POTENTIAL HYDROLOGIC EFFECTS OF DEVELOPING COAL AND OTHER GEOENERGY RESOURCES IN OREGON--A REVIEW

By William C. Sidle

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Factors for converting units of the inch-pound system to International System of Units (SI)

To convert from	To	Multiply by
	Length	
inch (in.)	millimeter (mm)	25.4
foot (ft)	meter (m)	0.3048
mile (mi)	kilometer (km)	1.609
	Area	
acre	hectare (ha)	0.4047
square mile (mi^2)	square kilometer (km^2)	2.590
	Volume	
gallon (gal)	liter (L)	3.785
acre-foot (acre-ft)	cubic meter (m^3)	1,233
cubic foot (ft^3)	cubic meter (m^3)	0.02832
cubic mile (mi^3)	cubic kilometer (km^3)	4.1655
	Mass	
pound (avoirdupois)	kilogram (kg)	0.4535
ton	metric ton	0.907
	Specific combinations	
gallon per minute (gal/min)	liter per minute (L/m)	3.785
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	0.02832
	Temperature	
degree Fahrenheit (°F)	degree Celsius (°C)	5/9 (°F -32)
	Thermal energy	
British thermal unit (Btu)	joule	1055
British thermal unit (Btu)	kilogram calorie (kg/cal)	0.252

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ABSTRACT

Coal occurs in many places in Oregon, but the only large reserves of high quality are in the Coos Bay and Eden Ridge coal fields in southwestern Oregon. About 3 million tons were produced from the Coos Bay field before mining ceased in the 1940's. Reserves in the two fields are estimated to be at least 250 million tons, including federally owned coal in the Siuslaw National Forest under lands leased to Northern Energy Resources Co.

Geoenergy resources in Oregon, in addition to coal, include noncommercial deposits of oil shale, natural gas, and geothermal heat. Commercial quantities of natural gas were discovered at Mist in northwestern Oregon in 1979. Gas presently is being produced from five wells and additional exploratory drilling is underway. More than 2 million acres of Oregon land is under lease for petroleum and natural gas exploration, mostly in the Astoria embayment-Willamette syncline, central (Oregon) Paleozoic-Mesozoic basin, and eastern Tertiary nonmarine basin.

The Cascade Range and eastern Oregon contain sizable resources of geothermal heat, of which a small part has been developed for space heating at Klamath Falls and Lakeview. Thirteen Known Geothermal Resource Areas (KGRA's) comprising 432,000 acres have been identified, 422,000 acres are currently leased for geothermal development. KGRA's judged to have potential for generation of electrical power are Newberry Crater, Crump Geyser, and Alvord Desert.

No adverse hydrologic effects have been noted to date from coal or other geoenergy exploration or development in Oregon, and no effects are expected if Federal and State regulations are adhered to. The southwestern Oregon coals would have to be mined by underground methods. Potential hydrologic impacts would be local increases in sedimentation, turbidity, and

mineralization of surface and ground water. Water-quality degradation, including both thermal pollution and increased concentrations of dissolved minerals, could result from geothermal development. Other potential problems include land subsidence and consumptive use of water associated with both coal and geothermal development.

INTRODUCTION

Increasing demands for energy emphasize the need to develop all geoenergy sources, including coal, petroleum and natural gas, and geothermal energy. Increased exploration and development of Oregon's geoenergy resources in future years may result in hydrologic problems similar to those associated with geoenergy development elsewhere.

Purpose and Scope

The purpose of this investigation was to examine the potential impacts on the water resources of Oregon from the exploration for or development of coal, petroleum and natural gas, or geothermal energy. This report includes discussions of (1) location and brief description of coal and oil shale deposits, likely areas of petroleum and natural gas exploration and development, and Known Geothermal Resource Areas (KGRA's), (2) the present and potential development of these resources; and (3) potential or postulated effects of geoenergy development on the water resources.

