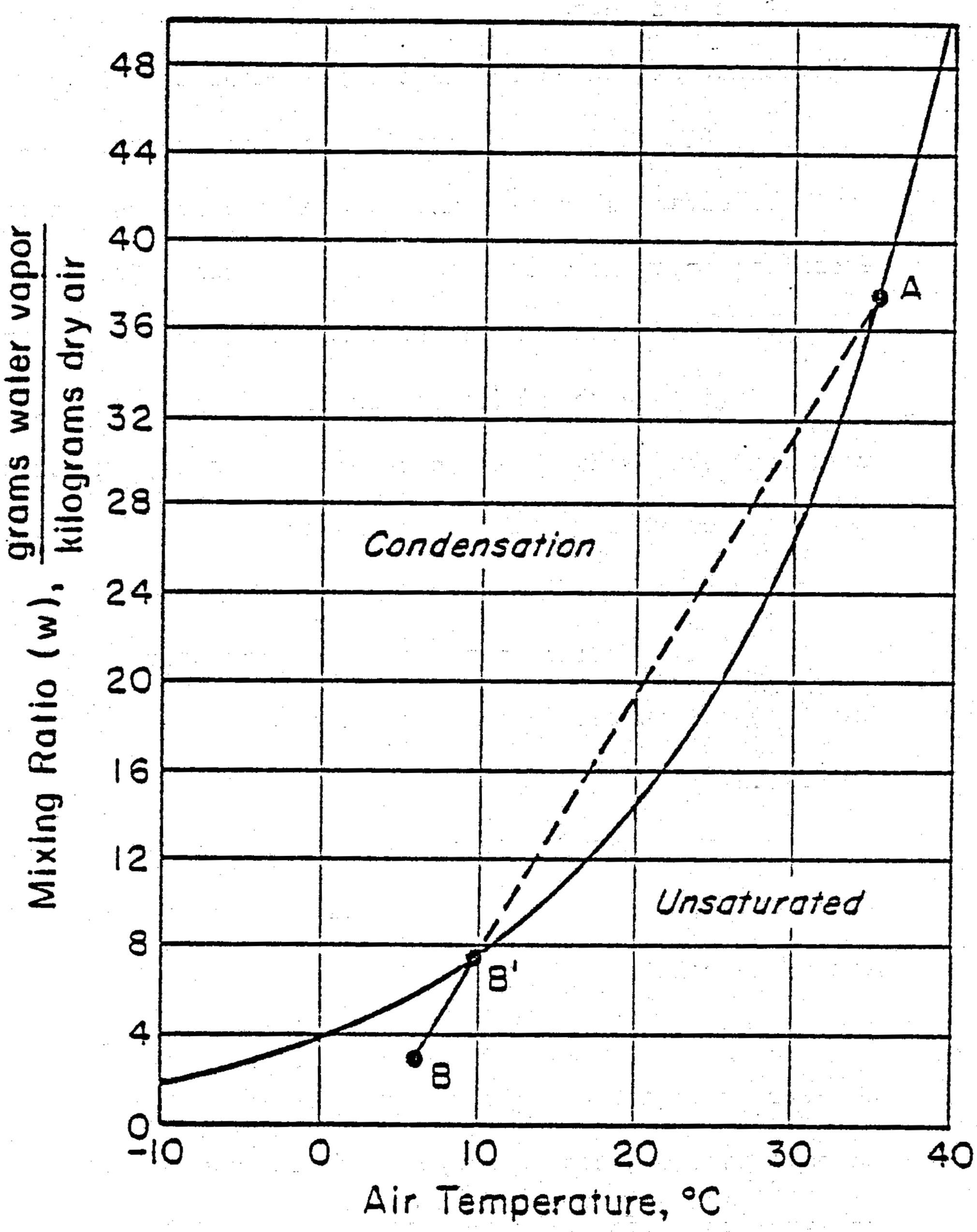



Figure A-6. Psychrometric Chart Used in Estimating Visible Plume Length.

a function of dry bulb temperature at 1000 mb pressure. The curved line represents the saturation (or maximum) amount of water vapor at the given temperature.

If point A represents the cooling tower plume at the exit (35°C, saturated) and point B represents ambient conditions, then, as the plume is mixed with the ambient air, the temperature and mixing ratio w (grams of water vapor per kilogram of dry air) at the plume axis will follow the saturation line from point A to point B'. (Here it is assumed that no super-saturation will occur in the plume. If super-saturation occurs, the plume will follow a path somewhere between the saturation line and the straight dashed line.) From B' to B, the plume is unsaturated and will be represented by a straight line. At B' the plume is just saturated, so that this is the point at which re-evaporation of the condensed plume will occur. The distance downwind at which the plume mixing ratio is reduced to the value at B' is thus an estimate of the length of the visible (condensed) plume. If the straight line A-B does not intersect the saturation line, re-evaporation can occur immediately and the visible plume, if present, disappears quickly.

Available surface data from Ontario airport include monthly-mean dry bulb temperature (T) and relative humidity (f) for four times of day. For each of these T-f combinations, the ambient mixing ratio w was determined and plotted with the temperature on the psychrometric chart at the point corresponding to point B on Figure A-6. A tower exit temperature of 35°C and an initially saturated plume were assumed, and the plume saturation mixing ratio $w_{ps}$ at the point of re-evaporation was determined graphically. This was then converted to a re-evaporation concentration $\chi_r$ (g $m^{-3}$) by using the density of dry air at station pressure (950 mb) and plume re-evaporation temperature.

A summary of $\chi_r$ for the four times of each day and month is given in Table A-2. Here, NP means that no visible plume, or only a short (<100 m) plume, will occur.

Table A-2. Re-evaporation Plume Moisture Concentrations $\chi_r$(g $m^{-3}$), Based on a Graphical Interpretation of the Psychrometric Chart, by Month and Time of Day at Ontario Airport, Ontario, Oregon. (NP means no visible plume, or a very short plume.)

| TIME (MST) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0500 | 3.4 | 4.2 | 5.8 | 6.8 | 9.7 | 13.7 | 20.5 | 19.5 | 11.7 | 7.1 | 4.6 | 4.0 |
| 1100 | 4.3 | 5.6 | 8.6 | 14.8 | 22.2 | 26.3 | NP | NP | 24.9 | 13.4 | 6.6 | 4.6 |
| 1700 | 5.2 | 7.8 | 13.0 | 24.2 | 35.2 | NP | NP | NP | NP | 24.3 | 10.0 | 6.2 |
| 2300 | 3.8 | 4.8 | 6.8 | 11.0 | 16.5 | 22.2 | 40.1 | 27.5 | 21.4 | 9.7 | 6.0 | 4.5 |

2. Gaussian Plume Model: The method used for estimating downwind moisture concentrations is based on the statistical Gaussian model. The main assumptions for this model are:

(a) Concentrations downwind from the source follow the normal probability distribution in both the vertical and cross-wind directions.

(b) The substance released is inert. It is not strictly correct to treat water as an inert substance, but, lacking a simple method for treating a substance which changes phase, this assumption is made. In effect, this assumption ignores latent heat that is released through condensation. If a condensed state persists, this heat release will cause the plume to rise higher than an otherwise similar, dry plume.

The governing Gaussian Plume Model for a point source is:

$$\chi_p(x, y, z; H) = \frac{Q}{2\pi \sigma_y \sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\left\{\exp\left[-\frac{1}{2}\left(\frac{z - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + H}{\sigma_z}\right)^2\right]\right\} \quad (4)$$

where

$\chi_p$ = downwind plume moisture concentration at distance $x$ ($g\ m^{-3}$)

$Q$ = source strength ($g\ sec^{-1}$)

$U$ = mean wind speed ($m\ sec^{-1}$)

$x$ = downwind distance (m)

$y$ = crosswind distance from plume centerline (m)

$z$ = vertical distance from ground level (m)

$H$ = effective emission height (sum of source height $h_s$ and plume rise $\Delta H$) (m)

$\sigma_y$, $\sigma_z$ = standard deviation of plume concentration in the horizontal and vertical respectively (m).

$\sigma_y$ and $\sigma_z$ are functions of downwind distance x and Pasquill stability categories. $\sigma_y$ and $\sigma_z$ can be found from charts such as those found in Turner (1970).

Although the assumed source in this study is a bank of cooling towers, for visible plume length estimations the point source equation, Eq. (4) is used. Previous studies have shown that individual plumes from such a source begin to merge after about 50 m and all plumes have combined by about 500 m (Hanna, 1974c). A study of a similar cooling tower (Hanna, 1974b) showed that visible plume lengths are most satisfactorily modeled if it is assumed that all plumes combine. Since a combined plume will take longer to disperse to the re-evaporation point, conservatism is also maintained by using the point source equation.

At the plume axis (y = 0, z = H), equation (4) reduces to

$$\chi_p(x, 0, H; H) = \frac{Q}{2\pi \sigma_y \sigma_z U}\left(1 + \exp\left[-2\left(\frac{H}{\sigma_z}\right)^2\right]\right) \qquad (5)$$

where the bracketed term accounts for plume reflection from the ground. Except for conditions of downwash (defined in the next section), there should be little surface reflection. Even with downwash, it has been observed that the plume typically recovers and begins to rise again after about 100 m (Hanna, 1974a). Further, if the wind is blowing nearly parallel to the line of cells, the cooling tower presents less of an obstruction and therefore downwash is less likely to occur (Reisman, 1972).

If no reflection is assumed, the point source equation reduces to

$$\chi_p(x, 0, H; H) = \frac{Q}{2\pi \sigma_y \sigma_z U} \qquad (6)$$

At the downstream point where re-evaporation occurs, the total plume concentration $\chi_r$ determined from the psychrometric chart is a mixture of cooling tower moisture $\chi_p$ and entrained ambient moisture $\chi_{amb}$. In the calculations, this means that $\chi_p$ must be smaller than would be necessary if entrained ambient moisture were not considered; i.e., considering the effects of entrained moisture will result in longer estimates of visible plume lengths. For conservatism, the approximation

$$\chi_p = \chi_r - \chi_{amb} \tag{7}$$

was used, although this is not an exact relation. In effect, the background concentration of moisture was subtracted from that necessary for re-evaporation. $\chi_{amb}$ was determined from the climatological data.

Monthly mean windspeeds and cloud cover for the times of day shown in Table A-2 were used to determine Pasquill stability categories at those times. Equation (6) was then applied, with $Q_w = 10^5$ g $sec^{-1}$, to estimate the maximum visible plume lengths as the distance x at which $\chi_p = \chi_r - \chi_{amb}$. Results are presented in Table A-3a.

Table A-3a. Maximum Visible Plume Lengths (100's of meters) for a Hypothetical Site at Vale, Oregon. Estimated using $\chi_p = \chi_r - \chi_{amb}$.

| | Months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | J | F | M | A | M | J | J | A | S | O | N | D |
| 0500 | >20 | >20 | 18.5 | 15 | 11 | 14 | 9 | 10 | 19 | >20 | >20 | >20 |
| 1100 | >20 | 13 | 3.6 | 2.7 | 1.2 | 1.2 | <1 | <1 | 1.4 | 3.4 | 15 | >20 |
| 1700 | 16 | 7.7 | 3.2 | 2.4 | 1.3 | <1 | <1 | <1 | <1 | 2.5 | 8 | 12 |
| 2300 | >20 | 29 | 14 | 5.2 | 3.8 | 4.7 | 2.8 | 3.8 | 7.4 | 20 | >20 | >20 |

For comparison, Table A-3b presents maximum visible plume lengths from calculations in which entrained moisture was disregarded. For short visible plumes, (which occur in drier conditions), the results are nearly the same.

Table A-3b. Maximum Visible Plume Lengths (100's of meters) for a Hypothetical site at Vale, Oregon. Estimated using $\chi_p = \chi_r$.

| | Months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | J | F | M | A | M | J | J | A | S | O | N | D |
| 0500 | 15 | 13 | 9.2 | 7.5 | 6.1 | 8.6 | 6.8 | 7.7 | 11.5 | 15.5 | 13.5 | 13 |
| 1100 | 8.3 | 6.9 | 2.5 | 1.9 | 1 | <1 | <1 | <1 | 1.2 | 2.5 | 7 | 8.1 |
| 1700 | 7 | 4.9 | 3.1 | 2.2 | 1.1 | <1 | <1 | <1 | <1 | 2.2 | 5.3 | 6.5 |
| 2300 | 13 | 10.1 | 7.9 | 3.9 | 2.8 | 3.7 | 2.4 | 3.1 | 7.2 | 11.3 | 10.2 | 12.5 |

In addition to the assumptions discussed previously, it was implicitly assumed that surface values of U, T, and f are applicable at plume height. Increased windspeeds at plume height will disperse the plume more quickly and visible plume lengths will be shorter. The source we are considering is low, so that variations in T and f should be small.

Two additional sources of potential error are uncertainties in the dispersion coefficients $\sigma_y$ and $\sigma_z$ at large distances from the source, and innacuracies in graphically determining re-evaporation concentrations $\chi_r$. For these reasons, results in Tables A-3a and A-3b should be considered order-of-magnitude estimates, particularly for plume lengths greater than 1 km.

D. FOG OCCURRENCE: Estimates of the maximum probabilities of increased fog occurrence from water vapor emissions from the cooling tower are made in terms of hours per year. The method is similar to that used for estimating plume lengths except that the results are averages over a year rather than for specific times of day and month.

1. Downwash: This analysis of fog occurrence is based on the frequency with which the condensed part of the plume touches the ground. As air flows across the cooling tower complex, the air may form a wake and captive eddy on the lee side. The boundary region of this wake is characterized by intense turbulent exchange with the free air flow. At sufficiently high wind speeds, the cooling tower plume is bent and partly entrained into the wake, and thus brought to the ground. This is known as downwash.

According to a criterion suggested by Briggs (1973), downwash occurs when the product $4(W_o/U - 1.5)R_o$ is less than 1.5 times the building height. By this criterion, downwash will occur at windspeeds greater than 3.5 m $sec^{-1}$ for a cooling tower of height 25 m.

In addition, the occurrence of downwash depends upon the direction of the wind in relation to the tower orientation and is most likely when the wind blows perpendicular to the row of cells. Observations have been made of wind blowing parallel to the length of a similar tower at speeds up to ten m $sec^{-1}$ with no downwash, and of wind blowing perpendicular at speeds as low as one m $sec^{-1}$ with downwash (Hanna, 1974a). In the case of wind blowing parallel, less of an obstacle is presented to the air flow by the tower, and plume merging is enhanced, resulting in increased buoyancy.

2. Local Distribution of Moisture and Wind: For air at a given temperature T and relative humidity f, the saturation deficit $\Delta w$ (g $kg^{-1}$) is defined by

$$\Delta w = w_s - w \quad (8)$$

where w is the actual mixing ratio and $w_s$ is the saturation mixing ratio at temperature T. The relative humidity is defined by

$$f \equiv \frac{e}{e_s} \qquad (9)$$

where e is the vapor pressure (the partial pressure exerted by water vapor) and $e_s$ is the saturation vapor pressure. Since $^e/e_s = {^w}/w_s$, w may be approximated by

$$w = \frac{w_s f}{100}. \qquad (10)$$

Knowing the density of air, we can convert $\Delta w$ to a concentration deficit $\Delta\chi$ (g $m^{-3}$), by which is meant the amount of additional moisture that must be added to achieve saturation and condensation. In this manner, using climatological data from Ontario airport, an annual joint probability distribution of $\Delta\chi$ and windspeed U was derived (Table A-4). This table was used as representative of the Vale site.

Table A-4. Annual Joint Probability Distribution of $\Delta\chi$ (g $m^{-3}$) and U (m $sec^{-1}$) at Ontario Airport. (Effective values, used in calculations, in parentheses).

| | | | $\Delta\chi$ Class ( g $m^{-3}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 |
| | | | 0-0.5 | 0.5-1.0 | 1.0-2.0 | 2.0-5.0 | 5.0-10.0 | >10.0 |
| U-Class (m $sec^{-1}$) | | | (0.01) | (0.5) | (1.0) | (2.0) | (5.0) | (10.0) |
| 1 | 0-2 | (1) | 0.134 | 0.035 | 0.066 | 0.087 | 0.068 | 0.078 |
| 2 | 2-6.5 | (4) | 0.05 | 0.031 | 0.060 | 0.109 | 0.082 | 0.104 |
| 3 | 6.5-11.0 | (9) | 0.002 | 0.002 | 0.008 | 0.033 | 0.025 | 0.023 |
| 4 | >11.0 | (11) | | | | | 0.001 | |

It should be noted that the windrose created for the Vale site (Figure A-5) and Table A-4 have slightly different windspeed class intervals. This is because two sets of data (T/f probabilities and wind direction frequencies) were tabulated in the data source in two different ways (see Appendix). However, since the classes are roughly the same, and since the Vale windrose is an extrapolation of data from Ontario airport and thus only an approximation, the windspeed classes and effective speeds defined in Table A-4 are used in subsequent calculations.

3. Long Period Average Concentrations: Following a recommendation by Hanna (1974a), a modified Gaussian plume model is used for estimating ground level fog occurrence. For wind directions in 22 1/2° sectors, the average long-period ground level concentration at distance x from a continuous point source is given by (Gifford, 1968):

$$\chi(x) = \sqrt{\frac{2}{\pi}} \frac{Q}{\sigma_z \, U(\frac{\pi x}{8})} \exp\left[\frac{-H^2}{2\sigma_z{}^2}\right] . \qquad (11)$$

This equation is obtained by letting z = 0 (ground level) in Eq. (4), integrating from $y = -\infty$ to $y = +\infty$, and dividing by the width (arc length) of the 22½° sector at distance x. Equation (11) is used for distances greater than one km, where the point source approximation is valid. At distances less than one km, the line source approximation:

$$\chi(x) = \sqrt{\frac{2}{\pi}} \frac{Q}{\sigma_z U \; (\frac{\pi x}{8} + 100 \text{ m})} \exp\left[\frac{-H^2}{2\sigma_z{}^2}\right] \qquad (12)$$

is used. This equation gives the average, long-period concentration over a section of width ($\frac{\pi x}{8}$ + 100 m) at distance x from the line source. (100 m is the length of the cooling tower complex).

In using Equation (12), it is assumed that the wind is blowing perpendicular to the line of towers. This assumption is conservative because:

(i) As the wind blows more parallel to a line of cooling towers, the plumes merge more quickly, which results in increased buoyancy and higher initial rise. With higher initial rise, the plume will touch the ground less frequently near the tower.

(ii) At windspeeds greater than 3.5 m $sec^{-1}$, downwash is more important than vertical diffusion in bringing the plume to the ground near to the source. Downwash is most likely to occur when the wind is perpendicular to the tower. Downwash is considered in the selection of H, the effective plume height.

In equations (11) and (12), the effects of atmospheric stability are accounted for in the dispersion parameter $\sigma_z$. Properly, a long term average concentration $\chi$ should be calculated using joint probabilities of windspeed and stability. However, this information is not available for any site near enough to the Vale site to be representative. For this reason, and for simplicity of calculations, it is assumed that the atmosphere is nearly neutral for the purpose of annual averages. For this condition, $\sigma_z$ is given as a function of distance by (Briggs, 1973):

$$\sigma_z = (.07x)(1 + .0015x)^{-1/2} \qquad (13)$$

where x is the downwind distance in m.

4. Plume Rise: When downwash does not occur, final plume rise $\Delta H$ can be approximated, for near neutral and unstable conditions, by

$$\Delta H = \frac{1.6\,F^{1/3}}{U}(10\,h_s)^{2/3} \tag{14}$$

where $h_s$ is the source height, U the average windspeed, and F the buoyancy flux (Briggs, 1969). The buoyancy flux F is given by equation (3). For a plume temperature of 35°C (308°K) and ambient temperature ranging from 0°C (273°K) to 25°C (298°K), F for a single cell ranges from 50 $m^4$ $sec^{-3}$ to 150 $m^4$ $sec^{-3}$. For a merged plume, with $R_o$ replaced by an effective radius $R_{o_{eff}} = \sqrt{10}\,R_0 = 14.5$ m, F ranges from 450 to 1500 $m^4$ $sec^{-3}$. Plume rise $\Delta H$, using these ranges, is shown in Table A-5.

Table A-5. Plume Rise Ranges Using Equation (14) (Unstable/Neutral Atmosphere)

| U | ΔH (1 cell) | ΔH (10 cells) |
|---|---|---|
| 1 m $sec^{-1}$ | 230 - 340 m | 500 - 725 m |
| 4 m $sec^{-1}$ | 60 - 85 m | 120 - 180 m |

In stable conditions, final plume rise is given by (Briggs, 1969):

$$\Delta H = 2.9\left(\frac{F}{Us}\right)^{1/3}, \tag{15}$$

where s is the stability parameter, defined by

$$s = \left(g/T\right)\left(\frac{\partial T}{\partial z} + \Gamma\right) \tag{16}$$

where $\Gamma$ is the dry adiabatic lapse rate, approximately equal to

0.01°C $m^{-1}$. For $\frac{\partial T}{\partial z} = 0$ (isothermal) $s \approx 3 \cdot 10^{-4}$ $sec^{-2}$. Plume rise ranges using this equation are presented in Table A-6.

Table A-6. Plume Rise Ranges Using Equation (15) (Stable Atmosphere)

| U | ΔH (1 cell) | ΔH (10 cells) |
|---|---|---|
| 1 m $sec^{-1}$ | 160 - 230 m | 330 - 500 m |
| 4 m $sec^{-1}$ | 100 - 150 m | 210 - 310 m |

Because of ambiguities in buoyancy flux determinations which depend upon the plume and ambient temperatures, and uncertainties in plume rise estimations using empirical formulas from data taken at various sites, plume rise values were selected from the low side of the ranges listed in Tables A-5 and A-6. This selection also is a conservative approximation. In addition, because the four m $sec^{-1}$ windspeed class is greater than the downwash criterion of 3.5 m $sec^{-1}$, the effective plume height for this class was arbitrarily lowered to 25 m.

During periods of downwash, the effective source height for a low mechanical draft cooling tower is zero (Hanna, 1974a). Because the plume in this situation may quickly recover and start to rise, effective plume heights for the 9 and 11 m $sec^{-1}$ classes were selected as 15 m. Table A-7 lists effective plume heights as used in the remainder of this analysis.

Table A-7. Effective Plume Heights for Windspeed Classes

| wind speed (m $sec^{-1}$) | 1 | 4 | 9 | 11 |
|---|---|---|---|---|
| effective plume height H (m) | 150 | 25 | 15 | 15 |

Effective plume heights for 4, 9, and 11 m $sec^{-1}$ windspeeds account for the frequent occurrence of downwash at these speeds. Downwind concentrations of moisture for each windspeed class under steady conditions are shown in Figure A-7.

5. <u>Calculations:</u> Let subscript i denote the windspeed class (i = 1 to 4), subscript k the $\Delta X$ class (k = 1 to 6), and subscript w the wind direction class (w = 1 to 16). Let x(m) denote downstream distance and $\chi_{iw}(x)$ (g $m^{-3}$) the cooling tower moisture concentration at distance x for windspeed class i and direction class w, from Figure A-7. Let $f_{iw}$ be the fraction of time that the wind blows in direction w and speed class i.

If $\Delta\chi_k$ is the effective $\Delta\chi$ for $\Delta\chi$ class k, let $\acute{g}_{ikw}(x)$ be such that

$$\acute{g}_{ikw}(x) = 0 \quad \text{if} \quad \chi_{iw}(x) < \Delta\chi_k$$
$$\acute{g}_{ikw}(x) = P_{ik} \quad \text{if} \quad \chi_{iw}(x) \geq \Delta\chi_k \qquad (17)$$

where $P_{ik}$ is the joint probability of $\Delta\chi$ class k and windspeed class i, from Table A-4. Then, for windspeed class i and direction class w, the amount of time during which fog could occur at distance x as a fraction of the time that the wind blows in that direction with that speed, $g_{iw}(x)$, is given by

$$g_{iw}(x) = \sum_{k=1}^{6} \acute{g}_{ikw}(x). \qquad (18)$$

Since there are 8760 hours in a year, the annual probability of cooling tower-induced fog in terms of hours per year at distance x for direction class w, $N_w(x)$, is

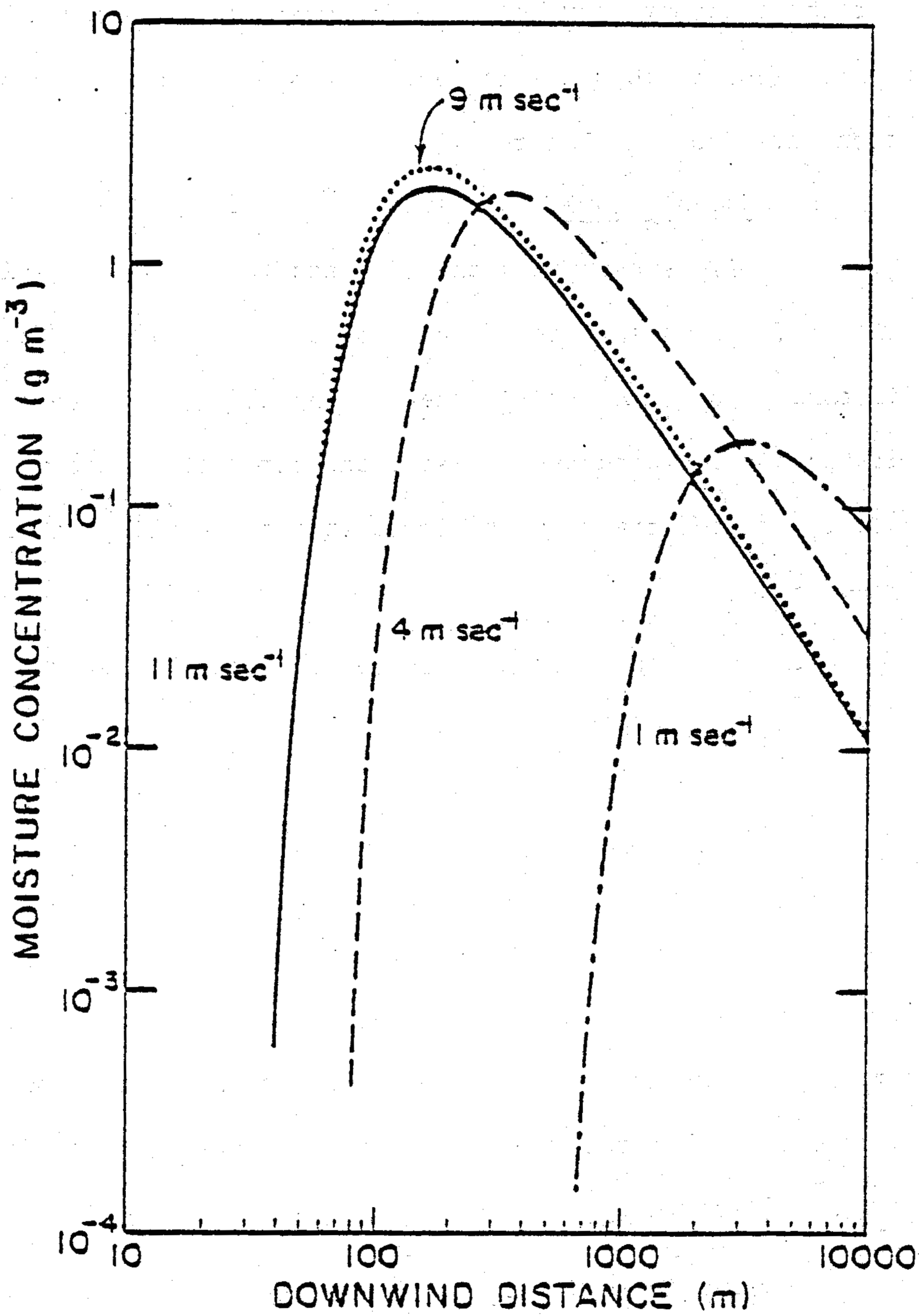



Figure A-7. Downwind Surface Moisture Concentration $\chi$(g $m^{-3}$) for Windspeeds and Effective Plume Heights in Table A-7. (Values shown correspond to $\chi_{iw}(x)$ in Equation (17).)

$$N_w(x) = \left( \sum_{i=1}^{4} f_{iw}(x)\, g_{iw}(x) \right) \left( 8760 \right) \text{hr yr}^{-1} \qquad (19)$$

Equation (19) was used for distances greater than 100 m. Closer to the tower, downwash is more important than turbulent diffusion in bringing the plume to the ground. Consequently, $N_w(x)$ at $x = 100$ m was estimated by assuming that downwash always occurs when the wind is in the 9 or 11 m sec$^{-1}$ ranges, i.e.,

$$N_w(100) = \left( \sum_{i=3}^{4} f_{iw} \right) \left( 8760 \right) \text{h yr}^{-1} . \qquad (20)$$

The results of this analysis are depicted in Figures A-8 and A-9. The numbers represent the probabilities, in terms of hours per year, of cooling tower-induced fog. Figure A-8 was constructed using only $\Delta\chi$ class 1, defined by $0.01 \leq \Delta\chi < 0.5$ g m$^{-3}$ (i.e., letting $g_{iw}(x) = g_{i1w}(x)$ in equation (18)), and so represents only the time when the ambient air is nearly saturated, approximately 19% of the year, mostly during the winter months. With generally low windspeeds during this condition (see Table A-4), and with little downwash, cooling tower fog probabilities are found to be nearly uniformly distributed at distances up to 1.5 km, with relatively low probabilities of occurrence. Also, because of the high relative humidities, there will be natural occurrence of fog or rain during some portion of this time, which may be augmented by cooling tower emissions. With predominantly westerly winds, the selected site is upwind from several sewage disposal ponds which are also likely contributors to

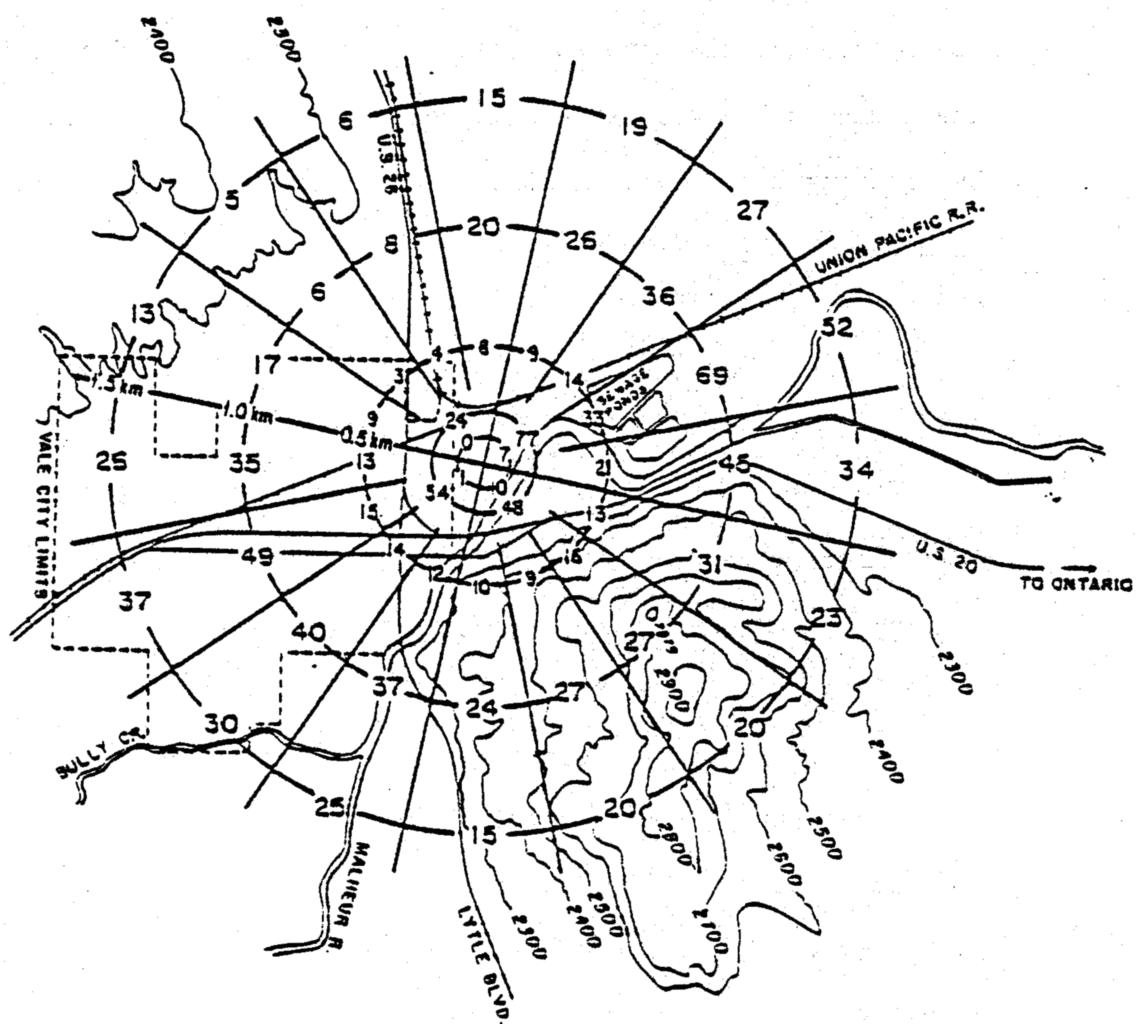



Figure A-8. Hours per Year During Which Cooling Tower Fog Could Augment Naturally Occurring Fog. 100 and 200 m Figures Are Quadrant Averages. Other Figures are 22½° Sector Averages.

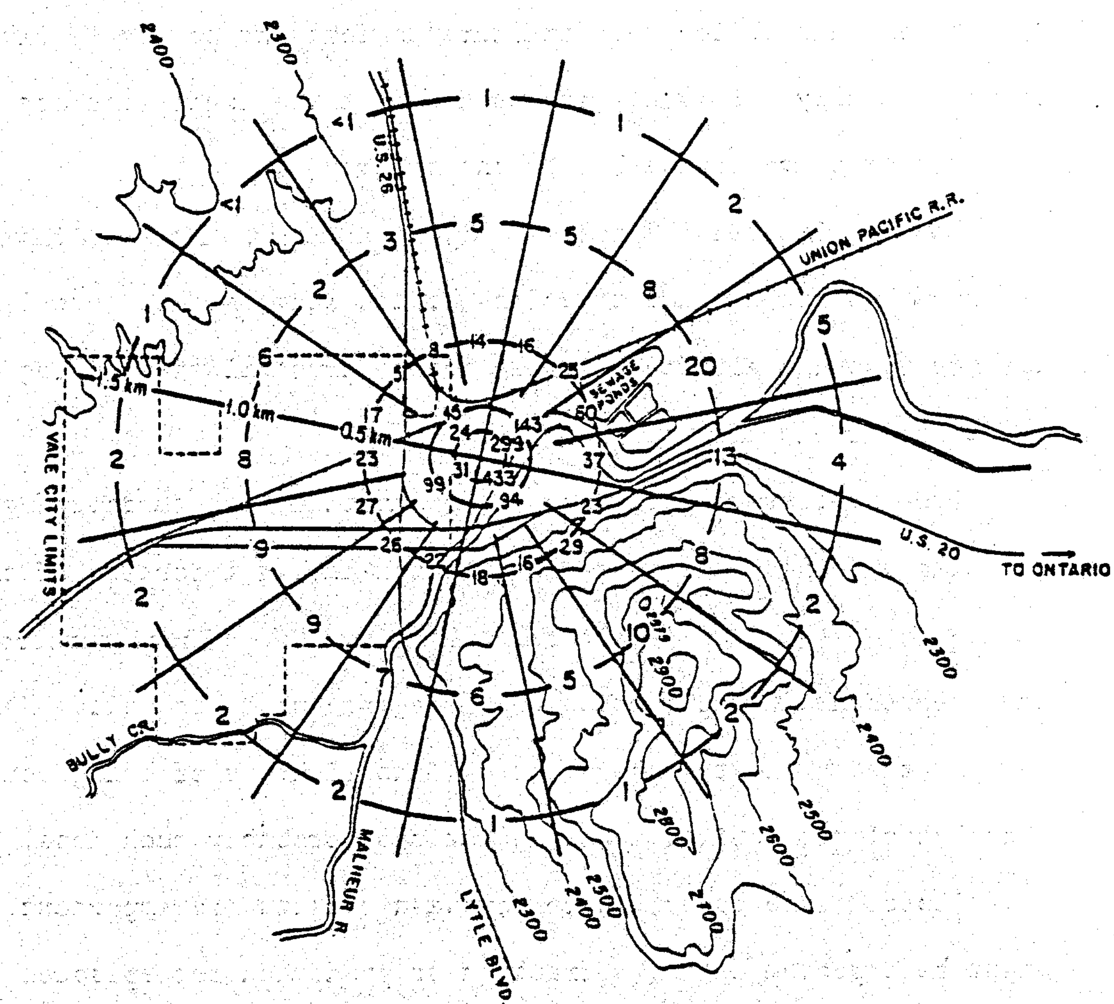



Figure A-9. Extra Hours of Cooling Tower Fog per Year, During Periods When No Fog Occurs Naturally. (100 and 200 m Figures Are Quadrant Averages. Other Figures are 22½° Sector Averages.)

fog occurrence in the vicinity. The Malheur River, also in close proximity, could also be a source of naturally occurring fog.

Figure A-9 represents periods of the year when $\Delta X \geq 0.5$ g $m^{-3}$ (i.e., letting k run from 2 to 6 in equation (18)). During these periods, the ambient air is lower in moisture content and no fog is likely to occur naturally. Fogging effects during these conditions are primarily a result of plume downwash near the tower.

In both Figures A-8 and A-9, differences in elevation have been disregarded. Since a plume traveling to the southeast is more likely to impinge upon the elevated terrain there, probabilities of fog occurrence are likely higher.

Sub-freezing temperatures in conjunction with surface fog can lead to icing. Icing would most likely occur during a portion of those hours in Figure A-8 (naturally occurring fog periods). These numbers would then represent an upper bound for icing frequency as well. Near highway 20, there will then be at most 10 to 15 hours of icing per year attributable to cooling tower operations, probably much less.

Close to the tower, where downwash effects are important, icing might be expected during a fraction of predicted fog episodes which corresponds to the natural frequency of occurrence of sub-freezing temperatures. Sub-freezing temperatures occur 15 to 20% of the time annually in the Vale area. Thus, near the cooling tower (100 m and less), cooling tower induced icing would occur at most during 80 to 90 hours per year, probably less.

6. <u>Fog Intensity</u>: In the foregoing analysis, fog intensity was not considered. Fog intensity in terms of horizontal visibility is

given by Trabert's formula

$$V(m) = 2\left(\frac{g}{m^2 \mu m}\right) \frac{D\ (\mu m)}{\omega\ (g\ m^{-3})}\ , \tag{21}$$

where V is visibility (m), D is the average fog droplet diameter (μm), and $\omega$ is the liquid water content (g $m^{-3}$) (Hanna, 1974c).

Figure A-7 gives downwind cooling-tower plume moisture concentrations $\chi$(g $m^{-3}$) under conditions for the various windspeeds considered. Near the cooling tower (distances less than 200 m), fog occurrences are due mainly to downwash at high windspeeds. $\chi$ at these distances for high windspeeds ( 9 and 11 m $sec^{-1}$) ranges from 1.0 to 2.0 g $m^{-3}$. A lower limit to visibility is given by assuming that all of this moisture is in liquid form, so that $\omega$ in Equation (21) is given by $\chi$. With an average fog droplet radius D of 10 μm, resulting visibilities are 10 to 20 m near the tower.

At further distances, extra fog results from downward turbulent transport of moisture from the elevated plume with low windspeeds and nearly saturated ambient conditions. From Table A-4, 96% of the 9 and 11 m $sec^{-1}$ windspeed classes and 81% of the 4 m $sec^{-1}$ class occur with $\Delta\chi$ greater than 1.0 g $m^{-3}$, which is larger than $\chi$ for these windspeeds at distances beyond 200 m; that is, these windspeeds occur under a relatively dry (unsaturated) conditions. Consequently, a lower limit to visibility at these distances is given by assuming a one m $sec^{-1}$ windspeed and saturated conditions, so that most of the plume moisture condenses. In this case, maximum moisture concentration occurs at 3000 m with $\chi$ = 0.19 g $m^{-3}$ which, if all in liquid form, corresponds to a visibility of 100 m from Equation (21).

In reality, visibilities will be greater because, except for saturated ambient conditions, not all of the plume moisture will be in condensed form.

In this analysis, it was assumed that the wind blows perpendicular to the row of cooling tower cells. With wind blowing parallel to the cooling tower, downwash is minimized and plume merging is enhanced. With the resulting increased buoyancy, initial rise is greater and the plume is less likely to contact the surface. Consequently, fogging effects will be reduced if the structure is oriented parallel to the prevailing wind direction, in this case south-southwest to north-northwest.

This type of analysis could also be used for estimating concentrations of inert non-condensable gases emitted through the cooling tower exhaust. However, the contaminant of most interest, $H_2S$, is a reactive species. An analysis of expected $H_2S$ concentrations is thus complicated by chemical transformations which would decrease $H_2S$ concentrations and increase concentrations of its chemical products $SO_2$, sulfates, and $H_2SO_4$ aerosol.

It should be noted that a statistical analysis such as this, based on annual probabilities of wind and moisture concentrations, overlooks seasonal variations and diurnal wind-stability correlations. Thus, for example, there will be a much larger proportion of induced fog during the winter, when cold temperatures result in smaller ambient saturation deficits.

It should also be re-emphasized that, because of the assumptions made, the results of this study should be considered upper limits only. Actual cooling-tower-induced fog occurrences will probably be much less.

E. DRIFT DEPOSITION: In the preceeding discussion of fog enhancement it was assumed that, because of their small diameters and settling speeds of a few cm per second, fog droplets do not settle out of the plume. However, drift droplets, with diameters typically 50 to 1000 μm, have terminal velocities on the order of 1 m $sec^{-1}$, so that their deposition from the plume to the ground because of gravitational settling must be accounted for. As the terminal velocity $V_T$ of a droplet is a function of its diameter, the downstream distribution of deposition depends upon the droplet size distribution. As the droplet falls through unsaturated air, some of it may evaporate and the resulting mass loss will decrease its settling velocity, allowing it to be carried farther, even to the point of total evaporation. In addition, droplets with terminal velocities smaller than the typical turbulent fluctuations of vertical windspeed will be dispersed through turbulent diffusion.

The following analysis of the amount and distribution of drift deposition utilizes a simple ballistic method which does not account for evaporation or turbulent diffusion. The implications of disregarding evaporation and turbulence are also discussed.

1. Trajectory Drift Model: Using a cooling tower water flow rate $L = 10^5$ gal $min^{-1}$ and a drift rate DR of 0.01% of the flow, the average drift from all 10 cells is 630 g $sec^{-1}$, or 63 g $sec^{-1}$ $cell^{-1}$. Figure A-10 presents the cumulative drift droplet mass fraction, as a function of droplet diameter, of drift from a similar cooling tower at

The Geysers, California (Rosen and Molenkamp, 1978). Table A-8 is a tabulated summary of this figure, with stagnant air terminal velocities for each size class as determined by Gunn and Kinzer (1949).

For this analysis, it is assumed that, in the absence of downwash, an individual drift droplet exits from the tower at the updraft velocity, $W_o$. As it moves downwind, it is displaced from the plume centerline to the plume edge. At the breakaway height, $z_b$, defined as the height at which the droplet is horizontally displaced from the plume centerline a distance equal to the initial plume radius, $R_o$, the droplet breaks away from the plume and falls to the ground at its terminal velocity $V_T$. This method used for estimating $z_b$ is the one used in the Wolf drift deposition model, a trajectory model documented in Policastro et al. (1979). In this model it is assumed that the vertical plume velocity decreases linearly with height, so that the vertical velocity $w(z)$

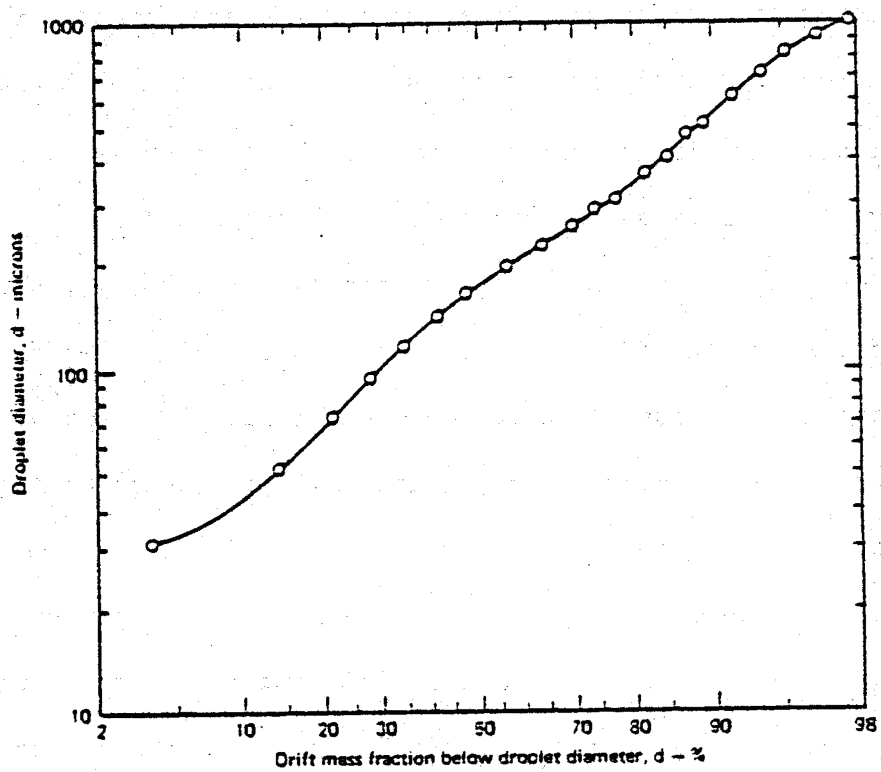



Figure A-10. Drift Data for a Mechanical Draft Cooling Tower at a 100 MW Geothermal Unit at The Geysers, California. Figure reproduced from Rosen and Molenkamp (1978).

Table A-8. Drift Data from Unit 11, The Geysers, California (Rosen and Molenkamp, 1978). Terminal Fall Velocities from Gunn and Kinzer (1949).

| Droplet Diameter, D (μm) | Identifier* | Terminal Velocity, $V_T$ (m sec$^{-1}$) | Mass Fraction, $m_i$ | Cumulative Mass Fraction |
|---|---|---|---|---|
| 0- 50 | | 0-0.07** | 0.13 | 0.13 |
| 50- 100 | a | 0.07**-0.27 | 0.16 | 0.29 |
| 100- 200 | b | 0.27-0.72 | 0.29 | 0.58 |
| 200- 300 | c | 0.72-1.17 | 0.18 | 0.76 |
| 300- 400 | d | 1.17-1.62 | 0.08 | 0.84 |
| 400- 500 | e | 1.62-2.06 | 0.04 | 0.88 |
| 500- 600 | f | 2.06-2.47 | 0.03 | 0.91 |
| 600- 700 | g | 2.47-2.87 | 0.02 | 0.93 |
| 700- 800 | h | 2.87-3.27 | 0.02 | 0.95 |
| 800- 900 | i | 3.27-3.67 | 0.01 | 0.96 |
| 900-1000 | j | 3.67-4.03 | 0.02 | 0.98 |
| >1000 | k | >4.03 | 0.02 | 1.00 |

* The identifying letter corresponds to identifying letters in Figure A-11(a-d).

** $V_T$ for droplets of diameter less than 80 μm calculated using Stoke's Law.

at height z is given by

$$w(z) = W_o - \frac{W_o z}{\Delta H} = \frac{dz}{dt} \qquad (22)$$

where ΔH is the maximum plume rise.

The vertical velocity of the drift droplet, $w_d(z)$ is given by

$$w_d(z) = w(z) - V_T \qquad (23)$$

where $V_T$ is the terminal fall velocity of the drift droplet.

Integration of Equations (22) and (23) from height zero (height of cooling tower) to height z yields, respectively, the time t for the plume centerline to reach height z, and the time $t_d$ for the drift droplet to reach height z.

$$t = \frac{\Delta H}{W_o} \ln\left(\frac{W_o}{W_o - \frac{W_o}{\Delta H} z}\right) \qquad (24)$$

$$t_d = \frac{\Delta H}{W_o} \ln\left(\frac{W_o - V_T}{W_o - \frac{W_o}{\Delta H} z - V_T}\right). \qquad (25)$$

Because the drift droplet takes longer to rise to a specific height than does the plume centerline, it undergoes a horizontal displacement from the plume centerline. This horizontal displacement will be equal to the initial plume radius, $R_o$, after a time given by

$$t_d - t = \frac{R_o}{U} \qquad (26)$$

where U is the ambient windspeed.

Substituting t and $t_d$ from Equations (24) and (25) and solving for z yields the breakaway height $z_b$:

$$z_b = \frac{(V_T W_o - W_o^2)\left[\left(\exp \frac{R_o W_o}{U \Delta H}\right) - 1\right]}{\frac{W_o}{\Delta H}\left[W_o - V_T - W_o \exp\left(\frac{R_o W_o}{U \Delta H}\right)\right]} \tag{27}$$

The time of rise of the drift droplet to height $z_b$ is then given by Equation (25), using $z_b$ for z. Assuming no evaporation, the distance to deposition is

$$x = U \left[\frac{(z_b + h_s)}{V_T} + t_d\right] \tag{28}$$

where $h_s$ is the height of the cooling tower. Equation (28) was used for the 1 m sec$^{-1}$ windspeed class.

At higher windspeeds, downwash effects must be considered. For this purpose, an effective plume height H is assumed. If the drift droplets begin their fall at height H, the distance to deposition is

$$x = U \frac{H}{V_T} \tag{29}$$

For the 4 m sec$^{-1}$ windspeed class, H was set equal to $h_s$. This is equivalent to allowing the droplets to begin their fall at the cooling tower exit. For the 9 and 11 m sec$^{-1}$ classes, H was set at 15 m to account for increased downwash at these speeds.

It was further assumed that all drift droplets within a given diameter range $D_i < D < D_{i+1}$ fall uniformly over a 22½° sector bounded by distances $x_i$ and $x_{i+1}$, the distance to deposition for droplets of diameter $D_i$ and $D_{i+1}$, respectively. Thus, if $Q_d$ is the drift rate (g $sec^{-1}$) and $m_i$ the mass fraction of droplets in the diameter range $D_i$ to $D_{i+1}$, the deposition rate $F_{di}$ at distances between $x_i$ and $x_{i+1}$ is

$$F_{di} = \frac{16\ Q_d\ m_i}{\pi\left(x_i^{\ 2} - x^2_{\ i+1}\right)} \quad g\ m^{-2}\ sec^{-1}. \qquad (30)$$

2. Calculations: Calculations were made for each windspeed class, using i) a single cell as the source ($Q_d$ = 63 g $sec^{-1}$, $R_o$ = 4.6 m), and ii) ten cells as the source ($Q_d$ = 630 g $sec^{-1}$, $R_{o_{eff}}$ = 14.5 m). Figures A-11(a-d) illustrate the results. In these Figures, the bars represent distances over which droplets in a given diameter size range, identified by the adjacent letter here and in Table A-8, are assumed to fall uniformly. The upper curve is the ten cell curve and the lower curve the one cell curve. The two curves were interpolated between 50 and 500 meters and the resultant curve is the solid black line.

In addition to the deposition rate (g $m^{-2}$ $sec^{-1}$) for each windspeed class, Figures A-11(a-d) show the equivalent precipitation rate (mm $hr^{-1}$). A precipitation rate of one mm $hr^{-1}$, or about one in. per day, is equivalent to the rainfall rate during a very rainy winter day in Western Oregon. The relative severity and effects of various precipitation rates are shown in Table A-9 (Roffman, 1979). It should be recalled here that, in addition to other assumptions, a drift rate of 0.01% of the cooling tower flow was assumed. With a drift rate of

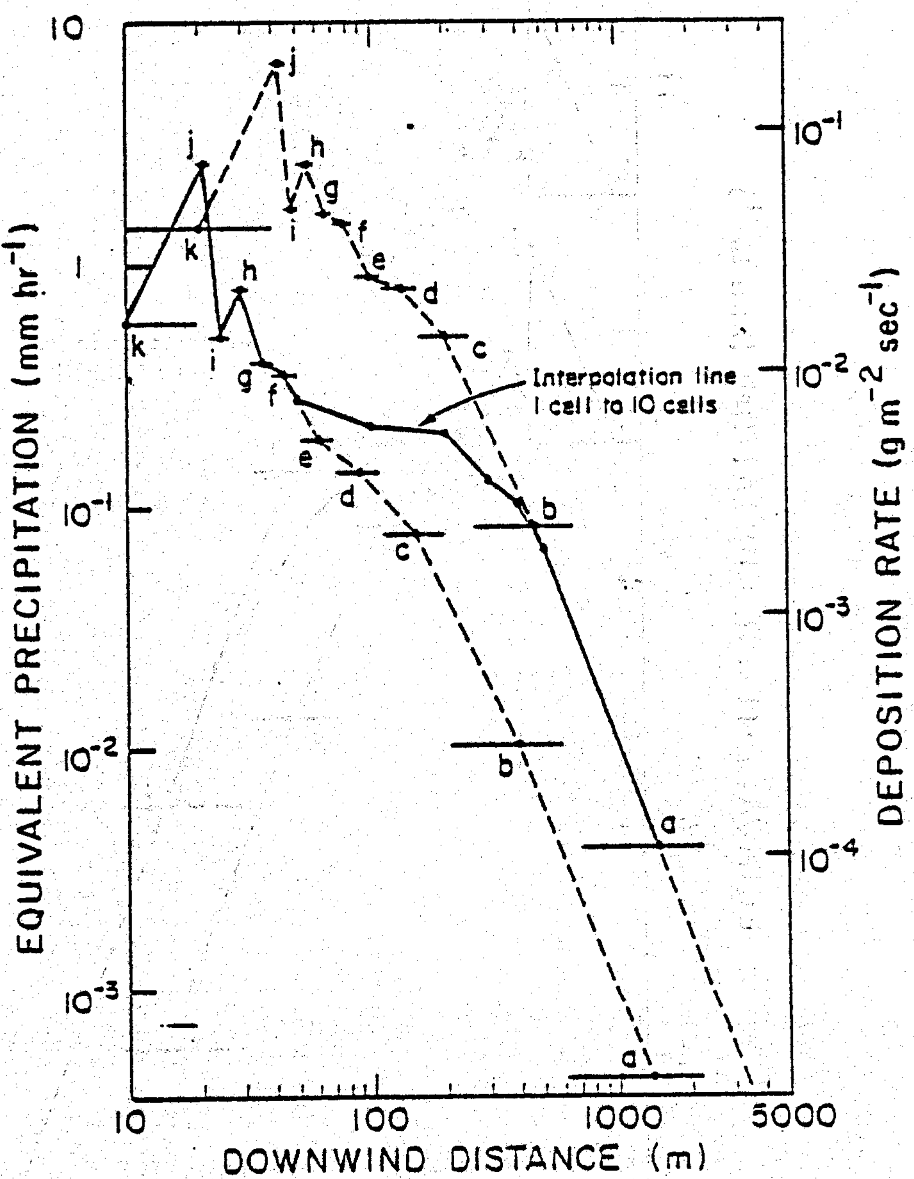



Figure A-11a. Cooling Tower Water Drift Deposition Rate (g m$^{-2}$ sec$^{-1}$) and Equivalent Precipitation Rate (mm hr$^{-1}$) for U = 1 m sec$^{-1}$ and H = 150 m. (Letters correspond to droplet diameter classes of Table A-8.)

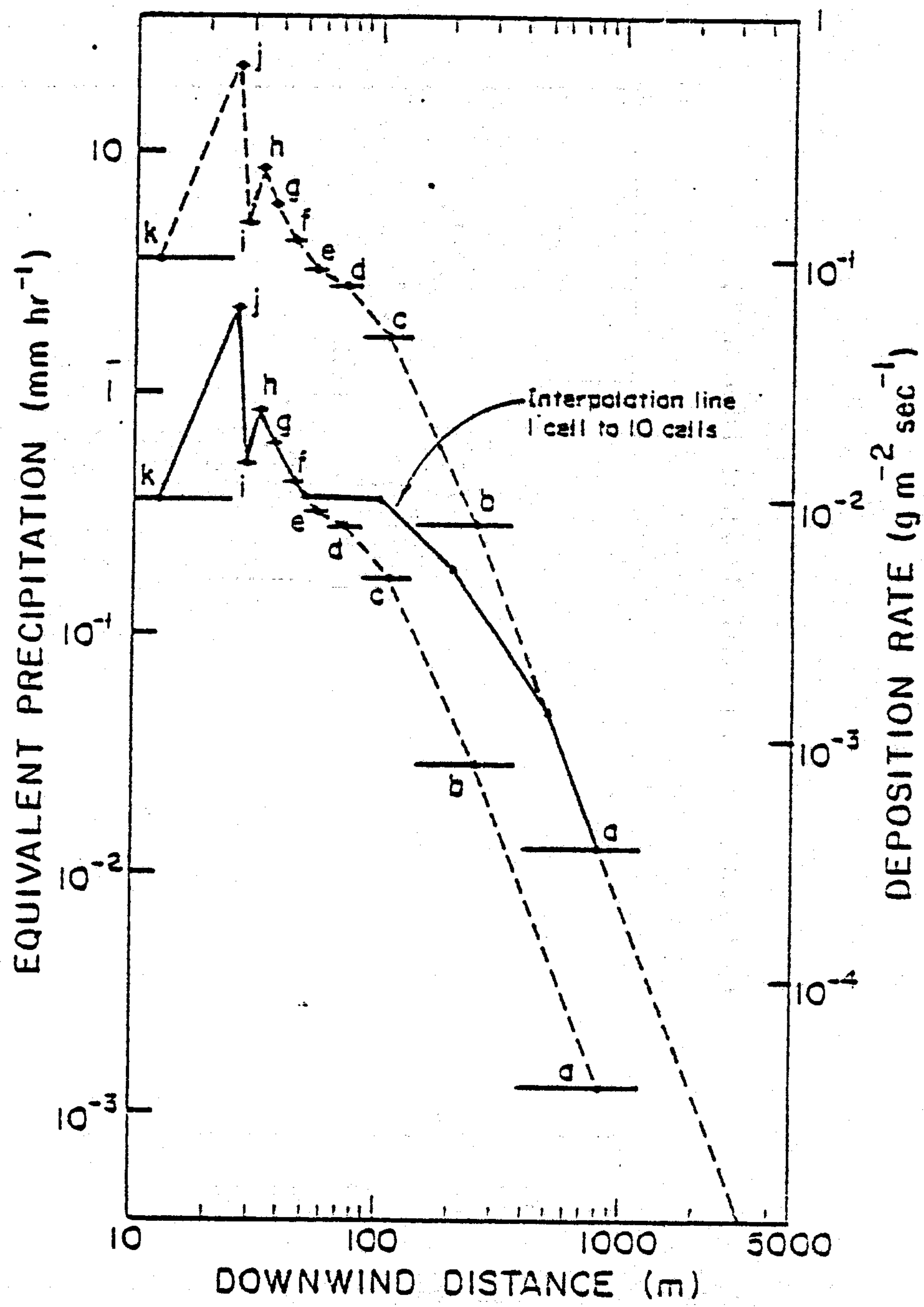



Figure A-11b. Cooling Tower Water Drift Deposition Rate (g $m^{-2}$ $sec^{-1}$) and Equivalent Precipitation Rate (mm $hr^{-1}$) for U = 4 m $sec^{-1}$ and H = 25 m. (Letters correspond to droplet diameter classes of Table A-8.)