All data and information were obtained from published literature or other sources. The study was a statewide reconnaissance investigation and was concerned with hydrologic problems that may develop from exploitation of the geoenergy resources. Future studies may be needed in connection with specific hydrologic problems or areas, such as geothermal power in Alvord Valley.

Acknowledgments

Several individuals and agencies made significant contributions to this investigation. Garth Duell, Northern Energy Resources Co., furnished unpublished information pertaining to proposed coal projects in Oregon. Vernon C. Newton, Oregon Department of Geology and Mineral Industries, and Delores Yates, Mineral Leasing Service, provided information on current petroleum and natural gas exploration and leasing in the State. John W. Lund and Paul Lienau, Oregon Institute of Technology, supplied numerous publications concerning the State's geothermal resources. Paul Grim, National Oceanic and Atmospheric Administration, and Jack Sceva, Environmental Protection Agency, provided data on environmental impacts of geothermal development. David Sinclair, U.S. Bureau of Land Management, provided information on petroleum, natural gas, and geothermal leases on Federal lands. Andrew L. Schaedel, Oregon Department of Environmental Quality, furnished water-quality data for many areas in Oregon.

COAL

Coal has been mined in Oregon since the 1850's, when many seams were opened to provide fuel for local consumption. As much as 3 million tons had been mined through 1945, principally from the Coos Bay field (Baldwin, 1973). Since then, coal production in Oregon has declined to nearly zero.

The major known coal fields of Oregon include the Coos Bay, Eden Ridge, and Rogue River coal fields (fig. 1). Additional small tonnages of coal either have been or could be developed from the Vernonia area of Columbia County, the Wilhoit area of Clackamas County, the Waldo Hills area of Marion County, the Eckley and Squaw Basin coal areas of southern Coos County, and the Shasta Costa coal area of Curry County. Other counties in which thin seams of low-grade coal are known to crop out include Tillamook, Lincoln, Yamhill, Douglas, Grant, Morrow, Wheeler, Wasco, and Wallowa (Mason, 1969).

Coos Bay Coal Field

The Coos Bay coal field, the largest coal deposit in Oregon, is on private, city, county, State, and Federal lands in the western part of Coos County. The elliptically shaped field is approximately 30 mi long by as much as 12 mi wide, with an area of 250 mi^2 (fig. 1). It encompasses the Coos Bay estuary and several tributary sloughs and a part of the Coquille River basin. Outlying areas raise the areal extent of coal to 400 mi^2 (Mason and Hughes, 1975).

General Geology

The principal coal beds occur in the upper and lower sandstone members of the Coaledo Formation of Eocene age (Allen and Baldwin, 1944). The lower and upper members of the Coaledo consist of medium-bedded tuffaceous sandstone made up largely of basaltic glass. They are separated by the middle member, which consists of as much as 213 ft of dark tuffaceous shale of more acidic composition.

The Coos Bay coal field occupies a structural basin about 15 mi wide and 30 mi long, elongated north and south. Rocks in the basin have been deformed into several steep and almost parallel folds which trend northward. One of these folds, the Beaver Slough syncline, extends over a large part of the basin, and the coal-bearing sequence is exposed mainly along the flanks of the syncline. North-trending faults in the northern part of the field were interpreted by Duncan (1953) as high-angle thrust faults. Several smaller west-northwest- and northeast-trending faults with displacements of less than 100 ft offset the coal beds in the mined areas (Duncan, 1953).

Character of the Coals

The coal seams range in thickness from less than an inch to more than 19 ft. The principal coal bed in the field, the Beaver Hill (Newport) bed of the Coaledo Formation, occurs throughout the central part of the field, where it ranges from 4 to 8 ft in thickness. The second most important and