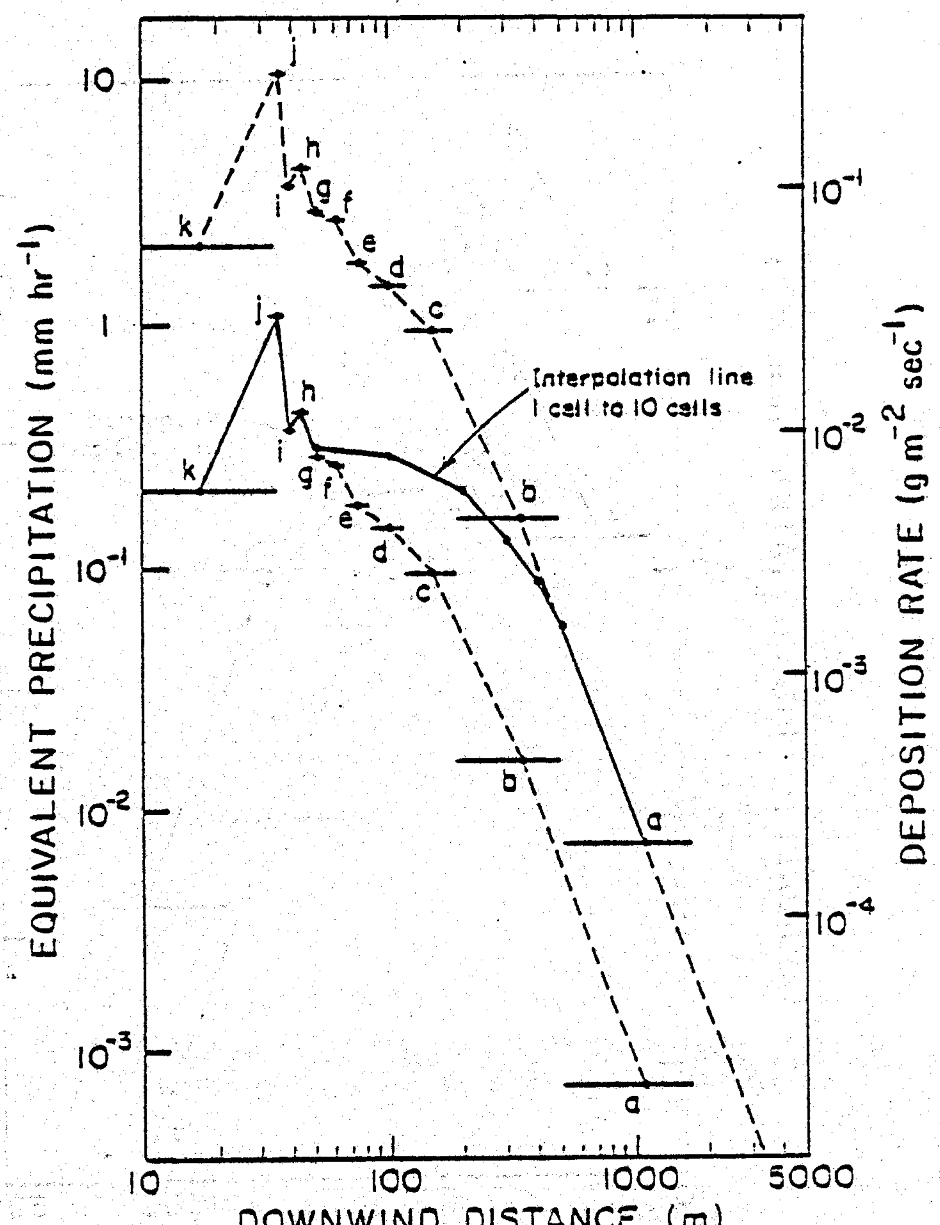



Figure A-11c. Cooling Tower Water Drift Deposition Rate ($g\ m^{-2}\ sec^{-1}$) and Equivalent Precipitation Rate ($mm\ hr^{-1}$) for $U = 9\ m\ sec^{-1}$ and $H = 15\ m$. (Letters correspond to droplet diameter classes of Table A-8.)

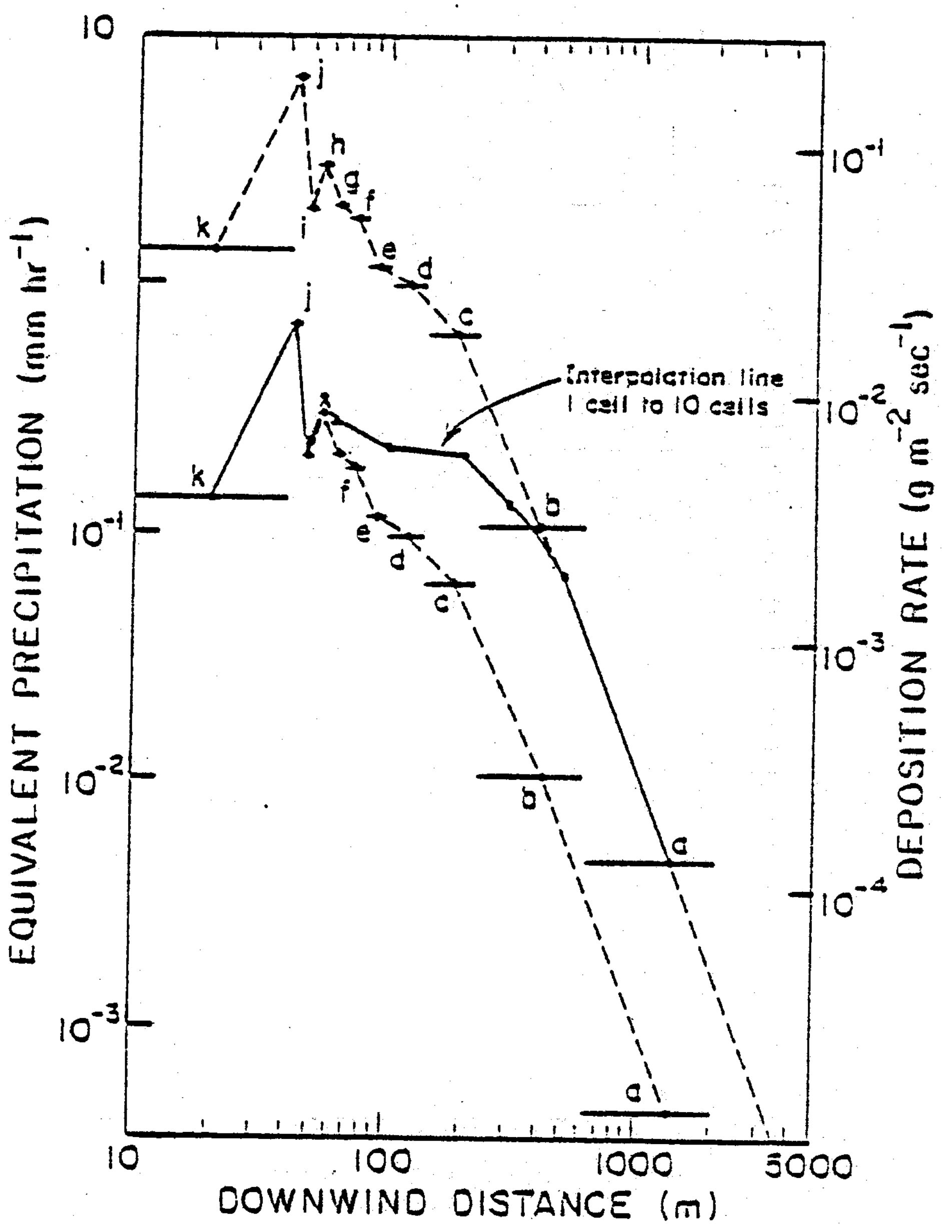



Figure A-11d. Cooling Tower Water Drift Deposition Rate ($g\ m^{-2}\ sec^{-1}$) and Equivalent Precipitation Rate ($mm\ hr^{-1}$) for $\bar{U}$ = 11 $m\ sec^{-1}$ and H = 15 m. (Letters correspond to droplet diameter classes of Table A-8.)

0.001%, common with many of today's cooling towers, the values in Figures A-11(a-d) would be an order of magnitude less.

Table A-9. A Guide of the Degree of Nuisance Associated With Precipitation Rates of 0.0005 mm $hr^{-1}$ to 0.05 mm $hr^{-1}$. Table reproduced from Roffman (1979).

| Precipitation Rate, mm/hr | Degree of Nuisance | Potential Effect |
|---|---|---|
| Less than 0.0005 | Unnoticeable to the sense | Difficult to detect with a sensitive paper |
| 0.0005 to 0.005 | Would normally pass unnoticed | Readily detected with a sensitive paper |
| 0.005 to 0.012 | Easily detected but not obstrusive | Produces a slight tingling sensation on the face |
| 0.012 to 0.025 | Noticeable, opinions are divided on nuisance | Stains parked cars, windows and glasses |
| 0.025 to 0.05 | Definitely a nuisance | Wet ground if humidity is high |
| Greater than 0.05 | Highly objectionable | Wet ground and may cause puddles of water |

Using the hypothetical Vale windrose (Figure A-5, Table B-10) and Figures A-11(a-d), the annual average moisture deposition from cooling tower drift for each of the 16 sectors was calculated. This is shown in Figure A-12 in units of $10^2$ g $m^{-2}$. Using a water density of 1 g $cm^{-3}$, the numbers on Figure A-12 correspond to equivalent annual rainfall units of $10^{-2}$ cm. Thus, the maximum annual average deposition of drift moisture (218 x $10^2$ g $m^{-2}$ at 100 m in the north-northeast sector) is equivalent to an annual average precipitation of 2.2 cm. Since the annual rainfall in the Vale area is 18.5 cm (7.29 in), precipitation augmentation from moisture deposition with this drift rate would be small, though perhaps significant. At distances of 500m and beyond it would be negligible.

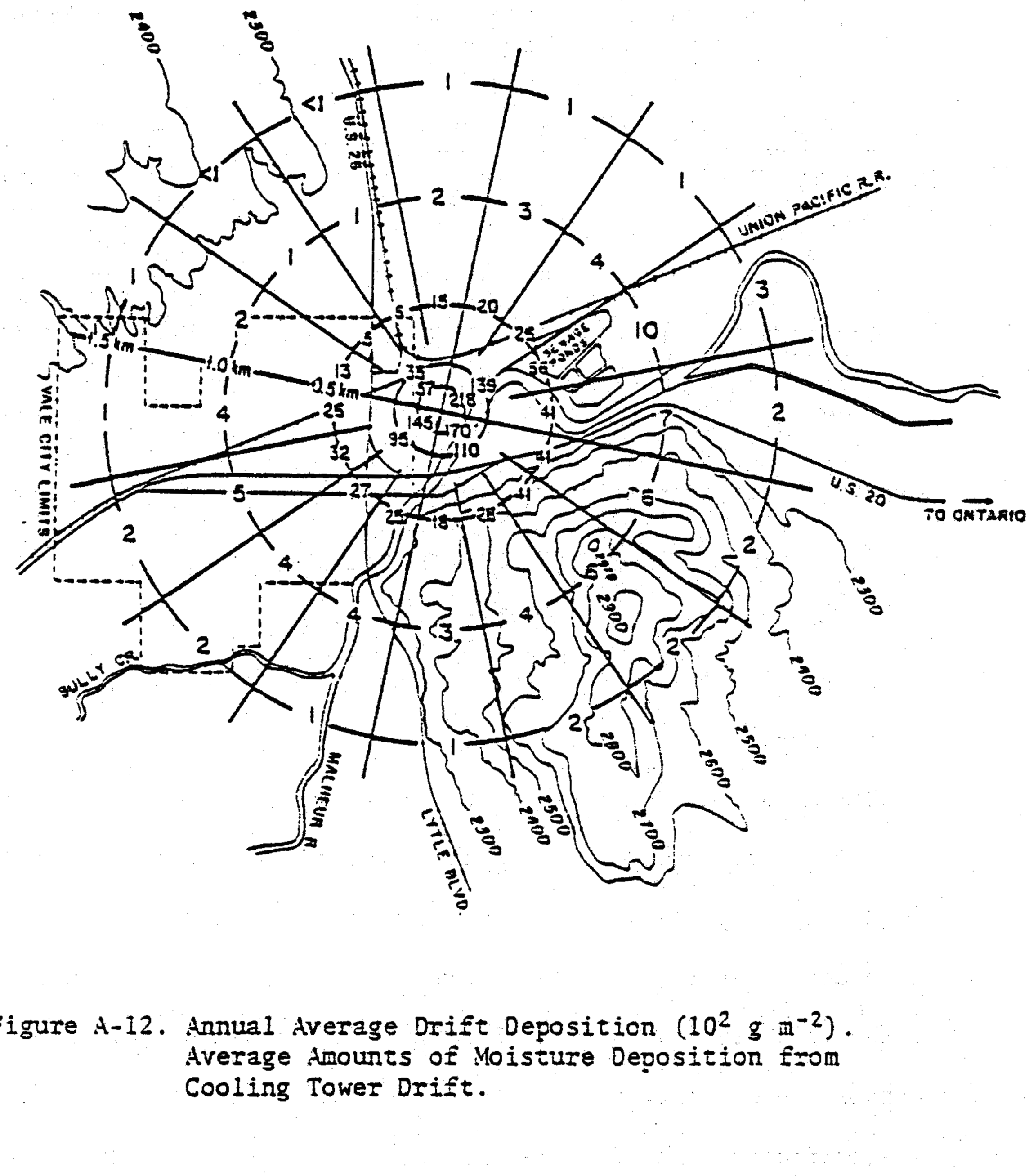



Figure A-12. Annual Average Drift Deposition ($10^2$ g $m^{-2}$). Average Amounts of Moisture Deposition from Cooling Tower Drift.

Surface deposition of cooling tower drift may, however, have a significant effect if contaminants (e.g., dissolved boron and arsenic) are present in the cooling tower water in large enough concentrations. If the concentrations are known, the resulting deposition may be estimated from Figure A-12 by multiplying these numbers by the appropriate factor. For example, boron (B) concentration in water from Vale hot springs has been found to be 9.4 mg $\ell^{-1}$, or $9.4 \times 10^{-4}$ g B per 100 g of hot springs water (Mariner et al., 1974). If we assume the same concentration in cooling tower water, the amount of boron deposition in the area of maximum annual drift deposition ($218 \times 10^{2}$ g $m^{-2}$) would be 0.2 g $m^{-2}$ per year. This would occur with a flashed-steam system using geothermal water as a condenser cooling medium and no abatement. Of course, to be meaningful, an analysis of this kind should include an assessment of the effects of contaminants such as boron, mercury (Hg), or arsenic (As) on humans and local plant and animal species at predicted concentrations. In the case of boron, this is not clear.

3. Review of Assumptions: In this analysis, it was assumed that the effects of turbulence could be ignored. The validity of this assumption depends upon the relative magnitudes of the droplet terminal velocities and turbulent fluctuations of vertical windspeed which are typically 0.10 to 1.0 m $sec^{-1}$ (Hanna, 1974a). Van der Hoven (1968) suggests that for terminal velocities greater than one m $sec^{-1}$, turbulent diffusion effects can be ignored. Droplets with terminal fall velocities near the low end of the range of turbulent fluctuations can be assumed to be dispersed according to the Gaussian plume model. From Table 10, it is

seen that for droplet diameters less than 200 μm, turbulent diffusion effects may be significant. Most current models place the critical droplet diameter at 100 μm (Chen and Hanna, 1978). Consequently, the results of this ballistic method of analysis are most accurate close to the tower where the larger drops fall. At distances beyond 200 m the method overpredicts, so that this method is conservative at large distances. Since predicted deposition rates at 500 m are an order of magnitude smaller than predicted deposition rates at 200 m and lesss, the method is most accurate where impacts are most significant.

In using this method, evaporation effects were also ignored. Since evaporation leads to a proportionately larger mass loss for small droplets than for large drops, the result of disregarding evaporation is also most significant at large distances. The net result is that deposition rates will be displaced away from the cooling tower.

## F. SUMMARY

1. Critical Assumptions: This analysis was based on several assumptions, which were made for simplification and conservatism of predictions. These assumptions were discussed in the text. The most critical assumptions were:

(a) Selection of source parameters. The selected parameters were based on descriptions of existing geothermal sites and should be generally representative of a 100 MW geothermal electrical generating plant using present technology. The drift rate of 0.01% of the cooling tower water flow rate is on the high side of drift rate ranges at existing mechanical draft cooling towers. With a drift rate of 0.001%, drift effects would be an order-of-magnitude less.

(b) Applicability of Ontario Airport data to the hypothetical Vale site. Airflow patterns in areas of complex terrain are difficult to assess. An attempt was made, considering topography, to extrapolate the surface windrose at Ontario airport to the Vale site. This should at least represent long-term gross features of windspeed and wind direction patterns at Vale.

(c) Selection of effective plume heights. Because of i) uncertainties in the applicability to the present case of dry plume rise formulas, with their necessary buoyancy flux estimations, ii) lack of wind-stability correlation data, iii) a desire to maintain conservatism of predictions, and, especially iv) a desire to incorporate plume downwash effects, low plume heights were arbitrarily selected for the higher windspeed classes.

2. Conclusions: Within the limits of the above assumptions, the following conclusions can be summarized:

(a) Visible Plume Length. Longest visible plumes would occur during nighttime and in the day during November through February. Plume lengths during the day in the rest of the year would be less than 300 to 400 m and, for most of this time, less than 200 m. The impacts of a visible plume are potential ground shadowing and aesthetic obtrusion. Since the winter sky in the Vale area is typically 65 to 80% cloud-covered, shadowing effects would be negligible. Aesthetic objections while hard to define, should be minimal except for these cloudy winter days.

(b) Fog Enhancement: Near the cooling tower, fog would result mainly from downwash in high winds. This fog would occur mostly in the northeast and southeast quadrants at distances less than 200 m, at most 300 to 400 hours per year, mainly in the winter. Visibilities during these periods should be greater than 10 to 20 m.

At further distances, 500 m and greater, fog would occur during periods of low ambient saturation deficit (i.e., high relative humidity) and so could augment existing fog. Fog occurrences near Highways 20 and 26, including downwash fog, should amount to no more than 40 to 50 hours per year. In most cases, this would result in visibilities greater than 100 m.

Within the Vale city limits, fog occurrences would amount to less than 40 to 50 hours per year, with visibilities greater than 100 m.

Icing could occur when fog is present with sub-freezing temperatures. Along Highways 20 and 26 and within the Vale city limits, this would result in icy conditions during at most 10 to 15 hours per year.

In the Rhinehart Buttes area, to the southeast, fog occurrence could be higher than predicted as the plume contacts this elevated terrain.

In the east-northeast direction, the direction of prevailing winds, cooling-tower fog would probably enhance already existing fog in the vicinity of several large sewage ponds at distance of 0.5 km from the tower, as well as evaporation fog from the Malheur River.

To put these conclusions in perspective, it should be noted that natural fog occurrence amounts to 3.5% annually at Ontario Airport. This is equivalent to 300 hours per year.

(c) Drift Deposition: Without considering contaminants dissolved in drift water, the most significant impact of cooling-tower drift would be within 100 m of the tower. This impact is primarily associated with the objectionability of drift "rain". With a cooling tower drift rate of 0.01%, the maximum equivalent precipitation would be near 2.7 mm $hr^{-1}$ with a 1 m $sec^{-1}$ windspeed at a distance of 20 m from the tower. Even with a drift rate of 0.001% and a resulting precipitation rate of 0.27 mm $hr^{-1}$, this would be regarded as highly objectionable by Roffman's (1979) classification scheme.

At distances of 300 m from the tower (roughly the distance to Highways 20 and 26), with the wind blowing toward the highways, the equivalent precipitation rate would be 0.1 to 0.2 mm $hr^{-1}$ with a drift rate of 0.01%. With a drift rate of 0.001%, equivalent precipitation rates would be 0.01 to 0.02 mm $hr^{-1}$, noticeable but not necessarily objectionable.

At distances beyond 200 m, the annual moisture contribution from drift would be at most $10^4$ gm $m^{-2}$, about 1 cm, with a 0.01% drift rate. The Vale area has about 18.5 cm of precipitation annualy. Consequently, in terms of annual precipitation augmentation, the impact of cooling tower drift would be small except very near to the tower.

Data are insufficient to assess the impact of non-condensable gases and contaminants dissolved in drift water. More information is needed on the site-specific chemical composition of geothermal fluids and the efficiency of abatement systems which would be used, as well as the behavior of the chemically active contaminants $H_2S$ and $SO_2$.

Finally, as stated previously, the results of this study should be considered highly tentative. Its purpose was to be more instructive than conclusive. Impacts could be minimized by locating the plant at a more remote site, away from urban areas and major highways, and by orienting the cooling tower parallel to prevailing winds. A more precise analysis would require detailed information on the chemical composition of the geothermal fluid used, plant operating characteristics, types and efficiencies of pollution abatement systems, and local meteorology as measured at the site. In particular, more data would be needed relating wind and stability characteristics.

# APPENDIX B

# ONTARIO AIRPORT CLIMATOLOGICAL DATA

Ontario Airport OREGON

[illegible]

Table B-1. Temperature - Windspeed - Relative Humidity: Percentage Frequency of Occurrence for Selected Combinations, Annual, at Ontario Airport. (Reproduced from *Climatological Handbook of the Columbia Basin States*, 1968.)

Ontario Airport

| WEATHER | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| THUNDERSTORM | | * | * | 0.1 | 0.4 | 0.3 | 0.3 | 0.4 | 0.2 | 0.1 | * | | 0.2 |
| RAIN OR DRIZZLE | 5.3 | 4.3 | 5.4 | 4.4 | 3.4 | 3.4 | 0.5 | 0.9 | 1.4 | 4.4 | 7.2 | 5.9 | 4.3 |
| FREEZING RAIN OR DRIZZLE | 0.7 | 0.3 | | | | | | | | | | 3.2 | 0.1 |
| SNOW OR SLEET | 7.9 | 5.3 | 2.2 | 0.1 | | | | | | * | 0.3 | 6.4 | 1.9 |
| HAIL | | | | | * | | | | | | | | |
| HOURS WITH PRECIPITATION | 13.3 | 9.2 | 7.4 | 4.9 | 3.6 | 3.4 | 0.3 | 0.9 | 1.4 | 4.4 | 7.4 | 11.9 | 6.1 |
| FOG | 5.1 | 1.7 | 1.1 | 0.1 | | | | | * | 0.2 | 7.4 | 10.2 | 3.3 |
| SMOKE OR HAZE | 0.3 | 0.6 | * | * | | * | | | 0.4 | 0.9 | 0.7 | 0.4 | 0.3 |
| BLOWING SNOW | * | 0.2 | | | | | | | | | | | * |
| DUST OR SAND | | | | 0.1 | * | 0.1 | 0.1 | 0.1 | 0.1 | * | | | * |

Table B-2. Weather: Percentage Frequency of Various Weather Components at Ontario Airport. (Reproduced from *Climatological Handbook of the Columbia Basin States*, 1968.)

Ontario Airport

OREGON

[illegible]



Table B-3. Temperature - Windspeed - Relative Humidity: Percentage Frequency of Occurrence for Selected Combinations, by Months, at Ontario Airport. (Reproduced from *Climatological Handbook of the Columbia Basin States*, 1968.)

Ontario Airport

OREGON

[illegible]

[illegible]



[illegible]

[illegible]

Table B-3. Temperature - Windspeed - Relative Humidity: Percentage Frequency of Occurrence for Selected Combinations, by Months, at Ontario Airport. (Reproduced from *Climatological Handbook of the Columbia Basin States*, 1968.)

Ontario Airport

OREGON

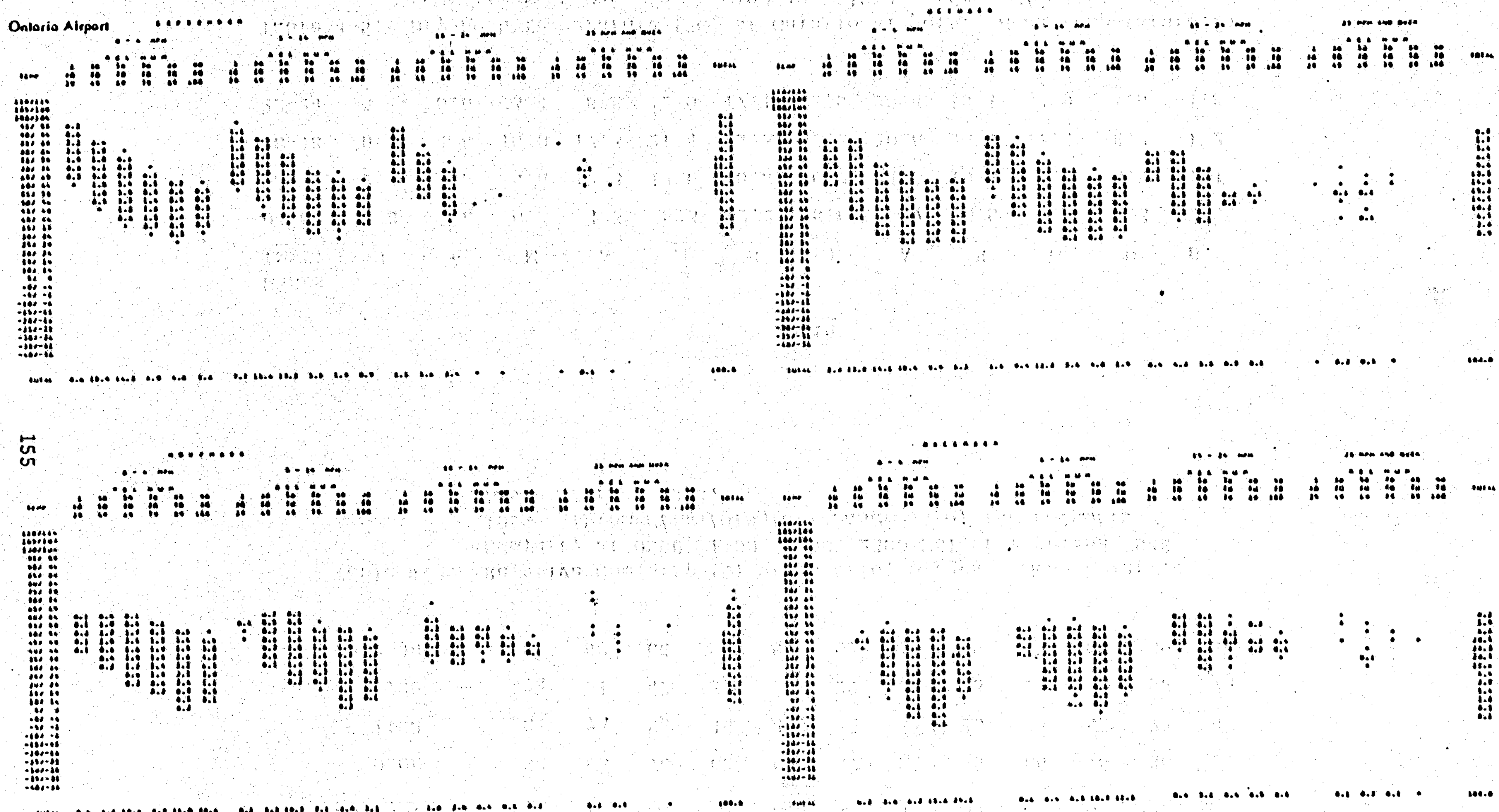


Table B-3. Temperature - Windspeed - Relative Humidity: Percentage Frequency of Occurrence for Selected Combinations, by Months, at Ontario Airport. (Reproduced from *Climatological Handbook of the Columbia Basin States*, 1968.)

| Hours (MST) | J | F | M | A | M | J | J | A | S | O | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Month** | | | | | | | | | | | |
| 0500 | 84 | 83 | 78 | 68 | 68 | 67 | 52 | 55 | 66 | 76 | 86 | 87 |
| 1100 | 81 | 73 | 58 | 46 | 44 | 42 | 33 | 36 | 43 | 53 | 73 | 82 |
| 1700 | 78 | 61 | 42 | 30 | 30 | 29 | 22 | 23 | 27 | 37 | 58 | 76 |
| 2300 | 82 | 80 | 68 | 55 | 57 | 52 | 39 | 45 | 53 | 66 | 80 | 86 |

Table B-4. Relative Humidity (%) at Ontario, Oregon. Mean Relative Humidity at 0500, 1100, 1700, 2300 MST, for period 1948-1954. (From *Climatological Handbook of the Columbia Basin States*, 1968).

| Hours (MST) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Month** | | | | | | | | | | | |
| 04-06 | -4.8 | -2.6 | 0.3 | 4.3 | 8.3 | 12.2 | 16.6 | 15.7 | 10.5 | 4.3 | -0.3 | -2.9 |
| 10-12 | -2.8 | 0.6 | 5.6 | 12.3 | 17.0 | 20.8 | 26.2 | 24.6 | 19.4 | 11.5 | 3.8 | -1.1 |
| 16-18 | 0.3 | 4.6 | 10.0 | 17.3 | 21.4 | 25.3 | 32.3 | 30.6 | 26.0 | 17.4 | 8.2 | 1.2 |
| 22-24 | -3.5 | -0.6 | 3.4 | 8.8 | 12.9 | 17.1 | 22.5 | 20.4 | 15.1 | 7.9 | 1.9 | -1.8 |

Table B-5. Dry-bulb Temperature (°C) at Ontario Airport. Mean Temperature for Four Times of Day, for period 1948-1954. (From *Climatological Handbook of the Columbia Basin States*, 1968.)

| Hour (MST) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Month | | | | | | |
| 0500 | 2.3 | 2.3 | 2.9 | 3.3 | 3.2 | 3.0 | 3.0 | 2.6 | 2.3 | 2.3 | 1.9 | 2.4 |
| 1100 | 2.4 | 2.5 | 3.7 | 3.6 | 3.4 | 3.1 | 2.7 | 2.5 | 2.2 | 2.4 | 2.1 | 2.3 |
| 1700 | 2.7 | 3.2 | 4.2 | 4.2 | 4.0 | 3.7 | 3.2 | 2.7 | 2.6 | 4.0 | 2.2 | 2.5 |
| 2300 | 2.5 | 2.7 | 3.1 | 3.4 | 3.8 | 3.4 | 3.9 | 3.6 | 3.0 | 2.8 | 2.3 | 2.3 |

Table B-6. Windspeed ($m\ sec^{-1}$) at Ontario Airport. Mean Windspeed for Four Times of Day for period 1948-1954. (From Table III-2 of *Climatological Handbook of the Columbia Basin States*, 1968.)



| Hours (MST) | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Month | | | | | | |
| 04-06 | 6.5 | 6.3 | 5.8 | 4.8 | 4.7 | 4.0 | 1.7 | 2.5 | 2.1 | 3.4 | 5.4 | 6.9 |
| 10-12 | 7.5 | 7.4 | 7.0 | 5.8 | 5.7 | 4.4 | 2.0 | 3.1 | 2.9 | 4.6 | 7.1 | 7.8 |
| 16-18 | 7.4 | 7.3 | 7.2 | 6.3 | 5.9 | 5.1 | 2.1 | 3.8 | 3.2 | 4.9 | 6.7 | 7.9 |
| 22-24 | 6.6 | 5.7 | 6.0 | 4.8 | 4.3 | 4.0 | 1.8 | 2.5 | 2.5 | 3.8 | 5.6 | 7.0 |

Table B-7. Sky Cover at Ontario Airport. Mean Tenths of Total Sky Cover for Four Times of Day, for period 1948-1954. (From *Climatological Handbook of Columbia Basin States*, 1968.)

Ontario Airport

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]



Table B-8. Wind: Percentage Frequency by Directions, in Selected Speed Increments by Months, for Ontario Airport. (Reproduced from *Climatological Handbook of the Columbia Basin States*, 1968.)

| | Speed Category (m $sec^{-1}$) (effective speed) | | | | | |
|---|---|---|---|---|---|---|
| Direction | 0.5-1.6 (1) | 1.6-5.6 (4) | 5.6-11.4 (9) | >11.4 (11) | Total Percent | Average Speed (m $sec^{-1}$) |
| N | 1.5 | 2.6 | 0.25 | | 4.35 | 2.6 |
| NNE | 1.9 | 3.8 | 0.24 | | 5.94 | 2.5 |
| NE | 1.9 | 2.8 | 0.04 | | 4.74 | 2.1 |
| ENE | 1.7 | 2.3 | 0.02 | | 4.02 | 2.6 |
| E | 1.8 | 2.0 | 0.03 | | 3.83 | 1.9 |
| ESE | 1.4 | 2.4 | 0.1 | | 3.90 | 2.3 |
| SE | 1.0 | 1.7 | 0.28 | 0.01 | 2.99 | 2.8 |
| SSE | 1.3 | 3.0 | 0.8 | 0.04 | 5.14 | 3.3 |
| S | 1.1 | 1.8 | 0.22 | | 3.12 | 2.6 |
| SSW | 0.9 | 1.5 | 0.13 | 0.01 | 2.54 | 2.5 |
| SW | 1.4 | 2.3 | 0.25 | 0.02 | 3.97 | 2.6 |
| WSW | 2.6 | 7.9 | 0.7 | 0.04 | 11.24 | 2.9 |
| W | 2.3 | 5.3 | 0.58 | 0.03 | 8.21 | 2.9 |
| WNW | 1.4 | 2.9 | 1.1 | 0.09 | 5.49 | 3.7 |
| NW | 1.3 | 3.7 | 3.8 | 0.12 | 8.92 | 4.8 |
| NNW | 1.5 | 4.3 | 4.4 | 0.23 | 10.43 | 5.2 |
| Calm | 11.1 | | | | 11.1 | |
| Total | 36.1 | 50.3 | 12.94 | 0.59 | 99.93 | 2.9 |

Table B-9. Annual Wind Percentage Frequency by Direction for Ontario Airport. (Based on data in *Climatological Handbook of the Columbia Basin States*, 1968.)

Speed Category (m sec$^{-1}$)
(effective speed)

| Direction | 0.5-1.6 (1) | 1.6-5.6 (4) | 5.6-11.4 (9) | >11.4 (11) | Total Percent | Average Speed (m sec$^{-1}$) |
|---|---|---|---|---|---|---|
| N | 1.2 | 2.3 | 0.25 | | 3.75 | 3.1 |
| NNE | 2.1 | 2.7 | 0.24 | | 5.04 | 2.8 |
| NE | 2.2 | 3.3 | 0.04 | | 5.54 | 2.6 |
| ENE | 2.9 | 3.4 | 0.02 | | 6.32 | 2.5 |
| E | 1.9 | 2.9 | 0.48 | | 5.28 | 3.1 |
| ESE | 0.7 | 2.1 | 0.03 | | 2.83 | 3.0 |
| SE | 0.3 | 0.6 | 0.08 | 0.01 | 0.99 | 3.3 |
| SSE | 0.3 | 1.0 | 0.1 | 0.01 | 1.41 | 3.5 |
| S | 1.0 | 1.8 | 0.2 | 0.03 | 3.03 | 3.2 |
| SSW | 1.5 | 2.0 | 0.5 | 0.01 | 4.01 | 3.3 |
| SW | 1.9 | 3.1 | 0.29 | 0.02 | 5.31 | 3.0 |
| WSW | 3.0 | 7.5 | 3.5 | 0.04 | 14.05 | 4.3 |
| W | 2.1 | 4.6 | 2.5 | 0.03 | 9.23 | 4.4 |
| WNW | 1.5 | 2.8 | 3.7 | 0.11 | 8.11 | 5.5 |
| NW | 0.9 | 3.6 | 3.7 | 0.11 | 8.31 | 5.6 |
| NNW | 1.6 | 1.9 | 2.0 | 0.08 | 5.58 | 4.7 |
| Calm | 11.0 | | | | 11.0 | |
| Total | 36.1 | 45.6 | 17.64 | 0.45 | 99.79 | 3.4 |

Table B-10. Annual Wind Percentage Frequency by Direction for Hypothetical Vale Site, extrapolated from Ontario Airport Data and used in Calculations of Annual Fog Occurrence and Drift Deposition.

SECTION C

of the

OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW STUDY*†

# WATER RESOURCES AND WATER QUALITY IMPACTS RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

by

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Livermore, California

† Sponsored by

U. S. Department of Energy

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# WATER RESOURCES AND WATER QUALITY IMPACTS RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON


## ABSTRACT

This report provides a survey of Oregon's Known Geothermal Resource Areas (KGRA's) particularly in regard to regional water resource characteristics and 1979 geothermal development activities. Water use requirements were estimated from a projected 25 year development scenario for nine major geothermal resource areas in Oregon. Potential significant water use requirements include: the Alvord and Vale KGRA's, which reportedly have geothermal resources particularly suited for electrical power generation, and the Cascades' hot water resources, which have potential use in direct heating.

A review of the chronological account of geothermal activities and impacts was projected for each of Oregon's KGRA's. Water quality issues and concerns regarding prospective geothermal activities within the resource areas were identified and ranked. The major concerns were: potential surface water pollution and degredation, changes in the ground-water regime, both chemical, thermal and hydraulic, erosion and sedimentation, subsidence and land mass movements.

Water quality baseline information was collected about Oregon's geothermal resources. The chemical attributes of Oregon's hot springs and wells were compared and considered as models for heated waters to be drawn for electrical power generation or direct use heating. On the basis of water quality standards, most of the thermal spring waters would be undesirable to discharge directly to surface waters following thermal recovery. A call was made for improving the water quality data base and establishing meaningful monitoring of Oregon's geothermal energy resources.

# I. INTRODUCTION

The environmental issues which will determine the acceptability of geothermal resources utilization need to be resolved for exploration of Oregon's resources. Known hydrothermal reservoirs in Oregon need to be assessed and demonstrated by the state and industry to utilize hydro(geo)-thermal resources optimally in terms of economic and environmental constraints.

Environmental impact data relevant to geothermal resource development are sparse since there are only three sites in the world with a significant history of geothermal power generation. While electrical power production from geothermal resources is a relatively new industry, geothermal hot water and steam have been used beneficially for centuries. Non-electrical space and direct heat uses by industry have been manifest for decades. The growing shortage of oil and natural gas is expected to cause a rapid increase in the utilization of geothermal resources; concurrently there is an increased environmental consciousness regarding exploration, development and utilization of natural resources which brings us to examine the potential water resource and water quality impacts associated with the development of geothermal resources within the State of Oregon. Exploitation of geothermal energy, like that of any other energy source, can result in negative impacts on the water quality of an area.

However, if we identify the key water-quality issues related to the development of Oregon's geothermal resources, and collect available information about them, we can direct our efforts towards studies that will efficiently identify and evaluate the potential impacts of such development. If we then identify and use the correct types of pollution control technology to control unavoidable impacts, the impacts of geothermal development on Oregon's geothermal resources will be minimal.

This report supersedes the March 1979 Oregon Geothermal Environmental Overview Workshop's water quality sessions' record, which is presented in the Appendix. This report expands on the workshop discussions and subsequent reviews. Additional bibliographic documentation has been provided concerning Oregon's environmental water data base and on the water related impacts and water assessments of emerging energy technologies associated with the potential regional geothermal developments.

## Objectives

The goals of this project parallel those of the overview workshop, which are:

- Identify water quality issues of concern in the development of geothermal energy.
- Prioritize these water quality issues.
- Inventory and assess the available data on these issues.
- Determine gaps in the data and information.
- Suggest needed water quality studies.

In accomplishing these goals it was hoped also to satisfy some tasks associated with Oregon State University's Water Resources Research Institute's efforts with the Pacific Northwest River Basins Commission on providing a "Water Assessment of Emerging Energy Technologies" with a focus on geothermal activities in the State of Oregon, including:

- selection of candidate areas for potential location of emerging (geothermal) technologies;
- comparison of siting criteria of geothermal energy technologies to siting characteristics in each water accounting unit;
- evaluation of resource requirements of energy development patterns and water accounting unit's resource availability; and
- quantification of water deficits of emerging energy deployment patterns.

## Scope of Investigation

The purpose of this report is to assess current and future water quality issues facing the State of Oregon as concerns the potential development of geothermal energy as a resource. A systematic statewide investigation of water resource and water quality information relating to potential geothermal activity has been made. Characteristics and potential activity for Oregon's known geothermal resource areas (KGRA) have been identified. Estimates of water use for direct heat utilization and power production have been compiled; the combined Western Cascade use projections are the largest of the systems considered, being as much as 40,000 l/s (1400 cfs) for supplying 2000 MWt direct heating.

A section of this report delineates regulations for maintaining water quality during geothermal resource developments.

A comparison has been made of recently reported water chemistry of the state's thermal springs and wells with accepted water quality standards for human, irrigation and livestock consumption. On the basis of present water quality standards, most of Oregon's thermal waters are undesirable for disposition to surface waters.

A ranking of general environmental impacts (ecological, air, water, solids and noise pollution) has been made for seven identified KGRA's of the state, encompassing periods from pre-lease exploratory stage through field and operational stages of geothermal energy extraction. The scenario outlined in the geothermal projections section has been used for estimating water requirements of geothermal activities.

Available bibliographic materials regarding water resources and water quality for the Oregon KGRA regions has been studied. Limited information was found. Accordingly, baseline studies and geothermal monitoring studies emphasizing the gathering of water resource and water quality information are recommended.

A summary of the water quality session of Oregon's Geothermal Environmental

Overview Workshop is included in the Appendix.

This report is based on available published findings and reports of others and is not original research. This discussion is limited to hot-water dominated resources. A general discussion of geothermal resource types can be found in Reference 27. Similarly, discussions of power production technology from various geothermal resource types can be found in References 76 and 86.

Economic analysis of water resource and water quality impacts and waste water treatment technology were considered to be beyond the scope of the work of the overview. Geothermal energy development pollution control technologies, including processes concepts and costs of waste water treatment and disposal, are covered in a recent EPA publication.[36] It is recommended that this report be periodically edited and upgraded to include economic analyses of proposed geothermal projects waste water treatment as new information becomes available on geothermal site selection in Oregon and as baseline water resource and water quality data improve.

We are grateful for the information that has been made available for this report and thank those who have contributed to elements of the various sections.

We hope that by providing this information, rational development of geothermal resources can progress with minimal impact on our environmental resources. Finally, we feel we have adequately identified the probable occurrence of water resource and water quality impacts associated with geothermal activities in Oregon's KGRA's; we wish to emphasize that in some cases the severity of the effects may be low even though the chance of occurrence might be ranked high.

## II. OREGON GEOTHERMAL PROJECTIONS

### Oregon's (KGRA's) Known Geothermal Resource Areas

Table I is a current compilation of Known Geothermal Resource Areas (KGRA) reservoir temperatures, electrical power potentials, intended power cycle types and water utilization estimates associated with projected geothermal developments within Oregon. KGRA's and PGRA's for Oregon are delineated on Figure 1.

Because the site specific locations, depth of strata, resource quality and volume to be tapped of most of these potential geothermal developments are not firm, it is difficult to relate what aquifers and water courses might be specifically influenced by recovery and use of the available geothermal energy. Similarly, since the State's geothermal resources have not been fully assessed in terms of: development character (liquid dominated, liquid dominated-binary, or vapor dominated), production type (electrical power vs. space heating), reservoir extent (strata depth, geologic formation, resource quality and potential volume), it is difficult to discuss geothermal exploration,

TABLE I. OREGON KGRA POTENTIAL POWER CHARACTERISTICS AND ESTIMATED WATER USE

| POTENTIAL AREA | SUBSURFACE TEMP °C | ELECTRICAL POWER | | | DIRECT USE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | POTENTIAL MWe (2) | COOLING WATER REQUIREMENTS (3) L/s | CONVERSION CYCLE | PRESENT MWt | FLUID REQUIRED L/s (5) | 3-5 yrs (total) MWt | FLUID REQUIRED L/s (5) | 5-25 yrs (total) MWt | FLUID REQUIRED L/s (5) |
| KLAMATH FALLS KGRA - 50,300 acres | 130 | No | | | 60[6] | 600 - 1200 | 72[6] | 720 - 1440 | | |
| ALVORD KGRA - 176,835 acres | 180 - 210 | 300 | 2500 - 5000 | FLASH | | | | | | |
| VALE KGRA - 22,998 acres | 160 - 180 | 770 | 6141 - 12,830 | BINARY/ FLASH | VERY LOW | | 5 | 50 - 100 | | |
| GLASS BUTTES | UNKNOWN | | | BINARY/ FLASH | | | | | | |
| ONTARIO - ORE IDA | | | | | | | 28 | 280 - 560 | | |
| LAGRANDE | 120 | No | | | VERY LOW | | 2-3 | 20-30 to 40-60 | | |
| LAKEVIEW KGRA - 12,165 acres | 160 | 123 | 1025 - 2050 | BINARY/ FLASH | .48[4] | 4.8 - 9.6 | 15 | 150 - 300 | | |
| MT. HOOD KGRA - 8,671 acres | 170 - 200 | | | BINARY/ FLASH | | | 2 | 20 - 40 | | |
| CASCADES | | | | BINARY/ FLASH | | | 100 | 1000 - 2000 | 2100 | 21,000 - 42,000 |

(1) Source - Bowen, R.G.
a. Geothermal Environmental Overview Study Workshop Presentation Mar. 26-29, 1979
b. Personal communication July, 1979
(2) MW electrical for 30 years
(3) Source - Environmental Readiness Document Sept., 1978 DOE/ERD-0005
(4) Source - Wilmer, Rodney D. et al. "Potential Environmental Issues Related to Geothermal Power Generation in Oregon," The Ore. Bin Vol. 39 no. 5, May, 1977
(5) Source - lower bound; Howard, J.H. Ed. "Present Status and Future Prospects for Non Electric Uses of Geothermal Resources Oct, 1975 UCRL - 51926
upper bound; related to personal communication with Paul Lineau (OIT) July, 1979
(6) Personal communication with Paul Lineau (OIT) Aug., 1979.

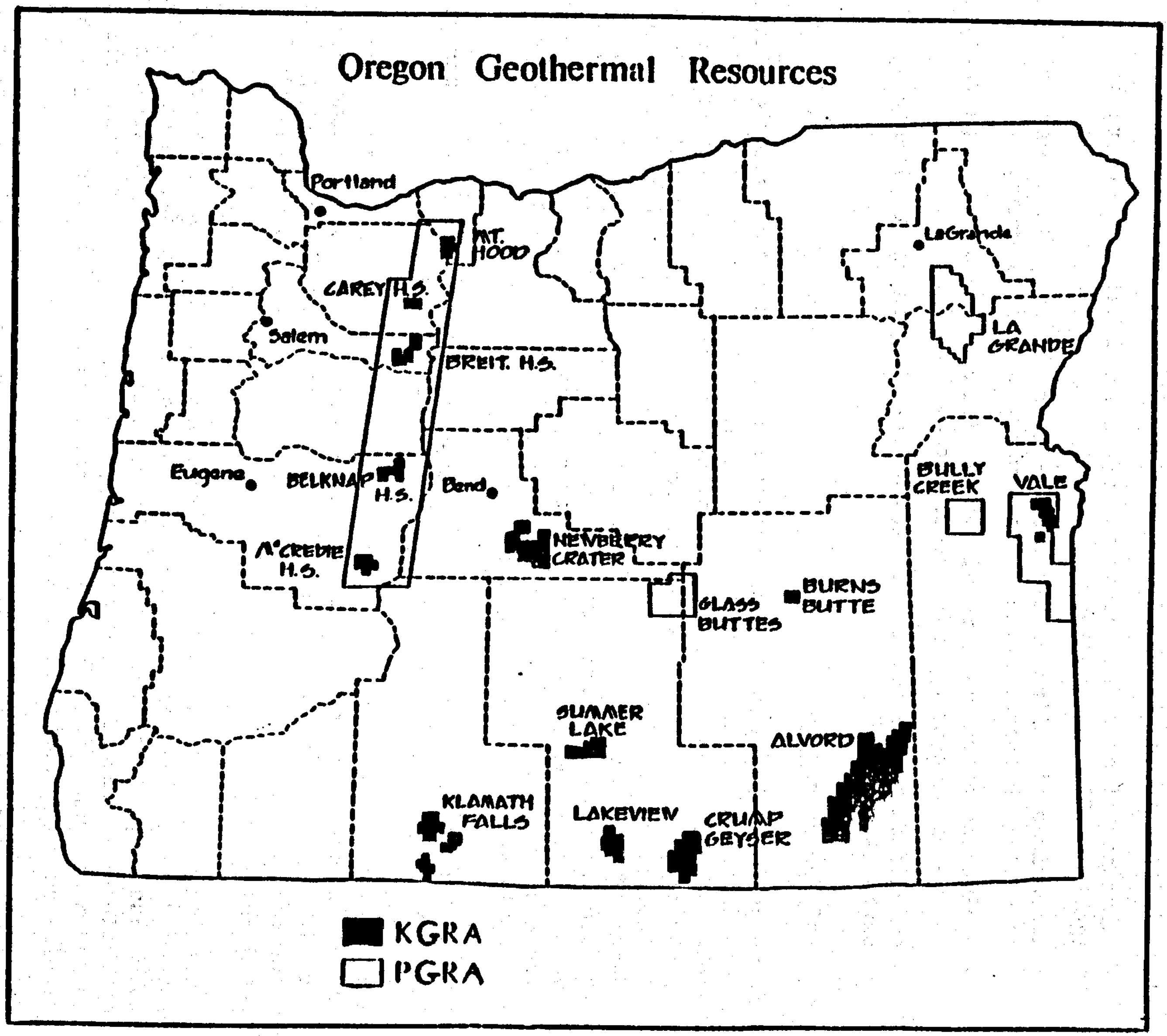


FIGURE 1. OREGON'S KNOWN (KGRA) AND POTENTIAL (PGRA) GEOTHERMAL RESOURCE AREAS

development and production activities which would significantly impact water quality aspects of particular aquifers and watersheds. The lack of such information has been a failing of most Environmental Impact Statements (EIS) which have been written to date (1979) for the development of Oregon's geothermal resources.

In this report we too must deal with regional KGRA's rather than specified sites for discussing possible water quality impacts connected to exploration and development of geothermal energy within the state. There is limited quantitative information available about possible water quality impacts because the type of resource, its depth, quality and production characteristics at specific sites in each KGRA is unknown. In other words, a scenario of projected development activities has been designated (Table I) for which we are to next consider the water resource and quality issues for each KGRA. The overall scenario may either underestimate or overestimate possible developments in the State of Oregon.

## Resource Applications and Economic Value

### 1. Historical Applications of Geothermal Resources

Geothermal energy is the heat energy that exists within the earth's crust. Geothermal energy is one of only a few energy resources indigenous to Oregon. Although identified geothermal resources in Oregon have lower temperatures than in some other areas of the United States, resource assessment and utilization is taking place in the state. It should be noted that Oregon has presently the most extensive geothermal direct utilization of any state, examples include greenhousing (Lakeview, Klamath Falls, Cove, Vale), agricultural applications and processing (Klamath Falls, Ontario, Vale), space heating (Klamath Falls, Lakeview, Vale, Hot Lake, Haines, Breitenbush Hot Springs, Ontario) and numerous geothermally heated spas and pools.[32]

Geothermal utilization in Oregon predates the white man. Indians used the hot springs for cooking and medicinal purposes, as did early settlers. The first large scale commercial use of geothermal was in Klamath Falls in the 1890's and early 1900's, in a large resort-spa on the side of Klamath Union High School.[57] In 1928, Butler's Natatorium was constructed to take advantage of the hot water resource underlying the city. At present, over 400 wells serve more than 500 structures in Klamath Falls, including a hospital, city schools and the Oregon Institute of Technology. Other uses include mile pasteurization, concrete curing, highway snow removal, laundry hot water and heated swimming pools. Some locations utilize waste hot water discharged into storm sewers. Overall, about 60 megawatts thermal ($MW_t$) of the present $MW_t$ total of direct use geothermal energy is being utilized at Klamath Falls, (see Table I).

Some geothermal operations at Klamath Falls have resulted in significant economic benefits. For example, Medo-Bel Creamery estimates its annual fuel savings at $20,000. At Oregon Institute of Technology's old campus, annual fuel costs were about $100,000 (at pre-inflation prices). At the new larger campus (440,000 square feet), OIT spends about $25-30,000 annually for its geothermal heating system; if oil were used, it would cost $250,000 (11,000 bbls of equivalent oil). The economic value of the geothermal resource as energy can be computed on a site specific basis by comparing geothermal heating costs to conventional fuel costs. In most cases, the initial capital investment is higher for geothermal than for conventional fuel, but savings in fuel purchases over the life of the project usually exceed this gap relatively quickly in cases of direct heat applications. As conventional fuel prices rise, the economic value of geothermal energy as a substitute of these fuels will also rise.[57]

2. General Statewide Developments

It is probable that Oregon will eventually realize significant electric power generation from its geothermal reserves, but this is not a near term prospect.

Estimates of future direct use of Oregon's "beneficial heat" total 3,222 x $10^{18}$ J available. This resource would develop 3416 MWt for 30 years of exploitation or only 1025 MWt for a century of use.[53] Similarly, the future electric power potential for the state is 2031 MWt for 30 years of exploitation or 677 MWt-centuries. Estimates of future electrical power potential from Oregon's geothermal sources are influenced by the optimism of estimators relative to consideration of the total resource development and expected technological break-throughs. The resource potential summed from U.S.G.S. Circular 790 (dated 1978)[53] is more conservative than offered in U.S.G.S. Circular 726 (dated 1975) and the corresponding estimates made by Bowen,[98] as shown in Table I.

Direct use applications---especially in agricultural processing, greenhousing and district heating---hold the greatest immediate potential. For example, Ore-Ida Foods is converging its Ontario plant to geothermal process heat. This facility processes about one million pounds per day of frozen potato and onion products. If successful, the geothermal conversion project will reduce fossil fuel consumption by half and result in a net annual savings of $1 million. The new system is scheduled for operation in late 1979. Other potential agricultural applications include greenhousing, crop dehydration, alfalfa drying, beet sugar processing and mushroom growing. The Geo-Heat Utilization Center (OIT) has produced an assessment of "Agribusiness Geothermal Energy Utilization Potential of Klamath and Snake River Basins, Oregon."[44]

A three year geothermal resource assessment was initiated in 1976 at Mt. Hood. This cost-sharing project involves the Oregon DOGAMI, USGS, US-DOE and US-FS. Drilling at Timberline Lodge was completed in 1978, did not reach target depth and accordingly a suitable geothermal resource has not yet been identified for development of space-heating and snow removal systems.

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The narrative for some of this section was abstracted, updated and revised from Reference 32 "Preliminary Geothermal Profile, State of Oregon" Geothermal Policy Project, National Conference of State Legislatures, 1405 Curtis Street, Ste. 2300, Denver, Colorado, October, 1978, pages 7-9 and personal communications.[3,20,37]

Northwest Natural Gas Company (NWNG), continues to drill at Old Maid Flat on the west flanks of Mt. Hood. NWNG envisions a $50 million project involving a 43 mile (69.2 km) pipeline (48 inch diameter (1.22 m)) to major industrial users in the Portland area (including Oregon City and Camas, Washington) to supply geothermal district heating, pulp and paper processing industries.

Klamath Falls has received a DOE/DGE grant for a downtown geothermal heating district. The project Phase I is designed to provide heating for 14 city, county, state and federal buildings and is scheduled for operation by 1980. Total costs will be approximately $1.5 million of which approximately 75% will be contributed by DOE. Phase II will cover 11 city blocks by providing additional connections to adjacent building. Phase III will provide heating to 54 user blocks and will be completed in 3 to 5 years through a bonding program; the bonding will be repaid by connection and user fees. Subsequently Klamath Falls will examine its geothermal resources for additional applications.

As these examples indicate, Oregon is in the forefront of geothermal direct use development. Add to this Oregon's geothermal electrical potential and the contribution of the resource to the state's energy future appears highly significant. Additional information on geothermal resource development in Oregon is given in Section II,3 regarding the individual resource sites.

### 3. Water Resource Characteristics and Development Activities of Oregon's KGRA's

Oregon's geothermal resources are primarily the liquid-dominated type, as opposed to being vapor-dominated (dry steam) or geopressured. As noted in Table I, Oregon is blessed with moderate and low temperature liquid geothermal resources for development. A listing of the locations, temperatures, volumes, and energies of identified hot-water hydrothermal convections systems within Oregon are given in Table II.[53] Following this listing is a narrative of the water resource characteristics and activities of Oregon's KGRA's regions, including: Western Cascades, High Cascades, Brothers Fault Zone, Southern Basin and Range, Snake River Plain, and the Columbia River Region.

#### a. Western Cascades

Breitenbush Hot Springs KGRA[32]

Total KGRA acres: 13,445
Surface Temperature: 99°C
Estimated subsurface temperature: 150°C
Approximate number of hot springs: 60
Natural surface discharge: 56.66 L/s

Present Development Status. Space heating in two resorts and pool heating. Temperature gradient holes have been drilled by the Sunoco Energy Co. and the Department of Geology and Mineral Industries. Sale to

Sunoco of 5818 Acres in 4 parcels for geothermal development took place in 1979; 1 parcel received no bids (1,029 acres). Twelve noncompetitive leases have been issued in 1979 covering 15,887 acres.

Interest has been shown in examining the resource to assess the feasibility for direct-use or electrical applications.

Surface Water.[15] Streams in the Breitenbush Geothermal Area (BGA) drain into the North Santiam and Clackamas River systems. Among the larger tributary streams are the Breitenbush River, Collawash River, Whitewater Creek, Woodpecker Creek and Devils Creek.

The average discharge of the North Santiam River measured over a 48-year period at a gauging station 0.5 mile below Boulder Creek is 1,017 cubic feet per second (c.f.c.) or 736,800 acre-feet per year. This represents 63.94 inches of runoff per year.

Flow of the Breitenbush River has been gauged since 1932 at the station above Canyon Creek. During that period the average flow has been 533 $ft^3$/second, or 422,400 acre-feet per year, which is equivalent to 74.69 inches of runoff per year.

The sediment yield of streams in the Willamette Basin is low because of favorable physiographic and climatic conditions. Soils derived from the basaltic, andesitic, and pyroclastic rocks underlying the western slope of the Cascade Range were generally quite resistant to erosion, but may be locally unstable. Further protection against erosion is provided by the trees, shrubs and other plants that grow profusely in the moderate maritime climate.

The Willamette Basin Task Force report indicates that average annual yield of sediment in the High Cascades area is estimated to be 50-150 tons per square mile. The Western Cascades area yield is 150-300 tons per square mile. Median particle size of streambed sediments taken from the North Santiam at the Mehama sampling station is 120 mm compared to 0.6 mm in samples taken from the Willamette River at Portland. Weighted mean concentration of sediments measured at the same sites shows 45 ppm for the North Santiam and 71 ppm for the Willamette.

The Geological Survey has obtained temperature data for the North Santiam River below Boulder Creek since 1951. The highest temperature recorded was 19°C and the lowest was at the freezing point at several times during the winters of 1954, 1956 and 1974.

At the station Breitenbush River above Canyon Creek, the Geological Survey has stream temperatures since 1950. The measured highest temperature recorded was 18°C on July 27, 1973. Freezing temperatures have been recorded on several days in December 1972 and January 1973.

Waters in streams draining the BGA are of excellent chemical and biological quality. These waters have few colonies of coliform and streptococci and

# TABLE IIa

*Locations, temperatures, volumes, and energies of identified hot-water hydrothermal convection systems >150°C--* Source-Geological Survey Circular 790

| Name of area | Latitude (°N) Longitude (°W) | Estimates of reservoir temperature (°C) | Mean reservoir temperature (°C) | Mean reservoir volume ($km^3$) | Mean reservoir thermal energy ($10^{18}$ J) | Comments | Wellhead thermal energy ($10^{18}$ J) | Wellhead available work ($10^{18}$ J) | Electrical energy ($MW_e$ for 30 yr) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | O R E | G O N | | | |
| Newberry caldera | 43 43<br>121 14 | 180<br>230<br>280 | 230 ± 20 | 47 ± 16 | 27 ± 10 | Reported hot springs appear to be drowned fumaroles which issue along the shores of East Lake and Paulina Lake in Pleistocene caldera. Reservoir temperatures are inferred and based on temperatures estimated for other Quaternary volcanoes. | 6.9 | 1.74 | 740 |
| Crump's Hot Springs | 42 13.0<br>119 53.0 | 144 (I)<br>173 (A)<br>185 | 167 ± 9 | 7.2 ± 2.0 | 3.0 ± 1.2 | Several hot springs and seeps and one geysering well; maximum wel. temperature 121°C at 201 m depth; sinter deposits. | 0.74 | 0.144 | 61 |
| Mickey Hot Springs | 42 40.5<br>118 20.7 | 180 (A)<br>207 (I)<br>227 (K) | 205 ± 10 | 12.0 ± 6.7 | 6.5 ± 3.5 | Hot springs to 73°C discharging 100 L/min; mud pots; extensive sinter. | 1.63 | 0.38 | 160 |
| Alvord Hot Spring | 42 32.6<br>118 31.6 | 148 (A)<br>164 (J)<br>231 (K) | 181 ± 18 | 5.0 ± 2.1 | 2.2 ± 1.0 | Several hot springs to 76°C discharging 500 L/min in area about 0.5 $km^2$. | 0.56 | 0.117 | 49 |
| Hot (Borax) Lake area | 42 20<br>118 36 | 165 (C)<br>176 (I)<br>231 (K) | 191 ± 14 | 8.3 ± 3.5 | 4.0 ± 1.7 | Several springs to 96°C and one large pool (lake); total discharge 3500 L/min; sinter. | 0.99 | 0.22 | 91 |
| Trout Creek area | 42 11<br>118 23 | 140 (A)<br>143 (I)<br>180 | 154 ± 9 | 3.3 ± 0.9 | 1.25 ± 0.36 | Hot springs and seeps to 52°C discharging 200 L/min. Sulfate-water isotope geothermometer gives 235°C and may indicate leakage from the systems in the Alvord Desert (Hot Lake, Alvord and Mickey Hot Springs). | 0.31 | 0.056 | 24 |
| Neal Hot Springs | 44 01.4<br>117 27.6 | 173 (A)<br>181 (I)<br>210 (K) | 188 ± 8 | 3.3 ± 0.9 | 1.56 ± 0.44 | Hot springs to 87°C discharging 100 L/min; sinter. | 0.39 | 0.084 | 36 |
| Vale Hot Springs | 43 59.4<br>117 14.0 | 152 (A)<br>157 (I)<br>161 (K) | 157 ± 2 | 117 ± 56 | 45 ± 21 | Large area suggested by audio-magnetotelluric survey and heat flow anomaly. Hot springs in two groups to 97°C, but low flow rates. Another sulfate-water isotope determination gives 200°C. | 11.2 | 2.0 | 170 |

# TABLE IIb

*—Locations, temperatures, volumes, and thermal energies of identified hot-water hydrothermal convection systems 90–150°C*

(For reservoir temperature estimates, first number is most likely value, subscript is maximum value, and superscript is minimum value. Letters indicate method used to estimate temperature, as follows:

A. Quartz conductive
B. Quartz conductive, pH-corrected.
C. Quartz adiabatic
D. Chalcedony
E. Chalcedony, pH-corrected
F. Cristobalite
G. Amorphous silica
H. Na-K
I. Na-K-Ca
J. Na-K-Ca, Mg-corrected
K. Sulfate-water isotope
L. Surface
M. Reported well
N. Mixing
O. Renner, 1976

No letter indicates a subjective estimate. Mean values of temperature, volume, and reservoir thermal energy are followed by standard deviations. Temperatures given to three significant figures; in most cases volumes and energies are given to two significant figures. However, if the first digit is 1, three significant figures are given in order approximate to more closely uniform percentage accuracy.)

| No. | Name of area | Latitude (°N)<br>Longitude (°W) | Estimates of reservoir temperature (°C) | Mean reservoir temperature (°C) | Mean reservoir volume ($km^3$) | Mean reservoir thermal energy ($10^{18}$ J) | Comments | Wellhead thermal energy ($10^{18}$ J) | Beneficial heat ($10^{18}$ J) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | OREGON | | |
| | Summer Lake Hot Springs | 42 43.5<br>120 38.7 | 107 (D)<br>112 (I)<br>134 (A) | 118 ± 6 | 7.8 ± 2.8 | 2.2 ± 0.8 | Three springs to 43°C discharging 75 L/min. Sulfate-water isotope geothermometer gives about 190°C. | 0.54 | 0.130 |
| | Lakeview area (Hunters and Barry Ranch Hot Springs) | 42 12.0<br>120 21.6 | 143 (I)<br>149 (C)<br>158 (K) | 150 ± 3 | 15.3 ± 5.6 | 5.6 ± 2.0 | Several springs to 96°C discharging 2500 L/min; travertine and sinter. Two geothermal exploration wells 109 and 1650 m deep; several shallow wells used for space heating. | 1.39 | 0.33 |
| | Fisher Hot Spring | 42 17.9<br>119 46.5 | 95 (D)<br>123 (A,J)<br>123 (A,J) | 114 ± 7 | 3.3 ± 0.9 | 0.89 ± 0.26 | Spring discharging 75 L/min at 68°C. | 0.22 | 0.053 |
| | Weberg Hot Springs | 44 00.0<br>119 38.8 | 99 (D)<br>100 (J)<br>126 (A) | 108 ± 6 | 3.3 ± 0.9 | 0.84 ± 0.24 | Spring discharging 40 L/min at 46°C. $CO_2$-rich water; geothermometers may be unreliable. | 0.21 | 0.050 |
| | Barney Lake area | 43 10.9<br>119 03.2 | 105 (D,J)<br>105 (D,J)<br>133 (A) | 114 ± 7 | 3.3 ± 0.9 | 0.89 ± 0.26 | Several springs to 68°C discharging 550 L/min. Reservoir may be larger than estimated. | 0.22 | 0.053 |
| | Crane Hot Springs | 43 26.4<br>118 38.4 | 99 (D)<br>124 (I)<br>127 (A) | 117 ± 6 | 3.3 ± 0.9 | 0.91 ± 0.26 | Two springs to 78°C discharging 550 L/min. | 0.23 | 0.055 |
| | Riverside area | 43 28.0<br>118 11.3 | 96 (I)<br>116 (D)<br>143 (A) | 118 ± 10 | 3.3 ± 0.9 | 0.93 ± 0.28 | Several springs to 63°C discharging 200 L/min. | 0.23 | 0.056 |
| | McDermitt area | 42 04.7<br>117 45.6 | 84 (E)<br>90 (I)<br>120 (A) | 98 ± 8 | 3.3 ± 0.9 | 0.75 ± 0.22 | Several springs to 52°C discharging 750 L/min. | 0.188 | 0.045 |
| | Medical Hot Springs | 45 01.1<br>117 37.5 | 66 (I)<br>97 (D)<br>125 (A) | 96 ± 12 | 3.3 ± 0.9 | 0.73 ± 0.23 | Several springs to 60°C in two groups discharging 200 L/min. | 0.183 | 0.044 |
| | Little Valley area | 43 53.5<br>117 30.0 | 118 (D,I)<br>118 (D,I)<br>145 (A) | 127 ± 6 | 3.3 ± 0.9 | 1.11 ± 0.29 | Several springs to 70°C discharging 550 L/min. Sulfate-water isotope geothermometer gives 215°C. | 0.25 | 0.061 |

## TABLE IId

*Locations, temperatures, volumes, and thermal energies of identified hot-water hydrothermal convection systems 90-150°C—*

| Name of area | Latitude (°N) Longitude (°W) | Estimates of reservoir temperature (°C) | Mean reservoir temperature (°C) | Mean reservoir volume ($km^3$) | Mean reservoir thermal energy ($10^{18}$ J) | Comments | Wellhead thermal energy ($10^{18}$ J) | Beneficial heat ($10^{18}$ J) |
|---|---|---|---|---|---|---|---|---|
| | | | | | O R E | G O N | | |
| Mount Hood area | 45 22.5<br>121 42.5 | 90 (O)<br>125 (O)<br>150 (O) | 122 ± 12 | 3.3 ± 0.9 | 0.96 ± 0.29 | Fumaroles and acid-sulfate springs to 90°C; reservoir temperatures are speculative; may be a small vapor-dominated system. | 0.24 | 0.058 |
| Carey (Austin) Hot Springs | 45 01.2<br>122 00.6 | 87 (I)<br>98 (D)<br>126 (A) | 104 ± 8 | 3.3 ± 0.9 | 0.80 ± 0.24 | Several springs to 91°C discharging 950 L/min. Sulfate-water isotope geothermometer gives 181°C. | 0.20 | 0.049 |
| Breitenbush Hot Springs | 44 46.9<br>121 58.5 | 99 (D)<br>127 (A)<br>149 (I) | 125 ± 10 | 3.3 ± 0.9 | 0.99 ± 0.29 | Several springs to 92°C discharging 3400 L/min. Sulfate-water isotope geothermometer gives 195°C. | 0.25 | 0.059 |
| Kahneetah Hot Springs | 44 51.9<br>121 12.9 | 102 (I)<br>113 (D)<br>113 (D) | 109 ± 3 | 3.3 ± 0.9 | 0.85 ± 0.24 | Several springs to 52°C dicharging 200 L/min. | 0.21 | 0.051 |
| Belknap Hot Springs | 44 11.6<br>122 03.2 | 82 (I)<br>108 (D)<br>148 (K) | 113 ± 14 | 3.3 ± 0.9 | 0.88 ± 0.28 | Three springs to 71°C discharging 300 L/min; may be part of a larger system that includes Foley Hot Springs. | 0.22 | 0.053 |
| Foley Hot Springs | 44 09.8<br>122 05.9 | 81 (D)<br>106 (I)<br>111 (A) | 99 ± 7 | 3.3 ± 0.9 | 0.76 ± 0.22 | Four springs to 79°C; system may be larger and include Belknap Hot Springs 6 km to the northeast. | 0.190 | 0.046 |
| McCredie (Winino) Hot Springs | 43 42.6<br>122 17.3 | 81 (I)<br>96 (D)<br>96 (D) | 91 ± 4 | 3.3 ± 0.9 | 0.68 ± 0.19 | Several springs to 73°C discharging about 75 L/min. | 0.170 | 0.0[illegible]1 |
| Umpqua Hot Springs | 43 17.5<br>122 22.0 | 100 (J)<br>104 (D)<br>131 (A) | 112 ± 7 | 3.3 ± 0.9 | 0.87 ± 0.25 | Two springs to 46°C discharging less than 20 L/min; travertine. $CO_2$-rich water; geothermometers may be unreliable. | 0.22 | 0.0[illegible]2 |
| Klamath Hills area | 42 03.0<br>121 44.5 | 104 (D)<br>131 (A)<br>138 (K) | 124 ± 7 | 10.6 ± 3.0 | 3.1 ± 1.1 | Several wells to 127 m; maximum temperature 93°C at 127 (?) m; 9 $km^2$ area of silicified rocks. Thermal water used in greenhouse operation. | 0.78 | 0.1[illegible]7 |
| Klamath Falls area | 42 14<br>121 46 | 99 (M)<br>104 (D)<br>131 (A) | 111 ± 7 | 114 ± 55 | 30 ± 15 | Several wells ranging in depth from 40 to 550 m used for space heating; downhole temperatures as high as 113°C are reported. Area includes 74°C springs at Olene Gap 13 km to the southeast. Sulfate-water isotope geothermometer gives about 190°C. | 7.4 | 1.7[illegible] |

[redacted]3 IIe[redacted]S PA[redacted]E FOR[redacted]VERY[redacted]EVELO[redacted]OF LO[redacted]URCES[redacted]

LOW-TEMPERATURE (<90°C) GEOTHERMAL WATER[53]

| Name of Area | Wells Considered No. | Wells Considered Depths (m) | Wells Considered Temperature (°C) | Thermal Springs No. | Thermal Springs Temperature (°C) | Thermal Gradients[b] (°C/km) | Equilibration Temperature[c] (°C) | Dissolved Solids (mg/L) | Remarks[d] (asterisks relate specific comments to columns at left) |
|---|---|---|---|---|---|---|---|---|---|
| OREGON<br>Belknap - Foley Hot Springs | 2 | ~150 | 14,22 | 3 | 61-89 | 85,92 | *107 | 1,000-2,500 | Heat source probable lateral migration from Holocene volcanic centers. Heat flow 110-140 mW/m². Includes Belknap Springs KGRA, Foley Springs high-temperature system, and Bigelow Hot Springs. *Chalcedony and Na-K-Ca geothermometers (Belknap and Foley Hot Springs). |
| Willamette Pass | 2 | 150 | 15,21 | 3 | 41-71 | 80 | *97 | 1,000-4,000 | Heat source probable lateral migration from Holocene volcanic centers. Heat flow ~105 mW/m². Includes McCredie Hot Springs KGRA, Kitson and Wall Creek Hot Springs. *Chalcedony geothermometer (McCredie Hot Springs). |
| Craig Mountain - Cove (LaGrande) | 5 | 45-885 | 30-80 | 11 | 24-82 | 40-50 cond.<br>96 conv. | *89,92 | 225-525 wells<br>200-900 spgs. | Deep circulation in complexly faulted graben. Aquifer: Permian and Triassic greenstones. *Na-K-Ca geothermometer (Hot Lake Hot Springs), chalcedony geothermometer (Medical Hot Springs). |
| IDAHO<br>Western Snake River Basin, Oregon | 50 | 30-310 | 20-103 | 3 | 20-97 | 85 | *157 | ~1,000 | Deep circulation in faults, Grassy Mountain Basalt and Columbia River Basalt Group. High convective gradients at places. Heat flow 102 mW/m² (ave.). *Max. temperature at Vale Hot Springs high-temperature system. |
| Glass Buttes | 3 | 60-220 | 18-48 | — | — | 120-190 | — | — | Circulation in faults in rhyolitic dome; possible magmatic heat source. Heat flow 122-193 mW/m². |
| Northern Harney Basin | 7 | 50-300 | 22-72 | 5 | 21-27 | 150 | *110,125 | 400-2,000 | Deep circulation near rim of caldera(?). Aquifers in basin sediments, interlayered volcanic rocks. Heat flow 80-105 mW/m². *Quartz, Na-K-Ca geothermometers, respectively. |
| Southern Harney Basin | 20 | 30-160 | 22-25 | 15 | 20-68 | 75-140 | *130 | 100-2,000 | Deep circulation, possible magmatic source (rhyolitic intrusions). Aquifers in basin sediments, interlayered volcanic rocks. Water quality best in north (Brothers fault zone). *Quartz geothermometer in Harney Lake high-temperature system. |
| Alvord Desert | 4 | 35-95 | 16-22 | 10 | 36-97 | *47-300 | ** | 1,300-3,200 | Deep circulation in faults (?). *Four gradient holes <100 m deep in low-conductivity sediments. **Sulfate-oxygen isotope geothermometer (Alvord, Hot Lake, and Mickey Hot Springs( is 230°C |
| Lakeview | ~15 | 15-300 | 40-94 | 3 | 72-94 | 60-150 | *96-140 | ~1,000 | Deep circulation; possible heat source in Warner Range to east. Aquifers in valley-fill deposits. Heat flow ~105 mW/m². *Na-K-Ca geothermometer, Hunters and Barry Ranch wells. |
| Klamath Falls | ~600 | 20-550 | 15-95 | 8 | 16-87 | 30-1000 conv.<br>80 cond. | *105 | 250-3,000 | Deep circulation in range faults, Tertiary volcanic rocks. More than 500 wells used for space heating. Hottest waters have dissolved solids <1,000 mg/L. Many aquifers in Tertiary and Pleistocene rocks. Heat flow 60 mW/m² in Lower Klamath Lake basin. *Chalcedony, Na-K-Ca geothermometers for principal geothermal reservoirs. |

[b] Most thermal gradients reported in this table were calculated by subtracting mean annual air temperatures from maximum reported fluid temperatures in wells and test holes and dividing by the total depths of the wells. The resulting linear gradients do not reflect actual depths of occurrence of thermal waters or variations due to changes in thermal conductivity with depth, and they may be strongly influenced by convective flow in the wells and in the formations. At most places, therefore, the gradients do not represent conductive thermal gradients in the earth's crust. "Cond." = probable conductive gradients; "conv." = affected by convection.

[c] Temperatures of rock-water equilibration estimated by means of chemical geothermometers; mostly unreliable for low-temperature waters unless possible effects of mixing, ionic interference, high concentrations of dissolved solids, amorphous silica, and other factors are accounted for; not considered reliable for most of the lower temperature waters included in this table. In some areas where equilibration temperatures are not available for low-temperature waters, estimates from high-temperature (≥90°C) springs are given. Most of these estimates are taken from Brook and others, hydrothermal convection systems with reservoir temperatures ≥90°C, this volume.

[d] Thermal springs are defined for this report as those having surface temperatures at least 10C above mean annual air temperatures. Thermal wells are also defined on the basis of minimum temperatures 10C above mean annual air temperatures but, in addition, are required to have thermal gradients exceeding the 30 C/km average for continental crust rocks. Criteria used in selecting and defining the favorable areas include the temperature and thermal-gradient minima described above for thermal wells and springs. In addition, regional conductive heat-flow measurements were given considerable weight, especially in a few areas for which hydrologic data suggested only marginal favorability but for which regional heat flows were high. Heat flow is generally greater than 60 mW/m² in most areas. One index of water quality, concentration of dissolved solids, is reported for areas where it is known, but this index was not used as a basis for selection of favorable areas. Many confirmed high-temperature geothermal systems are not included in the areas listed. Although it may be assumed that conditions favorable for the occurence of low-temperature waters exist in the vicinity of most high-temperature systems, available data permit depiction of favorable areas only at a few such locations.

The tuffs and older volcanic rocks of the Western Cascades occur in the western and topographically lower parts of the BGA. They also underlie the High Cascade volcanic rocks at least in the western edge of the High Cascades. Breitenbush Hot Springs apparently issues from these rocks, and they are tapped by a well reported to be a few miles west of the BGA. Generally, these rocks have relatively low permeability and yield water only slowly to wells. Therefore, the hot springs may be associated with an unusual hydrologic phenomenon---perhaps a highly fractured zone or a layer of abnormally high permeability. In the Cascade foothills west of Willamette National Forest, these rocks yield water in quantities adequate for domestic supplies to wells ranging from about 100 to 600 feet in depth.

The only data available on ground water quality in the BGA is the analysis of water from Breitenbush Hot Springs. (See Table IV) That water may rise from considerable depth, so probably is not representative of water from shallower aquifers. Water from zones likely to be tapped by wells should be similar to water from streams, but somewhat higher in dissolved constituents. The ground water should be of excellent quality suitable for domestic and other uses.

Stream classification. Breitenbush River and all its tributaries are closed for industrial usage.

Carey Hot Springs KGRA (Part of Austin Hot Springs)[32]
(North of Breitenbush)

Total KGRA acres: 7,579
Total State and Private Acres: 160 (160 acres at Austin HS System being developed by PGE)
Surface Temperature: 86°C
Estimated subsurface temperature: 125°C
Natural surface discharge: 15.83 liters/second

Present Development Status: Recreational bathing only. Two shallow temperature gradient holes have been drilled in the vicinity in 1975 and 1976 by DOGAMI.

Leasing on the KGRA lands will not be considered until the Clackamas Land Management Planning process has been completed. The document is scheduled for release in late 1979. Noncompetitive leasing outside the KGRA is tentatively scheduled following receipt of Forest Service recommendation.

The potential for utilization of Carey Hot Springs is now well known at this point.

McCredie Hot Springs KGRA (South of Breitenbush)[32]

Total KGRA acres: 3659
Surface temperature: 73°C (164°F)
Natural surface discharge: 4.80 L/s
Estimated reservoir temperature: 75°C - 120°C

No geothermal development or leasing has taken place in the McCredie area.

have low concentrations of dissolved constituents, including heavy metals. Concentrations of nutrients such as nitrogen and phosphorus also are low. Analyses of water from Breitenbush and North Santiam Rivers, shown on pages 47 and 48, are representative of waters from streams in the area.

Streams in the area are tributary to rivers tapped for domestic water at the following recreation sites and urban areas:

| Site | Source |
|---|---|
| Oregon City | Clackamas River |
| City of Estacada | Clackamas River |
| Whispering Falls C.G. | Unnamed tributary, N. Santiam River |
| Riverside C.G. | Unnamed tributary, N. Santiam River |
| Whitewater C.G. | Whitewater Creek (no developed source) |
| Cleator Bend C.G. | Breitenbush River (no developed source) |
| Breitenbush C.G. | Unnamed tributary, Breitenbush River |
| City of Detroit | Breitenbush River |
| City of Idanha | *Cabin Creek |
| Breitenbush Forks Recreation Resid. Tract | S. Fk. Breitenbush River (no developed source) |
| Devils Creek Recreation Resid. Tract | Devils Creek (no developed source) |
| Breitenbush Hot Springs Resort (USFS permit) | Mansfield Creek |
| Villa Maria Lodge | Shallow Well |
| Chemeketans Cabin | Whitewater Creek (no developed source) |

*Outside the area influenced by the BGA.

Ground Water.[15] Little direct information is available concerning ground water in the BGA. The only known developed ground-water supply in the area is the well that supplies Villa Maria Lodge.

The volcanic rocks of the High Cascades, which occur in the topographically higher parts of the area, are generally considered to be highly fractured. They readily receive infiltration from precipitation and discharge water freely to maintain the dry-weather flow of streams. In most places, the regional water table in those rocks lies at a depth of at least a few hundred feet, reflecting the high permeability of the rocks and the depth of surface erosion. No wells are known to be drilled in these rocks in the BGA.

The alluvium along the Breitenbush River and the glacial deposits adjacent to local stream valleys consist of unconsolidated, poorly stratified and lenticular beds. Where these deposits have sufficient thickness and lie below the water table, they may contain ground water that could be used locally for domestic sources. Ground water in these deposits, immediately adjacent to streams, probably is in hydraulic continuity with the stream. Thus, these deposits may receive some recharge from the streams when stream stages are high and may contribute to streamflow during low-flow periods. To date, no wells are known to tap these deposits.

hydroelectric project operated by the Eugene Water and Electric Board. A unique feature of this project is the diversion of part of the McKenzie River flow through a tunnel into Smith Reservoir, and then back into the McKenzie River at Trail Bridge Reservoir through a power tunnel and penstock.

Discharge - Average discharge of the McKenzie River at the Clear Lake outlet (32-year average) is 486 cubic feet/second (cfs) and 352,100 acre-feet/year. Minimum discharge during the same period at the Clear Lake outlet was 160 cfs. At the gauging station below McKenzie Bridge the average yearly discharge (66-year period) was 1,693 cfs and 1,227,000 acre-feet/year. Minimum discharge during the period of record of this gauging station was 805 cfs.

For the North Santiam River at the Boulder Creek gauging station over a 50-year period average discharge is 1,020 cfs and 739,000 acre-feet/year. Minimum discharge is 250 cfs, recorded in 1909.

Temperature - Average temperature of the McKenzie River at the McKenzie Bridge gauging station is 45.5°F, with a minimum of 40°F and a maximum of 51.8°F. Temperatures measured at this station are the lowest in the McKenzie system. Low temperatures are attributable to the subterranean reservoirs, snowmelt, and glacier seepages comprising the source for this section of the river.

Temperature data have been recorded for the North Santiam River at the gauging station below Boulder Creek since 1951. The highest temperature recorded was 64°F on July 27, 1973. Temperatures at the freezing point were recorded on several days during the winters of 1954, 1956 and 1974.

Sediment - Discharge of the McKenzie River at the Coburg gauging station is 18 percent of the Willamette River's streamflow at Portland. Sediment yield at Coburg is 9 percent of the yield at Portland. For the North Santiam River at Mehama, streamflow is 10 percent of the Willamette River streamflow at Portland, while sediment yield is 6 percent of the Willamette River Sediment yield at Portland. Annual yield of sediment in the study area ranges from 50 to 300 tons per square mile.

Particle size of streambed sediments from the McKenzie River at the Coburg gauging station is 55 mm compared to 0.6 mm for the Willamette River at Portland. For the North Santiam River at the Mehama gauging station, particle size of streambed sediments is 120 mm.

Weighted mean concentration of sediments measured at the Coburg, Mehama and Portland gauging stations respectively is 34 ppm, 45 ppm, and 71 ppm.

Domestic Use - Surface water from the McKenzie River is the domestic source for approximately 125,000 persons in the City of Eugene and unincorporated Glenwood, Oakway and Santa Clara suburban areas. Exact figures are unavailable, but a substantial percentage of the 4,600 residents of the McKenzie Valley east of Springfield also rely on surface waters of the McKenzie River for domestic water supplies.

The draft environmental impact statement possible will be initiated in 1980 and leasing will not be addressed until the document is final. All lease applications received for this KGRA have been withdrawn.[97]

Belnap-Foley (McKenzie River area)[32]

KGRA acres: 4706
Surface Temperature: 71°C
Natural Surface Discharge: 75 gpm (5.7 L/s)
Estimated Reservoir Temperature: 149°C

Draft EIS in process of review (August, 1979); leasing is expected to occur during late 1980 summer.[97] Sunoco Energy Development Company applied for leases in area. Eugene Water and Electric Board (EWEB) working with various companies for future consideration for electrical power production.[71]

The possibility of geothermal resources in the McKenzie River area is suggested by hot springs issuing from Intermediate Age rocks at Belnap, Foley and Bigelow. All of these hot springs emerge within a few hundred feet of the 1800-foot contour. It has been suggested that this may represent a regional water table. Whether the hot springs are directly over their heat source or find their way through vents from geothermal systems related to more recent volcanism of the High Cascades farther to the east is a subject of conjecture. Some geologists suggest that the hot springs known at the surface may be recirculating relatively near surface waters, and that hot water or steam systems deeper underground may be effectively sealed off by relatively impermeable layers of silica derived from the abundant silica ash deposits of the Western Cascades. Chemical and trace element data collected and analyzed by the U.S. Geological Survey suggest thermal aquifer temperatures for Belnap Hot Springs ranging from a low of 56°C to a high of 135°C.[88]

The Oregon Department of Geology and Mineral Industries has drilled two wells in the Belnap Foley area for temperature-gradient studies. One of these wells, drilled on the floor of Horse Creek Valley, yielded temperature-gradient measurements well above the 7°C/100m minimum often used as a guideline for economically attractive geothermal resources. The second well was drilled on the lower slope of a ridge about 1/2 to 3/4 mile northwest of Belnap Hot Springs. Measurements in this well suggested an above normal, but lower than economically attractive, temperature gradient. Temperature gradients listed for both wells have not been adjusted to correct for lateral movement of cool ground water, a factor that can influence temperature gradient measurements at intermediate depths.[88]

Surface Water.[88] Drainage Systems, Reservoirs and Lakes - The Belnap Foley area is drained by the McKenzie and North Santiam River systems. Among the larger streams are Horse Creek, White Branch, Lost Creek, Deer Creek, Smith River, Parks Creek, Browder Creek, Lynx Creek, and Downing Creek. Also within the area are three reservoirs totaling 259 acres and eight lakes totaling 332 acres.

Trail Bridge, Smith and Carmen Reservoirs are components of a 90 megawatt

Surface Temperature: 90°C
Estimated Subsurface Temperature: 125°C

The only hot spring in the Mt. Hood area is Swim Hot Springs which flows at 1.58 L/s at 27°C. East and northeast of Crater Rock near the summit of Mt. Hood are at least 20 fumarolic vents with temperatures ranging from 50-85°C.

A three year resource assessment of the Mt. Hood Volcano was begun in 1977 as a joint effort by the U.S. Department of Energy, U. S. Geological Survey, U.S. Forest Service and the Oregon Department of Geology and Mineral Industries.

Mt. Hood Geothermal Assessment Project - current status participants: DOGAMI, USGS.

Studies completed (C) or in Progress (IP):

DOGAMI:
- gravity study of Mt. Hood cone and flanks (C)
- geology study of Columbia River basalts (C)
- stratigraphy study of Old Maid Flat area (C)
- geologic and geochemical survey of Mt. Hood andesites (C)
- heat flow analysis of 13 area wells (C) - (11 drilled by DOGAMI, 1 by NWNG, 1 by NWGTH Corp.)

USGS:
- seismic reflection and refraction studies (IP)
- spontaneous potential (IP)
- aerial infrared study of Mt. Hood cone and flanks (IP)
- gradient well drilling for hydrological data (water quality, temperature and depth) (IP)
- audiomagnetotelluric (IP) - subcontracted to Lawrence Berkeley Laboratories

In association with the Northwest Natural Gas Co., (NWNG) exploration drilling by the N.W. Geothermal Corporation, in return for partial funding by USDOE of drilling at Timberline Lodge and Old Maid Flat, is continuing. Drilling took place at Timberline Lodge during 1976, 1977 and 1978. Difficulties hampered the drilling process as the gradient hole string twisted off at 1380 feet. Temperatures were isothermal to 600 feet and thence the thermal gradient was reported as 200°C/km. Drilling provided data for the Mt. Hood geothermal assessment program, however the drilling did not reach target depth and accordingly a suitable geothermal resource wasn't identified for development of space-heating and snow removal systems which had been proposed for the Mt. Hood Lodge area.

NWNG is interested in providing district heating for industrial users in the Portland area; for example, for the processing of wood and paper products. At Old Maid Flat on the west flanks of the slope, a hole was drilled to 4002 feet in August, 1978; although the results were not conclusive, NWNG reports encouraging temperatures of approximately 79.4°C. Flow tests are being considered for this site. They are continuing during 1979 to explore on the west side of Mt. Hood, where twelve holes have been authorized; present drill sites receiving attention include one near highway 26 and another on McGee Creek.

The North Santiam River is the domestic source for approximately 120,000 persons including residents of Salem, Stayton, Turner, Keizer, suburban east Salem, and the Jan Ree Water District.

Within the study area the following sites utilize the McKenzie River or tributary streams for domestic water:

Fish Lake Campground
Clear Lake Day Use Area
Clear Lake Resort
Melakwa Boy Scout Camp
Scott Creek Recreation Residence Site
White Branch Youth Camp
Eugene Water and Electric Board residences

No use is made of surface water from the North Santiam River and tributary streams within or adjacent to the study area.

Groundwater. Little is known about the groundwater conditions of the Western Cascade formations in the study area since there has been little or no drilling exploration of water well drilling. The occurrence of water is probably controlled by the joint and fracture pattern, as many of the sedimentary and pyroclastic rock units which comprise the bulk of the formation are lacking in porosity and are impervious.

The High Cascade formations of the Belnap Foley, McKenzie River area have an extremely complex groundwater system. The combination of extremely porous and broken lava flow units with relatively impervious fine grained interbeds have produced perched water tables and confined aquifers with very large volume flows. The open and porous nature of the lava formations as well as the glacial deposits retains the bulk of the precipitation and produces an even discharge into the McKenzie River. The upper McKenzie River is primarily spring fed with large volume flows. Many of the springs are not exposed but discharge directly into the bottom of the river. Tremendous flows of water were encountered in the excavation of the Carmen-Smith diversion tunnel that required special design changes and increased cost of construction. The lava field and cinder blankets absorb the melting snow directly into the ground like a hugh sponge.

The only utilization of groundwater in the High Cascades has been for water wells for public use at recreational developments. Water wells in the McKenzie River valley are usually shallow and probably tap near surface water. Deeper wells encounter fine grained lake sediments with little or no water yield. These deposits blanket the bedrock. Well drilling is difficult in the glacial and alluvial deposits due to the coarse boulders which makes advancing the casing difficult.

b. High Cascades

Mt. Hood[32]

Total KGRA acres: 8,671 - (All National Forest Land)
The KGRA is in an area classified as Wilderness

the gauge. Sandy River has a runoff of 178 cm above a gauge 30 km west of the summit, and the West Fork of the Hood River has a runoff of 203 cm above a station 26 km northwest of the summit. The greatest runoff in the Mt. Hood area is reflected at a station on Bull Run River, 29 km northwest of the summit, where the average is more than 305 cm. The component of any deeply-circulating ground water in most of the springs is probably very small because the runoff is large.

Recently, Lawrence Berkeley Laboratory, the U.S. Geological Survey, and the Oregon Department of Geology and Mineral Industries conducted a study of the geothermal resources of Mount Hood. The report of this study[90] published February, 1979, contained geochemical analyses of streams, warm and cold springs, gas samples from the fumaroles, and rock samples. Repeated sampling of Swim Springs Waters (Mt. Hood's only warm-spring area located on the south flank) showed little overall change in water chemistry between summer and winter. Oxygen and hydrogen isotope data and mixing calculations based on analyses of Swim Springs and numerous cold springs, indicated that a large component of the warm water at Swim is from near-surface (snow and glacier melt) runoff. It is hypothesized that snow and glacier-melt water near the summit of Mt. Hood passes in close proximity to the hot central "neck" of the mountain, becomes heated, migrates down-slope and mixes with ambient cold water along its path with the result that a small portion of the mixed warm water surfaces at Swim Springs.[102]

<u>Newberry Crater</u> KGRA (Cascades and Brothers fault zone)[32]

Total KGRA acres: 31,284
Paulina Springs: 57°C (135°F)
East Lake Springs: 66°C (150°F)
Estimated subsurface temperature: Chemical concentrations are too close to those of normal groundwater to apply geothermometry techniques.

<u>Present Development</u>: None at present (resort heating in past). This is a promising area as best indicators are the recent glass flows (1400 yrs) and hot springs in both Paulina and East Lakes. An apparent problem is that there are heavy flows of cold ground water also in the vicinity.

U.S. Geological Survey is continuing a gradient hole drilling program begun in 1977. USGS well #2 down to 1300' in lake sediments with no observed heat anomalies.

Lease applications appear to cover the entire area of the Newberry Volcano. Leasing on noncompetitive lands may take place within the next 12 months (i.e., summer, 1980). KGRA lease sale is speculatively scheduled by 1981.

In 1975 Oregon House Joint Resolution 31 directed the Energy Facility Siting Council to designate Newberry Crater and surrounding roadless areas as unsuitable for thermal power plants.

Most of the interest in Newberry has been for power generation. Considering

There is some interweaving between interested agencies and developers regarding assessing Mt. Hood's geothermal resources. The USGS will cooperate on the drilling of two of NWNG's 12 holes. An additional 8 holes are part of the continuing (1978-1979) drilling program coordinated by the USGS; presently (August, 1979) they are on their 4th hole being drilled about the base of the mountain. Drilling will commence in August, 1979 at the base of Poochie Ski Run. The target of these studies is the finding of a suitable reservoir and determining its extent as previously, only marginal temperatures for a quality geothermal resource have been found on the west flanks of the mountain.

Regarding exploration impacts on water quality, the majority of the holes have been approved through the USFS environmental impact statement (EIS) and exploration permit process. To date, impacts on water quality have been minimal. Drill hole locations have been sited to satisfactory sites to minimize environmental concerns, including stream proximity. Above ground mud pits (steel basins) have been used instead of in-group sumps. Restrictions on use of foam in the drilling process has been maintained.[34]

Hydrologic Setting.[102] Mt. Hood lies along the axis of the Cascade Range, and receives most of its precipitation during the fall and winter from storms that originate in the north Pacific and move southward and eastward across the range. The average annual precipitation is about 102 cm at Portland and increases to the east, to a maximum near the crest of the range. Records of the National Weather Service show that at Government Camp the average is 230 cm. Precipitation decreases rapidly to the east and is only 25 cm within 50 km of the crest.

Precipitation falling above an altitude of about 1,500 m on Mt. Hood is inferred to be within a recharge area, and ground water tends to move downward. The transition from recharge to discharge area is manifested by a band around the mountain where springs tend to discharge, and below which perennial streams are common. Above the band, many streams are intermittent; in smaller channels there is runoff only during spring, from melting snow.

At depths ranging to at least 250m in the vicinity of Timberline Lodge, ground water occurs in perched zones between or within andesite flows. The warm water emanating at Swim Springs may have circulated deeper than some of the perched zones, probably originating at elevations higher than Timberline Lodge. The water comes to the surface at Swim, where there is an abrupt flattening of the topographic slope; Mt. Hood andesite flows tend to dip down the mountain, and some permeable zones may intersect the land surface here. The Swim area also lies near a contact between Mt. Hood andesite flows or andesite debris and pre-Mt. Hood andesite and basalts (Wise, 1968); these older rocks are less permeable and may tend to direct ground water to the surface.

Distribution of runoff of streams draining Mt. Hood corresponds that of precipitation. Records of a gauging station on Salmon River, 7 miles southeast of the summit of Mt. Hood (east of Trillium Lake near highway U.S. 26) show an average runoff of about 80 cm. per year for the drainage area above

Several reservoirs are located in the geothermal lease areas, most of which are less than 3 acre-feet. The primary purpose of the reservoirs is to provide water for livestock, but also provide water for wild life and habitat to the aquatic plants and amphibians. The availability of water in these reservoirs is adequate in most years. Projected needs for municipal, industrial, domestic, and livestock water will double by the year 2020. Ground water supplies are estimated to be adequate to meet the demand.

All of the streams flow into the Harney Basin which has no outflow. The Harney Basin watershed provides the all important habitat for waterfowl. However, the Malheur Lake levels fluctuate greatly from year to year. In 1972, a high water year, 250 cubic hectometers (200,000 acre-feet) flowed into the lake. In 1973, only 90 cubic hectometers (75,000 acre-feet) flowed into Malheur Lake. During the high water year of 1972, the Donner und Blitzen River contributed 55 percent of the inflow, and the Silvies River, direct precipitation, and Sodhouse Spring contributed 28, 13, and 4 percent respectively.

In the drought year of 1973, the Donner und Blitzen River was again the principal contributor of water with 62 percent of the total inflow. The Silvies River, direct precipitation, and Sodhouse Spring contributed 1, 25, and 12 percent respectively.

Groundwater inflow, other than Sodhouse Spring, appears to be negligible. A large amount of the snowmelt runoff does not reach the Malheur Lake because the stream waters are diverted for irrigation use.

Most of the outflow from the lake is from evaportranspiration (81 percent in 1972 and 96 percent in 1973), but some surface outflow from Malheur Lake goes through the Narrows into Harney Lake. Groundwater outflow also seems negligible.

<u>Southern Basin and Range</u> (Alvord KGRA)[32]

Total KGRA acres: 176,835
Surface temperature: 76°C
Estimated subsurface temperature: 200-210°C
Flow rate: 135 GPM 8.52 L/s approximate at Alvord Hot Spring
Present Development: None

Active area of exploration. Leases issued in 1976. Injunction delayed competitive sale. Speculation is that there will be a sale in January, 1980. Approximately 60 gradient wells have been permitted for drilling in the Alvord Valley.

The Alvord Valley is remote with rough terrain. Utilization, if the resource proves capable, will likely be for power generation.

Lawsuits concerning rejected landlease bids and environmental concerns are pending.

the rapid growth rate in Deschutes County, direct-use applications may prove economically viable if the resource is located such that pumping out of the crater would not be necessary.

Brothers Fault Zone (Burns Butte KGRA)[32]

Total KGRA acres: 640
Surface temperature: 68°C
Estimated subsurface temperature: 135°C
Estimated surface discharge: 9.17 L/s

No near term plans for the utilization of the resource are known.

Much of the precipitation falls during the winter months in the form of snowfall. July, August and September are the driest months with less than 10 percent of the annual total precipitation. Precipitation in this area is noted to increase at a rate of one inch for each 100 m (300 feet) gain in elevation. Mean annual precipitation at Burns is 15 inches.

Most of the runoff in the lease area occurs in winter and early spring and varies from 2.5 to 5.0 cm (one or two inches). Warm spring chinook winds cause rapid snow melt and consequently heavy runoff.

As typical of eastern Oregon, the evaporation rate is high with pan evaporation varying from 102 mm (40 inches) in the forested areas to 152 mm (60+ inches) in the lower, open valleys.

Average annual sediment production is less than one-tenth acre-feet per square mile but varies widely according to geology, soils, amount of runoff, slope, land treatment practices and upstream watershed conditions. Many of the smaller streams have little or no flow except during periods of melting snow and high runoff. Water temperatures for many of these streams are commonly 21 degrees C (70 degrees F) or higher in late summer and near freezing from November to April. They are generally well aerated with dissolved oxygen concentrations near saturation levels, averaging 8 to 12 mg/liter.

Water quality of the perennial streams is good to excellent but decreases substantially in the downstream portions because of increases in mineral content. The amounts of calcium and sodium vary; calcium is usually predominant during high flow periods.

Coliform contamination is generally low in surface waters due to the low human populations density. The coliform counts are higher in the areas of animal concentrations and soil bacteria.

Ground water is usually found in alluvial deposits and some volcanic rocks at a depth of 18 to 180 m (60 to 600 feet). These volcanic rock aquifers are only moderately permeable but the annual recharge to these aquifers is very low. The quality of the ground water is fair to good. The main water source for the City of Hines is located in alluvial material adjacent to the lease area.

old borax works in Sections 11 and 14, T. 37S, R. 33E. There are several thermal springs in this area and they follow a linear trend that have mapped as a fault (Figures 4 and 5). This line of hot springs trends N. 20W from 2 to 2-1/2 miles south of Alvord Lake. At the southern end of this line of springs a large pool has been formed, called Borax Lake or Hot Lake. It is about 275 yards in diameter and discharges about 900 gallons per minute. The series of hot springs have built up a deposit of porous siliceous sinter, so that they now discharge above the present valley floor. Because the deposited sinter is porous, the static pressure of the springs causes slow seepage of spring water over a considerable surface. Just west of this line of springs there is an outcrop of cemented, fine-grained conglomerate. This is thought to be a crest of a fault block which has become almost submerged under the action of erosion and the accumulation of more recent detritus at its base. This probably dips westward, and the line of hot springs errupts from the fault along its eastern scarp.

Springs in Borax Lake are the water source for Borax Lake, Lower Borax Lake Reservoir, and other channels in this drainage.

Water flows out of Borax Lake through two channels, one on the west side and one on the south side. On October 24, 1974, most of this flow went into ponds northeast of the Lower Borax Lake Reservoir, by-passing the reservoir. At other times most of the flow goes into the reservoir. If the Borax Lake were ever breached on the north and east sides, there would not be overland flow to the Lower Borax Lake Reservoir and channels downstream in T37S, R33E, Sections 3, 10 and 15. Flow from this source is usually greater in the fall than in late summer, but no additional flow data is available.

At the north end of the Lower Borax Lake Reservoir is a dike and headgate that were built to control water for irrigation. However, there has been no irrigation here for 5 years. If the flow were adequate, the reservoir could cover 27 to 30 acres. The normal high water floods about 20 acres and the reservoir is 4 to 5 feet deep at its deepest part.

At times there is no overland flow into the reservoir. Then the only flow is accretion from the slightly higher areas to the east.

Channels north of the Lower Borax Lake Reservoir drain into Alvord Lake. During the summer this flow is about .01 cfs in places. The northerly part of this channel are pools. In places there are flooded meadows 1 to 8 inches deep and 1 to 5 acres in size. In the fall, when the flow increases out of the Borax Lake, there is additional standing water.

Alvord Lake is ephemeral. Maximum water depth does not exceed a foot and it is usually dry by mid-summer.

Data in the files of Conservation Division, USGS, show that in 1959 a drill hole was made about a quarter of a mile east of the series of hot springs. It penetrated the porous sinter and produced steam when about 150 feet deep. The well was plugged off and abandoned.

Alford Valley is a long north-south fault trough east of Steens Mountain, one of the driest parts of Oregon. Alvord Lake itself is a playa, or intermittent lake, usually dry every summer except for a small pool known as Borax Lake, which is kept filled by a warm spring. Each year a very shallow pool or lake is created by rain and snowmelt, chiefly runoff from Trout Creek, a spring-fed stream flowing out of the mountainous area to the southeast. The alkaline waters of the lake are not usable for irrigation, and the wide flats that are periodically flooded are barren and do not support even the alkali-resistant plants.

Water. Hydrologic Cycle - Annual precipitation for the Southern Basin and Range is about 8 inches, distributed rather evenly through the year except for July and August, which together receive only 8 percent of the annual moisture, mostly from thunderstorms. The Steens Mountain, bordering the study area on the west is an effective barrier and as the air rises over the mountain, it loses much of its moisture. The entire study area lies in this rain shadow of Steens Mountain. Annual snowfall amounts to about 23 inches, with over 60 percent of this amount falling in January and February.

These lands are located in a closed basin, the Alvord Desert Basin, a north-south oriented structural valley. Water collects on the many small playas through the area and on Alvord Desert and Alvord Lake, which are both large playas. There it evaporates.

A number of perennial streams enter the study area from the west, draining the east slope of Steens Mountain. These include Castle Rock, McCoy, Mosquito, Willow, Cottonwood, Big Alvord, Little Alvord, Pike, Indian, Wildhorse, Carlson and Bone Creeks. Other drainage ways on the east slope of the mountain are intermittent, running water during spring snowmelt and summer thunderstorms. Trout Creek heading in the Trout Creek Mountains enters the study area from the south. Although a perennial stream, most or all of the flow is diverted for hayland irrigation upstream of the subject area or simply disappears in the ground and water from Trout Creek reaches its ultimate destination, Alvord Lake, only in the spring months of exceptional high water years.

There are three main areas of hot spring activity in the Alvord Valley graben. The northernmost is Michey Hot Springs in section 13, T.33S, R.35E; Mickey Hot Springs include fumaroles, several vents, clear pools 8 to 10 feet in diameter, sinter cones and boiling mud pots. The hot spring system has built a siliceous sinter apron approximately 1,300 feet in diameter. The entire area surrounding the springs had a hollow sound when walked over and water can be heard underground. The flow from Mickey Hot Springs has been estimated at from 20 to 100 gallons per minute.

The central area of hot spring activity is the Alvord Hot Springs in section 32, T34S, R34E. There are a series of 6 to 8 springs aligned in a north-south direction that Russell (1903) describes as being situated along the Steens Mountain fault. These springs flow approximately 135 gallons per minute.

The southernmost area of hot springs activity is located in and around the

Mickey Hot Springs - Sample taken from pool below main pool. Total solids in solution - 0.168 percent. $B_2O_3$ ppm.

Alvord Hot Springs - Sample taken in main vent. Total solids in solution-0.298 percent. Spectographic analysis of solids:

(1) Concentrations more than 10% -- Silicon, sodium
(2) Concentrations 10%-1% -- Potassium (high, Boron (low), Calcium
(3) Concentrations 1%-0.1%

Crump Geyser KGRA (East of Lakeview)[32]

Total KGRA acres: 85,663
Surface temperature: 78°C
Estimated subsurface temperature: 180°C
Flow rate: 0.073 L/s

Moderate amount of leasing activity and exploration.

Sale of 35,974 acres in 1975 went to Chevron. Reoffer of additional acres were taken by Chevron in 1976. Reoffer of additional lands in 1978 brought no bids.[97]

Very little is known about the Crump Geyser in hydrocycle.[51]

Klamath Falls KGRA

Total KGRA acres: 50,300
Surface temperature: 74°C
Estimated subsurface temperature: 120°C
Flow rate: 3.33 liter/second (Olene Gap Hot Springs)

Klamath Falls has the most wide-spread use of non-electric geothermal applications in the U.S. Over 400 wells supply space heat to 500 structures, including a college campus and a hospital. It is estimated that total use of geothermal energy is 60 MWt. Apparently only a small portion of the area's potential is being used.

In the 1978 summer the city drilled some wells to supply a greenhouse within College Industrial Park adjoining OIT. Problems occurred with the drilling procedure, reportedly with drilling mud leakage. Temperatures were measured and were found unsatisfactory for development; there is speculation that a cross fault exists between the resource and the wells. Accordingly the Industrial Park's pursuit of a local well for its geothermal heat supply has been abandoned with the possible prospects of using surplus hospital and OIT waste heating water.

Klamath Falls is developing a municipal heating district for its central building area. This project is to provide heating for 14 city, county, state and federal buildings by 1980. Following its first year of operation there will be a second phase expansion whereby additional connections will be made to adjacent buildings; this expansion will cover 11 city blocks. Phase III will be to provide services to 54 user blocks. Optimistic projections

There are a number of BLM owned shallow stockwater wells within or adjacent to the KGRA. Most are powered by windmills. Available data follows:

| | |
|---|---|
| T37S, R34E, W.M.<br>Sec. 22: NE¼NE¼ | Calderwood Desert Well<br>Total Depth 119 feet<br>Static Water Level 94 feet<br>27 GPM Bail Test with 5 foot drawdown |
| Sec. 31: SW¼NE¼ | Black Butte Well<br>Total Depth 68 feet<br>Static Water Level 37 feet<br>No Test Data |
| T32S, R35E, W.M.<br>Sec. 31: SW¼SE¼ | Mann Lake Well<br>Total Depth 230 feet<br>No Other Data |
| T34S, R35E, W.M.<br>Sec. 3: SE¼NW¼ | Alvord Well No. 1<br>Total Depth 196 feet<br>No Other Data |
| Sec. 10: SW¼SE¼ | Alvord Well No. 2<br>Total Depth 60 feet<br>No Other Data |
| Sec. 27: NW¼SE¼ | Alvord Well No. 3<br>Approx. 25 GPM<br>No Other Data |
| T35S, R35E, W.M.<br>Sec. 3: NW¼SE¼ | Alvord Well No. 4<br>Approx. 25 GPM<br>No Other Data |
| T32S, R36E, W.M.<br>Sec. 14: SW¼SW¼ | White Sage Well<br>Total Depth 160 feet<br>No Other Data |

Only in recent years have private land owners in the area drilled irrigation wells. The fact that this is the sump area of a closed basin would indicate that a large quantity of water may be available. Several irrigation wells in the area reportedly yield from 1,000 to 3,000 gpm from total depths of 100 to 400 feet.

Sediment Load - There is no known data on sediment loads carried by the streams of the area, although peak loads are probably less than 150 ppm.

Dissolved Solids - The hot spring water within the area of the Alvord Valley are saline with total dissolved solids around 3,000 milligrams per liter. Boron and lithium are anomalously high; in fact, boron in the form of borax was actively produced from the Hot Lake area at the turn of the century. Samples taken by Libbey (1960) are summarized below.

and dacitic ash flows; minor amounts of basalt and volcanic sediments. Specific capacities are largely untested, as well logs have not reported this unit within the Klamath Basin. This unit lies below lower basalt aquifer and at considerable depth.

There are many wells (reportedly ASO geothermal wells in 1979) located in the area, however, to date no serious decline in water levels has occurred. This is evidenced by observation wells. Annual water level fluctuations are greater in wells located in the recharge areas than those in the discharge areas.

Water quality is the highest in the recharge areas and declines in quality as it flows toward the discharge areas. Temperatures correspond to quality with the recharge area having the coldest water. Water in wells in the recharge areas have low temperatures of 40°F to 50°F and have small quantities of dissolved chemicals. (See tables for water quality)

There are several localities within the Klamath River Basin that have geothermal groundwater. The larger more developed area is in northeastern Klamath Falls. In 1975 there were approximately 400 wells utilized for heating purposes. The depth of these wells range from 100 feet to approximately 1800 feet. Temperatures average less than 190°F.

<u>Lost River Sub-basin</u> - the Lost River Sub-basin is a naturally closed basin. The river originates at the outlet of Clear Lake in northeastern California and drains the eastern 90% of the area considered in this analysis.

Lost River enters Oregon at the southeast end of Bryant Mountain flowing northwesterly on the west side of Langell Valley, continuing westward to the northern end of Poe Valley. It enters Klamath Valley through Olene Gap flowing southward along the east side of Klamath Valley and eventually discharging into Tule Lake in northeastern California.

Other main sources of water contributing to the Lost River drainage system are Gerber Watershed with an average runoff of 50,000 CFS and Bonanza Spring producing 100 cubic feet/sec. A diversion was made between Lost River and Klamath River for flood control and irrigation purposes. The Lost River Sub-basin includes the following five valleys: Langell, Yonna, Swan Lake, Poe and Klamath. The regional water table of these valleys is generally the Lost River. The river apparently is the local base level for ground water moving beneath these valleys.

Perched water tables occur above the regional water table, are evidenced by springs in the juniper tablelands and pine plateaus area. Flow from these springs may vary from less than 1 gpm to several hundred gpm.

The primary use of water is for irrigation of droplands in the Klamath Project area.

<u>Upper Klamath Lake</u> - The Klamath River drains only a small

have been made for completing phase III in three to five years (by 1984). Phase III would be covered by bonding and repaid by connection and user fees.[20]

Water[11] Hydrologic Cycle - Annual precipitation in the Klamath area totals 15 inches. Water in the Klamath Basin originates as precipitation with the majority of it falling during the period of October through March. December and January receive the maximum and July, August and September receive the minimum.

The juniper tablelands and pine plateau areas receive most of the precipitation in the form of snow. Mid-winter rains occur frequently at the lower elevations.

Precipitation can be divided into three categories once it has reached the earth's land surface: (1) surface runoff, (2) evaporation and transpiration losses and (3) seepage into the ground (recharge).

Surface runoff is by rivers such as Klamath River and Lost River. They are fed through snow melt, rain and discharge from springs.

Evaporation and transpiration occurs from lakes, from the soil and by vegetation. Evapotranspiration data on the vegetated areas have been estimated to be 1 1/2 feet/year from large stands of pine trees, and less than 1 foot from sagebrush and low lying open lands.

The remaining precipitation that is not lost percolates into the ground water table. Ground water flows through spaces between rocks or fractures. These spaces are generally less than 1 inch in diameter. Ground water can be found in four different aquifers.

Sedimentary Aquifer - stream and lake deposited silt, sand, clay, gravel, peat, chalk, and ash, volcanic ejecta, thin basalt and andesitic lava flows. Specific capacities completed in this unit range from 0.01 to 5 gallons per minute per foot of drawdown and average 0.45 gallons per minute per foot. Some black sand and gravel layers may yield 2-10 gallons per minute per foot of drawdown.

Volcanic Centers Aquifer - moderate to highly fractured basaltic, dacitic and andesitic lava flows and pyroclastic material associated with erruptive centers. Specific capacities of wells completed in this unit range from less than one to over 100 gallons per minute per foot of drawdown and average approximately 25 gallons per minute per foot of drawdown.

Lower Basalt Aquifer - highly faulted and fractured series of basaltic lava flows separated by layers of scoria and cinders. Specific capacities of wells completed in this unit range from 35-500 gallons per minute per foot of drawdown and average about 145 gallons per minute per foot of drawdown.

Volcanic Ash Aquifer - massive beds of light colored rhyolitic

Level of Potential Pollution - No reason is seen for an increase in pollutants, unless either:

1) New wells are allowed to discharge to the surface instead of being heat-exchanged with cool meteoric water; or

2) Wells are drilled into deeper aquifers (perhaps 900 m (3,000 ft.) or deeper).

The latter seems unlikely in the near future, because of the cost of the deeper drilling, and the general lack of interest in exploration for a deep geothermal aquifer for generation of electricity. If it occurs, new studies of chemistry, heat content and pollutants will be required.

Summer Lake Hot Springs KGRA[32]

Total KGRA acres: 13,631
Surface temperature: 43°C
Estimated subsurface temperature: 140°C

Sale of acreages in 1976 was for 7.521 acres; however these were relinquished in 1979. Summer Lake Hot Springs is a recreation site with several campsites and a geothermally heated pool. The bathhouse has been heated with geothermal energy for close to 60 years.

Summer Lake occupies the center of the floor of a basin bounded on the west by the bold scarp of forested Winter Ridge and on the east by gentler slopes covered only with desert vegetation. The lake water is shallow and saline. White crusts of crystalline minerals coat the dry part of the lakebed. In May and June, 1941, the water surface was at 4,147.2 feet altitude and the greatest depth was found to be "less than 2.5 feet" by a survey party of the U. S. Bureau of Land Management. The lake is practically dry at times. The lowest recorded water level was measured by leveling as 4,144.86 feet on September 30, 1961. The highest recorded lake level occurred from February to April, 1905, at 4,151.4 feet.

Most of the inflow comes from spring-fed Ana River. The springs appear at the head of Ana River about 4 miles north of the lake, beneath the water surface of a reservoir behind a diversion dam completed in 1923. The total flow of the springs has decreased from about 140 cfs, 1950-14, to about 90 cfs, 1951-63. The decrease is due in part to back pressure caused by submerging the springs and to diversions by wells from the same underground source of water.

The water of Ana River is used to irrigate meadowlands and to maintain a large refuge for migratory waterfowl. The decrease in spring flow coupled with increased use of water for irrigation and wildfowl propagation has caused less water to reach the lake; in recent years, therefore, the lake level has been consistently about 4 feet lower than it was from 1905 to 1912, and the concentration of dissolved mineral matter is correspondingly greater. The water of streams and springs entering the lake is relatively soft and is good for irrigation and domestic use.

portion (approximately 10%) of the area considered in this analysis. The river flows from Upper Klamath Lake southward through Link River to Lake Ewauna. It flows from Lake Ewauna along the northwest side of Klamath Valley over lava ridges near Keno, descending through a deep canyon into California. It eventually reaches the Pacific Ocean. The major water source for Upper Klamath Lake is the Williamson River (outside of the analysis area) and many springs beneath it. The portion of the area considered in this analysis contributes only a minor portion of the Klamath River flow.

Potential Pollutants[27] - The principal pollutant is heat; this is derived from all wells, whether heat-exchangers or direct consumers of geothermal fluid. Those holes involving heat-exchange do not discharge any mineralized water, as none is produced from the wells. Only those few holes consuming geothermal reservoir fluid have any geothermal discharge.

Water Pollution Potential

Summary of Baseline Water Characteristics - Klamath Basin groundwaters fall into two main chemical groups. Cool wells and springs are of the calcium magnesium bicarbonate type with low TDS (about 55 ppm). The second type of water, occurring in warm and hot wells and springs mostly within the basins of the Klamath graben, is sodium bicarbonate chloride sulfate water with TDS averaging 700 ppm (and reported as high as 4,000 ppm). Boron and fluoride concentrations increase with temperature. For a detailed discussion of water characteristics of Klamath Basin, refer to Geonomics (in press).

Water pollution data are very scarce, incomplete and probably meaningless. They show principally that pulp and paper operations at Klamath Falls and agricultural irrigation discharge more pollutants and possibly toxic substances than the geothermal system can be shown to contain. Among these industrial and agricultural wastes are pesticide residue, various phosphate fertilizers, and sulfate and chloride ions. Partial analyses of water from Klamath Lake and Klamath River show indications of these.

Potential Water Pollutants - The principal pollutants from this discharge are chloride ions (perhaps 50 to 60 ppm, Table IV) and boron, with about 1 ppm on the average. In comparison, local cool surface waters average less than 1 ppm boron and 1 to 10 ppm chloride.

Other polluting constituents are not recognized from the scattering of partial chemical analyses available to this study. However, no data are available concerning metals or other trace element contents of these waters. When these additional data are obtained, the pollution potential may be altered.

Potential Pollution Mechanisms and Pathways - Direct discharge from thermal wells goes into local surface waters. Most wells do not directly produce the reservoir fluid, but utilize heat-exchanging in the well with cool meteoric water supplied through the municipal water system. The heated municipal water is discharged to the sewer system when depleted of its heat. Those wells (principally OIT and Klamath Hills) consuming reservoir fluid at the surface, dispose of the heat-depleted fluid in a similar manner.

The western Snake River basin is divided, for the purpose of discussion, into five subareas, including: Ontario, Nyssa, Adrian, Vale and Bully Creek. To date, there has been no production of geothermal waters in the region except for a few shallow wells near Vale Hot Springs. However, the presence of other hot springs and warm water wells in the environs, along with the background knowledge of the subsurface geology from oil and gas tests drilled in the basin, indicate that the required conditions for non-electric utilization are present. The region has an average geothermal gradient of about 85°C/km. Geothermal fluid temperatures in the range of 90° to 100°C are expected at 1 km. depth at the Grassy Mountain Basalt and from 140° to 165°C from deeper drilling into the Owyhee Basalt. Fault related geothermal waters are expected to occur from near the surface to depths of 1 km. A discussion of the individual thermal water occurrences is given in the accompanying sections.

Surface Water - The two major rivers in this region are the Malheur River and the Owyhee River. Within the area of the EAR, the Malheur generally flows west to east, and joins the Snake River north of Ontario, Oregon. Major tributaries of the Malhuer within the geographical boundaries of the EAR are Bully Creek, Willow Creek, and the North Fork Malheur River. The Owyhee River flows south to north and joins the Snake River south of Nyssa, Oregon.

According to the Oregon Department of Environmental Quality (1975), "most of Oregon's water quality problems are directly associated with deficiencies in water quantity." With respect to the current established water quality standards in Oregon, both the Malheur and Owyhee Rivers exhibit substantial partial or full time noncompliance of temperature, turbidity, and suspended solids parameters. This occurs mainly during low flow periods.

Seasonally high turbidity measurements are due to land runoff and irrigation return flows. High temperatures are not due to heated effluent discharges, but rather from solar radiation heating diminished flows.

Average annual discharge measured at the Owyhee River below the Owyhee Dam is only 252 cfs. Note that discharge values for the Owyhee River are obtained below Owyhee Dam, and do not reflect quantities of water which have been diverted from the reservoir to regions outside the river basin. Maximum flows for the 1970-1975 period was 22,900 cfs and the minimum flow was 1.8 cfs in 1973-1974, illustrating the variability of discharge in this region.

Low flow augmentation of the Malheur River would help improve the water quality of this region. A proposal has been made to divert some water flowing into the Malheur Lake Basin (a closed basin without any natural outlets which adjoins the Malheur River Basin) to a reservoir which would be situated between the Malheur River and Malheur Lake Basins. This water would then be used to increase flows and water quality for either basin.

Ground Water - Shallow ground water is recharged annually from precipitation and infiltration. Due to the low precipitation rates in this area, ground water is not abundant, and occurrences are localized

A bed of silt and clay on the valley floor extends onto the foot of adjoining rock slopes for about 100 feet above the present level of Summer Lake. The high level of this alluvial deposit testifies to the previously much greater extent of Summer Lake. The clayey alluvium confines the extensive ground-water body in the volcanic bedrock. This ground water has a water table (pressure level) sufficiently high that the water will flow out over the clay confining layer at 50 to 100 feet above the level of the lake. Consequently, drilled wells and natural breaks in the confining blanket of clay allow the artesian ground water to flow from the lava bedrock. Numerous springs spill over the edge of the clay around the west and north sides of the basin, and a few rise in artesian fashion through the clay near the north end of the basin; Ana Springs is the largest of these.

Lakeview[32]

Total KGRA acres: 12,165
Majority of land in private ownership
Surface temperature: 96°C
Estimate subsurface temperature: 138°C
Flow rate: 600 gpm (37.85 L/s) Hunter's Hot Spring
Existing use: Commercial greenhouse and resort heating.