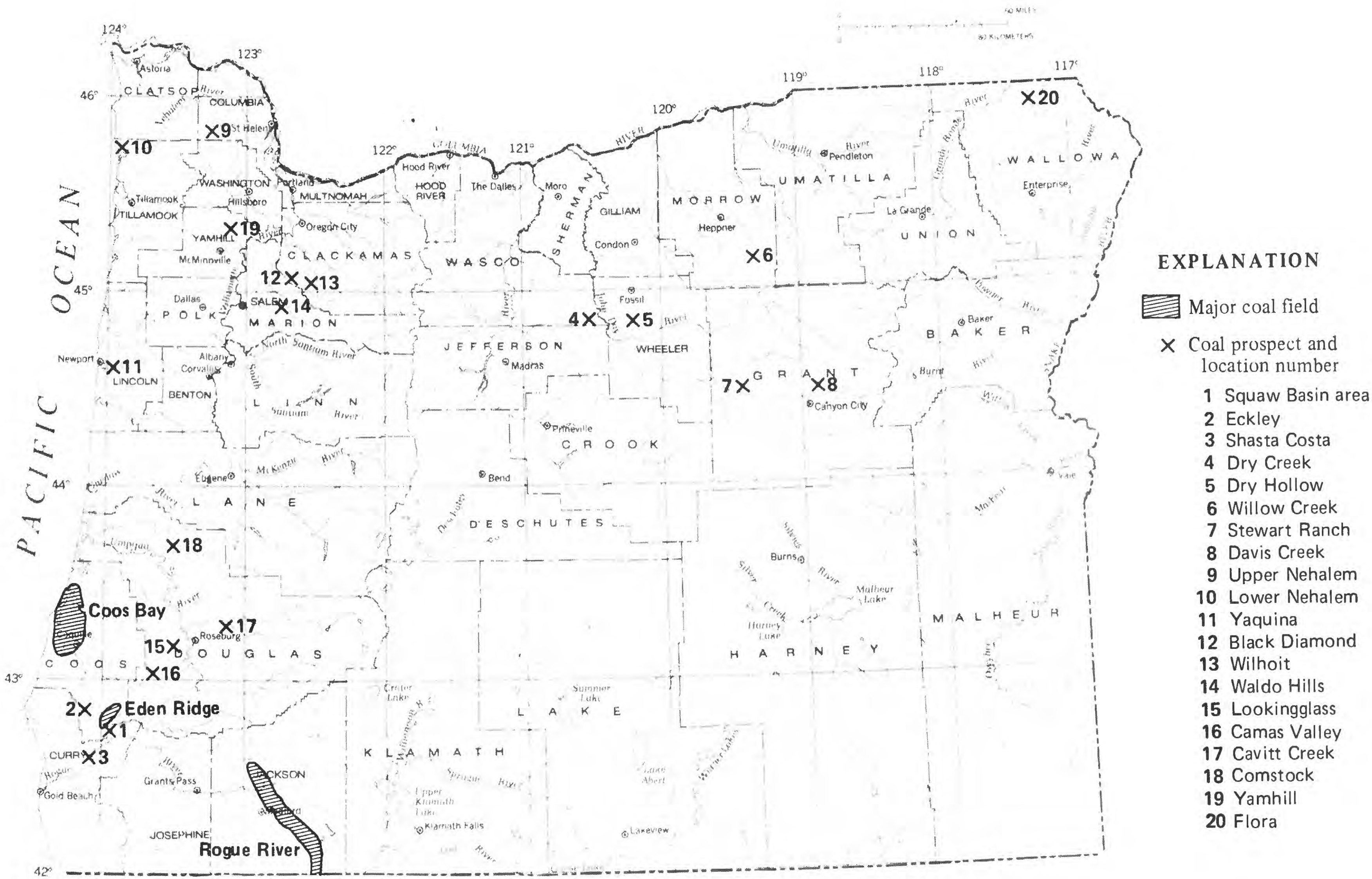

Figure 1. – Major coal fields and minor coal occurrences in Oregon. (Source: Mason and Irwin, 1955; Garth Duell, Northern Energy Resources Co., written commun., 1980; Wallowa Chieftain, 1980)

continuous coal bed in the central part of the field is bed D of the Coaledo Formation, which overlies the Beaver Hill bed (Duncan, 1953). Bed D is from 2 to 5 ft thick and generally contains 2 ft of clean coal. The thicker coal beds of 14 to 19 ft are shaly in many places. Detailed descriptions and sizes of partings were given by Allen and Baldwin (1944).