Activity:[99] City swim pool well cleaned out in 1979. Previously well had been rumored to be 200 feet deep but was found to be caved in. The restored well has been lined and logged for temperatures.

Hunter's well was until recently badly scaled up and less than a 3/4 inch stream was being emitted; following use of a cable tool for opening the well, a geyser-like flow resulted, having a 3" stream. The well was a concrete shaft to 40 feet depth and is connected by tunnel to gravity feed the lodge there. A pump installation for this facility is planned.

Planned Activity: A district heating system is being considered for Lakeview. The geothermal resource is presently unquestioned but additional gradient holes or wells are required before the regions subsurface temperature contours can be drawn. Approval for drilling tests have been given. Economic and engineering feasibility studies including hydrology, water quality, economics are being organized (1979) for serving the city with district heating.

A well to 660 feet is being used for observation purposes to determine permeability and resolve questions on the resource; this well may later be used as a possible reinjection site. Three blocks away the city uses a well for fresh water, drilled to 550 feet but which has been plugged back to 230 feet because of the heat zone. This information is being evaluated by NWNG for selecting a reinjection strata for the district heating system it is considering. Temperatures for these wells have not yet stabilized (August, 1979) thermally for establishing reinjection depths. Six additional holes are planned for assessing the resource.

Snake River Plain

with a probable thickness of 1 to 1.5 km. A major northeast-trending geologic structure, the Malheur River fault (Bowen and Blackwell, 1975) appears to parallel the Malheur River from Vale to Ontario.

Waring (1965) reported a 73°C hot spring along the Malheur River three miles west of Ontario. A field check has failed to confirm this occurrence and local residents did not know of it. No other surface indications are known to be present. The only shallow target zone is inferred from measured well gradients and here above-normal temperature may be found; water volume may not be adequate.[44]

## Nyssa Subarea[44]

This subarea is largely in the flood plain of the Snake River except for the northwest quarter which is rolling sagebrush-covered hills. Like other bottomlands in the region, high-intensity agriculture is the predominate land use and perishable high-value crops such as sugar beets, onions, potatoes, corn and beets, predominate. In the foothills dairying and cattle feeding are important industries. A fruit and vegetable cannery and a sugar mill are important processors of local crops and provide year-round employment in the region. The water for irrigaion is supplied mainly from surface sources and delivered by ditches and pipelines. As surface water allocations are used up, groundwater is beginning to supply increasing amounts of irrigation water. Outside of the cities, most domestic water is from shallow wells.

Rocks underlying the subarea are fine-grained claystone, siltstone, and sandstone of the Chalk Butte Formation. Terrace gravels cover the lower bench areas and fine-grained alluvium the flood plains of the Snake River. Two oil well tests show that the Grassy Mountain Basalt occurs at a depth of about 1 km and the Owyhee Basalt at about 2 km.

There are no geothermal manifestations known in this subarea; however, temperature gradients, both measured and those interpreted from water well logs, show geothermal gradients greater than 100°C/km at several locations. The most prominent geothermal anomaly is the Cow Hollow geothermal anomaly which extends into the southwestern edge of this subarea. Bowen and Blackwell (1975) have interpreted that this anomaly is caused by hot water or steam moving upward along the Willow Creek fault zone and that drilling to depth of 1 or 2 km should locate high-temperature water or steam. There is also a possibility that high-temperature fluids might be located by drilling near the strike slip fault interpreted by Couch (1977) as some measured gradients and water well data show above-regional gradients along the fault zone. The potential reservoir horizons, the Grassy Mountain Basalt and the Owyhee Basalt are probably nearer the surface in the western part of the subarea so drilling there would not have to be as deep as in the eastern section. In the eastern part of the Nyssa subarea, it is expected that the same deep reservoirs discussed earlier are present, and at depths similar to those at Ontario.

## Adrian Subarea[44]

This subarea lies along the transition zone between the Snake River Plain and

and utilized mainly for irrigation. In general, wells within the region produce less than 100 gallons per minute. Notable exceptions occur in gravelly alluvium along the Snake River, and the Idaho Formation. The cities of Nyssa and Ontario have wells which produce more than 1,000 gallons per minute from 40 foot thick gravels, and wells at a sugar refinery at Nyssa produce 200 to 300 gallons per minute from the underlying Idaho Formation.

Mariner, et al.[174] discusses the chemical characteristics of selected hot springs in Oregon. Three such springs are located within the area of interest, namely Mitchell and Beulah Hot Springs, and an unnamed hot spring near Little Valley.

Present demand for water in the Malheur River basin is higher than the amount naturally available. More than one-half of the water stored in Owyhee Reservoir is diverted to the Malheur River Basin (Oregon State Water Resources Board, 1969).

Cow Valley (T. 15S., R40E., and vicinity) had been declared a Critical Ground Water Area by the State in 1956 due to declining ground water levels (Bartholomew, et al., 1973). Since this declaration and resultant controls placed on ground water pumpage, withdrawals have stabilized to a point equal to the recharge, approximately 4,000 acre-feet per year. As long as ground water use remains below this figure, it is expected that the ground water table will remain stabilized (Bartholomew, et al., 1973).[13]

<u>Ontario ORE-IDA</u> (Near Ontario, Oregon)

Private Development Site Acreage: 200 Acres
Surface Temperature: No surface geothermal waters
Estimated Subsurface (7,000 ft.) Temperature: 149°C
Estimated minimum flow withdrawal rate: 800 gpm (50.5 L/s)
Existing uses: Ontario, OR - none
Planned Development: Commercial, industrial direct heating.

CH2M-Hill Boise office[3] provided engineering feasibility studies for ORE-IDA development on 200 acres. Regional oil well information related but restricted, wildcat hole information available for relating expected downhole temperatures and water availability for development.

Reinjection of spent geothermal resource waters cannot be entirely decided until production well and ORE-IDA industrial heating is established. Estimated depth for reinjection will be between 3000 and 7000 feet to prevent potable water contamination.

Nearly all of the Ontarior subarea lies within the bottomlands of the Malheur and Snake Rivers. With the exception of a mall block of hill land in the northwest corner, this is all high-use agricultural, industrial or residential land. Ontario is the trading center of the study area, and probably 75 percent of the population is located in the Ontario subarea. Most of the area is covered with recent alluvium from the Malheur and Snake Rivers; underlying the alluvium are siltstones and claystones of the Chalk Butte Formation zone located just south of the river, but a 320-m oil test in the SW 1/4 of Sec. 21, T18S, R45E.shows there is also a high geothermal gradient of 147°C/km on the north side of the river. Warm-water wells and the high geothermal gradients along the Willow Creek fault zone, the west boundary of the Vale horst, indicate rising thermal waters to the southeast of Vale.[44]

The Vale subarea is made up mostly of rolling foothills of the Owyhee Uplands that form the western and southern boundary of the Western Snake River. The Malheur River, one of the principal tributaries of the Snake, has cut a valley one to three miles wide and in places two to three benches or terraces have been formed by this erosion. Willow Creek, a tributary to the Malheur River, has also eroded a flat valley two to three miles wide and enters the Malheur Valley at Vale.

Farming activities and all of the homes are located within these two valleys and a few of their small tributaries. The uplands, consisting of rounded hills, are used for grazing. Land ownership patterns follow the topography, with nearly all of the valley land and near foothills under private ownership and the higher hilly land in federal ownership. The long growing season, nearness to processing plants and relatively abundant water has encouraged the development of large-scale farming within the valleys. Most of the water used for irrigation comes from ditches from nearby surface storage reservoirs.

Water quality of the Malheur River is low at present and intensive irrigation use degrades it further. This stream is seasonally warm, high in sediment and dissolved solids. Concentrations of basic nutrients, nitrogen and phosphorous, are high; phosphorous concentrations are particularly high. High nutrient concentrations have stimulated heavy algal growth. Concentrations of dissolved solids in the Malheur average over 1,000 mg/L. Bacterial contamination of the Malheur also exists. Dissolved oxygen concentration fluctuate with low flows and algal activity. One in ten year low flow for the Malheur is a low as 32 cfs for a period of one month. Sediment and dissolved solid contributions to the Malheur from National Resource Lands within the area are reportedly insignificant.

Ground Water - Several ground water aquifers exist within the area. Quality of water varies among the aquifers; some waters are not potable. Some deeper wells 500-600' produce warm water. Most potable wells within the town of Vale are 20-40'.

The shallow wells are located in flood plain alluvium of the Malheur River. With few exceptions groundwater for irrigation is limited to shallow gravel zones near existing streams. Lesser amounts of groundwater for stock watering can sometimes be located in perched lenses at relatively shallow depths in the foothills.

### Bully Creek Subarea[9,44]

Geothermal manifestations in the subarea are Neal (Bully Creek) Hot Springs in the NW 1/2 of Sec. 9, T18S, R43E, and an unnamed warm spring about one mile to the northeast of Neal Hot Springs. Neal Hot Springs has a maximum

Owyhee uplands. Along the eastern edge are the flat bottomlands of the Snake River. In the southwest corner of the Owyhee River has eroded a canyon several hundred feet deep. The presence of Mitchell Butte Hot Springs and Deer Butte Hot Springs within Owyhee Canyon, along with several more along this same trend in the Owyhee Basalt to the southwest suggest the presence of a major thermal zone. From geologists' reports it has been related that drilling to a depth of 0.5 to 1 km between the Owyhee Canyon and Adrian has a good chance of locating hot water between 50° and 100°C. After leaving the canyon the river meanders through a flood plain and joins the Snake River about 7 km north of Adrian.

Truck gardening takes place along the bottomlands of the Snake and Owyhee Rivers and the raising of hay, alfalfa and the other grain crops in the adjacent foothills. In the upland areas cattle raising and dairying are the main land uses. Most of the population in the subarea is located near the eastern edge in Adrian and along State Highway 201 which leads north to Nyssa and Ontario. Farms are present throughout all of the region except in the higher hills in the southwest corner. Surface water provides most of the irrigation water while shallow wells provide most domestic water.

Vale KGRA[32]

Total KGRA acres: 23,998
Surface temperature: 73°C
Estimated subsurface temperature: 160-180°C
Surface discharge: 1.26 L/s
Present Development: Several local uses for space heating
Planned Development: Geothermal heating and cooling for a mushroom growing facility.

The City is interested in a district heating system for publically owned buildings. The potential for non-electric applications for space heating and industrial processing (agribusiness) appears excellent.

The Vale subarea has been designated as a Known Geothermal Resource Area (KGRA) by the U.S. Geological Survey and geothermal leases on the federal lands within the block are offered for sale by competitive bidding. A total of 8,393 acres of the federal leases have been granted at prices ranging between $3 and $16.16 per acre. Geothermal leases have also been negotiated for much of the private land.

Vale Hot Springs, located on the eastern edge of the city of Vale, has a surface temperature of 97°C and a visible flow of 25 to 50 gallons per minute (1.50 to 3.0 l/2). Chemical analysis on the hot spring waters shows it has dissolved solids of 882 ppm. The alkali ratio indicates a minimum estimated reservoir temperature of 157°C (Mariner and others, 1975). A shallow well drilled 50 m east of the hot springs was reported to have temperatures of 110°C. Other shallow wells with temperatures slightly over boiling are located within a half mile of the hot springs, all on the south side of the Malheur River. On the north side of the river near Vale, just to the north of Rhinehart Buttes, shallow wells do not intersect the high-temperature

A Phase I examination of geothermal attributes for the area was initiated in 1975 and is compiled in Reference 39. Economics of space heating of homes, industrial uses are being evaluated. Phase II plans for improved resource definition and feasibility analyses proposed for increased geothermal utilization. A potato alcohol plant is being considered for development Southeast of Hot Lake.

Water - The Baker and Grande Ronde Valleys are structural depressions produced by folding and faulting. Most of the geothermal springs in the area are associated with faults bordering the valleys. Over 31 warm water (>21°C) springs and wells in the area have been identified.[39]

Powder River (drainage past Baker)[44]

The Powder River rises in the Blue Mountains. The peaks beside the headwater reaches of the river are the highest in the range, many of them rising to altitudes of 8,000 to 9,000 feet. From these mountains a multitude of little streams tumble swiftly down the steep canyons. The growing river flows more gently through the round, open valleys near Baker, then more rapidly again through alternating canyons and small irrigated valleys, to join the Snake River at Robinette. The low-water flow of many of the streams is completely used for irrigation. The water of Rock Creek is used to develop electric power, and Goodrich Creek furnishes the municipal water supply for Baker.

There is as yet no upstream storage to control the floods that occur at rare intervals. Flooding along the Powder River is sometimes due, at least in part, to ice jams as the late winter rains swell the streams. The average flow of the Powder River is 247 cfs near Richland from a drainage area of 1310 $mi^2$.

The Powder River has a significant concentration of dissolved solids (190 to 200 ppm of which 30 ppm is silica). Where the river emerges into open valleys, it has deposited its bedload of gravel and sand to construct alluvial fans, such as the one on which Baker is located. These gravelly deposits yield moderate supplies of water to wells. A total of only a dozen wells are used for irrigation in Baker Valley and the heating area of the Powder River. Not over 2000 acres are being irrigated by wells in the Powder River Basin. The chemical quality of the ground water of the basin is mostly good to excellent.

Grande Ronde River (flow past LaGrande)[44]

The large fault-block valley that lies between Union and Elgin became known to early French trappers as Grande Ronde, a name that soon was transferred to the river.

Rising in the snowbanks and springs of the Blue Mountains, the river meanders lazily through the large flat valley, much of the flow confined in a straightened cutoff channel known as the State ditch. In this valley reach, the principal tributary is Catherine Creek, which drains the southwest side surface temperature of 87°C and water analyses indicate that minimum subsurface reservoir temperatures are 173°C to 181°C (Mariner and others, 1974). Two water wells on the east edge of the subarea show above-normal gradients. The Nelson well in Sec. 34, T18S, R43E has a reported water temperature of 21°C at a depth of 58 m, which indicates a geothermal gradient of 157°C/km. The BLM Vines Hill well in Sec. 22, T19S, R43E, has a water temperature of 31°C from a 219-m depth, indicating a gradient of 94°C/km.

A prospective drilling target is along the western edge of the subarea. The Owyhee Basalt appears very close to the surface, probably covered only by a thin layer (0 to 1000 m) of Chalk Butte Formation. The high temperatures indicated by the geochemical analysis (Mariner, 1974) for Neal Hot Springs may give an indication of reservoir conditions. A fault zone postulated by Couch (1977) from geophysical data appears to be the zone of leakage of the geothermal fluids. From the present indications further drilling along this zone appears to be warranted.

Water - The Bully Creek Subarea is located in the foothills of the Owyhee Uplands; the Malheur River has excavated a flat valley about 3 km wide through the middle of the area and Bully Creek, following a valley about 1 1/2 km wide, flows in from the northwest. Along the north side of the Malheur River is a broad gravel covered bench with Bully Creek Valley dividing it into what is known as East Bench and West Bench. As an intermittent tributary of the Malheur, Bully Creek usually carries a high sediment load.

Farming takes place in the valley and in the bench area and grazing in the rest of the hills. Most of the irrigation water is provided by surface canals that use water from the Malheur River and from Bully Creek Reservoir.

Ground Water - Bully Creek, north of the main stem of the Malheur, drains the east slope of lava rock ridge. A few irrigation wells in this area obtain yields of 500 gpm from the lava associated with the Idaho Formation, the Malheur River and Bully Creek flood-plains; more wells will probably be constructed as more is learned about the subsurface of the part of the basin. Several springs are within the area including some which produce warm or hot water. In the East and West Bench areas there is sufficient water for domestic wells in the gravel terraces. Away from the valleys a few stock wells produce small amounts of water from perched zones. Quality of water from these aquifers vary. At least one aquifer contains water with a high dissolved minerals content and is not potable.

Columbia River

LaGrande[39] - Estimated important GRA acreage - 19,200 acres

| Temperatures | | Site | Discharge |
|---|---|---|---|
| Surface | Underground | | |
| 85°C | 115°C | Hot Lake Resort Hot Springs | 1700 gpm |
| 79°C | | Hot Lake Courtright Well | 30 gpm |
| 60°C | | Medical Hot Springs | 50 gpm |
| 57°C | 109°C | Radium Hot Springs | 300 gpm |

and federal pollution control requirements must be met in the process of development and operation of geothermal systems.

Environmental impacts anticipated with geothermal activities are projected for Oregon's developments in Section III water related environmental issues to be considered in geothermal energy direct heat or electrical power proje planning include:[104]

Water Quality - One of the most serious water quality concerns is that geothermal fluids released to natural aquatic bodies will degrade water quality and result in negative impacts to fish and other aquatic organisms. These negative impacts can be avoided by simply preventing geothermal discharges to aquatic bodies or by maintaining those discharges below harmful levels.

The disposal of toxic fluids is closely regulated in Oregon, with no discharges permitted. Direct heat projects should be designed to avoid or minimize equipment failure resulting in accidental releases of fluids to aquatic bodies. In areas where the geothermal fluids are potable or of irrigation quality, it may be possible to obtain permits for surface discharge or cascaded uses of the geothermal fluid (e.g., irrigation) after some of the heat is extracted.

Hot Springs - One of the most serious concerns associated with the withdrawal of geothermal fluid is its possible effect on hot spring activity. Geologic and hydrologic data are often insufficient to predict potential impact. As a result, the drilling of geothermal fluids in areas adjacent to hot springs is usually controversial and may be prohibited within a certain radius.

Subsidence - Land slides, liquefaction and mass earth movements may be a problem in any area if net fluid withdrawals exceed natural recharge or injection. The actual incidence of subsidence depends on the nature of the reservoir and the surrounding geologic formations — in fracture permeability reservoirs, subsidence should be negligible, whereas in sedimentary reservoirs subsidence could be a substantial problem. In this latter case, subsidence may be reduced through a well-planned program of injection of the geothermal fluids. Moreover, such injection also conserves the geothermal resource and would extend the reservoir's producing life.

Surface disposal of geothermal waters of similar quality of Oregon's thermal spring and well waters would presently be undesirable, based on water chemistry and current standards. Inter basin transfer, reinjection (or recirculation) of associated hydrothermal fluids will involve considerable flows which may significantly affect regional hydrology and must be ranked as a serious concern along with other water quality issues such as discharge of spent fluids to surface waters, erosion and sedimentation impacts, landslides and subsidence, resource depletion and ground water degredation.

Regulation Delineation Regarding Water Quality and Geothermal Resource Developments

The United States Geological Survey identifies the "geothermal resource base" of the Wallowa Mountains; it reaches the valley floor at Union, and from there it winds north through the valley to join the old channel of the Grande Ronde near Cove. The river has built a gravelly fan extending from its mountain canyon several miles eastward from LaGrande. Catherine Creek also flows across a gravel fan before reaching the Grande Ronde. From their confluence, the river meanders widely over a very flat part of the valley floor as far as the bedrock canyon carved through Pumpkin Ridge, below which the river enters the smaller Elgin Valley.

Economical supplies of water can be obtained from wells in the lava bedrock, in the gravelly alluvial-fan deposits, and in the sand and fine gravel beds within the valley alluvium. The water table stands close to the level of the valley floor, and springs flow from the bedrock and gravel aquifers around the edges of the valley. Springs rising along faultlines at Hot Lake contain water that is near boiling temperature.

The river drains 3,950 square miles, mostly mountainous and forested. Precipitation over the area is moderate (30 inches annually) annual run-off, would cover the basin more than 13 inches deep if it could be spread uniformly over it. The Grande Ronde River at LaGrande average discharge is 380 cfs (from a 678 $mi^2$ drainage area) and at Elgin is 660 cfs (from 1250 $mi^2$ drainage area). At Troy, where the drainage area is 3,275 square miles and the lowest streamflow measuring station is operated, the average flow is 3,200 cfs after the upstream needs have been taken out. The forests, meadows, and irrigated fields of the Grande Ronde basin consum or evaporate about 18 inches of water. This flow is about twice the total net inflow contributed to the Snake River by all other Oregon streams although the drainage area at Troy is less than a fifth of the total of the combined Snake River tributaries in Oregon (19,150 sq. mi.).

Ground water in the alluvium of the Grande Ronde Valley ranges from soft to only moderately hard; it varies in chemical content temporally and spatially in accordance with adjacent surface runoff. Warm to hot water occurs along geologic faults in the Powder and Grande Ronde River basins. This water carries large amounts of silica, sodium bicarbonate, chloride, and sulfate and is of poor quality.

## III. WATER QUALITY

### Introduction

This chapter covers delineations of Oregon's regulations regarding water quality, geothermal resource developments, and water quality issues and concerns related to proposed geothermal activities within the state.

Discussed in Section III is the current understanding among state agencies for the coordinated action of the development of geothermal resources. This proceeds with the developer complying with the Department of Geology and Mineral Industries (DOGAMI) rules, regulations and environmental protection stipulations relating to exploration and development of geothermal resources in Oregon. State water quality standards, Forest Service management goals

Act Amendments of 1972 (PL 92-500), the Clean Air Act as amended (PL 91-604 and PL 95-95), the Safe Drinking Water Act (PL 93-523), the Resource Conservation and Recovery Act of 1976 (PL 94-580), the Noise Control Act of 1972 (PL 92-574), and the Toxic Substances Control Act (PL 94-469). Laws aimed principally at broad-scale encouragement of energy resource development include: the Geothermal Stream Act of 1970, the Federal Nonnuclear Energy Research and Development Act of 1974, and the Geothermal Energy Research and Development Act of 1974. Laws aimed principally at broad scale protection of environmental values include: the National Environmental Policy Act of 1969, the Fish and Wildlife Coordination Act, the Endangered Species Act of 1973, the Wilderness Act, and the Marine Protection, Research and Sanctuaries Act of 1972. Generally these laws, programs and acts have specific goals for maintaining environmental quality and standards, which must be met by commercial or industrial developments.

Oregon's concerns for geothermal development include meeting the government regulations mentioned above. There are substantive and procedural requirements which developers are to follow in exploring and developing geothermal energy. Legal and institutional constraints to geothermal development along with a categorization of state laws in Oregon are presented in Reference 56. The article "Administrative Requirements for Development of Geothermal Resources, the State of Oregon"[48] is not a step-by-step checklist of requirements but a guide for overcoming hurdles faced by the geothermal developer. It is noted that Oregon's 1975 legislature vested all jurisdiction over geothermal wells in the Department of Geology and Mineral Industries.

The DOGAMI environmental protection stipulations (February, 1979), applicable for exploratory drilling for geothermal energy resources, apparently supercede and make moot previous agreements with other state agencies for conditions which might affect water quality. The DOGAMI drilling stipulations noted that a developer can proceed with limited authoritative constraint during the period of resource exploration, providing sufficient care is taken drilling, operating and abandoning test wells and accordingly meeting DOGAMI's drilling rules. If the resource is found then a site specific EIS is required before development can proceed.

DEQ and other agencies review the EIS and provide comments on the planned geothermal development. They list water quality standards established by the Oregon Department of Environmental Quality (DEQ) and the Forest Service Stream Management Goals. Generally, agency EIS review has involved resummarizing some environmental impact concerns and raising questions regarding federal enforcement of state environmental protection requirements by federal land managers.[31] It appears that existing state laws, regulations and agency agreements for fluid discharge cover geothermal exploration activities but are inadequate for fluid disposal from field development and operations.

## Concerns and Issues

### Introduction

Early developments of geothermal activities in California (1960) had imp d as all of the stored thermal energy above 15°C to 10 km depth in the earth for the 50 states. Oregon's law establishes 250°F (121.1°C) and well depth greater than 2000 feet (609.8 m) for applying geothermal regulatory requirements under the aegis of the Department of Geology and Mineral Industries (DOGAMI). Wells cooler than 250°F (121.1°C) and shallower than 2000 feet (0.61 km) would be administered by the State of Oregon's Water Resources Department (DWR), whereby a water right would be required for "beneficial use" if industrial use exceeds 5000 gpd (0.22 L/s). It should be noted that development on federal land requires a federal lease (BLM or USFS) and compliance with USGS operating regulations. Drilling on federal land also requires state DOGAMI permits for both shallow and deep wells, and compliance with DEQ regulations. Development on state land requires a DSL lease, DOGAMI permits, and DEQ regulations compliance; and development on private land requires DOGAMI permits and DEQ compliance.

As noted in Tables I and II, Section II, some of the KGRA's reservoir waters have temperatures below 250°F (121.1°C). Characteristics of geothermal resources cannot be determined without drilling of deep wells, a process that existing regulations allow only after issuance of permits from DOGAMI. On the DOGAMI permits, copies of the applications to drill are distributed to all potentially interested state agencies (DOGAMI, DWR, DOE, DSL, F&W, Hwy. Comm., etc.) for consideration before a permit is issued.

DWR policy is that geothermal fluids (from wells producing over 5000 gpd (0.22 L/s) must be reinjected or subjected to subsequent water filings. Land disposal of geothermal fluids needs a DEQ (Department of Environmental Quality) permit; while beneficial use does not require a DEQ permit, a water right is needed. A condition of understanding among state agencies seemingly exists for coordinated action on the development of geothermal resources. That is, the commercial developer has been encouraged to follow DOGAMI's "Rules and Regulations...Relating to Exploration and Development of Geothermal Resources in Oregon" and if the resource is found with temperatures above 250°F (121.1°C) and deeper than 2000 feet, production would follow under DOGAMI's authority. If the resource does not fit this description, its regulatory disposition would be handled on a case by case basis with the pertinent interested agencies. For this reason the geothermal water quality impacts suggested in the workshop discussions and expanded upon in this report are generalized for both warm water near-surface (hydrothermal) systems and deep geothermal systems without concern for temperature or depth limitations.

A survey of environmental regulations applying to geothermal exploration development and use is found in Reference 1 and a general guide for negotiating and obtaining regulatory approvals is given in Reference 102. Detailed information on leasing, statutory responsibilities and legal definitions is also given in the appendicies of this reference.

A summary of Federal Pollution Control Laws Administered by the Environmental Protection Agency requiring or related to geothermal pollution control is found in "Pollution Control Guidance for Geothermal Energy Development" by Robert P. Hartley.[36] The significant federal laws include those applying to all industrial developments, such as: the Federal Water Pollution Control design. Secondly, the probable impacts on surface runoff should be considered in terms of surface water degredation by geothermal plant effluents, drilling and testing runoff to streams, erosion and sedimentation of streams associated with road construction and site preparation, and land slides and subsidence contributions to stream sediment loads. Thirdly, probability of accidental spills, such as by well blowouts should be assessed. Fourthly, ground water degredation and interference with nearby wells by leakage of the geothermal well should be considered, in addition to resource degredation and reinjection effects. Finally, cooling tower drift components should be considered regarding their possible chronic effects with possible isolated storm runoff of assembled deleterious constituents.

Baseline water quality information sources for Oregon's KGRA's are presented in the next paragraphs.

Water quality standards for drinking water (Oregon, recommended and mandatory (USPHS), irrigating water (threshold and limiting), and livestock feeding (threshold and limiting) for numerous chemical elements and compounds are listed in Table III. Accordingly, the limits for potable water are indicated on Figure 2. This information is for use in comparing the quality of Oregon's thermal springs and well water quality data with acceptable use standards.

Table IV is a summary of regional thermal spring and well water chemical analyses recently published in Reference 89. Ranges of concentrations of elements and chemical compounds are listed in mg/L or ppm for each of the KGRA's of Oregon. Accordingly, the range of these concentrations found in Oregon's thermal springs and wells is indicated on Figure 2, along with the range accepted for potable waters.

It is noted that the chemical attributes of the waters of many of Oregon's thermal springs and wells exceed existing water quality standards, including many elements and total dissolved solids, as listed:

| | |
|---|---|
| Arsenic | all areas exceed (but LaGrande) |
| Bicarbonate | all areas exceed (but Klamath Falls, Alvord) |
| Boron | all areas exceed |
| Bromide | exceeded by Belnap, Breitenbush, Klamath, Alvord |
| Calcium | exceeded by Belnap, McCredie, Klamath Falls |
| Chloride | all areas exceed |
| Copper | all areas exceed |
| Fluoride | all areas exceed |
| Hydrogen Sulfide | exceeded by Mt. Hood (gas) and Alvord (water) |
| Iron | exceeded by Klamath, Alvord, Vale |
| Lead | all areas have ≤ 0.06 standard is 0.05 ppm |
| Lithium | exceeded by Alvord, Belnap, McCredie, Breitenbush |
| Manganese | exceeded by McCredie, Breitenbush, Klamath, Alvord |
| Mercury | exceeded at LaGrande |
| pH | exceeded by Klamath, Alvord, Burns, Vale, LaGrande |
| Sodium | exceeded by Belnap, McCredie, Breitenbush, Klamath Falls, Alvord |
| TDS | all areas exceed |

stringent requirements on water quality limits. As developments progressed, condensate quantities and surface waste discharges grew with resulting degradation of water quality in nearby streams. Ammonia releases in the surface discharges, were toxic to salmonids and boron posed agricultural problems. Reinjection of the effluent to lower aquifers provided resolve to the problem of direct discharge of condensate to surface waters. With reinjection the water quality problems associated with geothermal developments in these areas became more attributable to lax land management than from effluent discharges (i.e., erosion from road construction, failing sump pits and accidental breaks in condensate lines). Now associated requirements are sufficiently tight and methods of construction have become sufficiently improved that even the land management problems are minor. These experiences are important for the development of geothermal resources in Oregon because they show that problems can occur, problems can be mitigated and the resources can be successfully developed with present day technology without significant adverse impacts to regional water quality.

Water quality management actions within the regulatory system in Oregon will require measures to be taken to prevent geothermal waters from entering surface or ground waters of an area. For those suspecting some eventual degredation of water quality associated with geothermal developments will eventually occur, their concerns should be tempered by a benefit-to-cost analysis related to the development and potential impacts, damage and losses. That is, the probability of the impact should be assessed, the expected harm or loss identified and quantified in terms of net value, and the cost of increased protection to prevent the accidental impact should be put into balance in terms of trade offs with the benefits of developing the resource for its energy supply.

Management of geothermal developments are important but are beyond the scope of this report, which is directed to identifying water quality issues, availability of water quality baseline information and information needs. As geothermal energy developments progress, however, monitoring programs will be required to ensure the effectiveness of the program management. Information on stream and ground water quality will be necessary to evaluate impacts, if they occur. This report hopefully will supply identification of sources of available baseline information for geothermal developments now under consideration in Oregon. Monitoring programs should be planned to improve this meager data base and initially should be directed to resolve the issues and concerns mentioned in the next sections.

## Identification of Water Quality Impacts

In the process of identifying possible water quality impacts associated with geothermal developments, the first step should be to identify the possible water contaminants that exist in regional geothermal waters of the KGRA and to document the baseline chemical composition of the waters of the area's hot springs and wells. Constituents deleterious to future water re-uses should be identified. Information on the basic geothermal waters, condenser exchange waters, process wastes and cooling tower effluents should be found through exploratory drilling and projected process synthesis, analysis and

# TABLE IV. CHEMICAL ATTRIBUTES OF OREGON'S HOT SPRINGS AND WELL WATERS.

| Parameter | | Western Cascades | | | Mt. Hood (Fulmaroles) | Klamath Falls | Alvord | Burns | Vale | LaGrande | Lakeview |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Belnap | McCredie | Breitenbush | Swim Hot Spr. | | | | | | |
| Arsenic | As | .35 | .08 | .51-.54 | <.005 | N-.027 | .037-2.5 | .06 | .001-.05 | .01 | .06 |
| Barium | Ba | | <.1 | <.1 | | <1 | <.1 | | < 0.1 | <0.1 | <.1 |
| Bicarbonate | $HCO_3$ | 17 | | 142 | | 2:-1550 | 372-1250 | 49-128 | 127-198 | 62-£4 | 62-208 |
| Boron | B | 6.4 | 17.8-18 | 4.1-5.43 | .32 | .01-1.0 | .89-36 | .06-3.99 | .15-14 | .1-2.9 | 6.9-9.9 |
| Calcium | Ca | 210-455 | 460-500 | 90-100 | 13-60 | 1.2-180 | .6-17 | 1-15 | 3.0-36.6 | 3.6-10 | 8-15 |
| Chloride | Cl | 1300-1343 | 2200-2232 | 1170-1300 | <1.ↄ | 1.8-170 | 24-780 | 5-38 | .5-360 | 1.0-140 | 99-146 |
| Copper | Cu | .01 | .02 | .01 | | .01 | .01-.05 | | <.01-.02 | .01 | N-<.01 |
| Flouride | F | 1.2 | 2.68-2.7 | 3.4-4 | .23 | N-1.7 | 6.5-17 | .5-2.8 | .7-9.4 | .5-1.7 | 3.1-6.9 |
| Hydrogen Sulfide | $H_2S$ | | | | gas N-.181 | | 1.0 | | | | |
| Iron | Fe | .02 | .02-.1 | .02 | <.05 | N-1.4 | N-.12 | .01-.05 | <.02-.4 | <.02 | <.02-.06 |
| Lead | Pb | <.06 | <.06 | <.06 | | <.06 | <.06 | | <.06 | <.06 | N-<.06 |
| Magnesium | Mg | .2-13 | .9 | 1.3 | 2.8-48 | N-47 | N-2.2 | 1.4-5.7 | <.05-14.7 | <1-1.3 | .1-2.4 |
| Manganese | Mn | .02 | .05-.1 | .22 | <.05 | N-2.4 | N-.1 | | <.02-.06 | <.02 | N-<.02 |
| Mercury | Hg | <.0001 | | .0002 | | | .0001-.0008 | | .0001-.0007 | .0032 | .0004 |
| Nitrate | $NO_3$ | | | | <.02 | N-2.9 | N-2.5 | N-3.8 | .03-.14 | | .2-7.2 |
| Sodium | Na | 364-690 | 910-1000 | 690-720 | 5.4-136 | 19-580 | 230-1040 | 30-157 | 1.4-482 | 19-130 | 152-268 |
| Sulfate | $SO_4$ | 168-170 | 240 | 96-140 | 77-205 | .6-462 | 177-367 | 11-89 | 1-135 | 3.3-56 | 152-265 |
| Potasium | K | 15-69 | 22-28 | 31-34 | .02-11.7 | 1-18 | 10.8-69 | 1.8-6.9 | .4-16 | 2.7-5 | 2.2-9.5 |
| Aluminum | Al | | .01 | | <.02 | <.01-.03 | N-.058 | | .008-.28 | | N-.034 |
| Bromide | Br | 33 | | 5 | | .08 | 1-2 | | .5 | .34 | .4 |
| Strontium | Sr | 1.4 | | .73 | | .58 | N-.42 | | <.05-.16 | <.35 | .5-.32 |
| Lithium | Li | .95 | 1.4-1.98 | 1.8-1.9 | <.01-.013 | .02-.16 | N-2.1 | | .11-.4 | .33 | .2-.15 |
| Cesium | Cs | <.1 | .1 | .1 | | <.01 | <.1-.2 | | ≤.1 | <.31 | <.1 |
| Rubidium | Rb | .05 | .11 | .18 | | .02 | .1-.33 | | .02-.09 | <.32 | .05 |
| Iodine | I | .2 | | .1 | | .01 | .01-.2 | | .06 | .38 | .08 |
| Antimony | Sb | <.2 | <.2 | <.2 | | <.2 | .2 | | <.2 | .2 | <.2 |
| Ammonium | $NH_4$ | | .21-.25 | | .05 | .54-.55 | .026-.9 | | .1-1 | | .31 |
| Carbon Dioxide | $CO_2$ | | | | .68-17.4 | | | | | | |
| | Na*k | | | | | | | 37 | | | |
| Phosphate | $PO_4$ | .21 | .11-.61 | .25 | .09 | .02-.18 | .04-4.5 | 46-89 | .13-.21 | 1ↄ9 | .25 |
| | $SiO_2$ | 30.9-96 | 65.4-79 | 83-182 | 19-72.3 | 24-110 | 72-214 | N-92 | 32-180 | 45-8¹ | 66-146 |
| | $CO_3$ | <1 | | <1 | | N-21 | N-4 | | <1-1 | 4.9-12 | <1-6 |
| Uranium | U | | | | | | 0-.0001 | | | | |
| | $N_2$ | | | | .032-70.5 | | | | | | |
| | $O_2$ | | | | .017-19.5 | | | | | | |
| | $H_2$ | | | | .033-.58 | | | | | | |
| | $CH_4$ | | | | .0014 | | | | | | |
| | pH | 7.62 | 7.29-7.4 | 7.31-8.5 | 7.3 | 7.0-9.5 | 6.73-8.67 | 7.5-9.5 | 7.32-8.71 | 7.9-ↄ.21 | 7.3-8.4 |
| Total Dissolved Solids | TDS | 2506 | 4420 | 2439 | 983 | 159-833 | 180-2910 | 165-499 | 181-1381 | 148-588 | 531-905 |
| Specific Cond. | | 4300 | 6670-6730 | 4030 | 1300 | 173-2700 | 222-4590 | 194-716 | 115-2400 | | 813-1230 |
| Alkalinity | $CaCO_3$ | | 16-21 | 72 | 179 | 83 | 360-1196 | | 37-157 | | |

*Concentration ranges listed in mg/L (ppm).

Source - USGS and DOGAMI "Chemical Analysis of thermal Springs and Wells in Oregon"

## TABLE III. WATER QUALITY STANDARDS AND ACCEPTABLE LIMITS FOR DRINKING, IRRIGATION AND LIVESTOCK WATERS.

| Parameter | | Drinking Water: Recommended USPHS | Drinking Water: Mandatory USPHS | Drinking Water: Oregon | Irrigating Water: Threshold | Irrigating Water: Limiting | Livestock Feeding: Threshold | Livestock Feeding: Limiting |
|---|---|---|---|---|---|---|---|---|
| Arsenic | As | .01 | .05[c] | .01 | 1.0 | 5.0 | 1 | |
| Barium | Ba | | 1.0[c] | 1.0 | | | | |
| Bicarbonate | $HCO_3$ | range 25-550 | | | | | 500 | 500 |
| Boron | B | range <.1-1 | | .5 | .5 | 2 | | |
| Calcium | Ca | range .9-150 | | | | | 500 | 1000 |
| Chloride | Cl | 250[d] | | 25 | 100 | 350 | 1500 | 3000 |
| Copper | Cu | 1.0[d] | | .005 | 0.1 | 1.0 | | |
| Flouride | F | 1.7 | 2.2 | 1.0 | | | 1 | 6 |
| Hydrogen Sulfide | $H_2S$ | .002 | .05[d] | | | | | |
| Iron | Fe | .3[d] | | 1.0 | | | | |
| Lead | Pb | | .05[c] | .05 | | | | |
| Magnesium | Mg | range .8-55 | | | | | 250 | 500 |
| Manganese | Mn | .05[d] | | .05 | | | | |
| Mercury | Hg | | .002[d] | | | | | |
| Nitrate | $NO_3$ | 45 | 10[c] | | | | 200 | 400 |
| Sodium | Na | range 1.5-500 | | | | | 1000 | 2000 |
| Sulfate | $SO_4$ | 250[d] | | | 200 | 1000 | | |
| Potassium | K | range | | | | | | |
| Aluminum | Al | range <.25 | | | | | | |
| Bromide | Br | range <.21 | | | | | | |
| Strontium | Sr | <2[a] | 10[a] | range <6.5 | | | | |
| Lithium | Li | range .6 | | | | | | |
| Cesium | Cs | | | | | | | |
| Rubidium | Rb | | | | | | | |
| Iodine | I | | | | | | | |
| Antimony | Sb | | | | | | | |
| Ammonium | $NH_4$ | <.02 (asN)[b] | .5 (asN)[a] | | | | | |
| Carbon Dioxide | $CO_2$ | | | | | | | |
| | Na+k | | | | | | | |
| Phosphate | $PO_4$ | | | | | | | |
| | $SiO_2$ | range 50-800 | | | | | | |
| | $CO_3$ | | | | | | | |
| | U | | | | | | | |
| | $N_2$ | | | | | | | |
| | $O_2$ | | | | | | | |
| | $H_2$ | | | | | | | |
| | $CH_4$ | | | | | | | |
| | pH | | 6.5-8.5[d] | no change in Nat. pH (7.0-8.0) | 7.0-8.5 | 6.0-9.0 | 6.0-8.5 | 5.[illegible]-9.0 |
| | TDS | 500 | | 100 | 500 | 1500 | 2500 | 5000 |
| Specific Cond. | S.C. | | | | | | | |
| Alkalinity | $CaCO_3$ | | 20-400 | | 20 | 600 | | |

*Concentrations listed in mg/L (ppm)

Major Sources - Geonomics, Inc. ; Subsurface Enviornmental Assessment for Four Geothermal Systems For Oregon ; The Oregon Administrative Rules Chap. 340

Major Sources - Geonomics, Inc. ; Subsurface Enviornmental Assessment for Four Goethermal Systems For Oregon ; The Oregon Administrative Rules Chap. 340

Minor Sources - [a] Hammer, Mark J.; Water and Waste-Water Technology
[b] EPA; Quality Criteria for Water 1976

[c] Maximum contaminant level specified in National Interim Primary Drinking Water Regulations (EPA, 1976)

[d] Maximum contaminant level specified in National Secondary Drinking Water Regulations (EPA, 1977a)

[e] Acceptable Range for Potable waters; Geonomics (Figure 4)

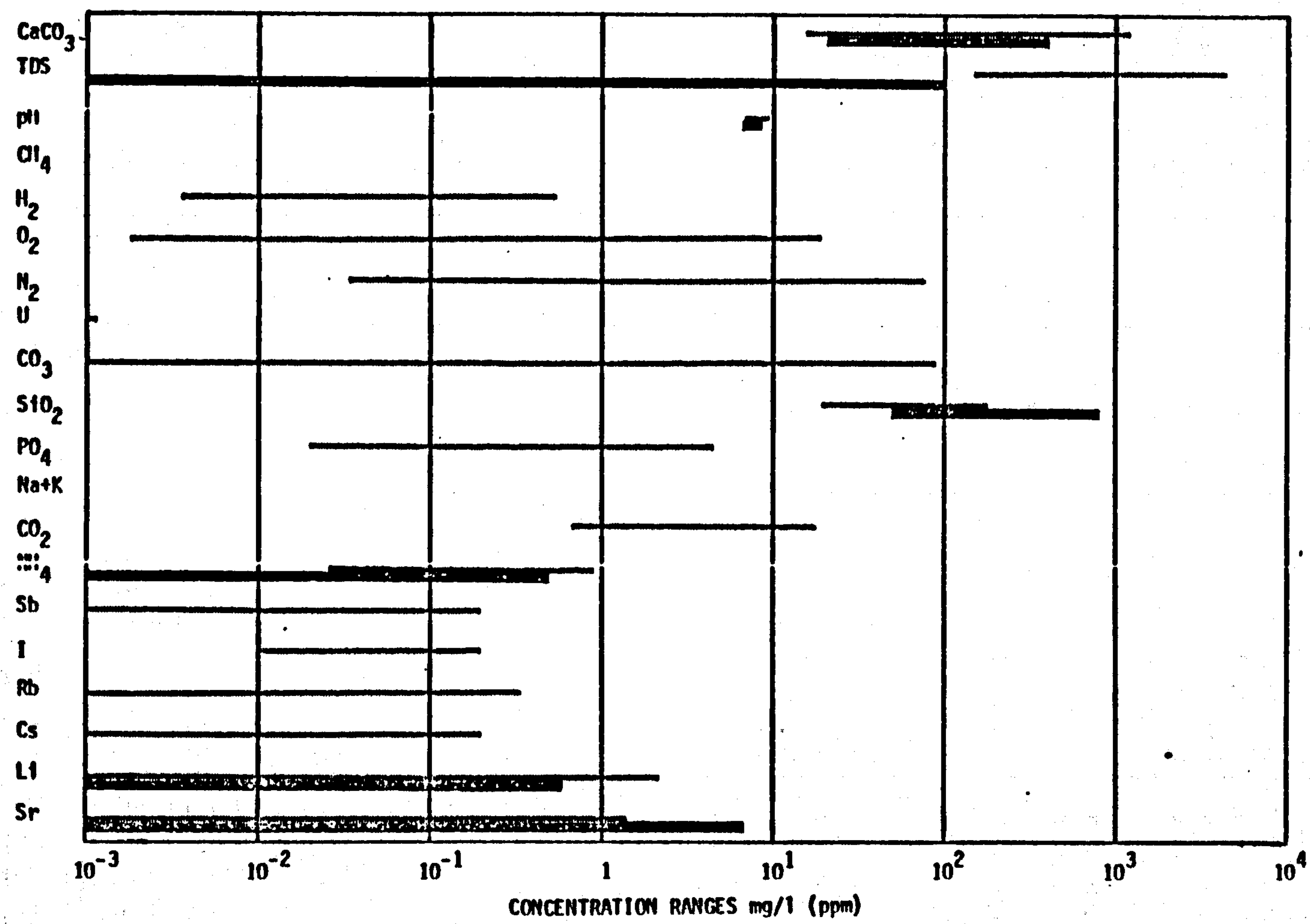
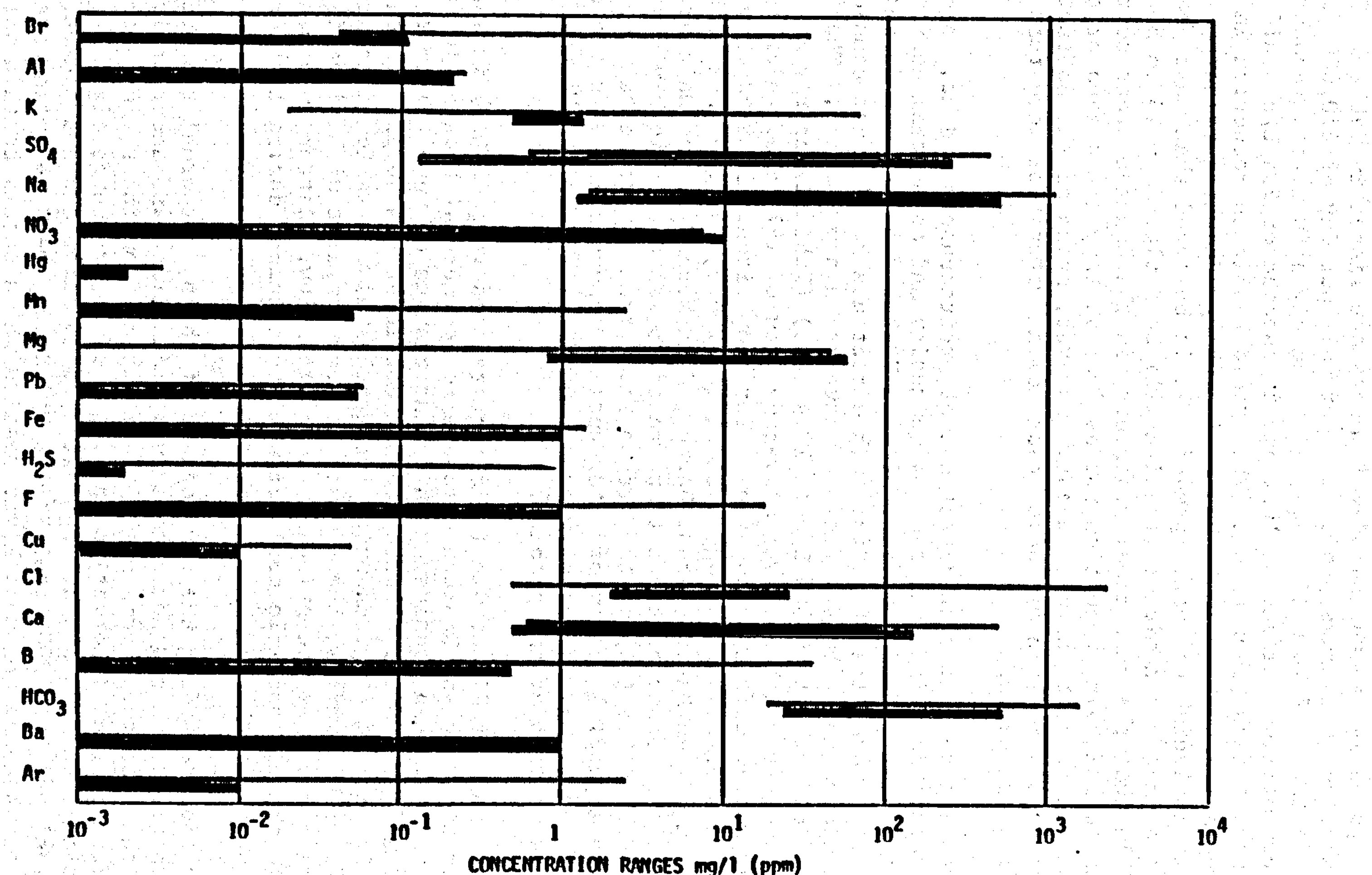



FIGURE 2. (Continued)




Source - USGS, DOGAMI "Chemical Analysis of Thermal Springs and Wells in Oregon"

FIGURE 2. OREGON'S HOT SPRINGS AND WELL WATER CHEMISTRY.

Fluid requirements for electrical power generation and direct use operations for Oregon's potential geothermal developments are listed in Table 1, Section II. Assuming an average production per well per day of 670,000 gallons of fluid and a total of 10 wells required to supply a 50 megawatt power plant, a total of 6.7 million gal/day or 10.4 cu. ft./second or 294 L/s would be required to support each power plant. This would result in reduction in streamflow from the area to the extent that additional groundwater recharge would be induced to replenish the water pumped. It is believed that most geothermal reservoirs under economic utilization will be depleted in 25 to 50 years. It is possible that the geothermal reservoirs in the Cascade areas contain enough water to maintain production for as long as they are needed or that they will be recharged by natural means. However, areas of the Southern Basin and Snake River plain may have insufficient waters for long term geothermal energy production.

It is interesting to note that direct use of Breitenbush's and Mt. Hood's geothermal waters is being promoted for community and commercial heating with projected transport distances as far as 70 km from the source fields. These associated water transfers for such direct use heating are considerable when compared to tributary flows of streams in a watershed. That is, the maximum flow rate of 40,000 L/s (1412.4 cfs.) (Table I) nearly matches the Cascade Range's Metolius River's average flow of 1479 cfs, which is almost entirely derived from spring flow. For comparison, the Sandy River near Bull Run has a mean annual average flow of 2,302 cfs, and the annual runoff for the Oregon Closed Basin (Burns, Harney, Hart Mountain, and Malheur Refuge) is 1650 cfs. The volume of these flow transfers was not seriously considered in the Breitenbush EIS (15) or the Oregon Geothermal Environmental Overview Workshop (See Appendix) review of water quality issues related to the development of geothermal energy of Oregon. However, the Belnap-Foley EIS[88] gave adequate mention of the problem.

If the upper range of direct use fluid requirements (40,000 L/s) is appropriated from the High and Western Cascades for commercial heating in the Willamette Valley, then consideration on the changes of runoff from the groundwater and geothermal resource connection to stream supplies should be given. If pumping of groundwater for geothermal use is found to significantly affect streamflow, there could be some conflict with fisheries' needs during periods of exceptionally low streamflow. Better information for analysis of this possible conflict will be obtained during test drilling and production testing.[88]

In the situation regarding the development of the hydrothermal resources of Mt. Hood, the resource has not become fully identified and accordingly the quality of the resource waters might be different from the region's thermal springs. From surface information the depth of the resource might be postulated to be at 1000 feet depth, when after exploration and assessment, it might be developed from 2000 feet.[80] At Mt. Hood, the developers, including NWNG[37] are seeding Columbia River Basalts which should contain waters of satisfactory quality for interbasin transfer, rather than the geothermal resources associated with deep circulation zones found along faults at other sites. If this resource can be established to provide fresh, clean well

No standards were found listed for Oregon's water for: Cesium, Antimony, Carbon Dioxide, Sodium and Potassium, Phosphates, Uranium, Calcium Carbonates, Rubidium, Iodine, or Ammonia.

On the basis of water quality standards most of the thermal spring waters would be undesirable to discharge directly into surface waters. Accordingly, disposal of related geothermal waters of similar quality would have to be through ponding with evaporation or reinjection into subsurface strata. Alternatively, surface water transfer and recirculating schemes could be used incorporating down-hole heat exchangers, providing the economics of the situation justifies the development of the geothermal resource. Perhaps appeals could be made for permits to discharge spent direct heat fluid appropriated from one area to subsequently be released into regional streams, if it could be shown that the resultant mix of the waters would meet the acceptable water quality standards, and if energy recovery benefits would be substantial to serve as a justifiable tradeoff.

## Ranking of Water Quality and General Environmental Impacts of Geothermal Activities

The Appendix presents the water quality session record of Oregon's Geothermal Environmental Overview Workshop held March 28-29, 1979 in Portland, Oregon. The primary water quality concerns with geothermal developments for the state were shown in Table I of the Appendix as: hot water disposal to surface waters, surface water degredation by contaminants from the geothermal plant's effluent, erosion and sedimentation impacts associated with construction efforts, land slides and subsidence, groundwater degredation by lowering of phraetic surfaces and subsequent change or regional hot springs' output and resource depletion. These concerns were accordingly ranked jointly by the workshop participants for each of the KGRA's. Subsequent to the workshop a review of the chronological account of geothermal activities and impacts was made[64] for each of the KGRA's.

Information for accurate identification and quantification of possible geothermal activity impacts on water resources and water quality is not available at this stage of development of the geothermal resources in the State of Oregon. However, it is possible to estimate the probability for occurrence (not severity) of effects. On a high-moderate-low basis, the probability for possible impacts during various stages of geothermal exploration, development and operation activities were estimated and accordingly presented in Table II. These rankings were assembled from reviewing of the Oregon Geothermal Environmental Overview Workshop's draft Proceedings and available KGRA environmental assessment reports. It should be noted that this tabulation covers periods from pre-lease exploratory operations through full field development and operational activities and that the impacts for the Oregon KGRA's are summarized and ranked for ecological considerations, air, water, solids and noise pollution concerns.

## Water Resources

Large quantities of energy underlie many of Oregon's geothermal areas; however, to transfer this energy to the surface requires large flows of water.

## TABLE V. CHRONOLOGICAL ACCOUNT OF GEOTHERMAL ACTIVITIES AND IMPACTS

CHRONOLOGICAL ACCOUNT OF GEOTHERMAL ACTIVITIES AND IMPACTS

| IVITY | ENVIRONMENTAL CHANGE | IMPACT | Breitenbush | Mt. Hood | La Grande | Alvord | Klamath Falls | Vale | Burns | REMARKS | line |
|---|---|---|---|---|---|---|---|---|---|---|---|
| se: Casual Use (no Notice of Intent Required) | | | | | | | | | | | I |
| resence of humans | Presence of humans | Disturbing to some forms of wildlife | L | L | L | L | L | L | L | | 1 |
| ight vehicles | Noise | Wildlife disturbance | L | L | L | L | L | L | L | | 2.a |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | L | L | L | L | L | L | L | | 2.b |
| erial photography | Noise (aircraft) | Disturbing to wildlife | L | L | L | L | L | L | L | | 3 |
| ater analysis | None | None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 4 |
| rew bivouac | Use and alteration of vegetation/soil in bivouac | Damage to plants and soil structure | L | L | L | L | L | L | L | | 5.a |
| | Noise of camp operations | Disturbance of wildlife | L | L | L | L | L | L | L | | 5.b |
| | Refuse accumulation | Modification of nutrient cycling system | L | L | L | L | L | L | L | | 5.c |
| se: Pre-Lease Exploratory Operations (Notice of Intent Required, no Application for Permit to Drill) | | | | | | | | | | | II |
| ophysical operations | | | | | | | | | | | |
| Drilling of shallow temperature gradient wells | Road damage (heavy equipment) | Accelerated soil erosion; vegetation damage | M-L | M | L | M | L | L | M-L | | 1.a |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | L | M | L | L-M | L | L | L | Strict regulations govern stream degredation. | 1.b |
| | Noise | Wildlife disturbance | L | L | L | L | L | L | L | Covered by state noise regulations. | 1.c |
| | Production of drilling wastes - piles of sludge | Nutrient cycle modification; (secondary) vegetation/soil modification | L | M | L | L | L | L-M | L | Strict regulations govern waste disposal | 1.d |
| | Preparation of drilling area - soil disturbance and vegetation removal | Soil/vegetation modification | L | M | L | M | L | L-M | L | | 1.e |
| ORV travel | Noise | Wildlife disturbance | L | L-M | L | L | L | L | L | | 2.a |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | L | M | L | H/M | L | L-M | L | | 2.b |
| | Vegetation crushing | Vegetation disturbance | M | M | L | M | L | L | L | | 2.c |
| | Soil disturbance | Soil disturbance | M | M | L | H/M | L | L | M | | 2.d |
| Explosives, seismic exploration | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | L | L | L | L | L | L | L | | 3.a |
| | Noise | Wildlife disturbance | L | L | L | L | L | L | L | | 3.b |
| | Soil/vegetation disturbance | Soil/vegetation disturbance | L | L | L | L | L | L | L | | 3.c |
| Camping and housing requirements of personnel | Use and alteration of vegetation/soil in bivouac | Damage to plants and soil structure | M | L | L | M-H | L | L | M-H | | 4.a |
| | Noise of camp operations | Disturbance of wildlife | M | L | L | L | L | L | M-H | | 4.b |
| | Refuse accumulation | Modification of nutrient cycling system | M | L-M | L | L | L | L | L | | 4.c |
| Post-Lease Exploratory Operation (Plan of Operations Required, Application for Permit to Drill Required for Deep Hole) | | | | | | | | | | | |
| building | Soil/vegetation disturbance | Damage to vegetation, insects and wildlife | H | M-H | M | M-H | L | M | M-H | | 1.a |
| | Noise | Wildlife disturbance | L | L | L | L | L | L | L | | 1.b |
| | Dust, increased stream sedimentation | Increased soil erosion; loss of habitat; loss of (secondary) fish habitat | H/M | M/L | L/M | M | M/L | M/L | M | | 1.c |
| ling pad construction | Soil/vegetation disturbance | Disturbance to soil/vegetation | M-H | M | L-M | H | L | L-M | M | | 2.a |
| | Increased soil erosion | Damage to plants, insects; increased soil erosion | M/H | M/H | L | H/M | L | L/M | M | | 2.b |
| construction and operation | Leakage of toxic materials: sump failure, overflow, leaching | Vegetation/wildlife damage; groundwater pollution; nutrient system disturbance | M-H/M | M | L/M/L | H/M | L | L/M/L | M | New technology and regulations greatly reduce chance of failure | 3.a |
| | Soil/vegetation disturbance, dust | Damage to soil/vegetation; damage to insects, wildlife; increased soil erosion and stream sedimentation; loss of (secondary) fish habitat | H | M-L | L | M | L | L-M | M | | 3.b |
| le lines | Noise | Disturbing to wildlife | L | L | L | L | L | L | L | | 4.a |
| | Projection of particles (physical damage to vegetation/habitat) | Vegetation/habitat disturbance | M | M | L | L | L | L | L | | 4.b |

0 - No Impact    M - Medium    X - Unknown
L - Low Impact    H - High

water, then the transfer of direct heating waters to the Portland area would be useful domestic supply. Accordingly, the disposal of spent hydrothermal fluids of acceptable quality would provide few problems. If the waters found at the resource level are not of satisfactory quality for discharge after commercial heating use in the Portland area, then it has been suggested that a surface or water well supply near the geothermal development area be used for the heat exchanger fluids in down hole heat exchangers at Mt. Hood. Subsequently, these waters would be transferred to the Portland area and used for industrial heating and then released for domestic use.

## Ground Water

Pumping of 6.7 million gal/day (294 L/s) from a deep geothermal source would deplete the overall groundwater storage by the volume pumped unless an equal volume was reinjected. Deep sources can be expected to be confined aquifers. The effects of pumping from such aquifers commonly extend over great distances from pumping centers, particularly where the aquifers have relatively low transmissivity values, as would be expected from aquifers in the tuffs and older volcanic rocks. One effect of such development could be the decline in water levels and yields of wells in the affected area, which may extend several miles from the pumping centers. Another possible effect could be the reduction of flow from hot springs in the environs. If these springs are closely associated with the source of geothermal fluid, the flow may decline soon after production of geothermal fluid begins.[88]

Disposal of spent direct use fluids appropriated from a different area may have its advantages if the chemical quality of the receiving waters needs refreshing. On the other hand, central continuous reinjection of 40,000 L/s of poor quality fluids to subterranean aquifers would possibly create problems such as ground movements, slides and uplifts of the upper strata, and affect regional aquifers, springs and seeps. Discharge of the geothermal waters directly into surface waters might have a negative impact if the thermal waters have elevated temperatures above those of the regional streams.

Until the High and Western Cascade resources are fully defined and the development options announced, there is need to challenge the potential benefits of energy supply and water quality enhancement of the developments with the possible negative impacts. There is continued need to reflect on the volume of flows being considered for transfer, in event the High and Western Cascades were to be developed for geothermal direct heat use.