The coal in the Coos Bay coal field is subbituminous B, subbituminous C, or lignite. Heat values range from 5,530 to 10,370 Btu per pound on an "as-received" basis. The coal is characterized by a relatively high moisture content and an ash content ranging from 4.5 to 45 percent and averaging about 15 percent on an "as-received" basis. In general, the sulfur content of the Coos Bay coal beds is small, ranging from 0.5 to 5 percent and averaging less than 2 percent. All coals have low friability indices and generally high slacking percentages, and 50 to 80 percent of the coal cleaves to lump proportions (Toenges and others, 1948).

Estimates of reserves in the Coos Bay coal field vary widely due to various methods and criteria applied. For example, tonnages are generally computed based on coal less than 1,500 ft below surface, seams greater than 30 in. thick, and dips less than 45°. Campbell (1913) estimated the "geological" reserves at 1 billion tons. Later estimates, based on some exploratory drilling and mining data by Allen and Baldwin (1944), Duncan (1953), and Toenges and others (1948), have indicated proven reserves of 60 million tons. Mason and Irwin (1955) stated that nearly 200 million tons can be estimated because earlier reserves represented only part of the Coos Bay coal field.

Exploration and Development

Mining in the Coos Bay coal field began in the early 1850's, and maximum production was reached in 1904. At one time, nearly 40 mines were in operation in the Coos Bay field. Earlier reports described these mines in varying detail (Diller, 1914; Diller and Pishel, 1911; Butler and Mitchell, 1916). Most mining was underground in moderately steep-dipping coal beds. The most productive mine, Beaver Hill, reached a depth of 1,400 ft below sea level, at a distance of more than 3,000 ft downdip from the portal before closing in 1923 due to the conversion to oil-powered locomotives on the Southern Pacific Railroad (Mason and Irwin, 1955). Cumulative production for the Coos Bay coal field totaled 3 million tons (Baldwin, 1973). Current production is negligible.

Presently, exploration is sporadic, but centers on the feasibility of small gasification plants keyed to local industry or production of coal for export. Carbonization tests on coals have yielded liquid hydrocarbons in amounts equaling the range of marginal-grade oil shales and offer prospects for low-grade synthetic petroleum (Beaulieu and Hughes, 1975). Also, production of byproducts such as coal tars and char has been postulated (Garth Duell, Northern Energy Resources Co., Inc., oral commun., 1980). Although the area has a well-developed transportation system, competition from other fuel sources and the uncertainty of proven reserves have hampered development. Improved techniques in longwall and hydraulic mining are needed to explore the steeply dipping coal seams.

Hydrology

Major surface-water bodies in the Coos Bay coal field include the Coos Bay estuary and associated sloughs, and the Coos, Millicoma, and Coquille Rivers. Typically, the water in coastal streams, above the zone of tidal influence, is low in dissolved solids and generally has a nearly neutral pH.

Coos Bay estuary is a 12,380-acre area, largely of tidal flats, tidal marsh, and eel-grass tidelands, which receives drainage from 820 mi^2. Head of tidewater is at Dellwood (RM 9) on the South Fork of the Coos River and at Allegany (RM 10) on the Millicoma River. Average depth of the bay is 5 ft.

Saltwater incursions occur during many winter storms. Most parts of the bay, however, contain partly to well-mixed water during most of the year. Saltwater-freshwater mixing is least in areas far removed from main tidal channels, such as the middle and upper reaches of the sloughs. Water circulation and the capacity to accommodate pollution are least around the edges of sloughs draining local watersheds (Beaulieu and Hughes, 1975, p. 119).