## Water Quality Baseline Information Available on Oregon's Geothermal Resources

Only limited information was found in the process of evaluating water resource (hydrology and water quality) impacts associated with the progressive developments of recovering available geothermal energy in Oregon.

Table II of the Appendix was put together during the March 28-29, 1979 Oregon Geothermal Overview Workshop water quality session to tabulate: 1) the availability of site specific water baseline information within Oregon's

## TABLE V. (Continued)

| ACTIVITY | ENVIRONMENTAL CHANGE | IMPACT | Breitenbush | Mt. Hood | La Grande | Alvord | Klamath Falls | Vale | Burns | REMARKS | line |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Clearing lanes for pipes, etc. | Soil/vegetation disturbance | Soil/vegetation disturbance; habitat modification, accelerated erosion | H | M | L-M | M-H | L/M | H/M | M/H | | 6.a |
| | Noise | Disturbing to wildlife | M | L | L | H/M | L | L | L-M | | 6.b |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L-M | L-M | L | L | L | M-H | | 6.c |
| Heavy equipment for trenching/foundation operations | Soil/vegetation disturbance | Soil/vegetation disturbance | H | L-M | M | M | L | H | M-H | | 7.a |
| | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 7.b |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L-M | L-M | M | L | L | M-H | | 7.c |
| Erection of above-surface pipelines | Barriers to migration | Habitat disturbance; visual environmental modification | M/H | L/M-H | L/M | L/M | L/M | L/H | M/H | | 8.a |
| | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 8.b |
| Road construction to and along pipeline lanes | Soil/vegetation disturbance; increased air pollution (dust) | Damage to soil profile. plants; damage to insects, wildlife; loss of (secondary) fish habitat; increased soil erosion | H | M | M | M/H/M | M/L/M | M/H/M | H | | 9.a |
| | Noise | Disturbance to wildlife | M | L | L | L | L | L | L-M | | 9.b |
| Power generation facility (construction) | | | | | | | | | | | |
| Access roads | Soil/vegetation disturbance | Damage to plants, insects, wildlife; loss of habitat; increased soil erosion | H | M | M | H/M | L/M | H/M | H | | 10.a |
| | Noise, air pollution (dust) | Disturbance to wildlife | M | L | L | L | L | L | L-M | | 10.b |
| Clearing of area | Soil/vegetation disturbance | Soil/vegetation disturbance; habitat modification, accelerated erosion | H | L-M | M | M | L | H/M | H | | 11.a |
| | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 11.b |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L-M | L-M | M | L | M | M-H | | 11.c |
| Temporary storage of equipment and construction material | Soil/vegetation disturbance | Soil/vegetation disturbance | H | L-M | L-M | M | L | M | M-H | | 12 |
| Transmission lines | | | | | | | | | | | |
| Clearing lanes | Soil/vegetation disturbance | Soil/vegetation disturbance; habitat modification, accelerated erosion | H | M | M | H/M | M/L/M | H/M/L | H | | 13.a |
| | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 13.b |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L-M | L | M | L | L | M-H | | 13.c |
| Foundation construction | Soil/vegetation disturbance | Soil/vegetation disturbance | H | L-M | L-M | H | L | M | M-H | | 14.a |
| | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 14.b |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L-M | L-M | M | L | L | M-H | | 14.c |
| Access/maintenance roads | Soil/vegetation disturbance | Soil/vegetation damage, wildlife habitat loss, damage to plants, insects, wildlife | H | L-M | L-M | H | M/L | M/L | H | | 15.a |
| | Increased air pollution (dust) with increased secondary stream sedimentation | Loss of (secondary) fish habitat; increased soil erosion | M-H/H | L-M | L-M | M | L/M | L | M/H | | 15.b |
| Equipment for laying lines | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 16.a |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L | L-M | M | L | L | M-H | | 16.b |
| | Load failure | Accelerated soil erosion; vegetation damage | H | L-M | L-M | M/H | M/L | M/H | H | | 16.c |

## TABLE V. (Continued)

| ACTIVITY | ENVIRONMENTAL CHANGE | IMPACT | Breitenbush | Mt. Hood | La Grande | Alvord | Klamath Falls | Vale | Burns | REMARKS | line |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Deep exploratory drilling | Noise | Wildlife disturbance | M | L | L | L | L | L | M | | 5.a |
| | Road damage (heavy equipment) | Accelerated soil erosion; vegetation damage | M | M | L-M | M/H | L | M | H | | 5.b |
| | Fumes-exhaust and well fumes | Visual pollution; atmospheric modification | M | L-M | L | H | L | L-M | H-M | | 5.c |
| | Soil/vegetation disturbance (clearing areas for storage, rocks, etc.) | Soil/vegetation disturbance | H | L-M | L-M | | L | L | M-H | | 5.d |
| Housing of personnel | Soil/vegetation disturbance (clearing areas for storage, rocks, etc.) | Soil/vegetation disturbance | M | L | L | M-H | L | L | M-H | | 6.a |
| | Creation of impervious surfaces | Accelerated erosion where runoff leaves impervious surface | H | L-M | L | M | L | L | M-H | | 6.b |
| | Sewerage and solid waste disposal | Pollution: visual, water, groundwater; nutrient system disturbance, air pollution if burning | M | L-M | L | M | L | L | M-H | | 6.c |
| Transport of personnel, materials and equipment | Noise | Wildlife disturbance | M | L | L | M | L | L | L | | 7.a |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M | L | L | L | L | L | M | | 7.b |
| | Road damage | Accelerated soil erosion; vegetation damage | M | L-M | L | M-L | M/L | L-M | M-H | | 7.c |
| Temporary installation of facilities | Dust, noise, increased stream sedimentation | Damage to plants, insects; loss of (secondary) fish habitat | M | L-M | L | M | L | L-M | M-H | | 8.a |
| | Soil/vegetation disturbance (storage of materials) | Soil/vegetation disturbance | M | L-M | L | M-H | L | L-M | M-H | | 8.b |
| | Creation of impervious surfaces | Accelerated erosion where runoff leaves impervious surface | M | L-M | L | M-H | L | L-M | H | | 8.c |
| Blow-out risks | Discharge of effluent | Pollution: air, surface and groundwater, production of toxins, accelerated erosion | H | M-H (1) | M | L | M/L | M | M-H | (1) High $H_2S$ content at Mt. Hood. | 9.a |
| | Noise | Wildlife disturbance | M | L | L | L | L | L | L | New technology greatly reduces risk | 9.b |
| | Emergency procedures; soil/vegetation disturbance | Soil/vegetation disturbance; modification of nutrient cycling system | H | L-M | L-M | L-M | L | L | M-H | of blowout. | 9.c |
| Equipment maintenance (oil, gas, detergent) | Discharge of detergents, organic compounds (oil, gas, etc.) | Pollution of soil, water; vegetation destruction | M | L-M | L | L | L | L | M | Regulations govern discharges. | 10 |
| Well abandonment and dismantling | Heavy equipment; increase human presence | Destruction of vegetation/soil disturbance | M | L | L | H | L | L | M-H | | 11.a |
| | Noise | Disturbance of wildlife | M | L | L | L | L | L | L | | 11.b |
| Drilling mud disposal | Exposure of environment to toxins: chromates, NaOH | Disturbance of nutrient systems; death of wildlife/vegetation/habitat destruction | H | L-M | L-M | M | L | L-M | M-H | Regulations govern discharges-reducing impact on environment. | 12 |
| Phase: Full Field Development (Plan of Operation and Application for Permit to Drill Required) | | | | | | | | | | | IV. |
| Extensive systematic drilling | | | | | | | | | | | |
| Pad construction | Soil/vegetation disturbance | Soil/vegetation disturbance; damage to plants, insects; accelerated soil erosion | H | M | M | H/M | M/L | H/M | H | | 1.a |
| | Dust, with secondary increased stream sedimentation | Local air pollution; loss of (secondary) fish habitat | M-H | L-M | L | L | L | L | M-H | | 1.b |
| | Noise | Wildlife disturbance | M | L | L | L | L | L | L-M | | 1.c |
| Storage of gear facilities | Soil/vegetation disturbance | Soil/vegetation disturbance | M-H | L-M | L | H | L | M | H | | 2 |
| Transportation to sites | Road damage (and maintenance operations) | Accelerated soil erosion; vegetation damage | H | L-M | L | M | L | M | H | | 3 |
| Road construction to new drill sites and supporting facilities | Soil/vegetation disturbance | Damage to plants, insects, wildlife; habitat disturbance, soil erosion | H | M | M | H/M | L/M | H/M | H | | 4.a |
| | Increased sedimentation of surface water | Loss of (secondary) fish habitat | H | L-M | M | L | L | L | M-H | | 4.b |
| | Dust, noise | Increased air pollution and wildlife disturbance | M-H | L-M | L | L | L | L | M-H | | 4.c |
| Pipelines from wells | | | | | | | | | | | |
| Movement of heavy equipment-transportation | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 5.a |
| | Dust, with secondary increased stream sediment load | Damage to plants, insects; (secondary) fish habitat damage | M-H | L-M | M-L | M-H | L | L | M-H | | 5.b |
| | Road failure | Accelerated soil erosion; vegetation damage | H | M | M-L | M | L | M | H | | 5.c |

TABLE VI. ENVIRONMENTAL (WATER RESOURCE AND WATER QUALITY) BIBLIOGRAPHIC DATA CROSS REFERENCE FOR OREGON'S KGRA'S.

| | General to Oregon | Western Cascades | Mt. Hood | LaGrande | Snake River Basin | Baker-Northern Malheur Counties | Baker Valley | Northern Malheur Resource Area | Vale Addition | Bully Creek | Klamath Falls | Drewsey Resource Area-Harney-Malheur | Harney Basin | Harney Valley | Burns | Alvord | Oregon Canyon | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Water | 66,67,68, 85,93 | 15,88 | 90, 102 | 39 | | | 9 | 12 | 13 | | 11,26,46,54, 78,84 | | 75 | 42 | 10 | 8 | 14 | 22 |
| Groundwater | 1,67 | 15,88 | 90, 102 | 55 | 92 | 17 | 9 | 12 | 13 | 49 | 11,26,43,47, 54,78,84 | 35 | 75 | 42 | 10 | | 14 | 26 |
| Thermal Waters | 6,7,30,50, 52,89 | 15,88 | 90, 102 | | | | 9 | | | | 21,26,45,46, 47,58,78,84 | | 75 | 42 | | 8 | 14 | 23 |
| Water Quality Standards & Regulations | 15,16,38, 33,36,39, 79,88,2 | | | | | | | | | | | | | | | | | 9 |
| KGRA Environmental Assessment Reports | | 15,16, 88 | 90 | | | | 9 | 12 | 13 | | 11,26,27 | | | | 10 | 8 | 14 | 13 |

## TABLE V. (Continued)

| ACTIVITY | ENVIRONMENTAL CHANGE | IMPACT | Breitenbush | Mt. Hood | La Grande | Alvord | Klamath Falls | Vale | Burns | REMARKS | line |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Operational activities related to geothermal power production | | | | | | | | | | | |
| Thermal discharges | Increased atmospheric temperature | Thermal modification | L | L | L | L | L | L | L | | 17.a |
| | Increased water temperature | Thermal modification | H | X | H | X | X | X | X | Strict regulations prohibit large increases in stream temperature. | 17.b |
| Condensate discharges | Increased air, water content | Fog and low clouds<br>Lower light penetration<br>Lower evaporation | H | H | L | L | L | L | L | State regulations govern air emissions | 18 |
| Blow-out risks | Discharge of effluent | Pollution: air, surface and groundwater, production of toxins, accelerated erosion. | M-H | M-H | M/L | X | L/L | M | M | New technology greatly reduces risk of blowouts. | 19.a |
| | Noise | Wildlife disturbance | H | L | L | L | L | L | L | | 19.b |
| | Emergency procedures; soil/vegetation disturbance | Soil/vegetation disturbance; modification of nutrient cycling system | H | M | M-L | X | L | L | M | | 19.c |
| Reinjection | Lubrication of faults | Seismic activity; (secondary) landslides, soil slumps, damage to structures, well casings | M | L | L | L | L-M | L-M | L-M | | 20 |
| Withdrawal of subsurface supportive matter | Lowering of surfaces with respect to sea levels; tilting of surfaces | Disrupts flows of seeps, springs, possible ponding; changes of drainage patterns; weakening foundations; damage to irrigation systems and roads | L | L | L | L | L-M | L-M | L-M | | 21 |
| High mineral content water discharge | Water discharge to environment with increasing levels of salts and toxins | Modification of terrestrial and aquatic hab tat; modification of nutrient cycling system | H | M | M | X | L | L-M | M-H | State and Federal regulations govern discharge of wastes. | 22 |
| Maintenance activities | | | | | | | | | | | |
| Solid waste disposal (personnel, etc.) | Sewerage and solid waste accumulation | Pollution: visual, water, groundwater; vat ient system disturbance, air pollution if burning | H | L-M | L-M | M | L | L | H | | 23 |
| Road maintenance | Noise, dust, soil/vegetation disturbance | Disturbance to wildlife; loss of plants, insects | M | L | L | M-H | L | L-M | M-H | | 24 |
| Facility repair | Possible discharges through leaks | Contamination of aquatic habitats | H | L | L-M | X | L | L | M-H | | 25.a |
| | Steam discharge when generators shut down | Fog and low clouds<br>Low light penetration<br>Low evaporation | H | L | L | X | L | L | X | | 25.b |
| | | Pollution of air, surface and groundwaters; production of toxins | H | M | L-M | X | L | L | H | | 25.c |
| | Noise | Disturbing to wildlife | M | L | L | L | L | L | L-M | | 25.d |
| Repair flood damage | Soil/vegetation disturbance | Soil/vegetation disturbance | H | M | M | X | L | M-H | H | | 26.a |
| | Discharge of salts and toxins | Modification of terrestrial and aquatic hab tat; modification of nutrient cycling system | H | M | M | X | L | L | H | | 26.b |
| Acid washings of "scaled" machinery | Discharge of salts and toxins | Modification of terrestrial and aquatic hab tat; modification of nutrient cycling system | H | L-M | M | X | L | L-M | M-H | | 27 |
| Solid waste disposal | Toxic elements discharge from the production of solid evaporites | Pollution to surface and groundwater from leaching of dump areas | H | M-H | M | M-H | L | M | M-H | Discharges prohibited without permit | 28 |
| Non-condensable gases and vapor discharge | Discharge of toxic substances to atmosphere | Modification of terrestrial and aquatic hab tat; modification of nutrient cycling system; $H_2S$ odors in atmosphere | H | M | M | M-H | L | L-M | M-H | Regulations limit discharges to atmosphere | 29 |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| | | Legislative issues | Oregon | | | | 33 | | |
| | | Exploration, leasing and drilling, data | Oregon | | | | 40 | | |
| | | Status geothermal, prospect wells, gradient holes shallower than 500' | Oregon, 41 gradient holes | | through Feb. 8, 1979 | depth, status | 23 | | |
| | | Geothermal exploration research | Oregon | | 1978 | Well & leasing permits & status, Ore-Ida, Mt. Hood Assessment | 81 | | |
| | | Environmental regulation for geothermal exploration, Dev. & Use | US-includes those for Oregon | | | | 2 | | |
| | | Geothermal site potential | for U.S. Oregon - Hot Lake, Alvord, Mickey, Vale, Breitenbush, Klamath Falls, Crump Lakeview | | | Chemical analysis, radioactive analysis | 30 | | data compilation incomplete |
| | Oregon Water Resources Department | Hydrologic data, groundwater quality | Oregon | | July 1974-December 1976 | | 67 | C | |
| | | Groundwater levels | Oregon | | 1968-1972 | | 1 | C | |
| | USGS | Water Resources Data | Oregon | monthly | 1977 | water quality temp., discharge spec. cond. | 93 | C | |

TABLE VII. BIBLIOGRAPHIC WATER QUALITY PARAMETRIC SUMMARY RELEVANT TO KGRA SITE ASSESSMENT.

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| B | USGS | Water chemistry, quality | Nevada & Oregon 35 spring in 13, 9 Oregon counties - Baker, Clackamas, Deschutes, Grant, Harney, Klamath Lake, Lane, Malheur, Marion, Umatilla, Union, Wasco | | 1974 | Al, N, P, As, Br, I, Rb, Cs, Strontium, Fe, Mn, Cu, Hg, $O_2$ + Ar, $N_2$, $CH_4$, $CO_2$, D, $O^{18}$ major elements temp., pH, spec. cond., $SiO_2$, Ca, Mg, Na, K, Li, $HCO_3$, $SO_4$, Cl, F, B. | 50 | C | |
| B | USGS | Water chemistry | Oregon 32 springs same areas as above | | summers of 1972 & 1973 | temp., pH, spec. cond., $SiO_2$, CA, Mg, Na, K, Li, $HCO_3$, $CO_3$, $SO_4$, Cl, F, B. | 52 | C | |
| | | Groundwater, irrigation wells, water quality | Owyhee River Basin Malheur River Basin Powder River Basin Burnt River Basin | | | | 92 | C | |
| | Water Resources Research Inst. OSU | Water quality | Oregon Rivers and Lakes | | | | 85 | C | |
| | Oregon Dept. Energy | Resource Assessment, estimates, leasing permits | Oregon | | | geothermal well status, leasing | 59 | | Planning report |
| B | | Area characteristics | Mt. Hood, Carey, Breitenbush, McCredie, Newberry Crater, Alvord, Crump, Geyser, Vale, Klamath | | | temp, flowrate, electrical potential, current status | 77 | | Preliminary profile |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| S | USGS | Hydrology and geochemistry | Klamath Falls | | summer 1976 to summer 1978 | well data, precipitation, water chemistry temperature | 46 | C | Final report |
| B | USGS | Assessment of Resources for U.S. temp. & energy types systems | 38 springs tested in Oregon | | 1978 | | 53 | C | Comments on status of wells |
| B | USGS | Assessment of geothermal resources for U.S. types systems | 28 springs in Oregon tested | | 1975 | temp. volume flow rates | 98 | C | Comments on status of wells |
| | USGS | Ground water study | Klamath Basin 550 wells | | 1970 | ground water levels, quality, occurrence, availability | 43 | C | |
| B | EPA | Study of radioactive elements in waters | Western U.S. Klamath Falls 13 wells & springs tested | | Nov. 1974 | $^{222}Rn$, $^{226}Ra$, $^{234}U$, $^{238}U$, $^{230}Th$, $^{232}Th$, temp., pH | 58 | C | |
| G | BLM | Environmental Analysis Record | Klamath Falls | | | anticipated impacts, characteristics of Environment water supply & quality, wells temp. & flow | 11 | C | Complete Environmental Analysis |
| G | BLM | Environmental Analysis Record | Bully Creek, Vale District | | 1976 | anticipated impacts, Env. characteristics water supply & (cont.) | 9 | C | Complete Environmental Analysis |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| | | Surface water records Precipitation records | Oregon | monthly | 1977 | weather records discharge | 68 | C | |
| | | Status of geothermal well permits, well. deeper than 500' | Oregon 21 wells | | current to Nov. 8, 1978 | status | 24 | | |
| B | USGS | Hydrological reconnaissance | Klamath Falls > 300 wells, 20 springs | | fall 1973 thru Sept. 1974 | regional hydrology groundwater flow, chemical content of groundwater, Si content temp. distribution | 84 | C | |
| R | | Uses of low to intermediate temp. fluids, heat extraction, reinjection | Klamath Falls | | | aquifer system uses geothermal fluids | 78 | | |
| I | Geo-Heat Utilization Center OIT | study corrosion problems | Klamath Falls, 6 wells | 6 months | Nov. 29, 1976 to May 29, 1977 | Chemistry & temp. rating, SIW, K, $CaCO_3$, Ca, alkalinity, pH, Na, Cl, Ec, Si, $SO_4$, SiA | 47 | C | |
| | | types goethermal heating | Klamath Falls | | | geo-chemistry of well | 45 | | |
| S | LLL | Hot water well study | Klamath Falls water samples from 46 wells | | summer 1974 | chemical analysis, temp. well depth, water level characteristics | 21 | C | |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| B | Pacific NW Regional Comm. | Geothermal Development feasibility study | Northeastern Oregon | | | impacts, gradient data, chemical makeup of water, flow rate | 39 | C | |
| B | | Geothermal exploration studies | Oregon 86 wells tested | | 1975 | temperature gradients monitor well data drill hole & well data | 6 | C | |
| B | BLM | Geothermal development- Final Environmental statement | Breitenbush | | Draft statement released Oct. 27, 1976 | Surface water supply, quality environmental impacts | narrative 15 appendix 16 | C | |
| B | EPA | Environmental Impact Assessment Subsurface | Klamath Falls | | Report released Nov. 1978 | pollutants & Env. effects chemical analysis water chemical characteristics wells water quality standards | 27 | C | Most comprehensive study covering Klamath Falls |
| B | EPA | Environmental Impact Assessment Baseline Data | Klamath Falls | | Report released Sept. 1978 | precipitation, temp. gradients hydrology, water chemistry, water flow & supply | 26 | C | Part of above study on Klamath Falls |
| B | DOE | Analysis of Geothermal Development | Alvord, Mt. Hood, Vale | | | development status, temp., area characteristics, lease (cont.) | 99 | C | |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | quality, wells temp. & flow | | | |
| G | BLM | Environmental Analysis Record | Vale Addition | | 1975 | Anticipated impacts, water supply & quality Environment well temp. & flow | 12 | C | Complete Environmental Analysis |
| G | BLM | Environmental Analysis Record | Alvord Desert | | 1974 | Anticipated impacts, wells temp. & flow water supply & quality, area environment | 8 | C | Complete Environmental Analysis |
| B | USGS | Geology and Groundwater Resources | Harney Basin | | Aug. 1930 - Sept. 1932 | thermal groundwater and springs, chemical composition discharge | 75 | C | |
| B | USGS | Quality of Groundwater | Columbia River Group Basalt | | | water quality-pH, temp., $SiO_2$, Fe, Mn, Al, Ca, Mg, Na, K, $HCO_3$, $CO_3$, $SO_4$, Cl, F, $NO_3$, $PO_4$, B, Hardness | 55 | C | |
| | EPA | Groundwater pollution problems | Northwest, Oregon-Grande Ronde, Burnt R., Umatilla R., Deschutes R. Basin | | 1970 | dissolved solids, Cl, $CaCO_3$, Alkalinity, Fe, Na, $SO_4$, $NO_3$, $SiO_2$, pH | 94 | C | |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| B | BLM | Environmental Analysis Record | Burns District | | Study released Feb. 1977 | Water availability, quality anticipated impacts | 10 | C | |
| B | BLM | Environmental Assessment Record | Northern Malheur Resource Area | | study released Apr. 1978 | chemical analysis of groundwater & springs precipitation, costs | 13 | C | |
| B | OSU UI | types & location geothermal resources | West U.S. | | | | 43 | C | |
| B | | Environmental issues | Oregon | | | exploration water quality noise, air pollution, electrical potential | 101 | C | |
| B | USGS | Environmental Analysis | Mt. Hood | | | chemical analysis of geothermal waters impacts on environment | 90 | C | |
| B | BLM | Environmental Assessment | Oregon Canyon | | Study released Aug. 1977 | environmental concerns & impacts | 14 | C | |
| B | | State Policies for Geothermal development | U.S. Oregon Policies included | | | | 83 | C | |
| | | Review of water quality standards | Oregon | | | Oregon standards for temp., turbidity, fecal (cont.) | 79 | | |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | information reservoir characteristics | | | |
| | USGS | Groundwater study | Baker Valley | | | chemical quality of water | 49 | C | |
| | USGS | Groundwater Resources | Klamath River Basin | | July-Dec. 1954 | geology, groundwater quality, temp., well records, aquifer characteristics groundwater characteristics | 54 | C | |
| | USGS | Groundwater data | Drewsey Resource Area Harney and Malheur counties | | 2 wells, 1928 & 1930-1979 Others 1956-1979 | chemical analysis, well data significance of chemical constituents | 35 | C | |
| | USGS | Groundwater data | Baker County-Northern Malheur County | | 1950, 1955, 1956 to 1979 | chemical analysis well data significance of chemicals | 17 | C | |
| | USGS | Groundwater Resources | Harney Valley | | Autumn 1968 Spring autumn 1969 | groundwater occurrence, recharge, discharge, quality thermal water quality, streamflow, availability for future development | 42 | C | |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| | EPA | Quality Criteria for Water | U.S. Oregon included | | | | 28 | C | |
| B | DOGAMI | Rules relating to geothermal dev. and exploration | Oregon | | | | 22 | C | |
| B | State siting task force | Nuclear and Thermal plant siting | Oregon | | | water and land use restrictions to plant siting | 66 | C | |
| B | EPA | Pollution Control Guidance | | | | pollution limitations, pollution technology summary of laws relating to geothermal pollution control | 36 | C | |
| B | LBL, USGS, DOGAMI | Geochemical study | Mt. Hood, Swim Warm Springs, Old Maid Flaits | | June 1977 - Oct. 1978 | Geochemical analysis of waters, rocks & gases, area hydrology | 102 | C | |
| | PNRBC | Hydrologic Information | Oregon | | | Water Resources | 69<br>70 | C | |
| | USGS | Surface Water Survey | Oregon | | | Overview of drainage basins | 72 | C | |
| B | USDA, FS | Environmental Study | Belnap-Foley | | | | 88 | continuing | |

TABLE VII. (Continued)

| Type of Study | Party Responsible | Descriptor-Purpose | Location, Watershed & No. of Stations | Frequency | Period of Record | Parameters Measured | Bibliographic Citation, This report | Status | Comments & Evaluations |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | coliforms, IDG, Antidegredation Policy, Toxic substances | | | |
| B | DOGAMI | Thermal Springs & Wells | Oregon | | | temp., flowrate well characteristics | 7 | C | |
| B | USGS DOGAMI | Analysis of thermal springs and wells | Oregon | | | flow rate, temp, pH, Spec. Cond, Li, Na, K, Rb, Cs, Na+k, Mg, Ca, Sr, Ba, Ca+Mg, Mn+3, Mn (TOT), Fe+3, Fe(TOT), Cu, Zn, Hg, B, $HBO_2$ Al, Pb, As, Sb, U, F, Cl, Br, I $NH_4$, $NO_3$, $PO_4$, $SiO_2$, $SO_4$, $CO_3$, $HCO_3$ | 89 | C | |
| B | J. Cooper | General Description of regions of high geothermal potential | Oregon | | | thermal reservoir characteristics, flow area uses | 18 | C | |
| B | USGS | Groundwater | Snake River Basin | | | information on irrigation wells, groundwater & water quality | | C | |
| B | | Administrative requirements | Oregon | | | Summary of state requirements for Geothermal development | 48 | C | |

The GEOTHERM information was recently used to create USGS Circular 790 Assessment of Geothermal Resources of the United States - 1978[53] which was most helpful in preparation of this report. The USGS western region's GEOTHERM file is maintained at Menlo Park by Mr. Jim Swanson (415) 323-8111. Water resource, temperature and quality information on Oregon's hydrothermal systems is currently being reviewed and updated by the USGS offices at Menlo Park.

### Lack of Information on Geothermal Waters and Recommendations for Water Resource Monitoring Associated with Geothermal Developments

There is a paucity of information relating the quality of deep (>2000 feet (0.61 km)) geothermal reservoirs in Oregon. The baseline chemical composition of surface hot springs and shallow wells of the KGRA are only indicative of what might be expected on commercially developing the geothermal resource at depth.[89]

Many states require observation wells as a permit requirement to provide baseline information on groundwater quality. Wells are needed for evaluating the geothermal resources and the groundwaters of the state; however, even shallow holes are too expensive for the developer to consider unless exploration is to lead assuredly to development of the geothermal resource. It has been related that for a 4000 foot hole in Eastern Oregon, a drill stem test would cost $30,000 (1979) and a 5000 foot well might cost $1,000,000. Such expense would be unjustified if the hole were only to be used for observational purposes on groundwater table drawdown, well interference studies, water quality analyses, and so forth, when there is no assurance to the industry that the resource can be economically developed.

Industry relates that there is no problem in going from exploration wells to development wells, as long as preliminary information is adequate to make predictions of the resource. The developer obviously seeks to find whether a geothermal reservoir will be economically viable, based on whether there exists: sufficient temperature for its intended use (for electric power production temperatures should be 150°C or greater; for space heating temperatures 50°C to 150°C are satisfactory, depending upon the particular use), sufficient volume of geothermal fluid in the reservoir to maintain production for 30 to 50 years or there must be hydrologic conditions that allow recharge of the reservoir, and the reservoir system has a natural means to accumulate fluids (e.g., via an impermeable barrier such as by faulting of geologic strata). Test holes are information producers and the data taken is held proprietary (beyond four years on submitting the information to DOGAMI) until the resource has been assessed and leases and claims filed by the developer. Thus, considerable time might elapse and expenses accumulated by industry before water resource and quality information might be released through public documents concerning possible environmental impacts. Initial flow testing only indicates the rate at which the well can be produced, not the life of the well or the ultimate reservoir capacity, nor if recharge potential exists. To determine if a reservoir has sufficient capacity to fulfill the needs of a major industrial or institutional user could require many years of production and longterm testing and monitoring.

geothermal regions, 2) ongoing or proposed projects which might offer water quality information, 3) the chances of finding adverse impacts for the regions which might limit geothermal developments, 4) suggested projects required to resolve impact concerns, 5) mitigation factors and regulation controls for limiting water impacts, and 6) the expected risks associated with geothermal development in the KGRA.

Several bibliographic searches were made through Oregon State University's Kerr Library computerized information retrieval terminal. Contacts were made with LIRS (Library Information Retrieval System), DOE Technical Information Center at Oak Ridge, Tennessee, and others. In general, it can be said that there is limited documentation on Oregon's geothermal water resources; reference to relevant information, which was found for this survey, is given in Tables VI and VII.

Table VI cites reference numbers associated with those of the test's bibliography for specific topics (including: surface water, ground water, thermal waters, water quality standards and regulations, and KGRA environmental assessment reports).

Table VII provides a summary of the various available reports (totalling 68 in number) which were found relevant for relating water resource information needed for this project. The studies are listed according to type: B - Baseline water quality (before any geothermal developments were initiated), M - Monitoring studies (including discharge and well drilling events), I - Impact Studies (e.g., condensate effects on biota), R - Resource Studies (e.g., water use studies, etc.) and S - Source Studies (e.g., condensate chemistry cooling tower drift, etc.). The tabulator also includes the location of the regional watershed considered, the responsible publishing agency, the purpose of the study, periods of record, water quality parameters measured and comments.

Such cross referencing of information would be an important extension of the Oregon Geothermal Environmental Workshop's documentation efforts.

The U.S. Geological Survey at 12201 Sunrise Valley Drive, Reston, Virginia initiated a geothermal resources computer file (GEOTHERM) in 1976.[91] The computerized file is an "attribute or properties" file containing basic descriptive and numeric data records which describe and characterize various attributes of regional geothermal resources. Through computer searches one should be able to obtain information on a particular geothermal field or area, associated information on chemical analyses of geothermal effluents and specific information on the well and drill hole including: pressure, temperature, mass flow, volume flow, enthalpy, area, volume, heat, and heat flux. It would be most helpful to gain access to such information directly as geothermal resources are being explored in Oregon but little information is presently available because of the need for maintaining the information as proprietary. Commercial developer's well and drill hole information is maintained confidential by Oregon's Department of Geology and Mineral Industries (DOGAMI) for at least four years before releasing it to other agencies or reporting sources. Accordingly, the USGS GEOTHERM computer file cannot be expected to be up to date.

Pollutant loading limitations may be based, as discussed earlier, upon effluent and emission standards when such are developed. In the interim, those limitations will be based upon calculations and judgments, by the permitting agency, as to loadings that will allow ambient air and water standards to be met. Also as discussed earlier, ambient standards may control limitations even after the development of effluent and emission standards, where the latter would allow ambient standards to be violated. Thus, ambient monitoring at receptor points will also be required, in most cases, in addition to effluent and emission monitoring.

This document suggests pollutant monitoring locations and frequencies. It does not describe actual sampling and analytical techniques. It recognizes that initial monitoring may be more cumbersome until the industry and a data base have been sufficiently developed, and until geothermal specific monitoring methodologies have been developed. EPA's Environmental Monitoring and Support Laboratory-Las Vegas is currently engaged in methodology development.

Air and Water Point Source Monitoring

Any planned waste liquid discharges or gas emissions resulting from materials used in the geothermal energy conversion process must be monitored by the operator in accordance with permit requirements. For liquid discharges, the required measurements may include volume, selected chemical constituents, suspended solids, temperature, pH, and radioactivity. Gas emission measurements will include volume and concentrations of regulated constituents such as hydrogen sulfide. Radiological analysis may be required. Any or all of the pollutants listed in Sections IV and V may require measurement.

Some planned direct discharges and emissions are likely to be intermittent, such as at wellheads, vents, and bypasses, while others may be continuous, such as at separators, mufflers, scrubbers, gas ejectors, cooling towers, and spent liquid drains. It is anticipated that, on the whole, continuous discharges, where permitted, will greatly exceed intermittent discharges in volume.

Monitoring of wastewater surface discharges and gas emissions should be conducted at each planned discharge site at a frequency commensurate with the character of discharge, e.g. less frequently for discharges of uniform character. Often, liquid effluents and gases will be combined and can be sampled simultaneously.

The frequency, duration, and method of sampling should be such that a calculated average constituent loading ± 50% will encompass the true average loading over any period of time.

In most cases, it is expected that discharges and emissions will be fairly uniform to the extent that they result from fluid consistently withdrawn from the geothermal reservoir. This would suggest that high frequency sampling is probably not demanded. The sampling frequency for continuous discharges might reasonably be monthly, with a sampling duration of 24 hours. For treated effluents and emissions, where treatment may not provide consistently predictable results, the required frequency may be weekly or more

After the exploratory and resource assessment period has passed, then some additional baseline information might ultimately be released regarding the water quality of a geothermal reservoir. Such information would be most beneficial on suggesting the water quality impacts of developing a KGRA but might be somewhat incomplete from the regulatory or environmental agency's perspective, and thus additional observational wells might be required at the development stage, rather than at the time of exploration of KGRA.

The uncertainty of availability of geothermal water, and of its possible effects on the shallower groundwater in the areas can be resolved if the spent geothermal fluid is returned to the production reservoir. Observation wells might subsequently be needed also to monitor where reinjection fronts pass, once a geothermal field is developed.

As geothermal activities in the state progress, then the forms and amounts of hot water available for electrical power and direct heating use will become more precisely known. Accordingly, the well and production sites will become identified through sales and leases. Site specific baseline surveys of the hydrology and water quality of regional (stream and ground) waters will need to be advanced prior to geothermal field development and operations in order to evaluate and control the possibility of adverse impacts following siting. These studies will need to be concerned with the transient as well as the spatial variations of the geothermal and ground water reservoir variables such as: depth, pressure, temperature, mass flow, volume flow, enthalpy, reservoir area, reservoir volume, heat flux, total stored heat, total recoverable heat, reinjection flows, geohydrologic and geochemical information. Supplying transient flow information according to the requirements for reporting to GEOTHERM, and following a systems perspective as offerred in Reference 29 on Regulatory Water Quality Monitoring, would be helpful. Such information would be needed for numerical modeling of geothermal reservoirs which would be useful in optimizing operations of power or direct heat plants. Details for surface monitoring of geothermal areas with emphasis on subsidence research is given in Reference 95. It is recommended that coordinated studies be initiated now to monitor the effects of development of Oregon's geothermal resources. Runoff from watersheds need to be gauged, stream sedimentation baseline established, ground water levels and quality monitored. This hydrologic and water quality information would serve as proper baselines for evaluating the impacts of geothermal water developments in Oregon.

Effluent and Emission Monitoring*

Monitoring as described here is primarily for the purpose of determining the quantity of pollutants discharged to the air, surface water, and ground water. As such, monitoring must include sampling and analysis for contaminants at effluent and emission points. These measurements will be required as a part of permit conditions to ensure that permitted loading limits are in fact met.

*This document derived primarily from Pollution Control Guidance for Geothermal Energy Development, EPA-600/7-78-101, pages 114-119.

## Ambient Water Monitoring

In the past, it has been common to require industries to monitor discharges, but not surface receiving water quality. The bulk of those measurements have been made by regulatory agencies. Permits may require geothermal developers to monitor ambient water quality. Even if ambient monitoring is not required, voluntary monitoring will likely be to their advantage, particularly if discharge loading limitations are based upon water quality standards. Limitations, thus developed, are intended to prevent violations of concentration limits within the receiving waters under all flow conditions.

Monitoring points should be selected to ensure, as a minimum, that the quality of surface water be monitored where it is accessible to the use of others. In many cases, this may be at the downstream point of intersection of the developer's property line and surface drainage. However, if the developer's property is leased public land, water quality and thus, monitoring stations may be maintained within the leasehold, since all but operationally unsafe areas may still be publicly accessible.

Surface water quality monitoring may be required even if there are no planned surface water discharges. One of the reasons for this is air pollutants from geothermal operations may result in atmospheric "fallout" contamination. Another is that, if surface containment is employed, leakage may occur.

Water quality monitoring should include the same constituents and properties for which effluents are monitored.

The locations, frequency, and duration of surface water ambient monitoring should be determined after consideration of several factors such as:

- size, flow, and flow variability of the receiving water body
- stream mixing characteristics
- volume of the discharge
- chemical and physical characteristics of the discharge and the consistency thereof
- waste water treatment system characteristics
- air emission characteristics
- downstream water uses
- upstream pollutional discharges
- stream ecology

Despite the apparent complexity of the monitoring selection process, the resulting monitoring scheme would be expected to be relatively simple. One extreme might be represented by a uniformly low volume, low salinity discharge into a large flowing stream. Monitoring then might be one grab sample upstream and one downstream taken monthly at points of well-mixed stream flow. The other extreme might be represented by a high volume, high salinity, relatively nonuniform discharge into a low or variably flowing often. Planned, intermittent, direct discharges, where the content and volume are not known prior to release, should be sampled whenever they occur, for a duration proportional to that for continuous discharges, perhaps 1/7 to 1/30 of the total discharge time.

All discharge permits will require that monitoring be done by the operator, that records of measurements be maintained for inspection by the regulatory agency, that loading data for all releases be submitted periodically to the regulatory agency and that standard violations be reported. The regulatory agency may sample discharges to confirm operator monitoring results and to determine permit compliance.

## Ambient Air Monitoring

An initial ambient air sampling and analysis program should be established by the geothermal operator for all geothermal energy conversion facilities which require emission monitoring. Such a program can be expected to last at least until data accumulation is sufficient to show that ambient air quality standards are not violated or adverse impacts do not occur as a result of the emissions.

Ambient air monitoring should be designed on a case-by-case basis to ensure receptor protection (or to detect standards violations) at the facility's boundary with other private or public property or even within its boundaries if the property is accessible for public use. Monitoring sites should be selected to conform with principal directions of pollutant transport by increased sampling frequencies at those points.

Ambient monitoring sites should be established on the basis of a prior continuous sampling program at all compass octants from the production facilities or the geographic center of the production field. Sites should be at distances from the source(s) sufficient to delineate pollutant dispersion characteristics and to encompass any area where concentrations above ambient may be caused by such source(s). The continuous sampling program should be of sufficient duration to include characteristic weather variations throughout the year. Sampling should be done within 5 meters (15 feet) of ground level, so that concentrations may be related to terrestrial receptor effects.

Where patterns are developed by the continuous sampling program, the same stations may be used for monitoring, with the sampling frequencies ascertained from an analysis of the concentrations vs. time distributions. The monitoring program might thus lie somewhere between the extremes of continuous sampling at all stations to no sampling at any stations. The latter would not be expected in most cases.

Any ambient air monitoring program will likely be subject to criticism, periodic reevaluation, and redesign to conform to expanded or reduced production or to natural factors not known at the time of program establishment. This may be particularly true for larger and expanding production facilities and/or those with relatively high non-condensible gas fractions in the raw geothermal fluid.

capability should exist to sample each aquifer at two or more points downgradient from principal injection wells. Existing water supply wells may be used where determined appropriate.

The frequency of ground water aquifer sampling will depend principally upon the rate of injection and the quality characteristics of the injected fluid vs. those of the aquifer. Higher injection rates of more saline brines would probably demand higher frequency sampling than lower injection rates of "Cleaner" fluids. In most cases, however, it is expected that a 30-day sampling frequency will be near the optimum. Various characteristics may demand more frequent sampling.

Simple grab samples should be sufficient for ground water monitoring.

### Land-Disposed Wastes

Land-disposed wastes requiring control by isolation are determined by chemical characterization. Monitoring of storage, treatment, and disposal sites under control of the geothermal operator will be required under State and Federal regulations to determine whether any constituents escape by leaching or percolation to surface and/or ground water. Monitoring requirements will be similar to those described above for ambient surface waters and for ground water. The most significant difference is that probably only the uppermost ground water aquifer may need to be monitored.

### Noise Monitoring

Monitoring of noise is accomplished by noise measurements at the property line or the boundary with other use areas, at points nearest the noise source. It is probable that a set monitoring schedule need not be established. Rather, measurements should be made upon a change in type or mode of operation. Measurement methodologies have been developed for many specific noise sources and can be integrated to measure overall noise at the boundary site.

A noise monitoring program should be established by the operator to assure himself that violations of local, State and Federal regulations do not occur. Because noise cannot be ignored, it may be monitored frequently by regulatory agencies.

### Baseline Air and Water Monitoring

Prior to geothermal energy production, the existing state and natural variations of air and water quality should be determined in detail by the developer in accord with the needs of regulating agencies. Baseline descriptions are in fact part of the requirement for environmental impact reports and analyses, which, in turn, are required for all projects on Federal Lands and most on state lands. Baseline assessment may require long-term, detailed measurements to establish the basis for differentiating natural and operation-caused changes.

The U.S. Department of Interior's Geothermal Environmental Advisory Panel stream already contaminated by upstream users. In this case, much more frequent monitoring might be required at several upstream and downstream stations. Several cross-sectional grab samples might be taken, flows measured, and data composited. In addition to determining constituent concentrations, effluent loadings may be confirmed.

Frequency of ambient water monitoring should be commensurate with variability in effluent characteristics and stream flow. However, it appears likely that in most cases, monthly sampling might be acceptable, because of the expected uniformity of discharge characteristics.

### Ground Water Monitoring

Spent fluid is likely to be injected in many, if not most cases to, or below the geothermal reservoir to alleviate reservoir depletion and subsidence. Injection is also likely to be the most environmentally acceptable disposal method for high salinity fluids, if performed properly.

Subsurface injection may be the disposal method of choice, even if spent fluid cannot be feasibly returned to the geothermal reservoir. This is the case in known geopressured areas, where injection would probably be to shallower aquifers with similar chemical characteristics.

Injection in any case will have the potential, as a result of unplanned or accidental system disruption, of contaminating aquifers usable for other purposes, such as drinking water. Such contamination could have the most serious consequences. If such contamination occurs, it may be difficult, if not impossible, to return the aquifer to its original condition. Careful monitoring may be the only way to ensure that significant contamination does not occur with injection.

Because of the serious nature of potential ground water contamination, the Environmental Protection Agency is currently conducting a study to design an adequate ground water monitoring methodology for geothermal operations. Many other studies of geology, hydrology, scaling and corrosion, reservoir dynamics, etc. by other agencies will have direct bearing on injection technology and, in turn, monitoring methodology. Until monitoring methodologies are fully developed, interim requirements will necessarily be imposed, based upon state-of-the-art injection technologies.

The ground water chemical characteristics of all aquifers overlying the geothermal reservoir should be monitored. The monitored constituents should include all those that would be measured if the waste water were surface-discharged, and perhaps others, if chemicals are added to promote injection.

Methods, principally electro-chemical, are being researched to monitor by injection well instrumentation, the location and extent of migration of injected fluids. Until such methods are perfected, monitoring may require sampling from wells into each aquifer. Sampling, by fluid retrieval, of multiple aquifers from one well should not be encouraged because of potential mixing. Sampling wells should surround the geothermal operation, and all should be located within a few hundred yards of reinjection wells. The these estimates are established, and a specific site selected, more accurate estimates of impacts can be made. Careful planning to avoid environmental problems, coupled with appropriate mitigation measures for limiting the severity of the impact of problems which cannot be avoided, can nearly always reduce impacts to acceptable levels and at reasonable cost.

There is need for a program of well-planned baseline measurement of water quality parameters near Oregon's hydrothermal areas, and the localities where the spent fluids will be emplaced. It is also important to find ways to identify geothermal fluids and ground waters, so that mixing of the different kinds of waters can be recognized. This can be done by establishing characteristic chemical fingerprints of all kinds of water in a region, or by use of tracer and tagging techniques in which easily detected elements are added to source waters.

To conserve and to achieve the greatest beneficial use of Oregon's geothermal resources and to protect ground water from damage that might be caused by excessive reservoir drawdown or by improper disposal of spent geothermal fluids, a program of reservoir management should be established at the beginning of reservoir development. Running records of geothermal well operations can be used to determine the rate at which the geothermal wells can be produced and to make predictions of the reservoir capacity. It takes a long time, measured in years, to determine finally whether a reservoir actually has the capacity to supply a certain quantity of water at a certain temperature, and for how long. Monitoring and engineering studies initiated at an early date will hasten such determinations. Monitoring of water chemistry over time will allow refined predictions of the quality of the disposal water; for example, if the original fluids are close to potable or irrigation water standards, the chemistry might change with time so that beneficial use of the fluid would be possible.

Many of Oregon's geothermal sites have high erosion potential and significant sedimentation problems might result from field activities associated with bringing a plant on line. Although there are concerns with sediment runoff into adjacent streams associated with clear cutting and road construction for logging, Oregonians accept the trade-offs of the impacts with industrial "progress". It is not likely that development of geothermal resources of Oregon's KGRA's would cause worse impacts than the logging industry. It is recommended that areas of highly erodible soils at specific sites be carefully mapped and that sediment loading of the streams be monitored to provide baseline information on possible impacts following operation of the geothermal development.

The limits to development for specific Oregon KGRA's tied to water resource interests include:

| | |
|---|---|
| Alvord (300 MWe) | Water may not be available in sufficient quantities for development and cooling water may have to be transported to site, economics of transmission distances need to be seriously considered. Area disturbance and erosional effects are of high concern regarding geothermal |

(GEAP) has prepared a document entitled "Guidelines for Acquiring Environmental Baseline Data on Federal Geothermal Leases."[77] The document describes procedures for gathering chemical, physical and biological data for a one-year period prior to submission of a plan for production, as required by the Geothermal Steam Act of 1970. The data are submitted to the U.S. Geological Survey Area Geothermal Supervisor, who may alter the requirements according to specific needs.

The Department of Energy, Division of Geothermal Energy has developed general requirements for describing baseline data acquisition and evaluation methodology in environmental reports on DOE-sponsored geothermal activities.[78] The U.S. Fish and Wildlife Service has prepared a handbook for gathering and assessing biological data, and for mitigating impacts.[79] Each of the sources of information should be used by the developer in setting up a baseline monitoring program.

Baseline water and air quality monitoring should be viewed as setting the stage for later ambient monitoring during full-scale operations. Thus, it should include measurements of the same constituents that will be monitored later during construction and operation of the energy conversion facility. With this view in mind, it would be expected that the operational monitoring would utilize baseline stations established earlier. This, of course, requires coordinated planning throughout development.

## IV. RECOMMENDATIONS AND CLOSURE

The primary emphasis of this report has been on the environmental effects that could result from geothermal resource development in the State of Oregon. The environmental effects considered were potential surface water pollution and degredation, changes in the groundwater regime, both chemical and hydraulic, subsidence and induced seismic events, which may in turn affect the ecology and socioeconomic conditions of a site.

It is recommended that geothermal resource and water quality information be made available to the public as early as possible during the exploratory and development stages of the geothermal activity by industry. As geothermal projects become advanced, it will be recognized there will be but a limited amount of money available for basic environmental research, and that it should be spent where it will do the most to alleviate severe impacts to water quality. The data needed from the developers will enable this money to be spent more efficiently. The research areas felt to be significant are: determining the hydrothermal reservoir characteristics and accurately projecting the potential water needs of the utility developing the site, ground water contamination, resource depletion, erosion, sedimentation and siltation, effects of transferring hydrothermal waters to other watersheds, and mass soil movements associated with subsidence.

Improved estimates of the magnitude of the resource, the type of heat-energy conversion method, and the size of industry to be served are urgently needed to provide an understanding of the potential water use of the facility. Once are sparse. It may be related that as the data base is improved, increased benefits on utilization of Oregon's geothermal resources can be achieved through a program of reservoir management. With an improved data base, careful planning can avoid some of these concerns and provide appropriate mitigation measures to reduce the severity of the adverse effects so that acceptable benefit to cost ratios can be achieved.

## V. ACKNOWLEDGEMENTS

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| | development, reinjected if used would be (med-high) concern. |
| Vale (770 MWe) | most water is already committed for irrigation, groundwater degradation of (medium) concern. |
| Mt. Hood | recreational and wilderness area, accordingly would be closed to power development; transfer of waters from region to other watersheds for utilization disposal would need to be resolved. High concern for surface and ground water, hot springs and resource degradation, reinjection if used would also be a prime concern. |
| Newberry Caldera | closed to development by State action. |
| Burns | groundwater degradation potential of medium to high concern. |
| Klamath | principal concern is heat degradation and water level degradation of the resource as currently being used; concern is for hot springs and resource degradation and the attendant effects of downhole heat exchangers and reinjection. |
| Western Cascades | principal concerns regarding hot springs and resource degradation; reinjection effects; area disturbances, erosion and landslides; and surface and ground water degradation. |
| Breitenbush | near Mt. Jefferson Wilderness and Breitenbush River; accordingly closed to power and industrial uses; transfer of waters to other watersheds for utilization and disposal need to be resolved. |
| LaGrande | hot springs and resource degradation of prime concern if geothermal developments proceed at large scale; groundwater degradation of medium high concern |
| Lakeview | water quality reinjection and contamination of resource. |
| Crump | little known about Crump Geyser hydrocycle. |
| Ore-Ida | water availability and reinjection and contamination of groundwaters of concern. |

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PRIMARY ISSUES

A tabulation of primary issues associated with regional geothermal development in Oregon is goven in Table 1 as generated in the workshop discussion sessions. Concerns (ranged as high, medium, low or chronic) included:

H hot water disposal into surface waters with resulting thermal degradation

H drawdown and degradation of ground water and hot springs

H potential negative reinjection aspects affecting intermediate ground water zones

H chemical degradation of surface water

H degradation of surface waters from construction related (roads, clearcuts, building pads, etc.) erosion and sedimentation

H land settlement, subsidence and landslides

L-M degradation of surface waters from well drilling and testing activities

L accidental releases associated with blowouts

C cooling tower plume releases of trace metals that ultimately could become bio-accumulated

C ecosystem damage

Rankings were assigned regarding the water quality concerns for seven regional sites, as well as overall concerns for the projected geothermal development within the State of Oregon.

Environmental problems associated with geothermal energy recovery include waste heat disposition, brackish water disposal, reinjection and reservoir depletion. There is associated concern with regard to casing requirements of the geothermal wells.

The disposal of thermal groundwater from wells into surface streams, and the resultant thermal pollution of the receiving waters was recognized as a problem in the southern part of the state. Both the Department of Environmental Quality and the State Water Resources Department rules and regulations discourage large scale discharges of this type. However, the existing rules do not adequately address the discharge of small amounts of thermal groundwater, (less than 5,000 gpd); these smaller discharges are primarily responsible for the existing thermal pollution problems. Programs are being considered by the state that would encourage or require the use of down-hole heat exchangers as a means of resolving this problem.

# OREGON'S GEOTHERMAL ENVIRONMENTAL OVERVIEW WORKSHOP WATER QUALITY SESSION RECORD

March 28-29, 1979
Portland, Oregon

Reporter: Larry S. Slotta


## ABSTRACT

The purpose of this section is to relate the key water quality issues related to the development of geothermal energy in the State of Oregon as discussed at the March 28-29, 1979 Oregon Geothermal Environmental Overview Workshop. This brief report lists the workshop participants' views of the current water quality data base for several potential geothermal areas in Oregon. Regional site developments for geothermal power are presently hindered for lack of a resource and an environmental data base. A format for collecting sources of available environmental data is listed for encouraging exchange of field information.


## INTRODUCTION

Water quality issues were discussed in sessions of the March 28-29, 1979 Oregon Geothermal Environmental Overview workshop. These concerns were prioritized for regional known geothermal resource areas (KGRA) under consideration for development within the state. The geothermal resource and water resource (environmental and water quality) information bases were noted to be lacking for proper assessment of geothermal potentials and impacts.

Leo Defferding, Project Manager of Battelle Pacific Northwest Laboratories, made a major presentation, in the introductory session, which altered the workshop participants to the key potential water quality issues surrounding geothermal developments. Defferding's presentation is appended.

Interactions among the natural systems that affect surface and subsurface water quality and the physical components within a typical geothermal plant are schematically shown in the systems analysis chart of Figure 1. (Figure 1 was abstracted from the Draft Proceedings of the LLL/GRIPS Geysers-Calistoga KGRA Water Quality Workshop, Jan. 1978, edited by K. Pimentel.) The issues and concerns discussed in the water quality sessions at the March 28-29, 1979 Portland geothermal workshop pivoted about the interactions noted in Figure 1 but with site specific considerations. Sites included: Klamath Falls, Ore-Ida Development and Vale in the Western Snake River Plain, Mt. Hood in the High Cascades, McCredie, Belnap, Austin Hot Springs and Breitenbush in the Western Cascades, Alvord in the Southern Basin and Range, and LaGrande. The attributes of Lakeview are considered similar to Klamath Falls and the attributes of Burns to be like those of Alvord. Figure 2 illustrates the regional KGRA (Known Geothermal Resource Areas) of Oregon.

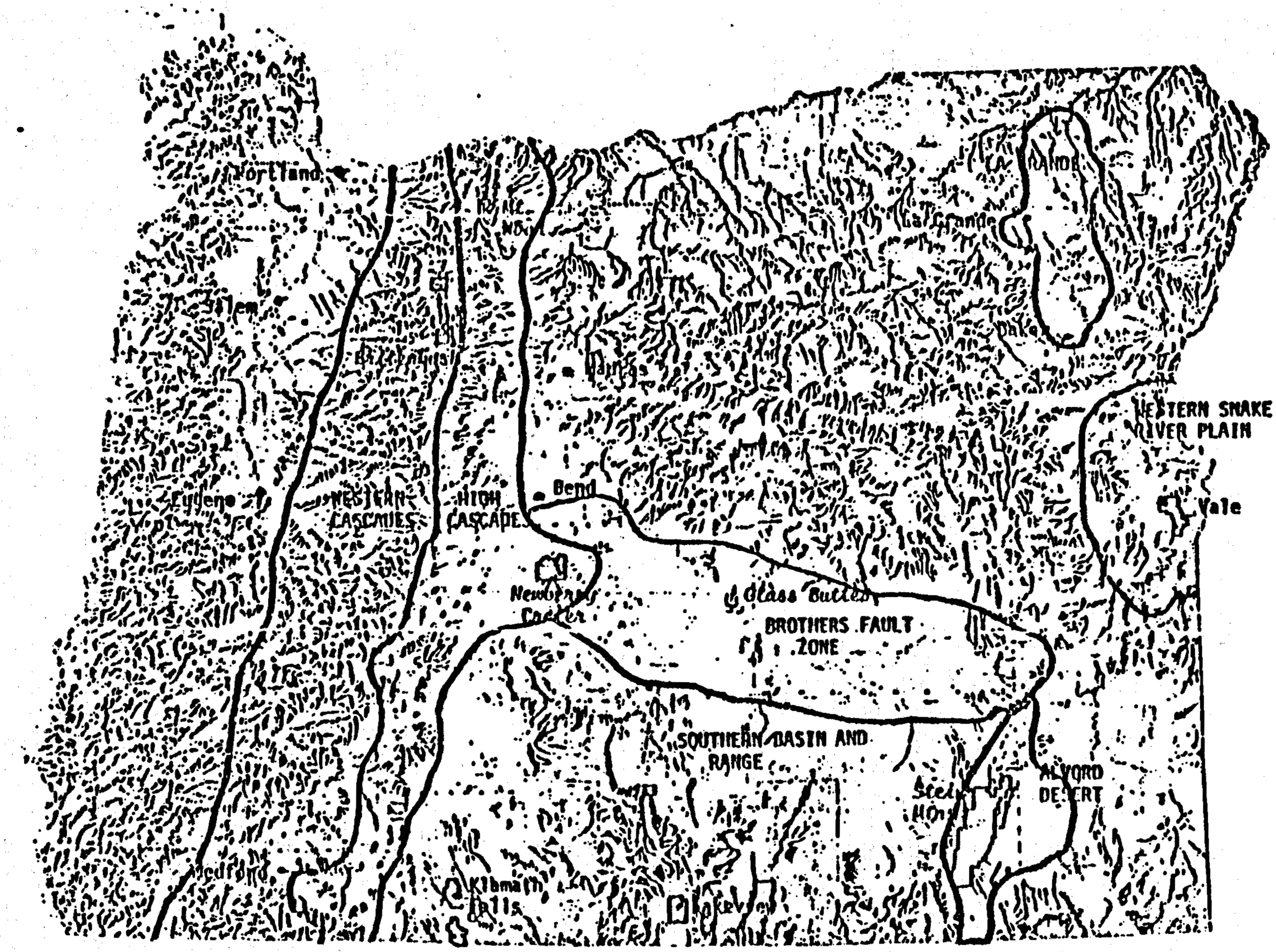
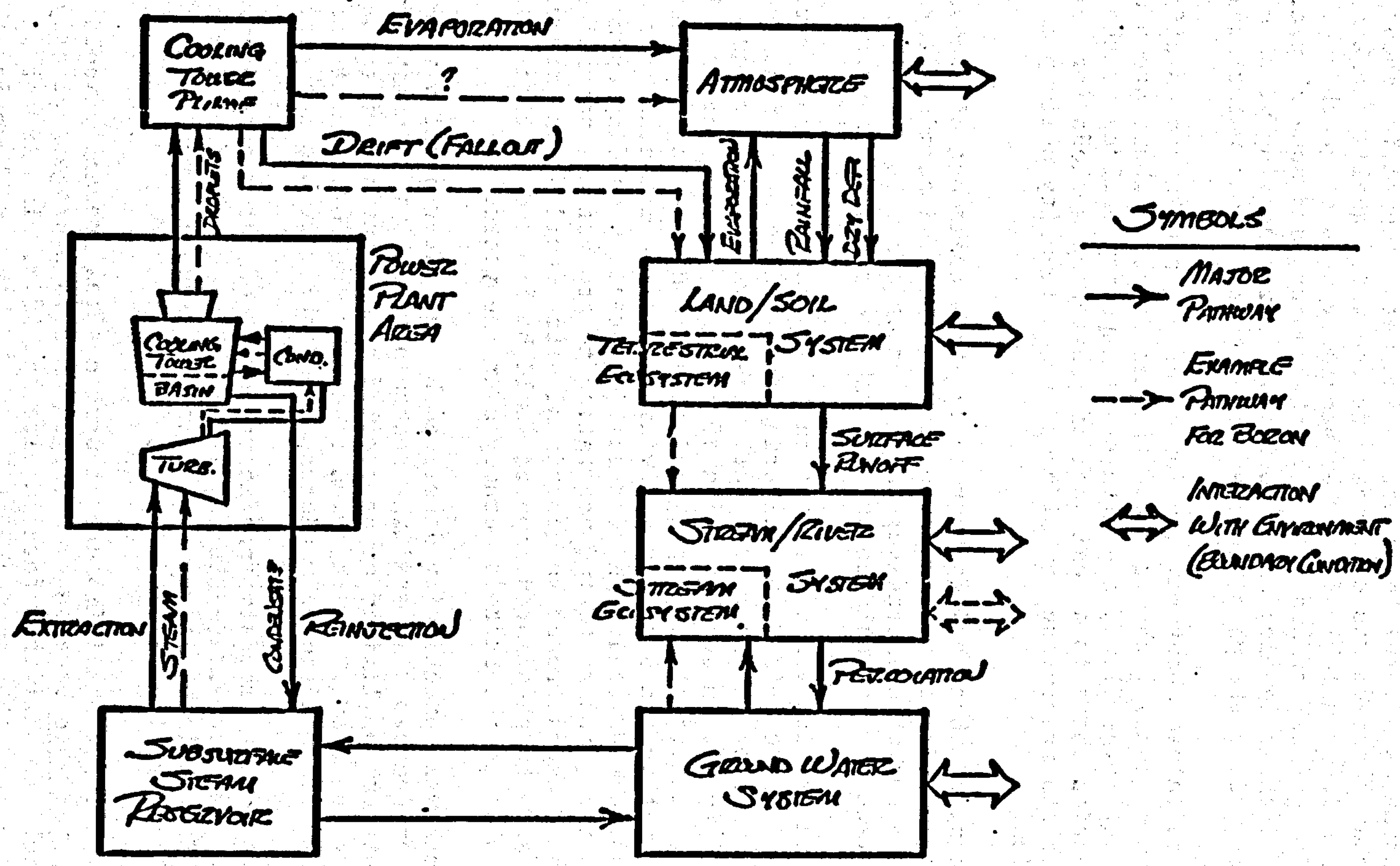



Figure 2. Known Geothermal Resource Areas (KGRA) of Oregon.

WATER QUALITY MODEL
GEOTHERMAL IMPACTS




Abstracted from LLL/GRIPS GEYSERS-CALISTOGA KGRA WATER QUALITY WORKSHOP DRAFT PROCEEDINGS, JAN 1978 K.D. Pimentel (ED.)

Figure 1. Water Quality Systems Model of Geothermal Impacts

It was recognized that secondary utilization of geothermal fluids can be accomplished through their use as irrigation water, provided they do not contain substances harmful to crops. Trace metal impurities encorporated in the discharge stream was of concern to the water quality workshop group. The opportunities available for other secondary uses of geothermal water, including drought relief and waterway enhancement, and aquaculture, were discussed and their development encouraged. Correspondingly, concern was expressed regarding the possible over development of hot water aquifers.

Concerns were raised about reinjection of excess condensate as affecting subterranean pressures, chemical and thermal fronts. There are problems with injecting large flows, and with trace impurity buildup in the aquifers. With reinjection there is a real lack of monitoring methods for determining resultant strata fracturing, subsidence, trace impurity buildup and aquifer contamination.

It was recognized that satisfactory sewage-type treatment of excess condensate bearing contaminants or high levels of dissolved solids before subsequent release would be expensive; in some cases the return of these waters to intermediate levels would be an acceptable disposal concept.

Problems with erosion and sedimentation in mountainous terrain were discussed. It was recognized that clearing and grading operations necessary for construction of access roads, well pads, power plants and/or processing plants could result in sedimentation of adjacent surface waters. It was brought out, however, that logging and forestry operations are successfully carried out within the State by applying mitigating measures, such as: soundly constructing roads and construction areas, providing open drainage on water courses, and restoring vegetation to protect the natural setting. In many cases, access roads to geothermal sites would be on improved logging roads and the associated impacts would be limited to that which has been acceptable to the State's economy over the years.

Well blowouts were practically dismissed by the water quality workshop discussion group because well drilling technology has sufficiently advanced that blowouts can be limited or controlled by responsible operators working with quality equipment. State rules regulating exploration of geothermal resources in Oregon adequately address the problem of blowout prevention.

Cooling tower drift, the atmospheric transport of water containing trace contaminants, was considered to be difficult to predict (or to ultimately measure). Nonetheless, it was considered an issue and would be listed as a potentially chronic negative impact.

In general, the potential impacts at Oregon sites presently would be constituted as variable because each Oregon site is hydrogeologically unique. Disposal problems will therefore be site specific. In view of the possible water quality and other environmental risks, there are benefits that warrant siting of geothermal demonstration projects at an early date.

DATA GAPS

The water quality discussion group next attempted to identify data gaps

# TABLE 1
## WATER QUALITY ISSUES AND CONCERNS
## OREGON GEOTHERMAL WORKSHOP 1979

| ISSUES CONCERNS | GENERAL | KLAMATH | ORE-IDA | VALE | HIGH CASCADES | WEST CASCADES | ALVORD | LA GRANDE |
|---|---|---|---|---|---|---|---|---|
| HOT WATER DISPOSAL TO SURFACE WATERS | H | H | | H | H | H | | H |
| RUNOFF | | | | | | | | |
| Surface Water Degradation by Effluent Contaminants | H | L | M depends on water quality | M | L-M | H (1) | | M |
| Drilling & Testing runoff to streams | L-M | L | L | L hot water M power | L-M | H (1) | L | M |
| Erosion and Sedimentation | H | L | L | L M | L-M | H steep slopes erosive soils | | M |
| Land slides and Subsidence | H | L | L | L M | L-M | H | | L |
| ACCIDENTAL SPILLS | L Blowout preventive techniques available to state where accidental spills will be ranked as low concern. | LL | ML-HL Possible interception of gas. Boron release on agriculture. | ML-HL | HL | HL | L | ML |
| GROUND-WATER DEGRADATION | H | M-H | M 8000' | L | M-H | M-H | M | H |
| HOTSPRINGS & RESOURCE DEGRADATION | H | H | | L | H Deep - L-M Shallow - M-H | H Deep - L-M Shallow - M-H | M | H (2) |
| REINJECTION EFFECTS | M | M-H | | L | H | H | M-H | M-L (3) |
| COOLING TOWER DRIFT | C | C | | C | C | C | C | C |

KEY: H - HIGH
M - MEDIUM
L - LOW
C - CHRONIC

Footnotes:
(1) Could be problematic due to inherent high water quality. Currently of low potential due to strict regulation.
(2) Numerous springs in area associated with fault scarps
(3) Significant water quality problems expected if hot water were to be discharged to Grande Ronde R. Down-hole heat exchangers recommended with geothermal exploitation.

TABLE II. WATER QUALITY DATA STATUS: AVAILABILITY AND REQUIREMENTS FOR ASSESSMENT OF POTENTIAL ENVIRONMENTAL IMPACTS BY GEOTHERMAL ACTIVITIES IN OREGON. (SOURCE OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW WORKSHOP, 1979).

| | GENERAL | KLAMATH | ORE-IDA | VALE | HIGH CASCADES | WEST CASCADES | ALVORD | LA GRANDE |
|---|---|---|---|---|---|---|---|---|
| AVAILABILITY OF SITE SPECIFIC WATER BASELINE INFORMATION WITHIN GEOTHERMAL REGIONS | Very limited information available. | Considerable info on surficial geology and shallow aquifer - little on geothermal res. | Little information available. | Little information available. | Eventual deep wells to 4000' Shallow wells in Breitenbush area | Surficial geology info fair-little available on groundwater. | Many gradient holes in area to 2000'. Surficial geology fair-very little pub. on groundwater. | Regional & geology groundwater reports available. |
| ACTIVE OR PROPOSED PROJECTS TO GAIN WATER QUALITY INFORMATION | Limited | District Meeting & Aquaculture projects. | Existing water quality low 100 mg/ liter TDS. Little known on ground water. Additional Ore-Ida Develop. | Chevron's well | USGS-DOE at Mt. Hood. | Minor comm. development, extensive exploration planned. | Extensive exploration planned if leases granted | City of La Grande's projects |
| CHANCE OF FINDING ADVERSE IMPACT TO TECH. DEVELOPMENT | Surface & Groundwater quality and G-W. Depletion biggest concerns. | None to date on doubling the flow on groundwater depth and temperature. Question on cross contamination of supplies Boron on agriculture. | Existing surface water of poor quality. Agriculture, boron, $H_2S$, methane. Question on water availability for make up water. | No conflict from groundwater Existing surface water of poor quality. | Wilderness limits development Sediment-slope problems, must model groundwater quality. Fish impacts. | Wilderness limits development Sediment-slope problems, must model groundwater quality. Fish impacts. | Technical capabilities demonstrated in Nevada similar to Alvord site. | No environmental problem. prevent contamination of Grande Ronde River and nice alpine lake. Economics of concern. |
| SPECIFIC PROJECTS REQUIRED TO RESOLVE TECHNOLOGY IMPACT | Field studies and exploratory wells supply proprietory information. | USGS-WRD Menlo Park. Oil hot water study being done ΔT as a function of time and concern for reservoir depletion | Evaluations of discharge waters if down hole heat exchangers aren't used. | Evaluation of site needed; | Groundwater models required and groundwater tracers recommended | Groundwater models required and groundwater tracers recommended | Evaluation of site needed. | |
| ESTIMATED MITIGATION COSTS FACTORS OR REGULATION CONTROLS | | Downhole injectors required No further dumping into lake Investigate cost & problems | Economics of heat exchangers Question on availability of ground water | None expected. | State mitigation on water quality already used by developer | State mitigation on water quality already used by developer | Aesthetics. | |
| PROGRAM DELAY RESULTING FROM ADVERSE FINDING | Existing regulations unclear standards needed | District delayed till 1981 for development. City is concerned with management. | None known | Deep well application 79 | Regulatory agencies continuous. | Regulatory agencies continuous. | Federal Delay. Application under consdieration 5 years to date resolved by courts within 1981. | Funding by DOE sharing grant |
| ENVIRONMENTAL RISK OF PROCEEDING WITH DEVELOPMENT | | High temperature ok to groundwater but not to streams. No detrimental effects to lakes to date. Common practice to use downhole heat exchangers for municipalities. (1) thermal degradation of surface water (2) depletion of quality & quantity of thermal $H_2O$. | Local concern for local wells Brackish reinjection of 2000 ppm. Boron effects on fish and agriculture from surface releases or return flows. | Remote area no obvious groundwater problems. No enough info to evaluate. | (1) Surface & groundwater quality degradation. (2) Aesthetic degradation | (1) Surface & groundwater quality degradation. (2) Aesthetic degradation | (1) Aesthetics (2) Hot Springs degradation (3) Ecostystems | Degradation of shallow aquifer & surface water quality. |

and to give recommendations for studies to lead to the practical utilization of geothermal energy. In general it was recognized that little is documented about Oregon's geothermal water resources. The forms and amounts of hot water that geothermal plants would have available for generations is not presently precisely known. Baseline surveys of the hydrology and water quality (for springs, streamflow and groundwater) of prospective geothermal fields are not available. These surveys need to be established prior to geothermal field development in order to evaluate the possibility of adverse impacts following siting. Little is known about the variation of the characteristics of Oregon's ground/geothermal waters with space or time. Continued withdrawal of geothermal fluid could reduce the amount of heated reservoir water and thereby change the temperature and chemical characteristics of nearby springs. In most geothermal areas, data on rock porosity, permeability, and storage are insufficient to assess the hydrologic nature of the reservoir. To assess impacts on water quality, data should be collected not only on standard water quality parameters but also on the local hydrologic systems and the characteristics of geothermal water that would disclose their impacts on surface and ground waters.

Table II is a tabular summary of discussions which occurred in the 1979 Oregon Geothermal Water Quality Workshop sessions regarding barriers to regional geothermal developments. The subject heading include:

Hydrology & Water Quality State of Knowledge
Chance of Finding an Adverse Impact to Technology Development
Mitigation Requirements (controls)
Period of Program Delay Resulting from an Adverse Finding
Environmental Risk of Proceeding with Technology Development

It was recommended that coordinated studies be initiated now to monitor the effects of development of Oregon's geothermal resources. Watersheds need to be monitored, stream sedimentation baselines established, and pertinent hydrologic and water quality information generated for potential geothermal sites. Presently, there are few water quality-quantity baselines for evaluating the effects of hot water development in Oregon.

It was reported that water quality information from mid-depths wells will exceed $2000 to $30,000 per water sample. Wells are drilled primarily for production and not for formation tests. It was suggested that developers be encouraged to gather and share as much hydrogeologic information as possible during exploration drilling for later environmental impact assessments.

CONSTRAINTS

The delay of geothermal development could be reduced with clarification of existing water quality, resource recovery, and discharge regulations and standards. State laws and regulations for fluid discharge cover geothermal exploration activities but are inadequate for fluid disposal from field developments. The disposal of geothermal fluids on land currently requires a Department of Environmental Quality permit. If, however, these fluids are put to a beneficial secondary use a Department of Environmental Quality

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permit may not be necessary; but a water right, issued by the State Water Resources Department, may be required.

Discussion was held on the "flexible" Oregon geothermal law in which 250°F was established as the minimum temperature for applying geothermal regulatory requirements. Presently most geothermal prospecting in Oregon has returned with water below 250°F resulting in some confusion for developers regarding regulatory restrictions. Representatives of Oregon's Department of Geology and Mineral Industries, and the State Water Resources Department both felt they could "flexibly" operate under the current rules toward progressive development of geothermal energy in the State.

Encouragement was given in the water quality session for some near term geothermal site demonstration studies within the State for proper utilization of hot water as a viable alternative energy resource.

ACKNOWLEDGMENTS

Participants of the water quality session are listed according to the following roles: R=Regulatory, D=Developer, E=Data Collector or Evaluator, and M=Modeler. Their contributions to the workshop discussions on water quality issues and concerns are gratefully acknowledged.

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SECTION D

of the

OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW STUDY*†

# ECOSYSTEMS

# RELATED TO THE DEVELOPMENT OF GEOTHERMAL

# ENERGY SOURCES IN THE STATE OF OREGON

by

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U. S. Department of Energy

TABLE OF CONTENTS

# ECOSYSTEMS

## RELATED TO THE DEVELOPMENT OF GEOTHERMAL

## ENERGY SOURCES IN THE STATE OF OREGON

## I. INTRODUCTION

The geographic areas in Oregon considered to have geothermal potential range from the Western and High Cascades to the high desert regions of eastern Oregon. They are large areas and have been only generally delineated in terms of the occurrence of geothermal resources. There has been no commercial development of the geothermal resource for electrical use in Oregon and as yet there is little certainty as to where within each area development may occur.

A recent study by Battelle Northwest identified five geothermal systems in Oregon which could begin producing electricity in the 1980's on an economically competitive basis (at >50 mwe for 30 years).[12] These systems are the Newberry Caldera (Brothers Fault Zone/High Cascades), Vale Hot Springs (Vale), Mickey Hot Springs (Alvord Valley), Borax Lake (Alvord Valley) and Crump's Hot Springs (Basin and Range Province). Of these, Newberry Caldera appears to be the best candidate for near-term development in terms of oconomics. However, Newberry Crater has been designated as unsuitable for siting of geothermal electric generating facilities by the Oregon Energy Facility Siting Council (see Section VII); according to current regulations, geothermal power plants greater than 25 mw may not be licensed in the Newberry Crater area.[39] Thus, although we can identify some sites with high resource potential, the existence of legal, economic and, in some cases, the types of environmental constraints to be discussed in this report may limit actual development. In addition, the nature of the geothermal resource in terms of generating capacity is largely unknown for large areas of Oregon; presently undiscovered resources may be the ones to be developed.

Because no geothermal development of this type has occurred in Oregon, no geothermal resource-ecosystems effects studies have been carried out which are specific to the ecosystems which may be affected in this state. Effects studies carried out at the Geysers KGRA in California do present data on certain species which occur in geothermal areas in Oregon.[29,33] However, the Geysers has no ecological counterpart in any of the Oregon geothermal areas and it can be assumed that even species common to Oregon and the Geysers are genotypically different and may react to emissions components differently. In addition, the physical and chemical characteristics of the geothermal resource in Oregon are only poorly defined; their qualitative and quantitative correspondence with Geysers emissions parameters is wholely conjectural. At this time it is not known to what extent information gained at the Geysers or elsewhere is applicable in making predictions about impacts to Oregon ecosystems.

TABLES



FIGURES

adopted administrative rule of the Oregon Energy Facility Siting Council (OAR 345-75-025(3)(c)).[38] The Energy Facility Siting Council (EFSC) has responsibility for establishing standards for the siting and regulation of geothermal electric generating facilities greater than 25 mw and geothermal pipelines greater than five miles long and six inches in diameter (ORS 469.470(3)).[47] The rule does not preclude siting merely on the basis of location of the species, but requires a determination that construction and operation will not jeopardize the continued existence of the species or destroy habitat critical to its existence.

As part of its administrative rule relating to endangered species, the EFSC has stated as policy its intention to expand the rule to include species whose existence in Oregon may be threatened, even though the species may not be threatened or endangered in other parts of its range.[38] By doing so it recognizes the value of rare species and peripheral and disjunct populations in terms of habitat diversity and stability, evolution of species, for scientific purposes and simply in terms of preservation of the state's diverse environment. A recently published report, which resulted from the Oregon Rare and Endangered Plant Project (discussed in the following part of this Section, is expected to form the basis for expansion of the rule with respect to plant species.[54]

An adequate data base is needed to assess the status of species which are suspected of being rare, endangered or threatened so that, if these species are encountered in a proposed development situation, a proper determination of whether the species' existence would be jeopardized may be made. In addition, these data may indicate, at an early stage, areas which have concentrations of such species and in which there would likely be severe constraints on siting of geothermal facilities.

A complete data base for rare and endangered species is also needed for use as a component in expansion of the state suitability/unsuitability classification for geothermal electrical generating facilities. This classification is discussed in Section VII of this report.

Available Data

The most comprehensive compilation of information on rare and endangered vascular plant species in Oregon is that of the Oregon Rare and Endangered Plant Project (c/o Jean Siddall, 535 SW Atwater Road, Lake Oswego, Oregon 97034). Participants in the project include approximately 300 professional and amateur botanists who have personal knowledge of species distributions and who have compiled information from field notes, herbarium specimens and the taxonomic literature. Information is also contributed by federal resource agencies; the BLM and Forest Service are employing increasing numbers of contractors and seasonal botanists to conduct inventories of federal lands. The Rare and Endangered Plant Project concerns itself both with species which may be endangered or threatened as biological entities (and are thus eligible for national listing) and with species which may be of interest in Oregon only, due to their rare or endemic status or because they are represented in Oregon as peripheral or disjunct populations of species which may be otherwise more widespread.

Geothermal heat cannot be effectively transported any distance and must be utilized essentially where it is found. This concentrates development impacts at the point where the resource exists and makes the nature of such impacts highly site and project specific. Since specific development sites are as yet unknown, it is not possible to know whether existing site specific inventories will be of use as baselines; care must be taken not to generalize unduly from such existing site specific data.

The ecosystems elements or attributes which are most sensitive and of most concern are:

- rare and endangered species
- unique ecosystems
- critical wildlife habitats
- agricultural and natural vegetative productivity

The potential effects to these ecosystems components include:

- habitat elimination
- habitat disturbance, including harassment
- surface water modification
- aquifer modification
- chronic, cumulative and synergistic effects, especially relating to emissions
- effects related to increased access; other effects caused by increased activity resulting from, but not necessarily specific to, geothermal development.

Other topics discussed at the OGEOS ECOSYSTEMS WORKSHOP held in Portland in March, 1979 included climate modification and its implications, noise, the relationship of physiography to potential effects and the adequacy of existing regulatory control of geothermal emission components, such as $H_2S$ and boron. A summary of the ECOSYSTEMS WORKSHOP is presented in Appendix A.

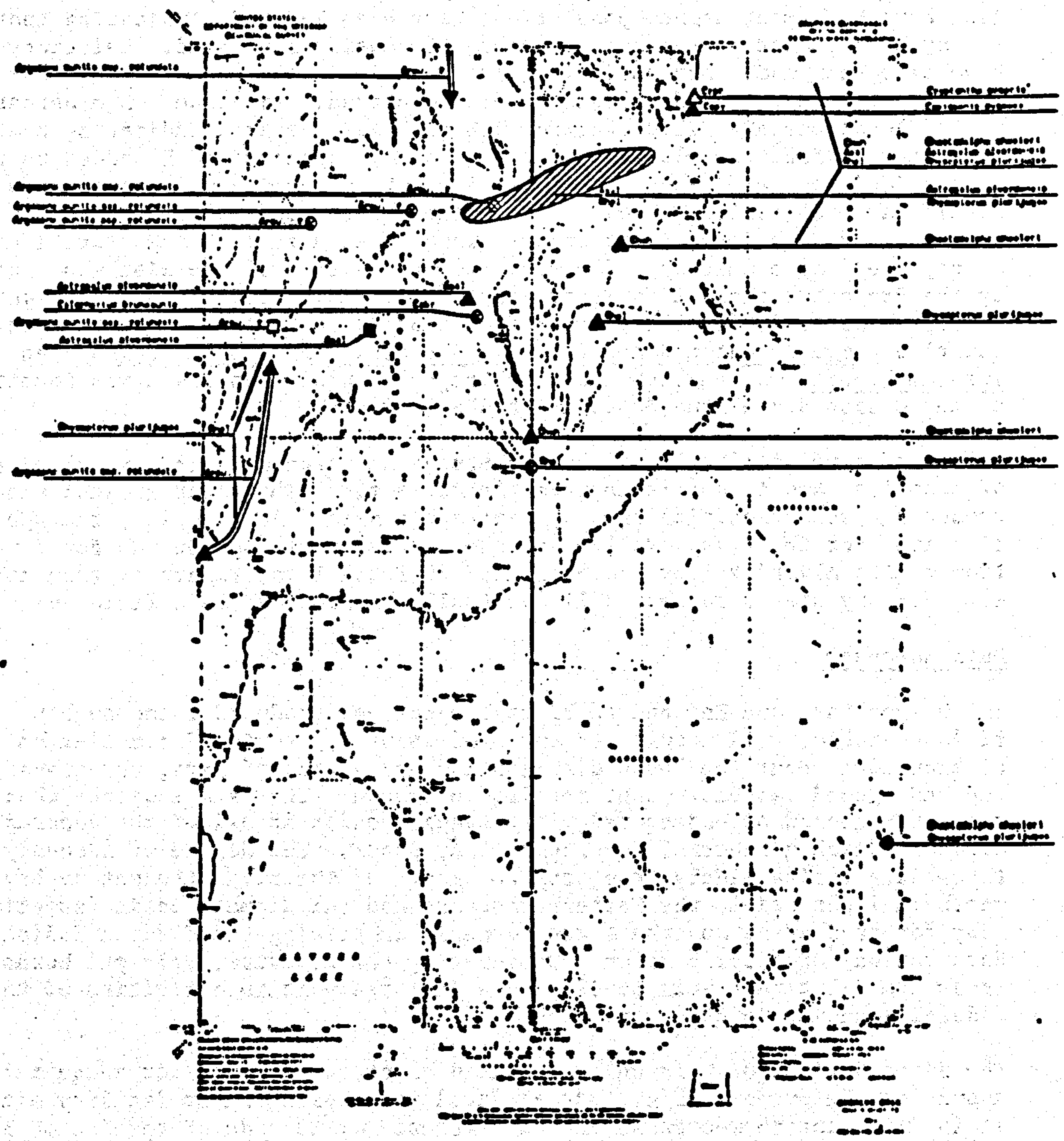
## II. RARE AND ENDANGERED PLANT SPECIES

### Issue

Endangered and threatened plant species are protected from activities which would jeopardize their future existence under the Federal Endangered Species Act of 1973 (P.L. 93-205).[11] No plant species which exist in Oregon have been officially listed under the Act at this time; however, fifty-one plant species have been formally proposed for listing as endangered and are protected, as if they were officially listed, from federal activities which would threaten their existence.[71]

This same set of species is protected in the siting process by a recently

# FIGURE 1. OREGON RARE & ENDANGERED PLANT PROJECT



## LEGEND

| Degree of Site Accuracy | Collected/Reported Before 1970 | Collected/Reported After 1970 |
|---|---|---|
| Exact site | ⊗ | ● |
| Approximate site | △ | ▲ |
| Site in general vicinity | □ | ■ |

The Plant Project has been working since 1974 with a provisional list of approximately 600 Oregon plant species.[51] Deletions of species from the list have been made as new populations have been located, indicating that the species is not as rare as previous information suggested. Deletions have also been made when sufficient evidence indicates that the species should not be considered threatened or endangered. Likewise, when herbarium record locations are field checked with negative results, indicating that there may be fewer populations than previously, species may be added to the list. Additions are also made to the list when significant threats to a species are identified. Project activities have been reviewed by the Oregon Rare and Endangered Plant Species Taskforce, a federal and state interagency steering committee. The most recent revision of the list was made by the Project technical advisory committee (mainly academic plant taxonomists) in June, 1979. The product of the determinations made in that review, entitled Rare, Threatened and Endangered Vascular Plants in Oregon---an Interim Report, was published by the Oregon Natural Area Preserves Committee to the Oregon State Land Board in October, 1979.[54]

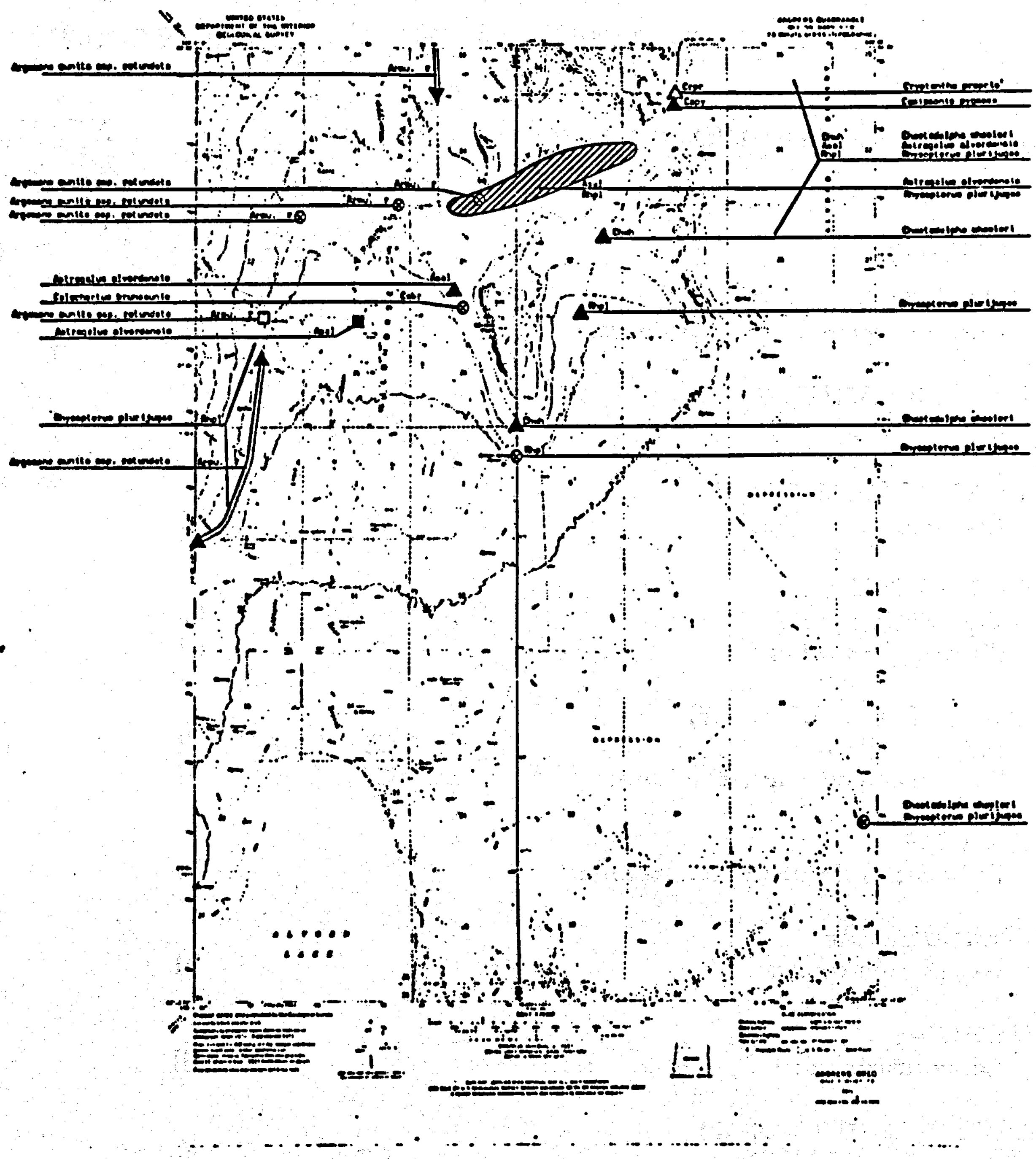
Information on species locations and status has been compiled by subunits of counties, and is available from the Project.[53] The Plant Project also produces species location maps by geographic area. As examples, the species list for the Alvord Valley and the species distribution map for a portion of the Alvord Valley are presented in Table 1 and Figure 1, respectively. Summary status reports will eventually be produced as a field guide.

## Data Adequacy

The Oregon Rare and Endangered Plant Project has produced a thoroughly field searched, well documented and professionally reviewed compilation of knowledge about the known distribution and status of rare, threatened and endangered vascular plant species in Oregon. The data indicate that rare, threatened or endangered plant species exist in all of the geographic areas in which geothermal development may occur. The degree of adequacy of these data varies widely from area to area. Of the areas thought to have geothermal potential, the Western Cascades and the Klamath Basin (especially many forested areas and the areas formerly comprising the Klamath Indian Reservation) are poorly known. Conversely, the Lakeview, Vale and Burns areas are relatively well studied, due in large part to activities of the federal agencies in those areas.[52]

The distributions of rare and endangered plant species are not adequately known for the purpose of geothermal development planning or facility siting. It is important to recognize that the absence of records of species at particular locations may mean that they have simply not been found or searched for, not necessarily that they do not exist there. In each case where specific development is proposed, site intensive inventories will need to be undertaken and impacts to species assessed. Where rare or endangered species will be affected, a determination will be made as to whether the species' continued existence would be jeopardized. Such a determination will be based in large part on the spatial and numerical relationship of the effected population to the rest of the species. The data base may be adequate for such

# FIGURE 1. OREGON RARE & ENDANGERED PLANT PROJECT



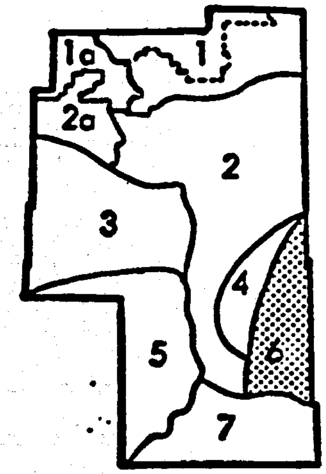
## LEGEND

| Degree of Site Accuracy | Collected/Reported Before 1970 | Collected/Reported After 1970 |
| --- | --- | --- |
| Exact site | × | ⊗ |
| Approximate site | △ | ▲ |
| Site in general vicinity | □ | ■ |
| Site in general area | | |
| Range | | |

TABLE 1. Rare, threatened or endangered plant species of the Alvord Valley, Oregon. From Report on the Rare, Threatened and Endangered Vascular Plants in Oregon, Appendix B, Siddall and Chambers, 1978.[53] List compiled by the Oregon Rare and Endangered Plant Project.

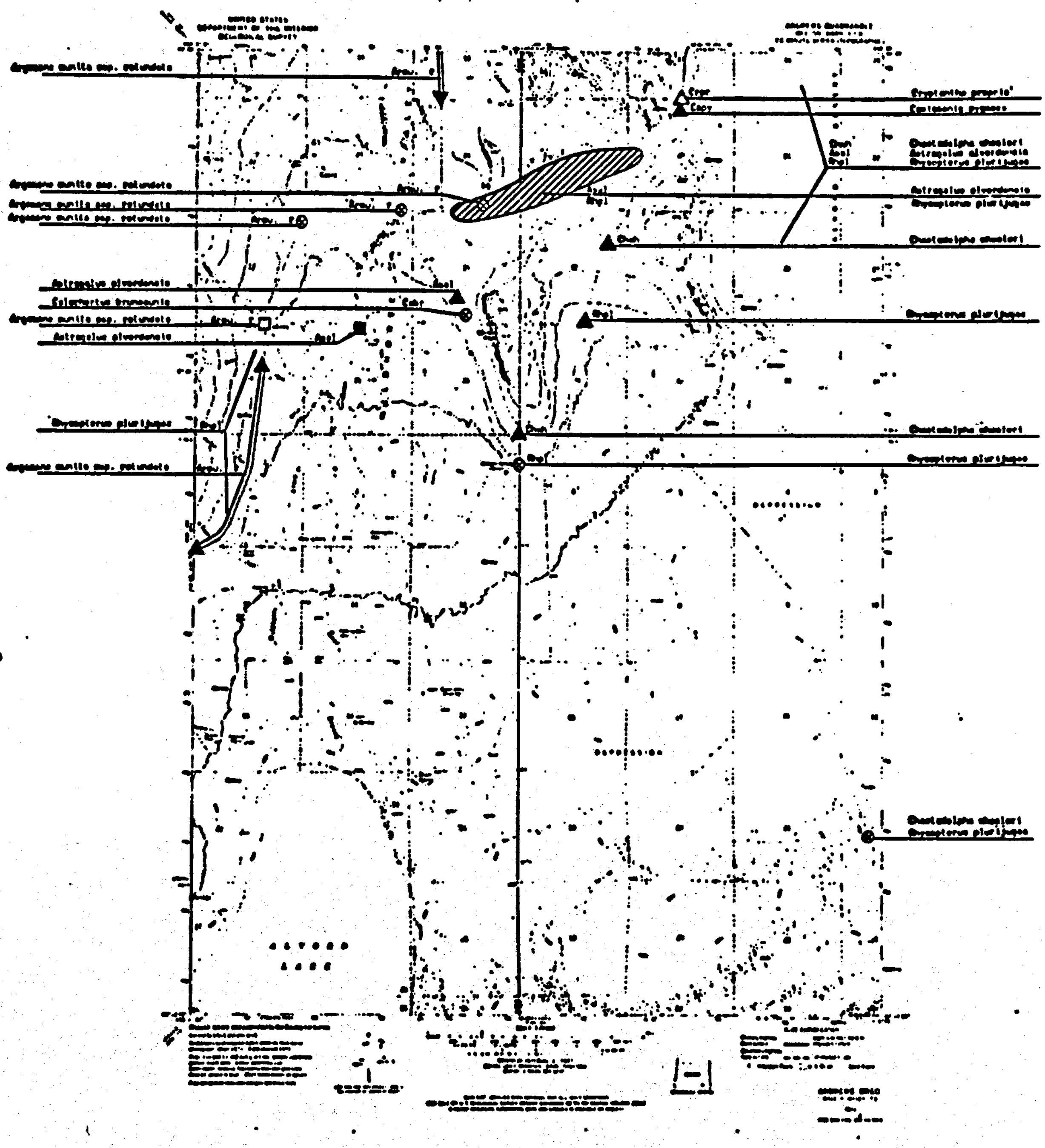
GEOGRAPHIC AREA LIST* HARNEY COUNTY

## Harney County Subunit 6 - ALVORD VALLEY




| Family/Species | Status+ S/FW | Status+ TF | Status+ OR |
|---|---|---|---|
| **ALISMATACEAE** | | | |
| Alisma gramineum var. gramineum | | | III |
| **APIACEAE (UMBELLIFERAE)** | | | |
| Rhysopterus plurijugus | CT | | Ib |
| **ASTERACEAE (COMPOSITAE)** | | | |
| Chaetadelpha wheeleri | | | III |
| **BORAGINACEAE** | | | |
| Cryptantha propria | | | Ib |
| Plagiobothrys salsus ++ | | | III |
| **BRASSICACEAE (CRUCIFERAE)** | | | |
| Draba douglasii | CT | | III |
| Rórippa calycina var. columbiae | CT | | III |
| **CACTACEAE** | | | |
| Pediocactus simpsonii var. robustior | | | III |
| **CAMPANULACEAE** | | | |
| Nemacladus rigidus | | | III |
| **CYPERACEAE** | | | |
| Carex limnophila - ? | | | III |
| **FABACEAE (LEGUMINOSAE)** | | | |
| Astragalus alvordensis | CT | | Ib |
| Lupinus biddlei | CT | | Ib |
| **HYDROPHYLLACEAE** | | | |
| Phacelia crassifolia | | | Ib |
| **LILIACEAE** | | | |
| Allium nevadense | | | III |
| Allium parvum | | | III |
| Calochortus bruneaunis | | | III |

FIGURE 1. OREGON RARE & ENDANGERED PLANT PROJECT



## LEGEND

| Degree of Site Accuracy | Collected/Reported Before 1970 | Collected/Reported After 1970 |
|---|---|---|
| Exact site | × | ● |
| Approximate site | △ | ▲ |
| Site in general vicinity | □ | ■ |
| Site in general area | —< | |

D-6

Alvord Valley - page 2 HARNEY COUNTY

| | |
|---|---|
| NYCTAGINACEAE | |
| *Mirabilis bigelovii* | III |
| ONAGRACEAE | |
| *Camissonia pygmaea* | |
| (*Oenothera boothii var. pygmaea*) | Ib |
| PAPAVERACEAE | |
| *Argemone munita ssp. rotundata* | III |

* All species listed on the "1977 Provisional List of Rare, Threatened and Endangered Plants in Oregon" are included in these Geographic Area lists.[51]

+ Status Legent

S/FW -- On Smithsonian Institution Report on Endangered Plant Species of the United States, January 1975 (published in the Federal Register, July 1, 1975) or the U.S. Fish and Wildlife Service listing of plants proposed as endangered, Federal Register, June 16, 1976-

CT -- candidate threatened, Federal Register, July 1, 1975.[55]
PE -- proposed endangered, Federal Register, June 16, 1976.[71]

TF ---- Recommended for listing as Endangered in Oregon by the Oregon Rare and Endangered Plant Species Taskforce, August, 1976.

OR ---- Distribution in Oregon

Ia = narrow endemics
Ib = regional endemics
IIa = wide range but rarely collected
IIb = widely disjunct populations
III = rare in Oregon; more abundant elsewhere
IV = unusual population

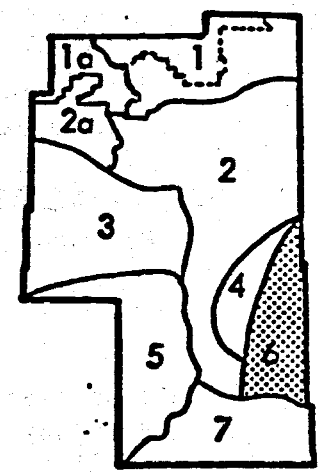
++ Species with ranges which include this subunit which therefore should occur here but for w-ich no sites are presently known.

Lists compiled by the Oregon Rare and Endangered Plant Project.

TABLE 1. Rare, threatened or endangered plant species of the Alvord Valley, Oregon. From Report on the Rare, Threatened and Endangered Vascular Plants in Oregon, Appendix B, Siddall and Chambers, 1978.[53] List compiled by the Oregon Rare and Endangered Plant Project.

GEOGRAPHIC AREA LIST* HARNEY COUNTY

Harney County Subunit 6 - ALVORD VALLEY




| Family/Species | Status+ S/FW | Status+ TF | Status+ OR |
|---|---|---|---|
| ALISMATACEAE | | | |
| Alisma gramineum var. gramineum | | | III |
| APIACEAE (UMBELLIFERAE) | | | |
| Rhysopterus plurijugus | CT | | Ib |
| ASTERACEAE (COMPOSITAE) | | | |
| Chaetadelpha wheeleri | | | III |
| BORAGINACEAE | | | |
| Cryptantha propria | | | Ib |
| Plagiobothrys salsus ++ | | | III |
| BRASSICACEAE (CRUCIFERAE) | | | |
| Draba douglasii | CT | | III |
| Rorippa calycina var. columbiae | CT | | III |
| CACTACEAE | | | |
| Pediocactus simpsonii var. robustior | | | III |
| CAMPANULACEAE | | | |
| Nemacladus rigidus | | | III |
| CYPERACEAE | | | |
| Carex limnophila - ? | | | III |
| FABACEAE (LEGUMINOSAE) | | | |
| Astragalus alvordensis | CT | | Ib |
| Lupinus biddlei | CT | | Ib |
| HYDROPHYLLACEAE | | | |
| Phacelia crassifolia | | | Ib |
| LILIACEAE | | | |
| Allium nevadense | | | III |
| Allium parvum | | | III |
| Calochortus bruneaunis | | | III |

and Wildlife as threatened or endangered in Oregon.[41] This is an unofficial list, which has not been codified as an administrative rule. Six federally protected species are included on the list; one federally protected species (the grey wolf) is not included, as it is believed to no longer exist in Oregon.[23,42] The only protection for the remainder of the species listed by ODFW is provided by their inclusion in a longer list of non-game species protected from "taking" by an Oregon administrative rule (OAR 635-07-360); no specific provision against habitat destruction is provided in the rule.[40]

At this time, animal species which may be threatened or endangered only in Oregon have not been included in the EFSC siting standard. However, the ODFW has submitted a list of "species of special concern" to the EFSC, which has indicated its intention to include such species in its siting standard relating to endangered species.[42,38]

Since both federal and state laws protect certain endangered or threatened species, an adequate data base is necessary to make proper status determinations in the siting process. In addition, since the lists of protected species are likely to expand, it is imperative that special attention be given to species whose status indicates that they are likely candidates for such listing; this should include the "species of special concern" denoted by the Oregon Department of Fish and Wildlife.

Available Data

The twelve species identified by the ODFW as threatened or endangered in Oregon and the eight species listed or proposed for listing by the U. S. Fish and Wildlife Service are listed in Table 2.[41,4] In addition, five fish species which have been proposed for inclusion in the ODFW list are shown.[32] Their present status is indicated and the geothermal regions known or suspected to include portions of these species' ranges are identified.[1,31,37,57]

Comprehensive review of distributions and status of rare and endangered vertebrate animal species have been presented in a series of publications of the Oregon State University Agricultural Experiment Station (Endangered Plants and Animals of Oregon: I. Fishes (Bond, 1974);[1] II. Amphibians and Reptiles (Storm, 1966);[57] III. Birds (Marshall, 1969);[31] IV. Mammals (Olterman and Verts, 1972).[37]) The lists of species considered rare or endangered in Oregon by these authors differ from the federal and ODFW lists, in that they are more inclusive, and in some cases, differ as to status designations. All state and federally listed vertebrate species are included. The Oregon State University publications include literature reviews, records of museum specimens, and comments from practicing professional and amateur zoologists as to the current distribution and status of the species.

Since the publication of these reviews there has been a scattered literature on rare and endangered animal species. Of interest here are those publications which deal with distributions and ecology of species known or suspected to occur in Oregon geothermal areas,[14,17,21,25,74] those which a determination for certain species, but in most cases additional field surveys would be required.

The existing data base appears to be sufficient to delineate geographic areas in which constraints on geothermal siting are likely due to concentrations of rare or endangered plant species. Such an evaluation has not been undertaken and is beyond the scope of this overview.

Recommendations

Expansion of the existing data base for rare and endangered plant species is needed to facilitate geothermal siting decisions once specific development is proposed. Both ecological and distributional information will be required, so that impacts may be properly assessed and so that the relationship of effected populations to the viability of the species may be determined.

Since the existing data base has been compiled and presented in various ways, future efforts should emphasize field surveys. Field inventories should be conducted:

- in those geothermal areas most likely to be developed or where development is considered most imminent
- by species known to exist within the geothermal areas; this will include field surveys of habitats where the species is expected to occur, throughout its total range.

Of critical importance is that data acquired in these inventories be entered into the Oregon Rare and Endangered Plant Project data base, so that species composition of particular areas may be readily assessed, and so that distributions and status of species may be reviewed in a comprehensive manner.

## III. RARE AND ENDANGERED ANIMAL SPECIES

Issue

Endangered and threatened animal species are protected from activities which would jeopardize their future existence under the federal Endangered Species Act of 1973 (P.L. 93-205).[11] Species designated by the U.S. Fish and Wildlife Service as endangered or threatened are noticed in the Federal Register and, subsequently, included in the species lists in 50 CFR Part 17. To date seven animal species which occur or may occur in Oregon have been listed under the Act and one specie has been formally proposed for listing.[4,72] These species are also protected in the siting process by the administrative rules of the Oregon Energy Facility Siting Council (OAR 345-75-025(3)(c)).[38] (Discussion of EFSC jurisdiction, its siting standard relating to endangered and threatened species, and anticipated expansion of that rule to include species of interest in Oregon only is included in Section II of this report. These subjects apply equally to animal species.)

Twelve animal species have been classified by the Oregon Department of Fish present species lists for particular geothermal areas,[18,26] and those which review the current status of rare or endangered species.[19,20,77]

A series of recent environmental documents produced by several federal agencies list rare or endangered species known to or expected to occur in the areas under consideration here.[62-70] The distributions are summarized in Table 3. Only those species listed or proposed for listing at the state or federal level have been included.

Of particular interest in this discussion are species of hot springs, as these are habitats most likely to be associated with geothermal development. Two rare fish species are known to occur in hot springs and lakes in the Alvord Valley: the Alvord Chub (Gila alvordensis)[1] and the Borax Lake Chub (Gila sp. -- to be described). The latter is endemic to Borax Lake and has only recently been recognized as distinct from the former. It is the subject of a doctoral thesis by Jack Williams at Oregon State University.[75]

Data Adequacy

Rare and endangered vertebrate animal species are known or thought to occur in all geographic areas in which geothermal development is being postulated, except the LaGrande region. Species classified as endangered or threatened fall into several categories and the adequacy of data varies among the categories.

1) Species which are genuinely rare or are rarely observed. For example, as of 1977, the Oregon Department of Fish and Wildlife reported that the kit fox, a species of the high desert valleys of Malheur, Harney and Klamath counties, had been sighted or taken only six times since 1968.[41] The wolverine, a species of remote high elevations in the Cascade, Blue and Steen Mountains, had been reported 25 times since 1965.[41] Other species known or suspected to occur in Oregon geothermal areas which fall into this category are the western spotted frog and the peregrine falcon.

Little is known of the specific locations of these species or of their habitat requirements. Data are certainly not adequate for planning geothermal development activities (in relation to these species) in areas where they are thought to exist. Site intensive inventories will be required once development is proposed, with further studies of habitat and behavioral requirements if these species are encountered.

2) Species which may be rather generally distributed, but are threatened by generally distributed habitat destruction. The bald eagle and the northern spotted owl are species which are dependent on mature forests. Despite federal land management policies to preserve known nest sites and snags, as these mature forests are harvested, potential habitats for these species decrease. Other widely distributed forms of disturbance, such as pesticides, powerlines and increased human contact, further affect the success of these species.

Locations of these species are fairly well known; the ODFW reported 145 bald eagle nest sites (61 active) for the 1974 breeding season

TABLE 2. Animal species listed or proposed for listing as threatened or endangered by the U.S. Fish and Wildlife Service or by the Oregon Department of Fish and Wildlife.[4,41]

| Species | Federal Status[4] | State Status[41] | Geothermal region known or suspected to include species' range[1,31,37,57] |
|---|---|---|---|
| Sea otter | | T | ----- |
| Wolverine | | T | High Cascades; Blues; Steens |
| Kit fox | | T | Klamath, Malheur, Harney Cos. |
| Columbian white-tailed deer | E | E | ----- |
| Grey wolf | E | * | ----- |
| Western spotted frog | | T | High Cascades; E. Oregon |
| California brown pelican | E | E | Klamath Falls area? |
| Aleutian Canada goose | E | E | ----- |
| American peregrine falcon | E | E | Malheur NWR; Lake, Deschutes Cos. |
| Arctic peregrine falcon | E | E | ? |
| Northern bald eagle | E | T | generally distributed; Deschutes, Klamath Cos.; Harney Lake |
| Northern spotted owl | | T | Western Cascades |
| Western snowy plover | | T | Lake, Harney Cos. |
| Warner sucker | | P | Warner Valley, Lake Co. |
| Alvord chub | | P | Alvord Valley, Harney Co. |
| Borax Lake chub | | P | Borax Lake, Harney Co. |
| Oregon tui chub | | P | Hutton Spring, Lake Co. |
| Foskett Spring dace | | P | Foskett Spring, Lake Co. |
| Oregon silverspot butterfly | P | | ----- |

-----------------

E -- listed as endangered
T -- listed as threatened
P -- proposed for listing
* -- according to the Oregon Department of Fish and Wildlife, the grey wolf is believed to no longer exist in Oregon.[23,42]

and 103 widely scattered pairs of spotted owls which had been recorded by Eric Forsman.[41] This information suggests specific areas likely to support these species.

Habitat requirements are well known for these species and some general things are known about their behavior in relation to human activity. This information is adequate for initial planning in those instances where specific locations are known. Recent experience gained by land management agencies in preserving and buffering habitats of these species should be directly applicable to geothermal planning and development.

3) Species which are endemic to particular areas and which may have always been rare. The Alvord Chub, Borax Lake Chub, Warner Sucker, Fosket Spring Dace and the Oregon Tui Chub are fish species, each endemic to one or to a few springs or lakes in Lake County or the Alvord Valley.[1,42] Each would be threatened in the event that its specific habitat was modified in some deleterious manner. Similarly, the eastern Oregon populations of the western snowy plover are highly dependent on Summer Lake and Harney Lake for breeding.[31]

Locations of these species are well known. The small numbers of populations indicate that the areas inhabited by these species should not be disturbed until thorough investigations of habitat requirements have been conducted and determinations have been made that activities relating to geothermal activities will not jeopardize the species. Because of the small numbers of individuals and populations involved and the extreme physiological adaptations of the hot springs species, it may be that no alteration of the physical and chemical parameters of these habitats will be possible.

Of importance with vertebrate animals is each species' behavioral tolerance to human intrusion and to specific aspects of development. Although some information is available for certain species, information on what types of disturbance affect particular species and what distances constitute adequate buffer zones is not complete. The subject is treated in Section V, Critical Wildlife Habitats.

Recommendations

Distribution maps of known occurrences and sightings should be prepared for the geothermal regions, in a manner similar to those being prepared by the Oregon Rare and Endangered Plant Project. These maps should indicate which locations are current and which are from old (not recently verified) records. To the extent possible, current distributions of rare and endangered species should be determined. For most species, this activity will probably have to suffice until specific development sites are proposed. As with all other ecosystems aspects, once specific development is proposed, the existing data base should be expanded for the particular area. Field surveys should be conducted to discover previously unreported rare and endangered species, to supplement existing information on species distributions, and to assess impacts to rare, threatened and endangered species.

Investigation of the habitat requirements of rare and endangered hot springs species, whose locations are known, should begin immediately. This is of critical importance for the Alvord Chub and the Borax Lake Chub, as the springs which they inhabit have already been identified as being likely candidates for geothermal electrical production.[12]

The existing data base on the extent of buffer zone necessary to protect the existence of rare or endangered species should be expanded where possible. Studies should be conducted concomitant with any new developments within the geothermal regions, as discussed in Section V.

The status of species which have been identified as species of concern in Oregon (as in the Oregon State University publications and the list of "species of special concern" transmitted to the EFSC by the ODFW),[42,1,31,27,57] but which have not been designated as protected species by state or federal agencies, should be assessed. Where appropriate, these species should be listed for protection. Although an area of investigation which is not specific to geothermal development planning, its accomplishment would preclude questions concerning the status of these species once geothermal (or other) development commences.

## IV. UNIQUE ECOSYSTEMS

### Issue

Certain ecosystems represent associations of organisms which have adapted to unusual environmental situations. Hot springs ecosystems are of particular concern because they may be especially vulnerable to the kinds of disturbance associated with geothermal development. Hot springs may be adversely affected or destroyed by the lowering of groundwater levels in the vicinity of a geothermal field, if the geothermal and hot springs reservoirs are connected, or simply by mechanical damage of the spring during exploration or development.

The waters of hot springs represent the limits of biological adaptation to temperature extremes and to various chemical substances. Hot springs are extremely diverse chemically and serve as reservoirs of metabolically unusual or unique microorganisms. A knowledge of these organisms and their adaptations is significant to the understanding of many basic scientific and applied technical problems.

Other habitats of concern are those which serve as outstanding examples of more or less common ecosystems. In addition to maintaining natural diversity, such areas, if preserved, serve as metersticks against which to measure similar habitats which are being changed by human activities.

An adequate data base is needed to insure that biologically unique ecosystems and representative samples of other natural ecosystems may be protected and preserved.

### Available Data

A map of thermal springs and wells in Oregon has been compiled by Bowen and Peterson.[2] Hot springs of particular biological interest in Oregon have been identified by Dr. R. W. Castenholz, an authority on hot springs' organisms.[3] These springs are listed in Appendix B. Fish species endemic to Oregon hot springs have been discussed in Section III. Data is available on the chemical composition and thermal characteristics of Oregon hot springs.[30,43] Data on the hydrological relationships between geothermal resources and specific hot springs is largely lacking.

Efforts to inventory significant natural ecosystems and to preserve examples have been made on federal, state and private levels. The Pacific Northwest Research Natural Area Committee of the U.S. Forest Service conducts intensive natural area studies and recommends designation of Research Natural Areas on federal lands.[16] The State Natural Area Preserves Advisory Committee recommends state-owned lands which should be preserved as State Natural Area Preserves. It has conducted a preliminary inventory of all state lands to determine potential preserve candidates. It also registers other lands which have natural area characteristics.[36]

A conference involving federal and state natural resource agencies, representatives of the academic community and the Nature Conservancy in 1973 resulted in publication of Research Natural Area Needs in the Pacific Northwest.[9] This publication identifies ecosystems within each of the state's geographic provinces which need to be represented by preserved natural areas and ranks them as to priority for attention. Possible locations of representative examples of ecosystems were identified, either as specific locations or as general geographic areas in which the ecosystem was known to occur.

The Oregon Natural Heritage Program of the Nature Conservancy identifies outstanding natural areas through a statewide inventory of natural communities, species and features. The Heritage Program consolidates information about federal, state and private lands and provides a statewide comprehensive overview of natural heritage resources.

Heritage Program data are collected as element occurrence data on plant communities, aquatic types, special plant and animal species and outstanding natural features. The data system includes: a map file containing element occurrence data recorded on 7.5' U.S.G.S. topographic maps; a geographic manual with detailed information on each mapped occurrence; and a computerized file containing abstracted information on each occurrence. In addition, there is a manual file with all non-locational information on each element, such as species' life history data, etc.[58] Natural areas data summaries for western and eastern Oregon were published in 1977 and 1978, respectively.[45,44]

The Heritage Program inventory has been transferred to and will be maintained in the future by the Oregon Department of State Lands.

## Data Adequacy

Biological inventory data for most hot springs within the geothermal areas is inadequate for the purposes of geothermal development planning. While significant research into the physiological and ecological requirements of many thermophilic organisms has been carried out, Oregon hot springs have not been systematically characterized. And, although Castenholz has indicated hot springs which he considers of particular biological interest, we do not know that all ecologically significant hot springs have been identified.

Determinations of hydrological connections between geothermal resources and specific hot springs have not been made. Thus, the potential for hot springs reservoir drawdown due to geothermal development is not known for specific cases and predictions of the type and magnitude of impacts to hot springs ecosystems cannot be made.

Data are not adequate for understanding the hot springs ecosystems, for predicting potential effects on them, or for making reasoned decisions as to whether particular springs need protection from geothermal development or can be allowed to be modified to some extent.

Data relating to potential natural areas in Oregon is substantively adequate for the purpose for which it is gathered. The inventories have not been completed, however, and representative examples have not been designated for protection. For the purposes of planning geothermal activities, which would not conflict with significant examples of ecosystems which might someday be chosen for preservation, these data are incomplete.

The status of most geothermal areas, with respect to containing unique ecosystems or best examples of ecosystems, is currently unknown.

Recommendations

Biological and physical/chemical inventories should be conducted of hot springs which are in areas expected to support geothermal development. Initial emphasis should be placed upon those springs which have been indicated as being of particular biological interest and any others in areas where development is considered most imminent. Investigation of these hot springs is a high priority as they are ecosystems which will be most faithfully associated with geothermal activity and, thus, most likely to be affected. Similar recommendations have been made by Castenholz and by the Geothermal Task Force of the Natural Area Preserves Advisory Committee to the State Land Board.[3,35]

The physical relationship of hot springs aquifers to those likely to be exploited for geothermal fluids should be investigated. This can be done by water monitoring programs which obtain flow rates and temperatures of springs and wells over time, and which sample the waters for analysis of selected elements. From these data hot spring and geothermal waters may be characterized and hydrological relationships assessed.

The state data base on ecosystems should be expanded and analyzed to the point of identifying examples of all significant ecosystems for each geographic province. This should be done in a timely manner, even though it may not be possible to provide for actual acquisition or preservation of the sites at the time. Such identification may allow development to avoid these areas and also could provide the basis for inclusion of the areas in the geothermal site unsuitability classification discussed in Section VII.

## V. CRITICAL WILDLIFE HABITATS

### Issue

Certain habitats are critical to the existence of particular wildlife populations. Such habitats may be of importance in a single portion of a species' life cycle as, for example, breeding, nesting or fawning, wintering or migration. They may be as small as single trees or snags for cavity nesting birds or may encompass very large areas as, for example, migratory routes. Certain habitats may be critical to single wildlife species, while others, such as wetlands, may be important to a large variety of species.

For geothermal development to occur in a manner least deleterious to existing wildlife populations, it is necessary to know the distributions of wildlife species and of habitats critical to each, so that direct habitat loss may be minimized. It will also be necessary to know enough about the behavior of individual species that their response to the activities associated with geothermal development can be predicted and taken into account in the siting and operation of geothermal facilities.

### Available Data

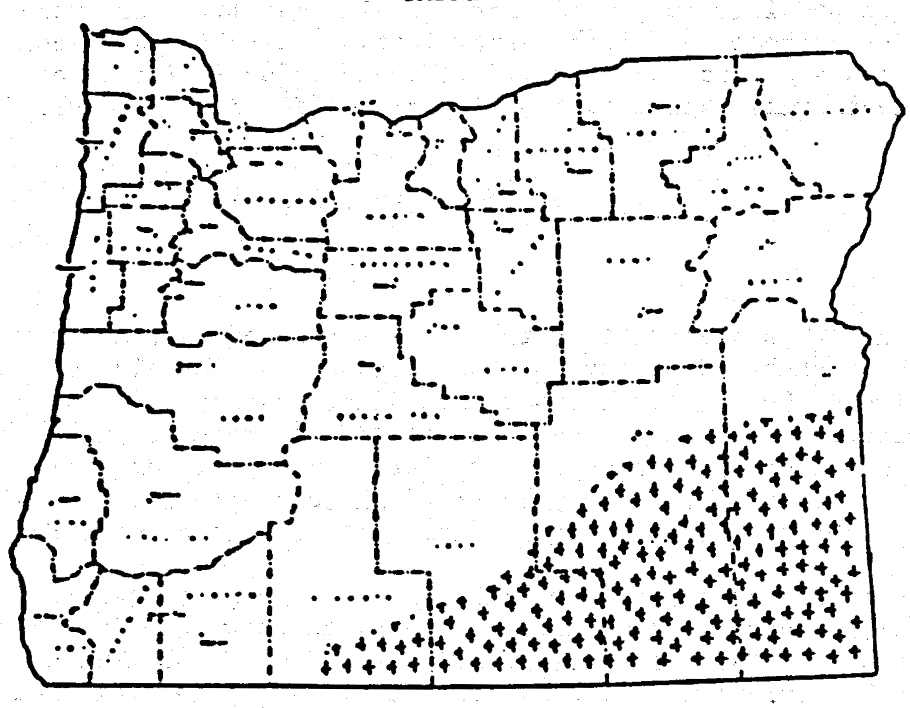
The Oregon Department of Fish and Wildlife has identified "habitats of special concern" in Oregon in a transmittal to the Oregon Energy Facility Siting Council (November 16, 1979), relating to wildlife protection.[42] It defines habitats of special concern as "areas where animals concentrate seasonally for purposes of reproduction, wintering, feeding and rearing of young; or, unique habitats limited in scope, often conspicuously different from surrounding vegetation and topography, and essential to maintaining species diversity and abundance." The list of habitats of special concern, species using the habitats and potential conflicts with each habitat type is reproduced here as Table 4. As noted in the letter of transmittal, the list can be used to identify wildlife values inherent in potential energy development sites.

Those conflicts denoted which are most likely to result from geothermal development are:

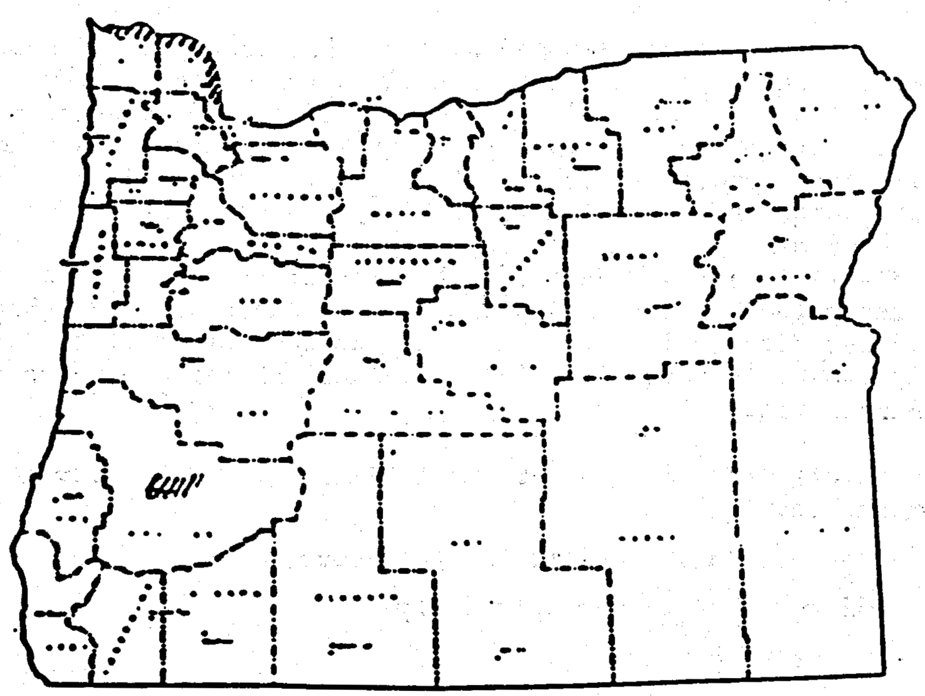
- conversion of habitat to other uses
- disturbance by human activity
- water withdrawal
- pollution

With respect to the discussion of hot springs and unique habitats in the previous section, it should be noted that alkaline lakes, landlocked springs

TABLE 4



KIT FOX



COLUMBIAN WHITE-TAILED DEER

and basins, mineral springs and water sources in arid lands are included in the list of habitats of special concern.