The land surface of the Coos Bay coal field is underlain principally by marine sedimentary rocks of low porosity and permeability; consequently, winter runoff is high, recharge to ground water is small, and streamflows are low during the summer base-flow period (Oregon State Water Resources Board, 1963). Ground-water withdrawals are negligible and the yields of wells are adequate only for residential supplies. However, moderate to large quantities of water are pumped from dune aquifers north of Coos Bay (Robison, 1973).

Eden Ridge Coal Field

The Eden Ridge coal field is at the southwestern end of Eden Ridge in the extreme southern part of Coos County, 25 mi east of the coast in the Siskiyou National Forest. Eden Ridge lies at an elevation of about 3,000 ft above sea level in fairly rugged forest-clad mountains. The coal area is topographically divided by the South Fork Coquille River into Eden Ridge coal field to the north and Squaw Basin coal field to the south.

General Geology

Coal occurs in the Tyee Formation of Eocene age and was described by Lesher (1914), Williams (1914), Campbell and Clark (1916), Daniels (1920), and Wayland (1965). The structure is a shallow elliptical basin, with the longer axis trending northerly. Four major faults with displacement of as much as 800 ft have been mapped in the area. Dips are at low angles. In the north, the beds dip from 5° to 15° toward the southwest and in the west as much as 17° east. The Squaw Basin coal field is south of the Coquille River adjacent to the Eden Ridge coal field and at the southern part of the northerly plunging synclinal basin.

Character of the Coals

Lesher (1914) stated that four beds--the Lockart, Carter, Anderson, and Meyers--are known to underlie Eden Ridge. The thickness of the 10°-20°-dipping Carter and Anderson coal beds averages 6.5 and 5.8 ft, respectively (Garth Duell, Northern Energy Resources Co., Inc., oral commun., 1980). In the Squaw Basin coal field, two coal beds (Donnell and Seven Foot) of undetermined thickness are believed to be stratigraphically lower than the Eden Ridge coal field (Wayland, 1965).

Coal in Eden Ridge ranges from subbituminous B to high-volatile C bituminous. The average heat values for Eden Ridge are higher than for the Coos Bay coal field and average just over 9,000 Btu per pound. Numerous clay partings and sand layers occur in all coal beds, but are much less abundant in the Anderson coal bed. Coal analyses indicate that the Anderson coal bed contains sulfur ranging from 0.2 to 2.0 percent, 33 percent volatiles, 31 percent fixed carbon, 35 percent ash, and is low in moisture (Campbell and Clark, 1916), making the coal slack less readily (Garth Duell, Northern Energy Resources Co., Inc., written commun., 1980). The few analyses available for the Squaw Basin coals indicate that they are subbituminous, with lower ash content than the Eden Ridge coals (Williams, 1914).

Reserves of 50 million tons or more have been estimated for the Carter and Anderson beds on Eden Ridge (Garth Duell, Northern Energy Resources Co., Inc., written commun., 1980). The estimated reserves would be substantially greater if the coal beds underlying the Carter and Anderson beds were also included. The coal would have to be mined by underground methods.

Exploration and Development

No coal has been developed in the Eden Ridge or Squaw Basin fields to date. Before the 1950's, poor accessibility had contributed to lack of detailed exploration. In 1956, Pacific Power & Light Co. began an intensive exploratory program at Eden Ridge. At that time the company was considering a 10,000-kW fossil-fuel-fired plant for base-load power and a high-head hydroplant on the South Fork of the Coquille River for peak-use periods. Outstanding Federal coal leases cover more than 3,700 acres in Eden Ridge, and active exploration was renewed in 1979 by Northern Energy Resources Co., Inc., a coal subsidiary of Pacific Power & Light Co. which holds the leases. This area also might supply coal to be utilized for milling and concentrating the nickel ore south of Eden Ridge (Garth Duell, Northern Energy Resources Co., Inc., written commun., 1980).

Hydrology

The South Fork of the Coquille River, which drains the Eden Ridge area, has water low in dissolved solids and nearly neutral in pH. This area is underlain mostly by marine sedimentary rocks and volcanic rocks of low porosity and permeability; consequently, winter runoff is high, recharge to ground water is small, and streams are low during the summer base-flow period.