Habitats critical for certain wildlife species are known to occur in each of the broad geographic areas being considered for geothermal development. The physical extent of the critical habitats varies among the areas; in addition, the significance of habitats in terms of a particular species' or set of species' well-being varies.

The Environmental Assessment Reports and Environmental Impact Statements which deal with the potential geothermal areas list, and in some cases map, the distributions of critical wildlife habitats known to occur in each region.[62-70] Emphasis is on big game species and waterfowl; in some cases limited information on upland game birds and raptors is included. Habitats mentioned in these reports as being significant are indicated by area in Table 5.

Figure 2 indicates major waterfowl flyways in the Pacific Northwest. They encompass at least parts of the Vale, Basin and Range and Brothers Fault Zone areas.[28] The Vale area is indicated as a major wintering area, due in part to large food supplies produced by intensive agriculture in the area. The saline lakes of south central and southeastern Oregon, especially Summer, Harney and Malheur Lakes, provide extremely productive wintering and breeding habitats. The Klamath Basin, while not a major wintering area, is a significant resting area for a high percentage of waterfowl in the Pacific Flyway.[22,28]

Harney and Malheur Lakes are within the Malheur National Wildlife Refuge and are, thus, protected by the administrative rules of the Oregon Energy Facility Siting Council, which designate areas "unsuitable" for geothermal electrical development (see Section VII).[39,46] Because of its management as a wildlife refuge and because of the location there of the Malheur Environmental Field Station, this area has been well studied. Much of the data acquired there may be applicable to non-protected areas proximal to the refuge.[13,26,27]

Additional information on critical wildlife habitats resides with the Oregon Department of Fish and Wildlife and the U. S. Fish and Wildlife Service, the agencies responsible for management of wildlife populations. Certain of these data have been published,[5,10,61] but a great deal of information is not readily accessible. The majority of the published data concerns big game species.

There is a scattered literature on critical habitats of non-game species, a large part of which deals with the distributions and habitat requirements of the northern spotted owl, osprey and other raptors.[7,8,14,19,20,25,50,59]

In addition, the Oregon Natural Heritage Program Inventory includes site data for critical habitats of rare or endangered animal species.[44,45]

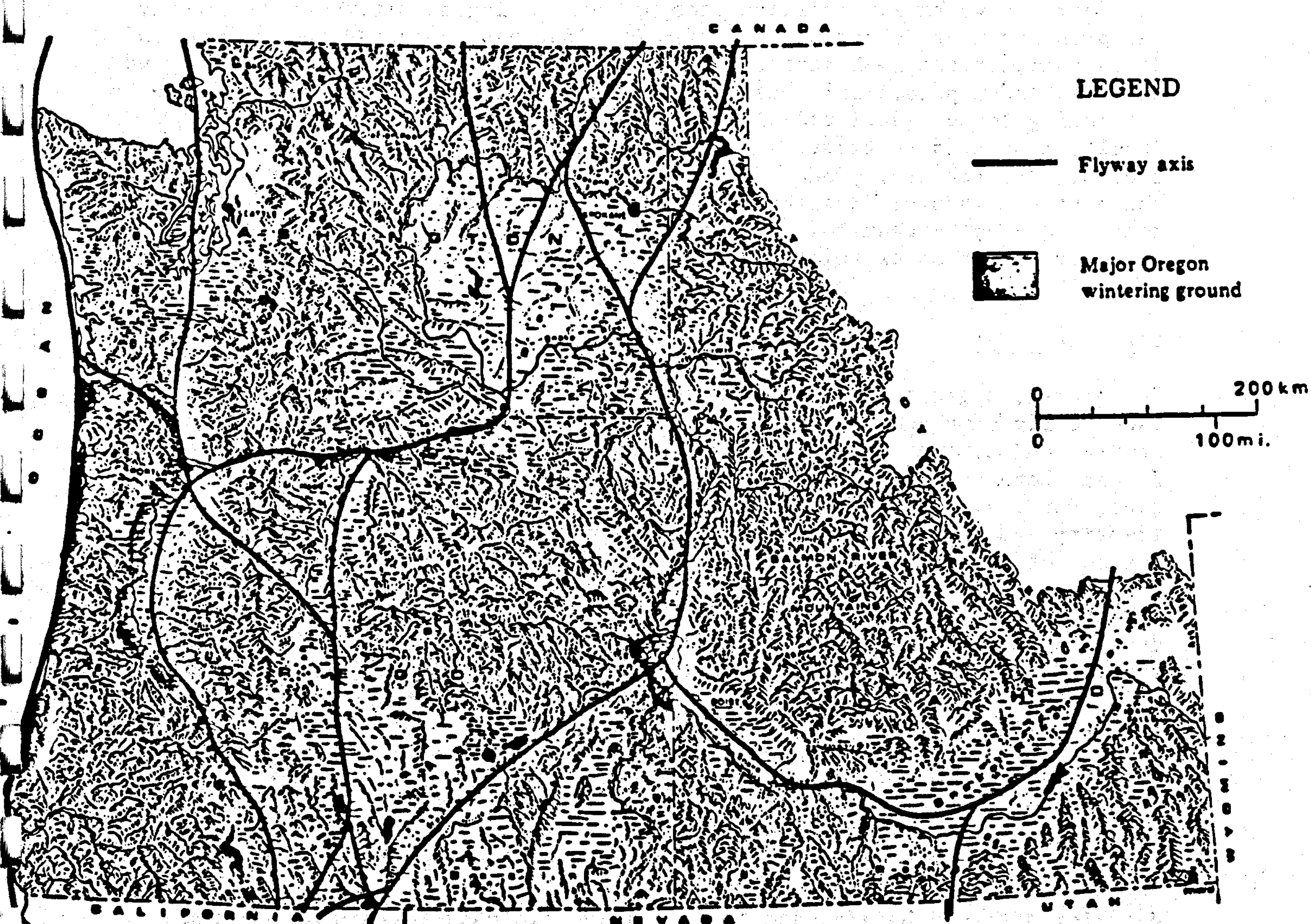
Relatively little is known about behavior patterns of individual species

TABLE 5. Critical Wildlife Habitats Known to Occur in Oregon Geothermal Areas[62-70]

| Habitat | Alvord Valley | Vale | La Grande | Basin & Range | Glass Butte | High Cascades | Western Cascades |
|---|---|---|---|---|---|---|---|
| Bighorn winter & summer range | ● | ● | | | | | |
| Antelope winter range | ● | ● | | | ● | | |
| Antelope summer range | ● | | | | ● | | |
| Antelope kidding | | | | ● | | | |
| Roosevelt elk winter range | | | | | | ● | ● |
| Rocky Mt. elk* | | ● | ● | | | | |
| Mule deer winter range | ● | ● | ● | ● | ● | | |
| Mule deer summer range | ● | | | | | | |
| Blacktail deer* | | | | | | ● | ● |
| Black bear* | | | ● | | | | ● |
| Waterfowl* | ● | ● | ● | ● | ● | | |
| Sagegrouse strutting | | | | ● | ● | | |
| Sagegrouse nesting | | | | | ● | | |
| Sagegrouse wintering | | | | | ● | | |
| Sagegrouse* | | ● | | | | | |
| Eagle wintering | | | | | ● | | |
| Bald eagle nesting | | | | ● | ● | | ● |
| Golden eagle nesting | | | | | ● | | |
| Osprey nesting | | | | ● | | | |
| Spotted owl nesting | | | | ● | | | |
| snags/cavity nesters | | | | | | ● | ● |

* use unspecified

FIGURE 2. Major flyways of the Pacific Northwest with Oregon wintering grounds. From Atlas of Oregon, Loy, 1976.[28]



relative to human activities and particularly to those activities associated with geothermal development. A two-year study which compared wildlife behavior and numbers on effected (quiet) and uneffected (noisy) study sites at the Geysers did not detect any obvious or drastic effects from noise or human disturbance.[24] Critical life cycle stages, especially breeding or wintering periods, may be more sensitive to human disturbance than these results indicate.

The ferruginous hawk, a species recognized as being sensitive to disturbance and prone to nest desertion during incubation, was subjected to experimental disturbance at the INEL geothermal site at Raft River, Idaho.[56,76] The study assessed the populational impacts of noises and other types of disturbance simulating those associated with routine operation at a development site. Results indicated that certain types of activities (approaching nests on foot or in a vehicle) produced significant impacts (lowered fledging rates), while other types of disturbance (intermittent, abrupt noises or continuous noises) did not appear to. From the study, preliminary recommendations were made for buffer zones relating to all human activities and to construction activities.

Data Adequacy

In general, a great deal is known about the distributions and critical habitats of big game and upland game species and waterfowl, since these are studied and managed by state agencies for sporting interests. In addition, federal land management agencies manage for game species and, to some extent, for cavity nesting birds and raptors. Much less well known are the identity and extent of critical habitats of many wildlife species which are not of any demonstrated economic importance.

Habitat data for game species are probably adequate for planning geothermal development, at least in terms of minimizing direct habitat modification or loss. Conversely, the habitat requirements for most small, inconspicuous animal species and the distributions of such habitats are too poorly known to assure protection of critical habitats.

Behavioral data are inadequate for determining appropriate buffer zones between critical wildlife habitats and geothermal development activities. Existing data suggest that the physical extent of the buffer zone required will vary according to species, type of disturbance and life cycle stage.

Existing data may be adequate to initially eliminate certain areas from consideration for geothermal development. Examples might be the areas at the east base of Steens Mt., which serve as important wintering and/or yearlong range for bighorn sheep, antelope and mule deer, and those areas adjacent to and including Summer Lake, which are important as waterfowl wintering and breeding habitats.

Recommendations

Critical wildlife habitat maps should be developed from existing information for the geothermal regions. Known critical habitats should be included as a component of the geothermal suitability/unsuitability classification discussed in Section VII.

Areas not included in known critical habitats of big and upland game, waterfowl, cavity nesting birds and raptors will need to be inventoried for inconspicuous animal species before extensive development of geothermal resources. This should occur on a site specific and project specific basis.

Critical wildlife habitats will require buffering from geothermal activities and from increased deliberate or inadvertent harassment which may ensue from increased human access. This will be especially important for habitats which support critical life cycle stages, such as reproductive or wintering periods. In each case where geothermal development is proposed near a critical wildlife habitat, behavioral studies of the species involved should be initiated, in order to determine adequate buffering of habitats prior to the siting of facilities. It is imperative that these behavioral studies be conducted before pre-development activities have altered baseline population levels or behavioral patterns. Behavioral reactions and population levels should be monitored during operation of the geothermal facility in order to assess the adequacy of the buffer zone provided and to allow for recognition and mitigation of unforeseen impacts.

## VI. NATURAL AND AGRICULTURAL PRODUCTIVITY

### Issue

Much of the state'e economy, and especially that of the regions being considered for geothermal development, is highly dependent on vegetative productivity. Timber production is of primary importance in the Western and High Cascades provinces; Douglas fir and ponderosa pine are economically significant over large areas which are now considered to have geothermal potential. In addition to timber, most provinces east of the Cascades have valuable grazing resources in the form of extensive areas of sagebrush and native grasses; alfalfa is widely cultivated for hay. Grain production is important in the LaGrande area. Intensive production of potatoes, onions and other vegetables on the rich agricultural lands of the Snake River Plain near Vale yields some of the highest total crop values in the state and forms the primary basis of that area's economy. Field crops, in addition to hay and grains, are also very important in the Klamath Basin.[28]

In addition to direct economic benefits, vegetative cover provides wildlife habitat, soil stability, watersheds and environments for recreational activities.

In order to preserve vegetative productivity and the benefits derived from it, it is important to know what the effects to vegetation from geothermal development will be. It is assumed that with proper planning direct loss of productive habitats will be avoided or minimized.

We will concentrate here on the issue of emissions effects of geothermal electrical production on natural and agricultural vegetation.

## Available Data

Prediction of the effects of geothermal emissions to natural and agricultural vegetation will depend on knowledge of a range of site- and project-specific parameters. These include:

- qualitative and quantitative composition of emissions;
- emissions pathways, including local meteorology, surface and groundwater systems, and soils;
- regional and local vegetation composition;
- uptake and accumulation behavior and sensitivity of individual plant species and of consumer and decomposer portions of food chains.

Emissions composition and magnitude will clearly be related to specific project design and to the nature of the geothermal fluid to be utilized. Information is available about the chemical composition of thermal springs and wells in Oregon and these data suggest pollutants which may be of concern.[30,43] However, since the hydrological connections between hot springs and geothermal reservoirs are largely unknown, these data may or may not be definitive. Based on experience at the Geysers and elsewhere, hydrogen sulfide, boron, flouride and heavy metals can be expected to be possible pollutants.[29]

Emissions composition and magnitude may be bounded by regional or project-specific regulatory limits in effect at the time of development. Present data are not adequate to allow predictions about the possible composition of power plant emissions for the various geothermal regions of Oregon.

Likewise, emissions pathways will be highly site-specific. Studies of vegetation stress and damage at the Geysers indicated both foliar and root uptake of boric acid (considered the most probable source of vegetation damage there).[29] Drift deposition on foliage appeared to be a more significant source of stress and damage than soil accumulation; little boron was present in deep soil layers. Most visible damage was confined to distances less than 500 meters from cooling towers and most stressed vegetation (as evidenced by aerial infra-red photography) was within 550 meters.

Meteorological information is available from a number of sources.[6,49,73] Hydrological data is compiled for both surface and groundwater regimes by the Oregon Department of Water Resources[48] and soil surveys and maps have been published by the U.S.D.A. Soil Conservation Service. In virtually every case, however, these data are on a relatively gross scale for prediction of emissions pathways and would need to be supplemented by site-specific studies. This is a normal circumstance in the energy facility siting procedure.

The natural vegetation of Oregon has been described in detail by Franklin and Dyrness.[15] Maps indicate the general vegetation regions and the text discusses the composition and circumstances of occurrence of major plant communities and associations within each region. Current data relating to types of agricultural crops in each county are available from the Oregon Department of Agriculture and the Oregon State University Extension Service.

*In situ* studies of the effects of geothermal emissions components on Oregon plant communities have not been carried out, since there has been no geothermal electrical development here. A recent study by Thompson and Kats of the effects of $H_2S$ did include several species which occur in Oregon.[60] That study indicated that Douglas fir, of major economic importance in the Cascades, is one of the species most sensitive to this pollutant. Ponderosa pine, the dominant species in most timbered areas east of the Cascades, was also tested, as were two crop species significant to Oregon agriculture, namely sugar beets and alfalfa.

As mentioned, the Geysers vegetation study indicated that boron caused most of the vegetation stress and damage near operating geothermal units.[29] Vegetation near the units exhibited symptons typical of boron toxicity, with big leaf maple (a minor component of Western Cascades forests) exhibiting the most extensive damage. For some species, including big leaf maple and Douglas fir, boron levels were significantly higher in damaged leaves than in undamaged leaves during some test periods.

Indirect evidence pointed to sulfate as a possible source of damage to Douglas fir and big leaf maple. Sulfate was measured at deposition rates similar to foliar fertilizer application rates, although it was sometimes higher in the circulating water. In comparisons of Douglas fir needles (two tests), damaged tissue had significantly higher sulfur concentrations than undamaged tissue. Similar results were obtained in one of three tests of big leaf maple leaves. However, in each case, boron levels were also significantly higher in damaged leaves, so the cause of damage is uncertain.[29]

The vegetation report from the Geysers contains a good general discussion of the impacts on vegetation caused by potential major components of geothermal emissions. It presents normal levels of elements in plant tissues and in the environment, threshold levels for damage or toxicity, and toxic symptoms of vegetation. General principles of plant-element interactions, gaseous uptake, root versus foliar uptake of dissolved solids, and element exclusion, uptake and removal mechanisms are discussed.

Additional data on the effects of geothermal emissions components are included in Responses of Plants to Air Pollution (Mudd and Kozloski, 1975).[34]

## Data Adequacy

The available data are adequate to describe the natural and agricultural ecosystems which may be expected to be effected by geothermal emissions. Even so, species inventories will be required once development sites are selected. Chemical composition of geothermal fluids and, thus, of potential emissions are poorly known; they will be described on a site- and project-specific basis. Emissions pathways will be so highly site-specific that data presented at currently available scales will not be sufficient for prediction of effects. Data on effects of various potential emissions components on individual species are available in only a few instances.

Recommendations

A thorough literature search should be conducted to delineate the known range of sensitivity of native (or closely related) species to suspected emissions components. In situ studies at operating geothermal power plants in other areas, such as the Geysers, may yield information which is directly applicable to Oregon species. The literature review will be useful in designing further effects studies.

It is not practical to recommend that all plant species present in potential geothermal areas in Oregon be assayed for their response to putative components of geothermal emissions. However, basic research should be expanded to include dominant native or important cultivated plant species which occur in areas where geothermal activity is considered most likely. Douglas fir, ponderosa pine, sagebrush, native grasses, alfalfa, onions and potatoes are among the species which should receive attention in a preliminary survey of emissions effects. Once area-specific information on geothermal resource chemical composition becomes available and the magnitude of emissions components can be predicted, effects studies keyed to locally occurring species and emissions can be designed.

Initially, major emphasis should be placed on studies of the effects of boron on key native vegetation and crops, since boron emissions from power plant cooling towers have been implicated as causing virtually all observed vegetation damage at the Geysers. Study of Douglas fir should be given high priority because it is so significant to Oregon's economy and as it is a species for which damage appeared to be related to tissue levels of boron and/or sulfur at the Geysers. In addition, since Thompson's work has shown it to be especially sensitive to $H_2S$, further investigations of the relationship of $H_2S$ to damage to Douglas fir are of critical importance.

Research on native and cultivated species should include the synergistic and cumulative effects of boron, $H_2S$ and heavy metals at low dosages, as well as the consequences to natural, agricultural and human food chains, in the event that significant effects to vegetation are discovered.

Results of literature review and physiological research should be used to formulate regulatory limits for different emissions components, perhaps by vegetation regions, depending on the variation in sensitivity of plant species.

Data on emissions composition, emissions pathways and local vegetation patterns will be acquired at the necessary level of detail for prediction of effects only on a site- and project-specific basis. One specific development is proposed, the types and concentrations of emissions (related to currently available emissions control technologies) will be assayed, baseline meteorological and hydrological patterns established, and the composition and baseline productivity levels of vegetative systems determined. Based upon projected emissions levels reaching the vegetation, predictions will be made as to the impacts to ecosystems productivity. The ease and confidence in predicting direct acute, synergistic, cumulative and food chain effects will be determined largely by the extent to which the physiological research recommended here has been conducted prior to this stage. Additional investigations keyed to local conditions and species will generally be necessary and it will be critical to monitor variation and trends in emissions, emissions pathways and vegetative productivity levels.

## VII. OREGON'S GEOTHERMAL SUITABILITY/UNSUITABILITY CLASSIFICATION

The Oregon Energy Facility Siting Council (EFSC) has jurisdiction over the siting and regulation of geothermal electric generating facilities greater than 25 mw (ORS 469.470(3)) and has the authority to designate geographic areas within the state which are suitable or unsuitable for use as sites for geothermal power plants (ORS 469.470(2).[47]* The Council will not accept applications for site certificates for sites within areas designated as unsuitable (OAR 345-40-020(2)).[39]** The designations of areas as suitable or unsuitable may be amended by the Council (OAR 345-40-020(3)).

To date the EFSC has classified as unsuitable designated natural resource areas, including national parks, monuments and memorials; wilderness and roadless areas; botanical, geologic, historic, scenic and recreation areas; research natural areas; wildlife management areas; and state parks.[39,46] In addition, the Newberry Crater area, including Newberry Crater, North Paulina Roadless Area, South Paulina Roadless Area and the Lava Cast Forest, has been classified as unsuitable for geothermal electric generation (OAR 345-40-030(3)).[39]

Figure 3 indicates those areas classified by the EFSC as unsuitable for use as sites for geothermal power plants. Note that all areas identified as "less suitable" on this map are designated as "unsuitable", according to OAR 345-40-030(1).[39,46]

<u>Recommendations</u>

The unsuitability classification should be expanded to include geographic areas with concentrations of sensitive ecosystems elements discussed in this report, particularly rare and endangered species, certain hot springs and other unique ecosystems, best examples of natural ocosystems and critical wildlife habitats. Other considerations, such as air quality, water restrictions and aesthetics, might also be incorporated into the classification scheme. Many participants in the ECOSYSTEMS WORKSHOP felt that high priority should be given to accomplishing a resource inventory of the Alvord Valley, with subsequent partitioning as to suitability or unsuitability for geothermal electrical development.

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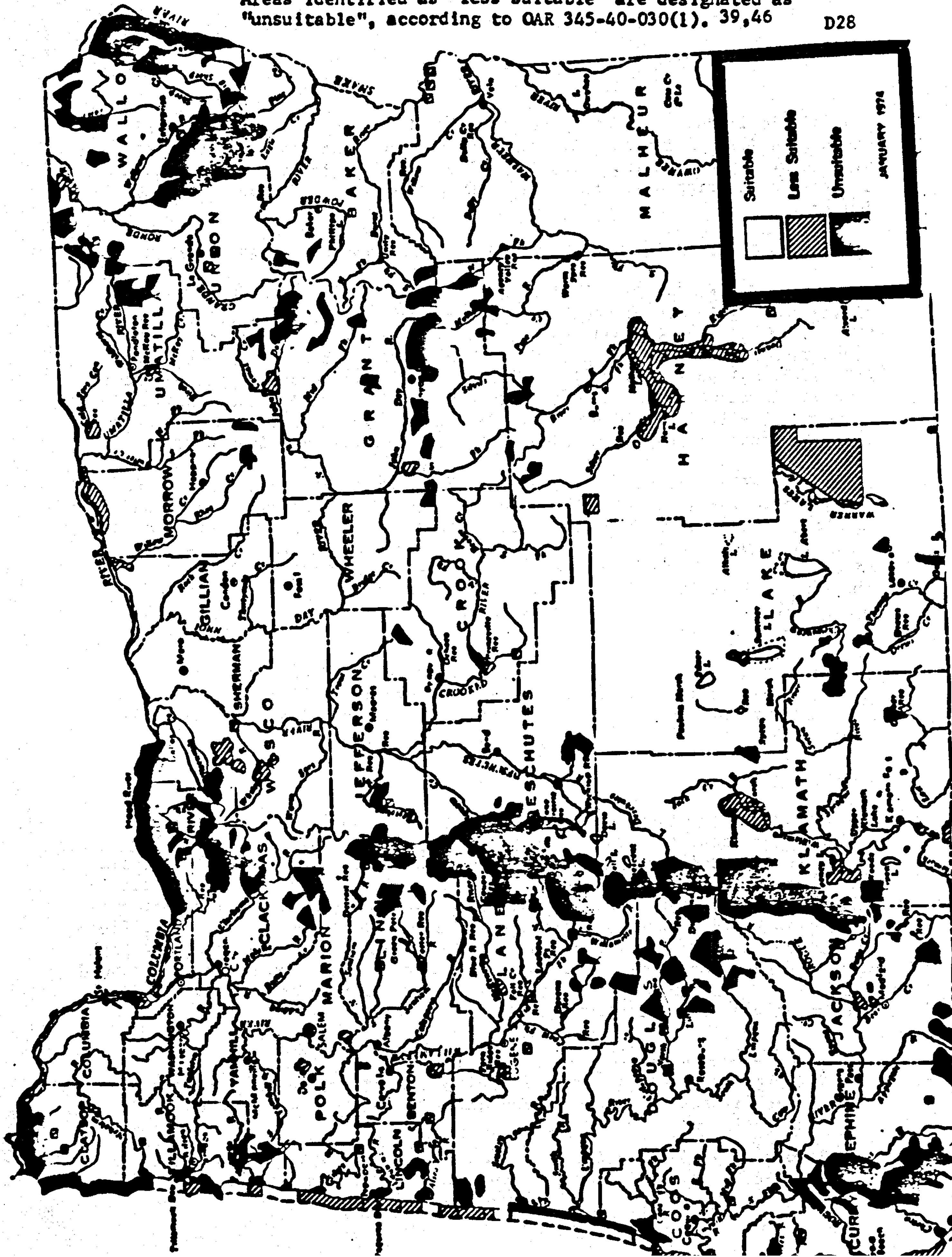
* ORS (Oregon Revised Statutes) include enabling legislation which provides statutory authority for state administrative agencies, councils and commissions.

** OAR (Oregon Administrative Rules) are adopted by state agencies, councils or commissions to implement the state statutes.

FIGURE 3 Areas classified by the Oregon Energy Facility Siting Council as unsuitable for use as sites for geothermal power plants. Areas identified as "less suitable" are designated as "unsuitable", according to OAR 345-40-030(1). 39,46 D28



# VIII. SUMMARY OF RECOMMENDATIONS

The recommendations presented in this report have been classified as being of high, medium or low priority. In general, highest priority has been assigned to those activities which would circumvent conflicts between geothermal development and important ecosystems components. The ranking is based upon ecosystems component studies; where appropriate and possible, emphasis on particular geothermal regions is indicated.

The recommendations are summarized below; details are included in the corresponding sections of the text.

## High priority

The Oregon Energy Facility Siting Council classification of areas suitable or unsuitable for the siting of geothermal power plants should be expanded to include geographic areas containing concentrations of sensitive ecosystem elements discussed in this report, particularly hot springs and other unique ecosystems, rare and endangered plant and animal species, prime examples of natural ecosystems, and critical wildlife habitats. Additional factors, such as water restrictions and air quality, should also be considered for inclusion as components of the classification.

It is proposed that the expansion of the suitability/unsuitability classification be organized by the Oregon Department of Energy, as a taskforce involving input from the Oregon Rare and Endangered Plant Project, the state Natural Area Preserves Advisory Committee, the Oregon Department of Fish and Wildlife and others with specialized experise in these areas. Recommendations would be made to the EFSC for inclusion in its suitability standard.

Initial recommendations should be based upon existing data bases; inventories should be delineated by the taskforce of areas for which the data are not adequate to make determinations of suitability or unsuitability. Additional recommendations should be made on a periodic basis, as new information on the status and distribution of components clarifies the suitability of particular geographic areas for geothermal development. It is felt that a classification which clearly identifies those areas with "high" ecosystems values will result not only in protection of these sensitive components, but will also clarify constraints prior to development activities and circumvent conflicts at the time of development.

Highest priority should be given to a survey of the Alvord Valley in order to delineate areas unsuitable for geothermal power plants. This is of critical importance due to the known existence of sensitive ecosystems components (including rare and endangered plant and animal species, unique hot springs and critical wildlife habitats) and due to the fact that geothermal sites there have been identified as likely candidates for development.

Biological, chemical and physical inventories of hot springs within the geothermal regions should be conducted. High priority is assigned to these investigations because these ecosystems are the most faithfully associated with geothermal potential and are, thus, the most likely to be disturbed by development activities. In addition, several hot spring areas have been identified which could begin producing electricity on an economically competitive basis in the near future; thus, potential disturbance of these springs may be imminent.

Initial emphasis should be placed on these springs where development is considered most imminent and upon those which have been identified as being of particular biological interest or which support rare, endemic fish species.

Additionally, for hot springs where development is considered most likely or where development is expected to occur in the near future, the hydrologic relationship of hot spring waters and geothermal fluids should be investigated through water sampling programs.

Medium Priority

The following recommendations for expanded inventories and field investigations are made for the purpose of facilitating siting decisions once specific geothermal development is proposed. The information to be derived from the inventories is also seen as cycling into future recommendations for classification of areas as suitable or unsuitable for geothermal power plants, as discussed previously.

The existing data base for rare and endangered plant species should be expanded. Field surveys should emphasize 1) areas where geothermal development is considered most imminent or most likely, 2) species known to occur in geothermal areas; this will include field surveys of habitats where these species are expected to occur, throughout their total range. New data should be incorporated into the Oregon Rare and Endangered Plant Project data base so that species composition of geothermal areas may be readily assessed and so that the distributions and status of species may be reviewed in a comprehensive manner.

The data bases of rare and endangered animal species and critical wildlife habitats should be compiled and expanded for the geothermal regions. Maps indicating the distribution of rare and endangered species and the distribution and areal extent of critical habitats should be refined. The status of "species of special concern," which have not been designated as endangered or threatened at the state or federal level, should be reviewed and their distributions included in the mapping effort. Where appropriate, species should be officially listed for protection.

The designation of prime examples of all significant natural ecosystems for future protection should be completed. Once these areas are identified, even though actual acquisition or preservation measures have not been initiated, development could proceed around them, thus preventing conflicts relating to preservation of natural areas.

Additional research as to the extent of buffer zones necessary for the continued existence of rare and endangered species and maintenance of critical wildlife species should be conducted. Such research may be done by utilizing experimental disturbances which simulate those associated with geothermal development and operation, or by assessing behavioral reactions of species to actual disturbance from other types of development.

Low Priority

Basic research should be conducted on the effects of geothermal emissions on dominant or economically important plant species. Initial emphasis should be placed upon the study of boron, as it has been implicated in causing most damage at the Geysers. Additionally, the effect of $H_2S$ on Douglas fir, a species particularly sensitive to sulfur, should be continued.

Relatively low priority has been assigned to these emissions studies, because the areal extent of vegetation damage around the Geysers cooling towers was quite small (less than 550 meter radius). This distance may, however, be significant in areas supporting intensive agriculture; crops grown in such areas (e.g., Vale) should be tested for their sensitivity to potential geothermal pollutants.

If appropriate, regulatory limits for geothermal emissions components should be formulated, based on species sensitivity.

Site and project specific studies will be necessary for rare and endangered species, unique habitats, critical wildlife habitats, vegetative productivity, etc., once geothermal development sites are proposed. These studies are given low priority here only because they cannot be conducted until the site, project design, and the nature of the geothermal resource have been identified and defined. Once this occurs, site and project specific investigations will be of highest priority.

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# APPENDIX DA

## OGEOS ECOSYSTEMS WORKSHOP SUMMARY

The ECOSYSTEMS Workshop considered the ecosystem elements of concern, classes of effects to these ecosystems from geothermal power development and methods by which the effects might be avoided or mitigated. Issues were identified which would be likely to be of concern in each of the geographic areas for which geothermal scenarios were being postulated.

The ecosystem elements or attributes which are most sensitive and of most concern are:

- -rare and endangered species
- -critical wildlife habitats
- -unique ecosystems, especially hot springs
- -agricultural and natural vegetative productivity

The potential effects to these ecosystem components include:

- -habitat elimination
- -habitat disturbance, including harassment
- -climate modification and its implications
- -surface water modification
- -aquifer modification
- -effects of noise
- -chronic, cumulative and synergistic effects, especially relating to emissions
- -increased access and other secondary effects, including urbanization

The relationship of physiography to these potential effects was discussed, as was the adequacy of existing regulatory control of geothermal emission components, such as $H_2S$ and B.

Methods to avoid or alleviate adverse impacts include site- and project-specific baseline studies and monitoring of emissions effects.

Compilation of a state data base for rare and endangered species, critical wildlife habitats and unique ecosystems would be valuable for selection of suitable sites. Geographic areas containing concentrations of sensitive ecosystem elements should be identified as unsuitable for development or partitioned according to suitability/unsuitability prior to development.

Specific biological resource information for the geographic areas under consideration comes primarily from five sources: KGRA environmental assessment reports, U. S. Forest Service and Bureau of Land Management inventories and resource management plans, input from Oregon and U.S. Fish and Wildlife personnel, information from the Oregon Rare and Endangered Plant Project, and the Oregon Heritage Program of the Nature Conservancy. Hot springs of particular biological interest have been identified by Dr. R. W. Castenholz, University of Oregon.

SECTION E

of the

OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW STUDY*†

# SOCIOECONOMIC ISSUES RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

by

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## I. INTRODUCTION

The purpose of this report is to identify social and economic issues which may influence the development of geothermal resources in Oregon. The report utilizes the general framework of the emerging field of social impact assessment. That framework includes the following components—a general model which places society (social systems) on the "receiving" end of proposed developments, efforts to distinguish between development-related and "exogenous" or outside impacts on society, and conceptual separation of economic, socioeconomic, and social impacts. This introduction briefly reviews these components, describes the procedures used in the preparation of this report, and provides an outline of this report.

### A. A General Framework

The basic social impact assessment model views proposed developments, such as those related to geothermal resources, as potentially significant interventions into ongoing social processes. Since social systems (groups, communities, organizations) continually change, analytical focus of social impact assessment focuses on how the proposed development will alter the future course of the social system under study. And, since developments do not uniformly impact all aspects or features of society, a major task of social assessment is to determine which aspects of society are most likely to be changed by the proposed development.

The question of <u>which aspects of society might be changed</u> closely parallels the organizing question for this report—which socioeconomic issues may emerge with the development of geothermal resources in Oregon. Just as the "which aspects" question typically leads to consideration of a comprehensive listing of social impact variables (See Figure 1), the "which issues" question leads to a review of possible natural resource-related concerns. A socioeconomic <u>issue</u> is roughly comparable to a socioeconomic <u>variable</u>, in that both refer to some specific aspect of society which may change because of the proposed development. The basic difference is best described as one of public motivation—an issue refers to some aspect of society which is seen as especially significant, and is likely to provoke strong public reaction or comment. A specific variable, while susceptible to change, is not necessarily also defined as a key issue by potentially impacted publics. Thus, identified socioeconomic issues are discussed in this report as key social impact variables. However, there are possibly other social impact variables which are not discussed in this report because they would probably not be seen as critically important to impacted publics.

A major challenge in nearly all social impact studies is to separate those changes which can realistically be attributed to the proposed development

FIGURE 1. Social Impact Categories, Variables and Components

| Social Impact Categories | Social Impact Variables | Social Impact Components |
|---|---|---|
| I. WAYS OF LIFE | A--Community Culture Change (Subculture, Trait, or Theme) | |
| | B--Leisure & "Cultural" Opportunities | |
| | C--Recreational Opportunities | 1--Carrying Capacity<br>2--Available Land & Facilities<br>3--Recreational Demand<br>4--"Optimal Recreationist" |
| | D--Special Group Access (Elderly, Handicapped, Poor, Transit-Dependent) | |
| | E--Security (Anxiety, Unpredictability, & the "Unknown") | |
| | F--Open Space | |
| II. SPECIAL CONCERNS | A--Minority & Civil Rights | 1--Minority Group Impacts<br>2--Civil Rights |
| | B--Historical & Archaeological Sites* | |
| III. BASIC VALUES | A--Value Orientations | |
| | B--Value Rankings | |
| IV. SYMBOLIC MEANING | A--Places | |
| | B--Practices | |
| | C--"Things" | |
| V. CONFLICT & COHESION | A--Physical Cohesion (Barriers) | |
| | B--Social Class | |
| | C--Attitude & Value Cohesion & Conflict | |
| | D--Action Alternative Cohesion & Conflict | |
| | E--Community Activities | |

| Social Impact Categories | Social Impact Variables | Social Impact Components |
|---|---|---|
| VI. SOCIAL INSTITUTIONS | A--Educational Institution | 1--Educational Resources<br>a--Funding<br>b--Programs<br>c--Personnel<br>d--Facilities & Equipment<br>2--Educational "Users" (Students & Employers)<br>3--Educational Characteristics of Population<br>4--Educational & Scientific Opportunities<br>a--Range of Opportunities<br>b--Access by Educational & Scientific "Users" |
| | B--Family Institution | 1--Family Characteristics<br>2--Family Economic Indicators<br>3--Family Forest Resource Use |
| | C--Economic Institution (Employment & Income) | 1--(Employment & Unemployment)*<br>2--(Income)*<br>3--Rural Poverty |
| | D--Economic Institution (Infrastructures) | 1--Transportation (Forest Access)<br>a--Legal Access Limits (Easements; Special Use Permits; Trespass)<br>b--Travel Time<br>c--Seasonality of Access<br>d--Transportation Equipment Type (Foot, Horse, Boat, Plane, Auto, ORV, Rail)<br>e--Transportation Facilities (Roads, Trails, Water, Airstrips, Railroads)<br>f--Experience Type (Travel-Through vs. Destination)<br>g--Travel Route "Difficulty"<br>2--Communications & Media<br>a--Media Market (Population Size & Structure)<br>b--Forest as "Supplier" of Information & Issues<br>c--Impacts on Media Advertisers<br>3--Utilities & Special Districts<br>a--Utility Uses of Forest Resources<br>b--Utility Access & Development<br>c--"Consumption" Impacts (Population & Economic Li<br>d--Supply Capability Thresholds (Population & Use Link)<br>e--Special Districts as Voluntary Associations & Social Support Systems |

| Social Impact Categories | Social Impact Variables | Social Impact Components |
|---|---|---|
| V. SOCIAL INSTITUTIONS (continued) | D--Econonic Institution (Infrastructures) (continued) | 4--Housing<br>a--Housing Supply System<br>b--Housing Quality<br>c--Housing-Related Economic Factors<br>d--Forest-Related Housing Materials<br>5--Emergency Preparedness & Law Enforcement<br>a--Natural Disaster Potential<br>b--Emergency Infrastructure<br>c--Normative Questions (What is "Legal"?)<br>d--Illegal (or "Deviant") Behavior (Incidence & Location)<br>e--Law Enforcement & Justice System (Personnel, Equipment)<br>f--Enforcement "Results" (Arrests, Convictions, Litigation, Property Impact)<br>g--Safety (Accidents)<br>6--Health<br>a--Physical & Mental Health<br>b--Health System Resources (Facilities & Equipment, Personnel)<br>c--Money to Counties (Public Health Services)<br>d--Health Services "Demand" (Population Change)<br>7--Social Services & Public Assistance<br>a--Social Services "Suppliers" (Funding & Personnel)<br>b--Social Services "Receivers"<br>c--Money to Counties (Social Services<br>d--Forest as Formal/Informal Social Service Organization |
| | E--Political Institution | 1--Governmental Size & "Density"<br>2--Government Financing<br>3--Citizen-Government Linkages<br>4--Voluntary Association Activity<br>5--Legislative & Partisan Political Activity |

| Social Impact Categories | Social Impact Variables | Social Impact Components |
|---|---|---|
| VI. SOCIAL INSTITUTIONS (continued) | F--Religious Institution | 1--Religion-Based Ethical Norms & Values<br>2--Religious System Resources |
| | G--Military Institution | 1--Official Forest Use<br>2--Forest Products Consumption |
| VII. LAND TENURE & LAND USE | A--Land Allocation & Use | 1--Actual Use Compatability<br>2--Suitability (Environmental Carrying Capacity)<br>3--Aesthetic Effects (Viewer Access)* |
| | B--Land Use Regulation | 1--Conditional Use & Building Permits<br>2--Comprehensive Planning & Zoning |
| VIII. COMMUNITY CONTEXT | A--Community Identity | |
| | B--"Sense of Place" | |
| IX. POPULATION DYNAMICS | A--Population Size (Growth, Stability, Decline) | 1--Population Size Perspectives<br>2--Population Size Change |
| | B--Population Density | |
| | C--Displacement of People | 1--Physical Displacement<br>2--Use Displacement |
| | D--Population Distribution | |
| | E--Population Mobility | 1--Geographical Mobility<br>2--Social Mobility |
| | F--Population Structure (Age & Sex) | |

from those which are likely to occur anyway or should be instead attributed to simultaneous new developments. The "exogenous variable" issue is one of the several unanswerables in social assessment and poses especially difficult questions where, as is the case in many of the areas potentially impacted by geothermal development in Oregon, localized development of energy resources are both new to rural, somewhat isolated communities and multifaceted. Exploration for natural gas and fossil fuels, and retrofitting of hydroelectric projects, are also being considered in the vicinity of many potential geothermal areas. This makes it very difficult to isolate the specific changes or issues which might be attributed to geothermal development. In many instances, the issues are similar, and the possibility of geothermal development may alter the amount or timing of change, but not the basic thrust.

"What's the difference between social and economic impacts?" is a frequent question. Although the emphasis should always be directed toward an integrated, interdisciplinary assessment, it is also useful to conceptually distinguish between social and economic impacts even though this report uses the general label of "socioeconomic" issues or impact variables. The approach used in this report recognizes three overlapping groupings of issues or variables: typical economic impacts, such as employment, income, and economic benefits and costs, socioeconomic infrastructure impacts, such as transportation, utilities, health services, and social impacts, encompassing the other social institutions and special clusters of variables or issues which may not be easily quantified or expressed monetarily, such as symbolic meanings, cultural and subcultural themes, and basic values. Figure 1 is a comprehensive list of possible impact variables in these three groupings. Appreciation of the full range of potential impacts is important, since "socioeconomic assessment" is often limited to consideration of a few key economic and infrastructure variables.

## B. Methodology and Overview of Data Base Resources

The preparation of this report can be divided into three stages: (1) a literature search for social and economic impact studies of existing or proposed geothermal developments outside of Oregon, (2) a review of studies and related material on Oregon and those subareas likely to contain geothermal resources, and (3) participation in two workshop sessions designed to solicit estimates of likely socioeconomic issues related to geothermal development in Oregon.

### 1. Non-Oregon Geothermal Social and Economic Impact Studies

Two of the most comprehensive studies which deal with potential socioeconomic impacts of geothermal development outside of Oregon are Sculler, et al. (1976) and Goodnight (1977). The first report ("Legal, Institutional, and Political Problems in Producing Electric Power from Geothermal Resources in California") is organized in terms of 10 groups of "nontechnical problems surrounding geothermal development." These are leasing, exploration, reaching agreement for utilization, power plant construction, transmission, financing, environmental reporting, the role of the California Energy Commission, proposed air pollution regulations, and the political economies of individual counties. Separate chapters deal with each "problem," and examine both statewide and local issues. In general, the report describes issues and problems with some reference to both historical situations and current developments in California. It does not provide a detailed case study analysis of any existing or planned developments, although the report does contain an excellent bibliography. Unfortunately, the chapter which might have included some of the most interesting discussion of socioeconomic issues (Chapter 12--The Political Economies of Counties) was also the shortest, and the 5 1/2 pages of text provide only the briefest overview, with a primary focus on responses of local government. Despite these limitations, the document provides a good overview of a full range of potential socioeconomic issues, and would be a valuable reference for persons interested in similar issues in Oregon.

The second report ("Community Impact Assessment of a Diversified Geothermal Energy Project Proposed for the Raft River Valley, Idaho") is a more typical community study.* The first half consists of socioeconomic profiles of the general area and the potentially impacted county and communities. In addition to the usual sections on economic and infrastructure (housing, education, etc.) conditions, the profile chapters also include sections on "Political Issues and Personal Philosophies" and "Social Considerations." In addition to a description of the cultural history of the area, these sections also describe attitudes of residents concerning geothermal development (which are generally very favorable), some of which were obtained through two small-scale public opinion surveys. The organization of the chapter which describes potential impacts parallels that of the profile chapters. In addition to a discussion of impacts on population, employment, and community services, there is also a section on "Political Issues and Social Considerations," which describes potential impacts on a variety of social conditions in the area. Finally, because of the relationship between the proposed geothermal development (an EDRA thermal loop test facility utilizing geothermal water) and land use planning, the last chapter presents an extensive discussion of growth management issues and strategies. In all, this appears to be a very comprehensive study which utilizes a variety of data sources and is sensitive to local socioeconomic conditions. It is a good sample study for those who might investigate similar local situations in Oregon. (The study area in southern Idaho bears some similarities [in obviously varying degrees] to the Vale, Ontario, Lakeview, and Klamath Falls areas in Oregon.) (The report also contains an excellent bibliography of growth impact studies, particularly those concerning coal and gas development in the Rocky Mountain states.)

### 2. Oregon Geothermal Social and Economic Impact Studies

In terms of materials on Oregon, preparation of this report involved neither primary data collection nor visiting KGRA's (although the authors had some

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* A similar study which addresses impacts in an urban area is CH2MHill (1979).

familiarity with the surrounding communities). In contrast to companion documents prepared for several other states (Utah, Louisiana), the Oregon project was not directed toward preparation of a socioeconomic overview of existing conditions. Thus, the information assembled on Oregon consists of existing documents and personal observations gathered from workshops and other sources.

The materials on Oregon fell into three categories: (1) social and economic background material prepared for Oregon KGRA's, (2) discussion of social and economic impacts which appear as sections of Environmental Impact Statements (EIS) (or, in the case of the Bureau of Land Management--Environmental Analysis Reports [EAR]) on proposed geothermal developments in Oregon, and (3) impact studies and other materials which, although not specific to geothermal developments, include information on geographical areas and communities adjacent to KGRA's.

The only document which assembles any social and economic background data by KGRA is "General Description of Oregon's Regions of High Geothermal Potential," prepared by Debra Justus, Oregon Institute of Technology, Klamath Falls. The ten page report very briefly summarizes key socioeconomic and geothermal resource characteristics for nine KGRA's, which have been grouped into four regions (Southern Basin and Range, Western and High Cascades, LaGrande, and Western Snake River Plain) and provides a quick first look at dominant socioeconomic conditions.

One of the most comprehensive listings of a variety of recent (1967-77) planning studies is "Community Planning in Oregon: A List of Publications," prepared by the Bureau of Governmental Research and Service, University of Oregon, Eugene. The bibliography is organized by the State's 14 Administrative Districts. With each district, there are separate listings for counties and communities. Since planning documents frequently contain a wealth of background socioeconomic data as well as summaries of citizen concerns, many of the documents could be very helpful in initiating a socioeconomic overview or impact study related to geothermal resources. While this document does not contain all such studies (federal Environmental Impact Statements, for example, are not listed) it is a helpful guide to a variety of locally-relevant studies. As one would expect, sparsely populated counties with few communities do not undertake many such studies. However, the studies that are listed and appear to have some relevance for geothermal impact studies are included in the discussion of the Regions and Subregions in Section III of this report.

As of July, 1979, over a dozen impact studies had been prepared for proposed geothermal activity in Oregon. Nearly all of these were Environmental Analysis Records (EAR), prepared by the Bureau of Land Management. A study which was presented in the form of an Environmental Impact Statement (EIS) was issued by the U.S. Forest Service (Willamette National Forest.* The format used in

*Final Environmental Impact Statement, Geothermal Development in the Breitenbush area, Willamette and Mt. Hood National Forests, 1978. A more recent study which focusses on the McKenzie area is Draft Environmental Statement, Geothermal Leasing in the Belknap-Foley area, Willamette National Forest, 1979.

the Bureau of Land Management is very similar to the standard EIS format.

The discussion of social and economic impacts in the Breitenbush Final Environmental Statement is based primarily on statistical data, with little emphasis on qualitative descriptions of potentially impacted communities. Recreational use of the area is given fuller treatment, and portrays the diverse recreational activities in the area. The impact analysis was less comprehensive, and discussion of community impacts focused more on what North Santiam communities could offer in the way of services than the possible effects of an influx of workers and their families on such services.

The two documents concerned with the Vale Area (Proposed Leasing Vale Addition, EAR, July, 1975, and EAR for Proposed Oil and Gas Leasing in the Vale Area, February, 1977) together provide a substantial data source for that area and a good example of a relatively comprehensive socioeconomic assessment. Neither document provides the detailed examination of issues that is found in the Raft River study mentioned above, but the mention of "human values" and "attitudes and expectations" in the 1977 document suggests at least an awareness of a fuller range of socioeconomic impacts than is usually addressed in such documents.

### 3. Workshop Sessions

In addition to the Socioeconomic Subsession of the Portland workshop, a second workshop was held as part of the Annual Meeting of the Northwest Anthropological Conference (Eugene, March 24, 1979). A summary of the Portland Subsession is included in Appendix A, and much of that material has been incorporated into this report. The Eugene meeting focused on potential impacts on traditional lifestyles and the extent to which geothermal development parallels impacts associated with other natural resource developments, such as dams. An issue which emerged at that meeting was the potential impact after the construction crews have left the community (the "bust" side of the "boom-bust" cycle), and, in the longer run, possible impacts of "decommissioning" a geothermal facility following the expected 30 year life cycle.

## C. Outline of Report

The outline of this report is as follows:

I. Introduction
II. General Statewide Issues
III. Socioeconomic Issues by Region (and Subregion, where appropriate)

(The following outline will be used for each of six Regions and Subregions)

A. List of Issues and Data Sentences (Prioritized)
B. List of Data Sources

IV. Six High Priority Socioeconomic Studies

A. Public Perceptions of Geothermal Development and the Symbolic Meaning of Special Places

B. The Economics of Geothermal Development in Oregon
C. Geothermal Development and Dispersed Wildland Recreation--Levels of Compatability and Conflict
D. The Applicability of the "Boom-Bust" Cycle to Geothermal Exploration and Development in Oregon
E. The Role of Geothermal Development in the Maintenance of Resource-Dependent Industries in Smaller Communities
F. Domestic and Community Geothermal Heating Applications: The Case of Klamath Falls, Oregon

The information provided in this report is seen as consistent with the general organization of the Oregon Geothermal Environmental Overview Study. Sections II and III-A identify key socioeconomic issues and variables related to geothermal development. Section III-B summarizes the existing data base and lists organizations and individuals who may be sources of additional information on likely issues and needed studies. Section IV presents an integrated look at what are seen as key socioeconomic issues in terms of what appear to be high priority socioeconomic studies for Oregon.

The format for the presentation of information on each of six areas (Section III) is as follows. First, a list of issues is presented, as in this example:

> Population Dynamics--How will geothermal development impact current patterns of population change? Current patterns include a shift from rural to urban, outmigration of young adults, and settlement by former migrant agricultural workers.

The term "Population Dynamics" is the general social impact variable which encompasses the issue. A comprehensive listing of such variables is shown in Figure 1. A person wishing to carry out research on the issue may therefore wish to consult a larger handbook on social impact assessment (U.S. Forest Service, 1979) which describes how to use the variable in a social impact study. The question is the specific issue. In the above example, it is believed that population change is a matter of concern, and that the issue could emerge as part of consideration of geothermal development. The data sentence which begins ("Current patterns include. . .") is a very brief statement of current conditions which bear on the issue. The information in these sentences was obtained from the document titled "General Description of Oregon's Regions of High Geothermal Potential" or other socioeconomic studies.

The listing of issues for the State and for each of seven Regions have been prioritized on two dimensions: (1) the importance of the issue to the State or Region and the extent to which the issue could be crucial to existing socioeconomic conditions and (2) the likelihood of the issue emerging in response to geothermal development. The second issue reflects past concern with similar issues and the extent to which interested organizations could successfully generate public concern with the issue. The ranking scene on each dimension is as follows: High, Medium High, Medium, Medium Low, and Low. To assist summary prioritization, a summary priority score was calculated for each issue, by assigning 6 points to a High ranking, 5 points to a Medium High ranking, etc. and combining the points on the two dimensions into a single score (ranging from 2 [Low on both dimensions] to 12 [High on both dimensions]).

Second, a listing of potential data sources is shown. This listing includes published documents, organizations which are likely to have conducted socioeconomic studies, and, in several instances, individuals who have expressed interest in specific socioeconomic issues or who have carried out socioeconomic studies in the area. This is not an exhaustive listing--it reflects the best efforts of the authors in the time allotted for this study.

While the very brief "study proposals" which comprise Section IV are not necessarily identical to the key issues identified elsewhere, they appear as "packages" which could provide needed data on a variety of interrelated issues. Section IV should be understood as an effort to suggest high priority socioeconomic studies, rather than general environmental impact studies which include social and economic impacts among a number of other factors.

## II. GENERAL STATEWIDE ISSUES

Most of the following issues emerged as part of the Socioeconomic Subsession of the Portland Workshop. All of the issues listed in this section are important issues. Some of them are mentioned again in a somewhat different form in the sections dealing with the seven areas (Section III). Further, they also emerge as part of the discussion of six high priority socioeconomic studies (Section IV).

The statewide issues have been grouped into three sections. Within each section, we have designated two or three issues as the highest priority (H). This prioritization was done by the authors of this report, and reflects both their best judgement and their appraisal of the concerns of Workshop participants. (It was not possible to include the prioritization as part of the workshop activities.)

### A. Economic Issues

(H) How will geothermal development impact Oregon's energy "self-sufficiency," and change present and future expenditures for "imported" fossil fuels?

(H) To what extent will a "Boom-Bust" cycle be experienced as part of geothermal development? Would a power plant have a positive economic impact on a small community such as Vale? Would it supply jobs, attract industry, increase the tax base? Or would the project be of greater benefit to outside interests?

(H) If the project were to occur outside the town limits, would the fraction of taxes and royalties filtered down from county and state coffers sufficiently offset the impacts of an incoming labor force and other effects of exploration and construction such as noise pollution?

If tourism is a primary local industry could the project seriously deteriorate the tourist attractions?

If direct-use applications are likely to be of immediate, tangible economic benefit to local or regional economies, where will incentives come from for an industry in which it is only profitable to develop power generating facilities?

Will geothermal development decrease utility rates? Slow the increase? How will it affect the mix of utility services currently provided?

From the point of view of organized labor, if the creation of energy equals the creation of jobs, who and how many will be employed? Where will they be trained?

B. Recreation and Land Use Issues

(H) Should development occur in areas which are highly valued throughout the state for aesthetic, historical, or ideological reasons?

(H) What trade-offs confront a rural community choosing between traditional land uses--particularly stock grazing and agriculture--and geothermal development?

Would development affect people's opportunities for recreation in a given area, whether or not they are local to that area, and whether they are backpackers, hunting and fishing enthusiasts, off-road vehicle operators, or sightseers?

Do hunting and fishing enthusiasts in particular comprise a "silent majority" which could represent a powerful lobby against geothermal if their recreational opportunities are impacted?

Who controls the resource if a KGRA occupies federal, state and private land?

How will centralized, urban geothermal space heating coincide with city zoning?

How will temporary communities be set up in uninhabited development areas, and how will they be managed?

C. Community Involvement and Public Perception Issues

(H) Many small towns have relatively unsophisticated planning capabilities. Will a local community be able to adequately plan for the changes which development would bring?

(H) How will development affect cultural identity in the locale being developed? Are changes in cultural identity or community self-image necessarily good or bad?

(H) Public perceptions of geothermal development are uncertain and nebulous. What is the relationship between this uncertainty and the overall "climate" towards development in Oregon?

What social and political conflicts may occur locally with exploration, construction, and development? Would a community react adversely to an influx of outsiders? The outsiders to the community?

Would a community have greater control over a resource best suited for power production or direct-use?

How would local political structures have to change to adequately manage the new industry and community changes it would bring?

Would a community react adversely to a power plant proposal if the electricity cannot be shown to be of direct local benefit?

Can development be halted after deep-well exploration has proven successful?

How would geothermal development impact community self-sufficiency, independence, and security?

## III. SOCIOECONOMIC ISSUES BY REGION

Vale KRGA

A. List of Issues and Data Sentences

M-H/M-H* Cohesion and Conflict--How will geothermal development impact attitudes toward governmental activities and land use planning? Local sentiments strongly support local control and reflect concern about intrusion from outside governmental bodies.

H/M-L Land Use/Agriculture--How will geothermal development impact existing agricultural and grazing activities? Some agricultural activities are highly dependent on irrigation and access to grazing lands. Geothermal development (and/or increased water-dependent agricultural processing associated with geothermal development) could impact water rights and distribution and water availability. A related potential impact is subsidence.

M-L/H Land Use/Recreation--How will geothermal development impact recreational activities? KGRA's near Vale are located on land used for recreation by local residents. Activities include hunting, fishing, and off-road vehicle use. Activities are highly dependent on fish and wildlife.

*See discussion of prioritizing system on pages E10-E11.

M/M Employment--How will geothermal development impact existing local labor market characteristics such as seasonal variation, dominance of agricultural skills, and vertical stratification (from landowners to migrant laborers)? Local labor force is highly dependent on agriculture and food processing. Existing levels of skill may not be sufficient to fill geothermal-related employment.

M-L/L Basic Values/Subcultures--How will geothermal development impact existing subcultural groups? Recent changes have had a major impact on the Basque community, and further development could impact the Mexican-American community.

L/L Population Dynamics--How will geothermal development impact current patterns of population change? Current patterns include a shift from rural to urban, outmigration of young adults, and settlement by former migrant agricultural workers.

L/L Basic Values/Rural Lifestyle--How will geothermal development impact the ability to preserve a rural lifestyle which is preferred by a segment of the population? Nearby areas, such as Ontario and Nyssa have grown rapidly, and this growth may impact lifestyle opportunities in the Vale area.

B. List of Data Sources

Summary of Background Reports, Malheur County Comprehensive Planning Office, Vale, 1977.

Appendix V ("Responses to Letter Soliciting Comment on Geothermal Leasing") of the Proposed Geothermal Leasing - Vale Addition Environmental Analysis Record includes some detailed comments on potential socioeconomic issues.

Western Cascades KGRA

A. List of Issues and Data Sentences

H/M-H Land Use/Wilderness Recreation--How will geothermal development impact adjacent National Forest Wilderness Areas (Mt. Hood, Mt. Jefferson, Mt. Washington, Three Sisters) and possible additions to these areas? A major concern of a segment of Willamette Valley residents has been protection of existing Wilderness Areas and potential additions to the Areas. Attention has often focussed on activities adjacent to Wilderness boundaries, because of potential visual and noise impacts and possible changes in Wilderness use (for example, improved road access increases trail use of adjacent areas). Although the obvious major issue would be geothermal development activity within the Wilderness Areas, potential impacts from adjacent lands is also an important concern.

M-H/M Land Use/Dispersed Recreation--How will geothermal development impact use of non-Wilderness forest lands by motorized and nonmotorized recreationists? Breitenbush and Mt. Hood areas receive heavy recreational use from Willamette Valley residents. Uses include the full range of forest recreation--hunting, fishing, hiking, camping, driving for pleasure, and off-road vehicles. Areas are adjacent to non-Wilderness Roadless Areas which offer Wilderness-type recreation. Geothermal activities (road construction, machinery movement, powerline rights-of-way) may parallel those currently associated with timber harvest and power transmission, and these impacts may be seen as an increase of activities which already exist in parts of the area. Other geothermal impacts (high noise level, steam plumes, pipeline rights-of-way) will be new to recreational users of the area and may have additional impacts.

M/M-H Cohesion and Conflict--How will geothermal development impact the complex network of governmental and private landowners in the area? The Breitenbush area contains an especially complex mix of ownerships and responsibilities. Existing hot springs are on both Forest Service and private lands. There are a number of long-standing mineral claims on Forest Service lands. There are also Summer Home Permitees on Forest Service land. The Forest Service is responsible for management of nearby Wilderness Areas, although the Corps of Engineers and the Oregon State Parks have recreational interests associated with the Detroit and Green Peter Reservoirs.

M-L/M Land Use and Symbolic Meanings/Thermal Resort Recreation--How will geothermal development impact recreational use and facilities at Breitenbush and McKenzie areas? Existing resorts have special historic meaning for many people in the Willamette Valley, and have only recently begun to attract increased recreational use (the Belknap area in the McKenzie Valley is undergoing renovation). The relationship between geothermal development and the future of these areas is complex. Their symbolic meaning suggests that issues could emerge if their existence was threatened by geothermal development. Existing recreational use is low, but could increase with additional investment in the facilities. However, it is also unclear whether a major expansion of recreational use would be favored by the public (or, perhaps, even by the current owners of the areas--McKenzie and Breitenbush both have a complex mix of public and private ownership).

M-L/M-L Community Services--How will geothermal development impact the provision of services in North Santiam communities (Detroit, Mill City, etc.)? The existing service base has been changing with some decline in forest products employment and some increase in tourism. Potential impacts related to geothermal development therefore depend on the scope of development. For example, inmigration could "replace" some of the population decline associated with forest products.

M/L Employment--How will geothermal development impact existing forest products-dependent employment? Potential impacts are complex. Former forest products workers could probably not readily move into specialized power-related employment, although they might fill transitory construction jobs. An indirect employment impact could occur where geothermal development influenced levels of timber harvest.

B. List of Data Sources

A Comprehensive Land Use Plan for the Minor Development of Blue River, Lane County Department of Environmental Management, Eugene, Oregon, 1975.

Corps of Engineers' studies on Detroit and Green Peter Dams.

Corps of Engineers' studies on Struble Dam expansion and Operation and Maintenance of Cougar Dam and Reservoir. (McKenzie Area)

Geothermal Development: Breitenbush Area, Final Environmental Impact Statement, U.S. Forest Service, Eugene, Oregon.

Hogg, Thomas C. and Courtland L. Smith, Socio-Cultural Impacts of Water Resource Development in the Santiam River Basin, Water Resources Research Institute, Oregon State University, Corvallis, Oregon, 1970.

Oil and Gas Leasing: Upper Willamette Environmental Analysis Record: Eugene District and Salem Resource Area, Bureau of Land Management, Eugene, Oregon.

Smith, Courtland, L. and Thomas C. Hogg, "Benefits and Beneficiaries: Contrasting Economic and Cultural Distinctions," Water Resources Research, 7, April, 1971. (Santiam Area)

Wilen, Richard N., The McKenzie Valley, A Social Situational Analysis, Willamette National Forest, Eugene, Oregon, 1977.

Additional data may be available through Lane County and the Lane Council of Governments, Eugene, The Mt. Hood National Forest, Portland, may have additional data on the Breitenbush Area.

High Cascades

A. List of Issues and Data Sentences

M-H/M-H Symbolic Meaning/Land Use/Recreation--How will geothermal development impact symbolic meanings and recreational use of Newberry Crater? The Newberry Crater-Paulina Lakes area has special significance for a segment of Central Oregon population, particularly in the Bend area. It is also an area of heavy recreational use and is adjacent to the LaPine area, which has extensive recreational home development.

M/M-H Land Use/Recreation--How will geothermal development impact recreational use of Mt. Hood and Timberline Lodge? Mt. Hood National Forest is the major forest recreational area for Portland area residents. The area receives heavy summer and winter recreation use, by motorized and nonmotorized recreationists. It has been the setting for several major environmental conflicts, such as those relating to ski facilities, Timberline Lodge (and parking at the Lodge), the Bull Run Reservoir, and trail preservation. The public visibility of such conflicts suggests that the area is carefully watched by a politically active segment of urban residents.

L/M-H Basic Values/Subcultures--How will geothermal development impact the Warm Springs Reservation? A number of issues could emerge if geothermal activities occur on the Reservation or if Indian water rights are directly or indirectly impacted. Additional issues include potential impacts on Reservation economic activity (tourism and forest products) and coordination with multiple governmental units.

B. List of Data Sources

Note: The following sources refer to the Mt. Hood and Warm Springs areas. The Newberry Crater/Paulina Lakes area data sources are those relating to Bend and Deschutes County and are listed in the section on the Brothers Fault Zone.

Comprehensive Plan, Warm Springs Community, Confederated Tribes of the Warm Springs Reservation of Oregon with technical assistance from Cornell, Howland, Hayes and Merryfield-Hill, Portland, Oregon, 1971.

Comprehensive Plan, Warm Springs Reservation, (same citation as above), 1968.

Summary: Critical Energy Issues for the CRAG Region, Columbia Region Association of Governments, Portland, 1976.

Timberline Lodge management has been the subject of extensive study and impact assessment by the Mt. Hood National Forest.

Additional data may be available from the Columbia Region Association of Governments (CRAG), Portland.

Brothers Fault Zone

A. List of Issues and Data Sentences

L/M Economic Base--How will geothermal development impact grazing and related agricultural activities? The area is sparsely populated, and the main economic activity is ranching.

L/M-L Land Use/Recreation--How will geothermal development impact tourism and recreation? The contribution of tourism to the economy is generally limited to businesses which are dependent on U.S. 20 traffic. However, hunting and rockhounding are important recreational activities which could be impacted by geothermal development.

L/M-L Community Services--How will geothermal development impact the provision of services in adjacent settlements (Hampton, Riley) and larger towns located some distance from potential geothermal resources (Burns, Bend)? The area is located roughly mid-way between Burns and Bend, and the only concentrations of population between these towns are found in small settlements. Thus, any increased activity would probably impact these small settlements, although the existing level of services is such that basic services (perhaps including housing) would be sought in Bend or Burns.

B. To the extent that issues involve Bend and Deschutes County, the following data sources may be helpful:

Bend Area Comprehensive Plan, Patterson, Langford, and Street, Medford, 1976.

Central Oregon Open Space Recreation Study, Central Oregon Intergovernmental Council, Redmond, 1974.

Deschutes County Overall Economic Development Plan, Central Oregon Intergovernmental Council, Redmond, 1976.

Deschutes County Overall Economic Development Plan, Deschutes County Economic Development Committee, Redmond, 1976.

Wilen, Richard N., Social Impact Analysis, Deschutes National Forest, Deschutes National Forest, Bend, 1977.

La Grande KGRA

A. List of Issues and Data Sentences

M/M-H Economic Base--How will geothermal development impact processing of forest and agricultural products (potatoes)? Much of the area's produce is exported in raw form--geothermal development could impact local food processing and lumber drying.

M/M-L Community Services--How will geothermal development impact the ability of smaller communities, such as Cove, to provide services in response to a temporary influx of construction workers? The Hot Lake Hot Springs area is adjacent to the small town of Cove--direct heat applications would probably be utilized locally rather than in the county's largest community (La Grande) some 15-20 miles away.

H-H/L Cohesion and Conflict--How will geothermal development which is water-dependent (greenhousing) impact existing water rights? Water rights are important to the area's dependence on agriculture.

L/M Land Use/Recreation--How will geothermal development impact existing hot springs resorts? Although the primary recreational activity in the area is oriented more to forest lands, intensive geothermal development could impact the operation of existing hot springs resorts, some of which are also capable of non-recreational geothermal uses (greenhousing).

L/M Basic Values/Subcultures--How will geothermal development impact existing cultural homogeniety of area? Relative isolation of area and reliance on traditional resource-dependent economic base (forest products and agriculture) have led to a higher degree of cultural homogeniety than is found in other areas, such as Bend and Ontario --geothermal-related immigration could impact this homogeniety.

B. List of Data Sources

Alternative Growth Futures for Union County, Oregon, Oregon State University Extension Service, Corvallis, 1977.

City of Cove Land Use Plan, Blue Mountain Intergovernmental Council, Enterprise, 1975.

Cove Area Land Use Plan, Blue Mountain Intergovernmental Council, Enterprise, 1975.

Economic Effects of Future Growth Alternative in a Rural Oregon County, Oregon State University Department of Agricultural and Resource Economics, Corvallis, 1976.

The Other Side of the Mountains: A Statistical Handbook of Northeast Oregon, Eastern Oregon Community Development Council, La Grande, 1975.

Profile of a Rural Growth Center: Union County, Oregon, Oregon State University Extension Service, Corvallis, 1977.

Twelve Decades: The Historical Context of Developmental Decisions, La Grande, Oregon, University of Oregon Bureau of Governmental Research and Service, Eugene, 1970.

Union Area Land Use Plan, Blue Mountain Intergovernmental Council, Enterprise, 1975.

Economists and sociologists at Eastern Oregon State College have worked with the U.S. Forest Service on a study of ranching life-styles in the Hells Canyon area.

Alvord KGRA

A. List of Issues and Data Sentences

H/H Symbolic Meaning--How will geothermal development impact the symbolic meanings of the Steens/Alvord area which are strongly felt by urban Oregonians, most of which have not actually visited the area? With heavy recreational use of areas (Cascades) which are closer to Willamette Valley urban areas, attention has turned to less populated, less developed areas, such as the Steens Mountains and Alvord Desert. While not having the heavily forested and high alpine characteristics of the Cascades, these areas are increasingly perceived as having high symbolic significance and therefore meriting special protection from development.

H/H Community Services--How will geothermal development impact what is currently an essentially uninhabited area? With the exception of the small settlement of Fields, and the community of Burns, there are no community services in the area. Even small-scale exploratory activity would require temporary "camp" facilities.

H/H Land Use/Recreation--How will geothermal development impact recreational use of the area and existing relationships between recreationists? Recreational use of the Alvord Desert is "light" by usual standards, although the environment is very fragile. Use of the Steens Mountains, adjacent to the Alvord and an integral visual and symbolic part of the Alvord, is moderate, but heavily concentrated by existing roads and camping and hunting facilities. Steens/Alvord area is also the focus of conflict between recreationists along dimensions such as roaded vs. non-roaded travel, off-road vehicles, possible Wilderness Area designation, appropriateness of large hunting encampments, and permissible levels of hunting activity.

H/H Population Dynamics--How will geothermal development impact the distribution of population within the area? In an essentially unpopulated area, any temporary or permanent location of new populations is likely to have an impact, even if they are "self-contained" with respect to community services.

H/M-H Educational and Scientific Activities--How will geothermal development impact use of the Alvord Desert for educational and scientific purposes? The hot springs, boiling mud pots, and rare species of fish represent a special resource which could be impacted by geothermal development. These features, in addition to other aspects of the fragile desert eco-system, could be impacted by geothermal development activities. Ecological impacts in the Alvord Region are, in general, more likely to become focal issues because of the special values associated with the fragile, non-renewable desert ecology.

M/M-H Cohesion and Conflict--How will geothermal development impact relationships between different resource interests and existing attitudes toward, and experience with, planning and management activities of different governmental units? The sparse population and rural, ranching lifestyle contrast with the government agencies (Bureau of Land Management), environmental organizations (Oregon High Desert Study Group), and private commercial organizations (absentee ranch owners) which are intensely interested in the future of the area.

B. List of Data Sources

Personnel at the Malheur Field Station may be an additional data source. Data may also be available from the Southeast Oregon Council of Governments, Vale.

Archeaological study teams which have carried out summer field programs in the Alvord may be an additional data source.

Southern Basin (Klamath Falls and Lakeview)

A. List of Issues and Data Sentences

Special Note: Socioeconomic issues in this Region reflect very different circumstances than in the remainder of Oregon. First, a history of geothermal domestic heating in Klamath Falls means that public concerns and lack of knowledge about geothermal resources are less likely to be an issue. This is less the case in Lakeview although even there it appears that the type of geothermal development (district heating and industrial use) will probably be similar to that of Klamath Falls. Secondly, development in Klamath Falls, and to some degree in Lakeview, is occuring in a relatively urban setting, which means that issues related to recreational lands and the placement of workers in a rural setting are less likely to emerge.

H/M-H Economic Base--How will geothermal development impact the economic base of Klamath Falls and Lakeview? In both areas, direct heating applications could assist the traditional forest products industry as well as provide the incentive for diversification.

M-H/M-H Land Use/Urbanization--How will geothermal development impact patterns of residential, commercial, and industrial land use? Direct heat applications, and, more importantly, the formation of heating districts could have an impact on land use patterns, to the extent that, for example, property users prefer to locate in areas served by geothermal resources.

M-M-H Community Services--How will geothermal development impact community services in Lakeview and Klamath Falls? Potential impacts in Klamath Falls center on waste water disposal, while those in Lakeview could involve a greater range of impacts on community services, should geothermal development stimulate economic expansion and inmigration.

M/H Symbolic Meaning--How will potential reductions in reservoir temperature and hot spring flow impact public percpetions of geothermal resources? Klamath Falls is an interesting situation because some residents already believe that individual and multi-family wells have impacted hot springs and that the potential for pollution of underground freshwater sources through reinjection is high. It is the experience with geothermal heating in Klamath Falls which makes it unique, and common understandings and perceptions of existing impacts on the resource could be an issue impacting future development, particularly where the development is an increase in scale and ownership (from single- and multi-family household heating to central heating district use by downtown offices).

M/M-L Cohesion and Conflict--How will geothermal development impact patterns of intergovernmental cooperation? Facility siting, pipeline location, and federal funding are all issues that involve several different governmental units. Although both areas have experience with federal agencies (U.S. Forest Service, airbase at Klamath Falls), increasing federal involvement in direct heat development (heating districts) may require new types of intergovernmental involvement.

B. List of Data Sources

The Klamath County Economy: Status and Prospects, Oregon Employment Division, Salem.

Klamath Falls Hot Water Well Study, Oregon Institute of Technology, Geo-Heat Utilization Center, Klamath Falls.

Klamath County Overall Economic Development Plan, Klamath County Economic Development Association, Klamath Falls.

Summary Development Plan, Klamath Falls Central Business District, Klamath Falls Planning Department, Klamath Falls, 1975.

The Geo-Heat Utilization Center, Oregon Institute of Technology is an important data source and depository.

Both the Fremont (Lakeview) and Winema (Klamath Falls) National Forests have personnel (cultural resource specialists, cultural geographers) who could provide additional data sources.

Studies of the proposed Pelican Butte Ski Area may include additional socio-economic data.

## IV. SIX HIGH PRIORITY SOCIOECONOMIC STUDIES

This section briefly describes six socioeconomic studies which could focus on different aspects of geothermal development in Oregon. All six are judged high priority, since the existing information base is very weak. However, we have also prioritized the six (see Figure 2), and indicated their relative applicability to different geographical areas within the state. The prioritization of the study was a "forced choice" ranking, and all six were ranked. However, it should be noted that all six are seen as priority studies; the ranking therefore provides an additional ranking of high priority studies.

The "titles" of the studies are as follows:

- Public Perceptions of Geothermal Development and the Symbolic Meaning of Special Places
- The Economics of Geothermal Development in Oregon
- Geothermal Development and Dispersed Wildland Recreation--Levels of Compatability and Conflict
- The Applicability of the "Boom-Bust" Cycle to Geothermal Exploration and Development in Oregon
- The Role of Geothermal Development in the Maintenance of Resource-Dependent Industries in Smaller Communities
- Domestic and Community Geothermal Heating Applications: The Case of Klamath Falls, Oregon

### Public Perceptions of Geothermal Development and the Symbolic Meaning of Special Places

This study would address two major issues. First, what are public perceptions and understandings concerning potential geothermal development in Oregon? Diverse segments of the public currently hold "images" of what they know about geothermal development, and, more importantly, will act in terms of those images on public questions relating to geothermal development. As mentioned elsewhere in this report, many features of geothermal development fall into the categories of "new" and "unknown" for most Oregonians. Oregonians are familiar with, and can understand changes in the scale of, natural resource activities such as timber harvest, hydroelectric power, transmission lines, and power generating facilities located at hydroelectric sites or in large urban areas (Portland, Eugene). They are less familiar with large drilling rigs, generating facilities located in rural areas (such as might be utilized at geothermal well-heads), and pipelines. While familiarity does not mean approval or acceptance, it is nonetheless important to obtain some information on the images and understandings currently held by diverse segments of the public in Oregon.

The second major issue which should be explored by this study is, what public

FIGURE 2. Prioritization and Area Applicability of Six High Priority Socioeconomic Studies

| Study | Issue Priority* | La Grande | Vale | Alvord | Brothers | Klamath Falls | Lakeview | High Cascades | Western Cascades |
|---|---|---|---|---|---|---|---|---|---|
| | | Area Applicability+ | | | | | | | |
| Public Perceptions | 1 | L/M | M/H | H | M | L | M/H | H | M/H |
| Economics of G-T | 2 | L/M | H | L | L | M | H | L/M | L/M |
| "Boom-Bust" | 3.5 | L/M | H | S | S | L | M | S | M |
| Recreation Impacts | 3.5 | L/M | M | H | M | L | M | H | H |
| Industry Maintenance | 5 | M | H | L | L | M/H | H | L | L |
| Domestic Heating | 6 | M/H | M | L | L | H | M | L | L |

*Prioritized in terms of issues which could impact the development of geothermal resources in Oregon

+Ranked in terms of applicability of study to specific areas: H--high, M--medium, L--low. (S--special situation, in which general topic of study may not be applicable to present situation in area, or where potential development would probably be severely constrained by site characteristics, such as geographical isolation.)

perceptions relate to potential impacts on places which are the focus of strongly held "symbolic meanings"? With respect to these places, symbolic meanings are perceptions, attitudes, or beliefs that are attributed to special characteristics of a place, even though the individual may not have visited the area and may hold what others may perceive as "incorrect" images of the same place. This is a particularly important issue for geothermal development. For example, some persons at the Portland workshop were perplexed at why the Newbery Crater area near Bend had so quickly been removed from consideration as a potential geothermal site. Someone else mentioned that probably 7-10 months of any typical scenic calendar devoted to either the Cascades or "famous" Oregon scenes would show possible areas for high elevation (or, in the case of Alvord, desert) geothermal exploration. It is especially important to study this issue in conjunction with the first issue (public perceptions of potential geothermal development) since public concerns about geothermal development will apply currently held understandings of possible impacts to strongly held symbolic meanings attributed to those special places considered for development activity.

The Economics of Geothermal Development in Oregon

Although several of the other priority studies have obvious economic components, a study which would give special attention to economic aspects of geothermal development is especially important. Among the many economic issues which might be investigated, the following appear to have the highest priority:

1. What are the economic advantages (benefits) and impacts (costs) of geothermal energy in comparison with alternative sources of energy available to Oregonians? This comparison would involve both existing (hydro, fossil, nuclesr) and future (solar, methane, wood fiber) sources. This comparative question also includes contrasts between those energy resources available within the state and those which must be "imported" from elsewhere.

2. How are the economic benefits and costs of geothermal development to be distributed among potential client and consumer groups? This question includes consideration of payment and distribution of royalties or profits, appropriate taxing policy, ability of local consumers (industrial, commercial, and residential) to benefit from localized geothermal development, and payment of development-generated local economic impacts.

3. What are the labor force and other employment impacts of geothermal development in Oregon? Although some matters related to this question could be covered in other studies ( boom and bust, maintenance of existing industry), an issue which is certain to demand study is the impact on employment. This is a particularly sensitive issue in those areas, many, if not all, where wood products employment

faces continuing instability and automation. (This is characteristic of many communities adjacent to KGRAs, such as Klamath Falls, Lakeview, La Grande, Lebanon, Sweet Home, Burns, and Bend). Matters which should be investigated by this study include potential transferability of existing skills into geothermal-related employment, impacts on patterns of labor organization (unions), required job training and retraining, and impacts on traditional intra- and intergenerational occupational mobility.

As with the other studies, the economic study must be placed within the current situation in Oregon. The economics of the energy situation in Oregon include a number of special features which are relevant to potential impacts of geothermal development. These include heavy reliance on hydroelectric power, which, together with use of wood fiber, give the impression of potential "state self-sufficiency" in energy production, concentrated energy-intensive industries, which are often the major industry in the community (aluminum production in The Dalles, Troutdale, heavy metals production in Albany), and a mix of public and private utilities, with continuing pressure in the major metropolitan area (Portland) for conversion to public utilities. An additional related factor is the very diverse and complex impact of the Trojan Nuclear plant and the proposed complex at Pebble Springs.

Geothermal Development and Dispersed Wildland Recreation--Levels of Compatability and Conflict

Several issues surround the potential conflicts between geothermal development and outdoor recreation. Although some questions focus on impacts at established geothermal resorts (Breitenbush, LaGrande), most relate to dispersed recreation away from highly developed campsites. This type of recreation is both motorized and non-motorized, and includes areas such as the Alvord Desert, designated Wilderness Areas and adjacent lands, and other areas (usually administered by the U.S. Forest Service or the Bureau of Land Management) which have only primitive road development or are currently roadless. The areas which might be impacted by geothermal development are very diverse, as is the recreation clientele which utilize the areas. A study is needed to begin to assess degrees of relative compatability and conflict between geothermal activities and dispersed outdoor recreation. In some of the Western Oregon areas the major nonrecreational activity is timber harvest. Some of the timber harvest activities may be similar to those associated with geothermal development (road construction and trucking) while others are less parallel (establishment of a drilling site). The study could begin with an examination of existing research related to timber harvest, and then move to examine parallels and contrasts with geothermal development. Of particular interest would be relationships between development and recreation at those higher elevations (generally above 6000 feet) where timber harvest activities do not occur.

The Applicability of the "Boom- Bust" Cycle to Geothermal Exploration and Development in Oregon

Many of the most pressing socioeconomic issues center on the extent to which geothermal exploration and development (and eventual decomissioning) will be accompanied by the "boom-bust" cycle which has been associated with other types of intensive energy development. This is an especially important issue for Oregon since many, if not most, of the geothermal sites are located in isolated rural areas for which the nearest "urban" center is a small, typically one-industry community.

Because there is a rapidly growing research literature on energy-related boom-bust cycles,* much of the effort in this study could be directed toward exploring the relative applicability of known boom-bust situations to potential geothermal development activities in Oregon. Attention should be directed to the scale and scope of exploration activity, associated employment and infrastructure impacts, and the extent to which geothermal exploration and development can be integrated with existing community lifestyles.

This study should be of particular interest to rural and small town people. (The study on the compatability with dispersed outdoor recreation would be of special interest to urban populations.) While communities on the "receiving end" of such cycles do not necessarily face uniformly negative impacts, much of the uncertainty accompanying new developments flows from questions relating to costs of providing services, impacts of population growth, potential conflict with differing lifestyles and values associated with the new development, and community stability after the boom is over. These questions are central to any investigation of boom-bust potential and are of special importance for considering geothermal development in areas which still await their first boom.

The Role of Geothermal Development in the Maintenance of Resource-Dependent Industries in Smaller Communities

Whereas major changes in energy supply, such as construction of a nuclear or fossil fuel plant, may, in turn, stimulate changes in the industrial base of adjacent communities, there are several interesting cases in Oregon in which locally based, direct heat geothermal development may facilitate the continuation of existing resource-dependent industry. Wood products, in Lakeview and Klamath Falls, and food processing, in Vale-Ontario, are both somewhat energy-intensive, and therefore could benefit from development of local alternative heat sources.

This is a high priority study because it addresses some of the problems facing small communities which are dependent on several large resource-dependent industries. Although it is obvious that energy cost is only one of the many

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*See Cortese and Cortese (1978) and Little and Lovejoy (1977).

factors which may threaten the future of the existing industrial base in these communities, locally available direct heat resources may have significant short-term (20-30 years) impacts and may provide more time for these communities to strengthen their industrial base. The usual response of resource-dependent communities has been to seek a new economic base, and this, in turn, may have a major impact on lifestyles associated with the traditional economic base. Geothermal development in areas such as Lakeview and Vale-Ontario may have the opposite effect, to the extent that it reduces energy costs for major resource-dependent industries and thereby sustains existing lifestyles.

Domestic and Community Geothermal Heating Applications: The Case of Klamath Falls, Oregon

From a socioeconomic perspective, Klamath Falls is an ideal site for an integrated study of the impacts of household and community heating applications. The situation is particularly intriguing because many households in the community have for many years drawn heat from single- or multi-family wells.* More recently, a community system is under construction to provide heat to a core of downtown buildings.

One of the key issues in the discussion of "energy alternatives" is the extent to which they offer the possibility of community (small-scale hydroelectric or wood fiber generating facilities) or even household (solar) "self-sufficiency." There are obviously a number of economic, social, and psychological issues related to relative community and household energy self-sufficiency, and the Klamath Falls case provides an exceptional opportunity to investigate two major questions. First, what is the impact of existing single or multiple family heating self-sufficiency on household expenditures, energy consumption patterns, attitudes toward energy and energy alternatives, and household "well-being"? Second, what is the impact of the development of a community heating system on households which have existing geothermal heating and on those households within the same community which do not have geothermal heating? This second question addresses the interrelationship of geothermal heating to other energy resources within a community, and is especially appropriate for the Klamath Falls situation because of the segment of the community which already has geothermal heating.

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*Some of these issues may have been addressed in the report titled Klamath Falls Hot Water Well Study, Oregon Institute of Technology, Geo-Heat Utilization Center, Klamath Falls, (no date).

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## VI. SUMMARY

This brief summary lists and prioritizes statewide and area-specific social and economic issues related to potential geothermal development, provides an overview of the state of knowledge concerning these issues, and outlines six social and economic studies which might be undertaken. The issues identified (both in this summary and in the Appendix on socioeconomic issues) range from the usual economic variables, such as employment and income, to standard "socioeconomic," community service concerns commonly associated with "boom-bust" cycles, as well as social and cultural issues which, though less susceptible to quantitative analysis, merit detailed consideration because they may form the basis for strong and sometimes emotional opposition to new "unknown" aspects of geothermal development.

Eight high priority statewide issues were identified (see Summary Table 1 and the more detailed discussion in the appropriate Appendix). Underlying these issues is the fundamental question of public perceptions of the potential "trade-offs" involved where geothermal development occurs in sparsely populated undeveloped or primarily agricultural areas. Unknown (in the mind of the public) geothermal impacts are weighed against known agricultural and recreational uses of rural lands, especially those unique areas which contribute to the "Oregon image." Other issues focus on potential community impacts, possible "boom-bust" cycles, and fiscal and tax consequences and changes in the local labor force. These issues are statewide in the sense that they tap matters of concern in many Oregon communities.

Summary Table 1 also lists priority issues for seven areas within this state. As expected, some statewide issues are also of special importance in certain localities. How these issues might emerge on geothermal developments obviously depends on factors such as pre-existing social and economic conditions, local experience with energy and other natural resource development and both the perceived and likely scale and timing of geothermal development. In terms of the general types of issues and their likely constituencies, the seven areas fall into two categories. Four of the areas, Western and High Cascades, Brothers and Alvord, are sparsely populated, with significant actual or potential recreational use, and have important symbolic value to predominately urban populations. Socioeconomic issues which emerge in response to geothermal development in these areas will be similar to other "classic" environmental or preservation issues which stress recreation, scenery and "unspoiled" areas. In contrast, issues in the other three areas (Vale, LaGrande and Klamath Falls) are more similar to controversies over planning and zoning, economic growth, and governmental involvement in local affairs. Constituencies are thus more likely to be local and reflect the concerns of small towns.

Are there issues which very probably will halt geothermal development at a particular site? One can conclude from the prioritizing in this report that some issues are more likely to attract public attention or crystallize public opposition. On the other hand, many state and local environmental controversies are triggered by issues which, although initially judged as relatively unimportant, bring forth a politically potent response from a mobilized public. Thus, a low priority issue could escalate into a major controversy in which, through the joining of a minor issue with more important concerns and an expansion of the involved public, geothermal development is delayed or halted.

A general assessment of the state of knowledge concerning social and economic issues related to geothermal development (especially in Oregon) is that although there is a growing literature concerning a variety of such impacts, there is little systematic information on either potential social and economic impacts of geothermal development in Oregon, or general data on the issues identified as important for such development in Oregon. The Appendix reviews data sources and existing materials. The several socioeconomic studies of geothermal development elsewhere typically concentrate on the usual economic and community infrastructure variables, and only indirectly explore other social and cultural issues. While studies of those Oregon communities with some geothermal experience (Vale-Ontario, Klamath Falls) could provide valuable information, there have been only limited efforts to obtain detailed socioeconomic impact data.

It would be foolhardy to predict that geothermal development in Oregon will proceed without the emergence of some public opposition. While many environmentally conscious Oregonians may be attracted by positive features of such development, issues concerning a variety of impacts and public perceptions (and misperceptions) of the major stages of geothermal development are likely to generate public controversy. Although a prior understanding of likely issues does not automatically minimize such conflict, a commitment to engage in studies directed toward such issues may facilitate public understanding of geothermal development. Six high priority socioeconomic study topics emerged as part of the identification of key socioeconomic issues. The following listing is further prioritized in terms of statewide interest. (Section IV of the Appendix on Socioeconomic Issues provides additional detail and a prioritization by geographical area.)

- Public Perceptions of Geothermal Development and the Symbolic Meaning of Special Places (Highest Priority). This study would examine public perceptions and understandings concerning potential geothermal development in Oregon and perceptions relating to possible geothermal impacts on places which are the focus of strongly held "symbolic meanings."

- The Economics of Geothermal Development in Oregon. Topics which could be addressed in this study include the economic advantages (benefits) and impacts (costs) of geothermal energy in comparison with alternative sources of energy available to Oregonians, alternatives for the distribution of economic benefits and costs of such development among potential client and consumer groups, and labor force and other employment impacts of the various stages of geothermal development.

- Geothermal Development and Dispersed Wildland Recreation--Levels of Compatability and Conflict. This study might explore several issues relating to potential conflicts between geothermal development and outdoor recreation, and examine parallels and contrasts with timber harvest impacts (probably the major non-recreational activity on Oregon timberlands).

- The Applicability of the "Boom-Bust" Cycle to Geothermal Exploration and Development in Oregon. Many community issues focus on the extent to which geothermal development will generate severe rapidly changing demands for community services. Contrasts with impacts associated with other types of energy development (gas and coal) may be useful.

- The Role of Geothermal Development in the Maintenance of Resource-Dependent Industries in Smaller Communities. This study would examine communities in which locally based, direct heat geothermal development may facilitate the continuation of existing resource-dependent industries, such as wood products and food processing. A closely related issue is the possibly favorable impact of geothermal development on local energy costs.

- Domestic and Community Geothermal Heating Applications: The Case of Klamath Falls, Oregon. A key issue in current discussions of "energy alternatives" is the possibility of community or even household energy self-sufficiency. Klamath Falls is an ideal site for an integrated study of the impacts of household and community heating applications.

Summary Table 1. Priority Social and Economic Issues*

| | Economic Issues | Recreation and Land Use Issues | Community Services and Public Perception Issues |
|---|---|---|---|
| Statewide Generic Issues (All H) | "Boom-bust" cycles<br>Oregon's energy self-sufficiency<br>Tax and royalty payments to local governments | Conflicts with agricultural uses<br>Aesthetic, historical, or symbolic land values | Community planning capabilities<br>Cultural identity<br>Public uncertainties |
| Vale | Coordination with irrigated farming and grazing access (H) | Local recreational use (fishing, hunting, ORVs) (H) | Community planning attitudes (MH) |
| Western Cascades | ● | Wilderness area impacts (H)<br>Coordination with dispersed recreation (MH)<br>Coordination with public and private landholders (MH) | ● |
| High Cascades | ● | Recreational use of Mt. Hood and Timberline Lodge (MH) | Symbolic meaning of Newberry and Paulina areas (MH)<br>Impacts on Warm Springs Indian Reservation (MH) |
| Brothers | ● | ● | ● |
| La Grande | Impacts on agricultural and forest products processing (MH) | Coordination with existing hot water rights (MH) | ● |
| Alvord | ● | Population growth and distribution (H)<br>Potential for increased recreational use and access (H)<br>Impacts on educational and scientific activities (H) | Symbolic meaning of Oregon desert (H)<br>Impacts on community services (H)<br>Lifestyle conflicts (ranching, farming, urban recreationists, absentee landowners) (MH) |
| Southern Basin | Impacts on community economic base (Lakeview and K Falls) (MH) | Coordination with urbanizing land uses (MH) | Impacts on community services (MH) |

* This summary lists only those statewide issues rated as high priority (H) and area issues rated as high (H) or moderately high (MH) priority. Many other issues were identified as meriting consideration, and these are discussed in the Appendix.

● No high or moderately high priority issues identified.

# Appendix A

## CONDENSED SUMMARY REPORT

Socioeconomic Subsession
OGEOS Workshop
March 28 and 29, 1979

The socioeconomic subsessions of the OGEOS Workshop were well attended with high sustained attendence over two days. A reconstructed list of attendees shows at least fifteen participants in addition to the subsession chairman, his associates, and LLL personnel who sat in on a portion of the first day's meeting. A significant range of interests and viewpoints was represented including utility and mineral exploration interests, environmental concerns, sub-state, regional perspectives, and various political and economic viewpoints. This variety led to healthy discussion and the fleshing out of a number of social and economic issues of potential impact to geothermal development in Oregon, but it also resulted in the lack of a consensus on the priority of the issues on a state-wide or regional basis. The cause of this disagreement--an inability to adequately conceptualize development scenarios for both direct-use and power production situations--represents a significant issue in itself.

It was decided at the outset that "socioeconomic" would be given a broad, inclusive definition for working purposes. The term was thus taken to indicate factors which have direct impact upon people, society, communities, political institutions, families, employment, taxes, and symbolic or cultural values. It was also necessary to distinguish between impacts related to exploration, direct-use, and power-production respectively. This distinction was difficult to maintain because of the difficulty in predicting where and in what manner sites will be developed.

Wednesday's subsession was devoted to the discussion of potential issues surrounding geothermal development in Oregon. Through the course of discussion five general categories of issues were identified: economic, political, recreational, land use, and other. Economic issues emerged from the points of view of (1) small town residents in eastern Oregon, (2) Willamette Valley residents, and (3) organized labor. Political issues centered on the potential impact of geothermal development on local decision-making processes, service sector capabilities, resource ownership and control, and community "image." The recreation, land use, and political categories are somewhat intertwined. Much has been said about how objections to geothermal development are largely "political," particularly when they are based on claims that wilderness areas are unsuitable for development. Rather than political, we consider this issue a land use conflict. When the issue concerns areas regularly used for recreational purposes (unlike wilderness areas), we consider this a recreational issue. Of course, our usage of the term political indicates public sector institutions and their domain rather than conflicts between opposing interest groups. Land use issues comprised three distinct types: (1) those related to resource control, ownership, and management, (2) those related to zoning in both urban and rural contexts, and (3) those related to areas of special, aesthetic value. It is worth noting that the issue of "visual pollution" was not brought out by the group. This problem is most likely linked to the more general issue concerning areas which are highly valued throughout the state for their special qualities or symbolic meaning. Both the Alvord Desert and Paulina (Newberry) Crater controversies reflect this issue. Other issues which did not easily fit into these categories included impacts on cultural identity and community self-image, the relationship between power production and energy supply and cost for adjacent communities (would local communities enjoy direct benefits of power production), and public perceptions and knowledge concerning geothermal development, energy trade-offs, and potential impacts. The specific issues in all of the above categories have been incorporated into the main report--they appear as part of the listing of statewide issues, discussion of six high priority socioeconomic studies, and the listing of issues for each of seven regions.

Thursday's subsession was devoted to both the attempted prioritization of these issues and the discussion of additional sources of data for research and bibliographic purposes (i.e., closing of data gaps). Two significant data gaps emerged. One is the lack of baseline economic and social data, appropriate for site-specific analyses, from various regions around the state. Input-output analyses, community profiles, and attitudinal studies are needed for modeling development patterns and socioeconomic impacts. Although the Oregon Land Conservation and Development Commission requires comprehensive land use planning on a local and regional level, there is still a shortage of reliable socioeconomic baseline data for much of Oregon. The group did suggest a number of studies which may be useful for the OGEOS.

The other data gap is also an issue in itself, and a contributing factor in many other issues as well. This is the lack of information on how geothermal development is likely to proceed in Oregon. In as much as this issue was responsbile for the disagreement on prioritization, it can be considered the single most important issue identified in the subsession. This issue is partly due to the difficulty in predicting site location and quality. It is also partly due to the fact that no site thus far developed is considered typical. In any case it seems to underlie other issues, is perhaps responsible for what have been called "perceived problems," and represents a need to inform the public of the parameters of geothermal development including the economic and environmental costs and benefits of both power production and direct-use applications.

Finally, it is clear that all of the issues should be addressed in a comparative framework, in which potential favorable and adverse impacts of geothermal are contrasted to those associated with nuclear and fossil fuel sources. Such an emphasis should also focus on the relative contribution of geothermal to Oregon's energy "self-sufficiency," in terms of the extent to which geothermal development could impact present and future expenditures for "imported" fossil fuels.

SECTION F

of the

# OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW STUDY*†

# NOISE ISSUES RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

by

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# NOISE ISSUES
# RELATED TO THE DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES IN THE STATE OF OREGON

## INTRODUCTION and SUMMARY

Present utilization of geothermal energy in Oregon is limited to four areas. Sources of hot water are used in each case. The wells used at present are shallow. The population in the areas varies from slight (Vale) to moderately dense (Klamath Falls). Noise problems during plant operation, after drilling operations and construction are complete, are almost nonexistent.

With the exception of the four regions of present hot water utilization, Klamath Falls, Vale, Lake County, and LaGrande, most of the area of current Oregon known Geothermal Resource Areas (KGRA's) are remote and presently used for summer homes and recreation activities. Exploration and test drilling in these remote regions may or may not be creating a noise problem for birds and animals that could reduce their use of present habitats.

Future sound problems resulting from the development of geothermal energy sources will be very dependent on what the present and future exploration and test drilling operations find. Hot water of the lower temperature sources presently being developed in Oregon has significant noise associated with exploration, test drilling, field development, and plant construction, but little with operation. The hoped for binary systems, flash steam systems, and dry steam systems each result in operational sound problems as well. The dry steam system is known to add extensively to the noise problem due to steam venting, the use of air drilling, and possible well blowouts.

The areas around Klamath Falls, Vale, Lake County, and LaGrande are sufficiently populous that the major receivers of sound from geothermal development activities are the people working on or near the sites or having homes nearby the well areas. People will, in these same capacities, be the receivers of sound from future development.

Even where the areas are presently remote, some amount of urbanization will be necessary during test drilling, field development, and facility construction. In cases where the water or steam will be used on site, some permanent urbanization will result.

During exploration and test drilling, sounds from the activities may prove disturbing to the present recreational uses. Where the areas are critical habitats for birds and animals, there could be permanent or long-term loss of these uses.

Sound levels resulting from geothermal energy field development facilities construction, and utilization are governed by federal regulations on geothermal development, state regulations on industrial noise. These each apply to ongoing projects and may apply to the project starting at different times during the project development.

Environmental assessments of a planned project are required by federal regulations which apply to federal lands only and possibly on state and private lands where federal money is to be used for development.

Much of the basis of this evaluation comes from the discussions during the workshop held on March 28, 1979. The report of this subsession[1] is on file with the Oregon Graduate Center for Study and Research. The following Issues/Recommendations are directly from that report:

1. Issues/Recommendations

   A. Inventories

      Issue is deficiency in present timing and process of the gathering of information on social and environmental systems.

      Recommendations include

      1. Early identification of

         a. Noise receptors

            1) Human

            2) Animal

               A) Fish and wildlife

               B) Domestic livestock

         b. Use areas

            1) Residential areas

            2) Recreational areas

            3) Sensitive habitats (breeding grounds, etc.)

            4) Migratory routes (land and air)

      2. Revisions in baseline requirements

         a. The time frame over which noise baseline data is to be gathered, i.e., one year, should shorten to a more reasonable time.

         b. Noise baseline data should be phased in at an earlier time than presently required, i.e., at full-field development state — which may be after considerable exploratory activity allowing up to four wells.

         c. Noise baseline data acquisition is in need of better definition.

   B. Mitigation of Impacts

      Issue is lack of recognition (in the literature and by other inquiry) of state-of-the-art in noise control.

Recommendations include

1. Application of existing technology in
   a. Cooling tower noise control
   b. Drilling noise abatement (rig enclosure, etc.)
   c. Site treatment and planning for noise reduction
2. Continued research in persistent problems, such as muffling of steam release.

C. Identification of Data Needs

Issue is outdated source level data in literature and reliance of public bodies and geothermal developers on this data.

Recommendation

Responsible public body, such as EPA, Office of Noise Control, should address the updating, publication and dissemination of current noise source data, including the noise sources attendant to exploration and construction phases.

Issue is inconclusive data on effects of noise on domestic animals, fish and wildlife, including birds.

Recommendation

Continue research in this area currently in research by Bonneville Power Administration and under grant by St. Mary's College, Moraga, California.

Further literature review is planned by this task force and will be reported in the conclusion to the study.

# NOISE SOURCES

## Dependence on Development Type and Phase

Geothermal energy may be developed for four basic types of uses depending on the temperature of the water or steam.[2,3,4,5]

1. Direct use of hot water called Hot Water Systems. Any surface temperature of water above ambient could be used directly to supply energy to an activity such as processing food, heat loss from occupied spaces, cooling occupied spaces, etc. Temperatures of 70°C or higher are needed to make the process useful on a large scale.

2. Use of the hot water to boil a secondary fluid which is to generate electrical power which is called a Binary System. This use would require surface temperatures in excess of 150°C where the boiling of the secondary fluid takes place.[3] Higher temperature will be needed to make the process economically feasible for relatively low energy cost areas such as Oregon.

3. Use of the flash steam obtained from water drawn from deep wells to generate electrical power usually called Flash Systems. Some flashing of water to steam takes place when surface temperatures exceed 100°C. Most evaluation of this system[3,5,30] put the lowest temperature for reasonable steam generation at 200°C.

4. Use of dry steam from wells to generate electrical power which goes under the name of Dry Steam Systems. Dry steam at any temperature can be used.

The development of a geothermal energy field can be broken down into four phases.[2,4] The first is Field Exploration and Proving. During this phase, potential areas of development are found and as many as four test wells may be drilled. The second is Field Development. This is the main well drilling phase. The third is Plant Construction. This is when the pumping facilities or the power generation facilities are constructed along with the extensive fluid delivery piping system. The fourth and last phase is Plant Operation. This is the phase which should be expected to continue for a number of years.

This division is not the only one possible but seems the most useful in examining the noise source and seems to best fit the major federal control regulations.[6]

The sources of noise from exploration activities are airplanes, trucks, engine generators, activities of crews living in area, and light drilling activities. During the proving part of this phase, heavier equipment is used and the sound levels from these activities can be expected to be higher and more prolonged. The extent of this phase may be from a few weeks to a number of years.[7]

The sources of noise during field development activities are the same as for the first phase but more activities will occur and larger power sources will be used. Air drilling may be used during this phase resulting in a substantial increase in sound levels. Air drilling has its major use in drilling in dry steam fields. It is therefore an unlikely method in Oregon. A well is operated to waste for proving and clean-out. In the case of dry steam, these operations can be extremely noisy. This activity is normally an on-going activity during the lifetime of the field and can exist concurrently with the next two phases. An upper limit estimate of as much as 8100 person-days of field development activity to fully develop a 200 MWe field can be made from data supplied from a government study.[7]

The facility construction phase is that during which the roadways, process factory, powerhouse, and living quarters may be constructed. The normal type construction sound can be expected. The extent of this activity depends on the size of the plant to be constructed but is limited in length by the completion of construction before the operation phase. Some on-going construction activity can be expected over the life of the field as roadway and fluid handling piping along with other construction may start with field development and continue as long as field development goes on.

The plant operation phase is the long term phase of operation. Noises peculiar to geothermal plants associated with this phase are running the fluid to waste for well clean-out and during plant outages. Normal plant sound such as those from the turbine-generator complex, steam jet ejectors, pumps, etc. will be present if the plant is not enclosed in a building. Cooling towers will be an important source of sound where low pressure is required for the generation of electric power. Another source of sound is the moving of workers and equipment on and off the site. These are the steady state sound levels to which the area will be subjected. The following table is presented to give a feel for some of the sounds encountered during different phases.

TABLE OF SOME TYPICAL SOUND LEVELS

| | Average Level @ 15.2 meters |
|---|---|
| **Drilling** | |
| Water Carrier[31] | 85 dbA |
| Air Carrier (No Steam)[31] | 88 dbA |
| **Construction** | |
| Trackers[11] | 88-96 dbA |
| Pile Drivers[32] | 101 dbA |
| Rock Drills[32] | 98 dbA |
| **Operation** | |
| Cooling Towers[13] | 69 dbA |
| Turbine Building[13] | 66 dbA |

## Existing Data

The literature contains a good deal of data on the sounds from planes, cars, and trucks used in exploration.[8,9,10] Data on drilling equipment is mostly on large drilling operations.[11,12,13] With some modifications, this data could be used for the well test drilling and proving during the first phase. Construction is limited during this phase but some road and living quarters must be constructed and maintained. Data on construction noise assessment[11,12] is readily available because such assessment has been a part of most Environmental Impact Statements for some years. Many of the past EIS's contain this data.

The drilling information[11,12,13] along with sound information on well blowouts, clean-outs, and test venting[12-15] is available in some detail. This along with the construction information, is sufficient to estimate the sound exposure of this phase.

The sound exposure estimates of the construction phase will not differ in the data used from any other assessment of construction sound. The data to be used for these assessments are readily available. While the present literature values differ from reference to reference, problems with this differing data can be avoided by selecting only that data that was taken in situations that exist and on equipment to be used on the project being evaluated. The large amount of data available allows such selection.

The operational phase, like the two phases that come before, will not always exist alone. Construction and field development will normally go on for most of the life of the field. Data on sound levels during plant operation[12,13,15] can be used to assess the sound level of exposure from plant operation and be combined with that of field development and facility construction to obtain an assessment of all sound exposures during this phase.

Required Data

The data for the above assessments, while found in many places in the literature, must be selected with care for that which will most closely apply to the situation and equipment being evaluated. The method of calculating the sound level exposures are well developed and as accurate, if not more accurate, than the data base to be used. The major need here is for the continued refinement of both the data base and the methods used. A report called Geothermal Handbook[4] gives a method of determining the time and extent of the use of equipment during each phase. This information can be used along with an assessment method used in the Bureau of Indian Affairs - Sherwood Uranium Project FEIS[17] to get the exposure of a given receiver at a given distance from the operation.

The best analysis will be no more correct than the source data used. Much of the present data dates back to the early 1970s. This was before any amount of work had been done on sound control. Reference 32 gives hoped for improvements in the sound from construction equipment. The Department of Environmental Quality has, and is, setting regulations on some construction equipment noise emissions. An effort needs to be made to update source data to include improvements that take place and to correct the present spread of data information.

# NOISE RECEIVERS

## Receivers Dependent on Area and Phase of Development

The receivers present will vary with the area or region being developed. In Klamath Falls, Lake County, LaGrande, and Vale, the receivers are the present population of people. The presence of people in these areas for long periods of time has most likely conditioned the animal and bird population that has remained, to noise and activity. A number of the possible areas in the Brothers Fault Zone, Cascades, and the Alvord Desert have had little or no exposure to human activities and the receivers are the animals and birds.

The phases of development will each bring the sounds and levels peculiar to that activity as discussed above. The extent to which the sounds may be a problem and the receivers that need to be considered must be related to the area. It is necessary, therefore, that an inventory of possible receivers and present noises be made before the activity starts. Great damage is possible to the present use of an area if an activity is started that will result in making that area unsuitable for that use. People and their needs must, of course, be of first consideration. But, if a desirable and irreplaceable recreational area is rendered unusable for that purpose, this should result from a considered and knowledgeable decision that a higher need is served that cannot be reasonably served otherwise.

## Receivers Common to all Areas

People are one of the receivers that will be common to all areas and development phases. People presently involved in the original area activities such as homes, camps, trails, and places of employment will be present to some extent in all of the areas. People associated with the geothermal development will also be present in all areas and development phases.

## Data That Presently Exists

Inventories of area use, people present, and the new people associated with the development are either known or can be readily developed.

Inventories of animals and birds along with the critical habitats and migratory routes of animals and birds are only known to a slight extent. Reference should be made to Ecosystems Workshop Report[18] and that section in this final report for information on this topic. For reasons noted later in this section, inventories of wildlife need to be made well before any extensive activities are started. This is especially true in areas that have not been occupied by people and in areas where critical habitats may exist.

There are presently a number of sources of information on the effect of sound on people engaged in certain activities such as sleeping, working, etc. Three of the more complete sources of this data are listed in the reference list.[8,19,20] The generally accepted protective sound level limits of an $L_{DN}$ of 55 for preventing task interference,[20] and $L_{DN}$ of 70 for preventing hearing loss,[20] and 80 dbA for work exposure to prevent hearing loss[19] and 90 dbA to stay within OSHA regulation limits[23] can be used for evaluating human exposure. Regulation could only be enforced where statute regulation or statute authorized regulation exist. These normally are higher than the above limits except for OSHA regulations which are statute authorized.

This type of information on animals and birds is very sparse. One text has recently been published that lists, reviews, and summarizes the present literature on this topic.[21] Many discussions of geothermal energy development make reference to possible problems with noise and animals but one EPA document[22] best summarizes these cautions:

> "These findings certainly suggest caution should be exercised in allowing sound intrusion into animal habitats, not only because of possible direct effects on animals themselves, but also on items in the food chain of the animal." (page 40)

The generally accepted protective sound levels are not known for animals and birds. The studies that exist on effects on animals are generally at levels at 60 dbA or above.[22] The EPA study[22] notes:

> "Clearly, the animals that will be directly effected by noise are those that are capable of responding to sound energy, and especially the animals that rely on auditory signals to find water, stake out territories, recognize young, detect and locate prey, and evade predators. These functions could be critically effected even if the animals appear to be completely adapted to the noise (i.e., they show no behavioral response such as startle or avoidance)." (pages 45-46)

The use of the normal descriptor for human response, dbA, may not be the best to evaluate animal and bird response as the frequency range perceived by animals and birds is much different.[21,22]

### Data Needed

Much of the data on animals and birds cited in the above section really shows more clearly what is needed than what is known. A good deal of study on the noise effect on wildlife is needed before the needed, considered, and knowledgeable decisions can be made on which area to enter and which needs to be held off limits to geothermal, or other type, development.

The sparsity of inventories noted in the Ecosystems section of this final report make it clear that we need a good deal of further inventory data before noise effects data could be used if and when it exists.

## SOUND PROPAGATION AND CONTROL

### Field Exploration and Proving

The sound levels of light and medium size airplanes and off-road vehicles are known. Once acceptable exposure limits are set, this data can be used to limit the exploration activities near especially critical habitats for animals and birds. Such a limit would not be necessary in most areas because of the limited time of such activity.

Test drilling with light rigs would increase the level of activity in a comparatively much more restricted area. Again, exposures could be calculated from known data and methods and a limit set for critical habitat if the data were available on which to establish that limit.

In each case the limit could be a time limit on present equipment with a longer time limit on specially sound treated equipment.

Baseline sound data would be necessary in setting such restrictions as there is good reason to believe that a level may only exceed the ambient by a given amount without adverse effects in some cases[22] for wildlife. This is true also for people and is made a part of the state sound regulations. Baseline data is necessary, in general, to prevent setting sound emission limits at or below ambients. Baseline data is needed before the activities start as it is not available after the activities are well along.

Field Development

The necessary information and methods are available to calculate or otherwise predict the sound levels from this activity. Normal sound control methods can be used to control the sound to levels consistant with the limits on human exposure. The exceptions to this seem to be well clean-out, steam venting, and well blow-outs.[11-13] These problems are not considered serious in liquid-dominated systems. Dry steam systems and high pressure water wells are not thought to be likely in Oregon. What would happen to critical habitats during this phase is not predictable at present.

Construction of Facilities

Sound control of construction equipment has a very long way to go before such equipment could be used in noise sensitive areas. An area exposed to these first three levels of development could be returned to any type of human use but it is uncertain if it could be returned to use by sensitive wildlife.

Operation

The operation of hot water use facilities will add little except increased human activity in the area. The operation of flash steam or binary systems will, in all likelihood, result in an increased sound level from the operation such as pumps, cooling towers, etc. The data and the methods of prediction are available for predicting sound levels for this phase.

# NOISE REGULATIONS

## Federal

The four major federal enabling acts are the following. Each supplies some means of control of sound from this type of field.

1. National Environmental Policy Act of 1969[24]

   - requires the EIS to address various parameters of noise pollution effects, including those of construction noise, as noted in Region X U.S. EPA "Guidelines to EIS Review"[25]
   - gives local authority (states and local governments) through Circular A-95[25] for EIS review, comment. State DEQ noise mitigation recommendations enter here

2. Geothermal Steam Act of 1970[6]

   - statutory authority for the enforcement of GRO Orders by the U.S. Geological Service
   - GRO Order No. 4 contains a specific noise limitation of 65 dbA maximum at the lease boundary or one half mile from the source
   - references adherence to all applicable state regulations, which by implication includes the Oregon Wilderness, Recreational and Scenic Areas[26] noise standard of 50 dbA maximum at 50 feet
   - statutory authority for the surface management agency (BLM or Forest Service) to require baseline study by the developer
   - the taking of animal and human inventories is an integral part of baseline assessments; noise impact analysis and prediction would rely on these inventories in the EIS report

3. Occupational Safety and Health Act,[23] amended

   - standards of limitation on noise exposure of work-place recipients

4. Noise Control Act of 1972,[27] amended

   - governs EPA source noise standards and includes review of Environmental Impact Statement by regional EPA noise representative

The one serious fault with the control from the four above sources is that the baseline studies for sound come after the Exploration and Field Proving Phase.

## State

The State Department of Environmental Quality has rules[28] on level of sound emissions that will apply during the Plant Operation Phase and can include drilling operations that go on as a part of energy production. The problem with DEQ regulations is that they apply only to residential property unless an area has been designated Quiet Zone.

The Oregon Nuclear and Thermal Energy Council State-Wide Siting Task Force Report[29] has set aside large areas as "Unsuitable" for power plants because of other uses. Noise was one of the reasons for this action.

These, along with the Wilderness Areas Rule[26] which limits sound sources in wilderness area to 50 dbA at 30 feet are the present state regulations.

## Local

There are at present no known local regulations.

# REFERENCES


1. "Report of the Noise Effect Subsession of Oregon Geothermal Environmental Overview Study Workshop;" by E. A. Daly and J. R. Egger; not published - on file with Oregon Graduate Center for Study and Research, April, 1979.

2. "Pollution Control Guidance for Geothermal Energy Development;" EPA 600/7-78-101; June, 1978.

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5. Geothermal Energy Utilization, by Edward F. Wahl; John Wiley and Sons, New York, 1977.

6. "Geothermal Steam Act of 1970 and Regulations on the Leasing of Geothermal Resources," Department of the Interior; August, 1977.

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8. "Highway Noise - A Design Guide for Highway Engineers," National Cooperative Highway Research Board Program Report 117, 1971.

9. "Manual for Highway Noise Prediction," by J. E. Wesler; Report No. DOT-TSC-FHWA-72-1, Transportation Systems Center, Cambridge, Massachusetts, 1972.

10. "FHWA Highway Traffic Noise Prediction Model," (Presently in draft only); FHWA-RD-77-108, U. S. Department of Transportation, December, 1978.

11. "Construction Education and Research Foundation Report Number 2, State of the Art in Noise," by E. A. Daly and M. B. Larson, Oregon State University Construction Education & Research Foundation, June, 1973.

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14. "An Environmental Overview of Geothermal Development: The Geysers-Calistog KGRA, Volume 3 - Noise," by P. Leitner, Lawrence Livermore Laboratory Report UCRL-52496, August, 1978.

15. "Factors Contributing to Annoyance By Geothermal Steam Venting Noise

at the Geysers," by R. R. Illingworth, Geothermal Environmental Seminar, 1976; Edited by F. L. Tucker and M. D. Anderson, Shearer/Graphic Arts, Lakeport, California, October, 1976.

17. "Sherwood Uranium Project-Spokane Indian Reservation, Final Environmental Statement," Volumes I and II, U. S. Department of Interior, August, 1976.

18. "Report of the Ecosystems Subsession of Oregon Geothermal Environmental Overview Study Workshop," by Sandra White and Dave White; not published, on file with Oregon Graduate Center for Study and Research, April, 1979.

19. "Public Health and Welfare Criteria for Noise," 55019-73-002, U. S. Environmental Protection Agency, July, 1973.

20. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety;" 50019-74-004; U. S. Environmental Protection Agency, March, 1974.

21. Effects of Noise on Wildlife; Edited by J. L. Fletcher and R. G. Busnel; Academic Press, 1978.

22. "The Effects of Noise on Wildlife and Other Animals;" NTID #300.5; U.S. Environmental Protection Agency, 1971.

23. Occupational Safety and Health Act (Public Law 91-596) Regulations, Federal Register, Volume 39, No. 207, pp. 37773-37778, October 14, 1973.

24. National Environmental Policy Act of 1970 - Amended 1979; Section 102 (2)(c) of PL-91-190.

25. "Environmental Impact Statement Guidelines," Circular No. A-95, U.S. Environmental Protection Agency, Region X, Seattle, Washington, 1973.

26. Oregon Administrative Rules, Subdivision 3, Wilderness, Recreational, and Scenic Area Rules, 1972.

27. Noise Control Act of 1972 (PL92-574); Amended 1976 and 1978.

28. Chapter 340, Oregon Administrative Rules, Division 35, Noise Control Regulations, 1977.

29. Oregon Nuclear and Thermal Energy Countil State-Wide Siting Task Force Report, 1974.

30. "Potential Environmental Issues Related to Geothermal Power Generation in Oregon," by R. D. Wimer, P. N. LaMori and A. D. Grant; The Ore Bin, May, 1977, Volume 39, No. 5; State of Oregon Department of Geology and Mineral Industries, 1977.

31. "Noise," by Philip Leitner; Environmental Control Technology for the Geysers-Calistoga KGRA, ILL/GRIPS Workshop, October 11-12, 1979.

32. "Noise from Construction Equipment and Operation, Building Equipment, and Home Appliances;" U.S. Environmental Protection Agency; December, 1971.

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APPENDIX 1. STEERING COMMITTEE MEMBERS

APPENDIX 2. WORKSHOP AGENDA

APPENDIX 3. WORKSHOP PARTICIPANTS

Appendix 1

## OGEOS STEERING COMMITTEE

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Appendix 2

# AGENDA

## OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW WORKSHOP

Willamette Center
2nd and Salmon
Portland, Oregon
March 28 and 29, 1979

<u>Wednesday, March 28th</u>

| | |
|---|---|
| 7:30 - 8:30 a.m. | Registration |
| 8:30 - 8:40 | Welcome and Opening Remarks<br>John Cooper, Oregon Graduate Center, Beaverton, Oregon |
| 8:40 - 8:50 | Geothermal Environmental Overview Projects: A Preliminary Assessment<br>Paul Phelps, Lawrence Livermore Laboratory, California |
| 8:50 - 9:10 | A Broad Look at Health and Environmental Issues Related to Geothermal Developments<br>Lynn Anspaugh, Lawrence Livermore Laboratory, California |
| 9:10 - 9:20 | Objectives of the Oregon Geothermal Environmental Overview Study<br>John Cooper, Oregon Graduate Center |
| 9:20 - 9:40 | Oregon Energy Perspectives<br>Michael Gainey, Oregon Department of Energy |
| 9:40 - 10:00 | Oregon's Geothermal Resource Areas - An Overview<br>Debra Justice, Oregon Institute of Technology |
| 10:00 - 10:20 | Break |
| 10:20 - 10:40 | Chemical Emissions from Geothermal Developments<br>John Evans, Battelle Northwest, Richland, Washington |
| 10:40 - 11:00 | Impacts on Water Quality<br>Leo Defferding, Battelle-Northwest, Richland, Washington |
| 11:00 - 11:15 | Noise Effects<br>Phillip Leitner, St. Mary's College, California |
| 11:15 - 11:30 | Air Effects<br>C. R. Molenkamp, Lawrence Livermore Laboratory, California |
| 11:30 - 11:40 | Pictorial Review of Geothermal Facilities<br>Richard G. Bowen, Geothermal Consultant, Portland, Oregon |
| 11:30 - 1:00 p.m. | Luncn |
| * 12:30 - 1:00 | Film: Imperial Valley Geothermal Environmental Study |
| 1:00 - 1:20 | Geological Effects: Seismicity and Subsidence<br>Neil Crow, Lawrence Livermore Laboratory, California |
| 1:20 - 1:40 | Ecosystems Effects<br>Phillip Leitner, St. Mary's College, California |
| 1:40 - 1:55 | Geothermal Development Forecasts for Oregon<br>Richard Bowen, Geothermal Consustant, Portland, Oregon |

* Optional

| | |
|---|---|
| 1:55 - 2:10 p.m. | Developer's View of Geothermal Energy in Oregon<br>Richard G. Benoit, Phillips Petroleum, Reno, Nevada |
| 2:10 - 2:25 | Environmentalist's Concerns for Geothermal Developments in Oregon<br>Elizabeth Frenkel, Sierra Club |
| 2:25 - 2:40 | Introduction to Workshop Discussion Groups<br>John Cooper, Oregon Graduate Center, Beaverton, Oregon |
| 2:40 - 3:00 | Break |
| 3:00 - 5:30 | Concurrent Subsession Discussions to Identify and Prioritize Major Environmental Issures<br>• Geological: Subsidence and Seismicity<br>• Socioeconomic Effects<br>• Ecosystem Effects<br>• Noise Effects<br>• Cultural Heritage (History, Archeology, etc.)<br>• Air Quality<br>• Water Quality |
| 5:00 - 7:30 | Open Cash Bar - Room 210, Riverside West Motor Hotel<br>50 S. W. Morrison Street, Portland, Oregon |

<u>Thursday, March 29th</u>

| | |
|---|---|
| 8:30 - 9:30 a.m. | Review of Previous Discussions by Group Leaders |
| 9:30 - 12:00 | Continue Discussion Groups<br>(a) Assess existing data base<br>(b) Identify data gaps<br>(c) Prepare discussion group reports |
| 12:00 - 1:30 p.m. | Lunch |
| 1:30 - 3:00 | Presentation of Discussion Group Reports by Group Leaders |

Appendix 3

## PARTIAL LIST OF ATTENDEES

## OREGON GEOTHERMAL ENVIRONMENTAL OVERVIEW WORKSHOP

| | |
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