Ground-water withdrawals are negligible, and yields of wells are adequate only for small residential supplies.

Other Coal-Bearing Areas

Compared with the Coos Bay and Eden Ridge coal fields, all other coal areas in Oregon are of little economic importance. A brief discussion of the Rogue River, Eckley and Shasta Costa Creek, and John Day Basin areas, and some minor occurrences follows.

Rogue River Coal Field

The Rogue River coal field is in Jackson County, on private, county, State, and Federal lands. Coal occurs in a long, narrow belt extending southward from Evans Creek in the northwestern part of the county to a point about 10 mi south of the Oregon-California State line, a distance of approximately 100 mi (fig. 1).

The coal area has been described by Diller (1914), Winchell (1914), and Yancey and Geer (1940). The coal occurs in sandstone and shale of the Eocene Umpqua Formation and is covered by extensive lava flows. The coal is subbituminous A or B rank and contains a large number of partings and bands of impurities that in places equal the number of coal banks.

Exploration has not been extensive enough to determine the geologic structure of the area, and it is difficult to determine the extent of the coal beds because the Eocene sedimentary rocks interfinger with lava flows. Diller (1909) noted that at most places in the field the beds dip gently northeastward and that the quality and quantity of the coal increases northeastward.

Prospecting for coal has been done throughout the area, and in many places the coal has been mined for local use, as for example on Evans Creek in the northern part of the field. Future commercial development of the Rogue River field is unlikely.

Eckley and Shasta Costa Creek Areas

The Eckley area, which has been described by Diller (1903), includes approximately 20 mi^2 in the Siskiyou National Forest in southern Coos and northern Curry Counties (fig. 1). The area is in mountainous terrain near the Sixes River, about 45 mi south of Coos Bay.

The coal in the area is high volatile C bituminous and occurs in rocks of the Arago Formation of Eocene age (Mason, 1969). Where observed, the coal beds are folded and faulted. The thickness of the coal beds differs greatly from place to place and, as a result of folding and faulting, the coal occurs locally in irregular masses. The coal contains many layers of carbonaceous shale (Mason and Irwin, 1955). Diller (1903) has indicated that the best coal crops out along the southern border of Coos County near the head of the Middle Fork of the Sixes River.

Diller (1903, p. 5) also described coal from a deposit near the mouth of Shasta Costa Creek near Agness in Curry County (fig. 1). He indicated that the bed ranges from about 4 ft of lignitic "pitch" coal to 10 ft of coaly shale. Analyses indicated that the coal was low in moisture but had little commercial value because it contained nearly 14 percent ash and more than 6 percent sulfur.

To date, no coal has been produced from the Eckley or Shasta Costa Creek areas.

John Day Basin Area

The John Day Basin includes parts of Grant, Wheeler, Gilliam, Sherman, Morrow, and Umatilla Counties in north-central Oregon. Topographically, the region is a maturely dissected plateau formed by a series of basaltic flows.

Subbituminous coal and lignite occur in the Mascall Formation of Miocene age (Collier, 1914; Mackay, 1938). Most of the coal is impure and has low heat values.

Subbituminous coal with large amounts of impurities occurs in the Clarno Formation of Eocene and Oligocene age. Widely scattered exposures occur from northwestern Wheeler County northeasterly to the central part of Morrow County at Willow Creek. At the Willow Creek site, seven separate coal beds, ranging in thickness from a few inches to about 3 ft, occur in a sequence of tuff and interbedded andesitic flows. The rocks have been highly faulted and folded, so that tracing coal for any distance is difficult.

The best coal in the Clarno Formation occurs near the John Day River at Dry Hollow in Wheeler County and near Dry Creek in Sherman County. The beds are thin and discontinuous, however, and contain a large amount of impurities. Two other known occurrences are Stewart Ranch near Dayville and Davis Creek near Canyon City, both in Grant County (fig. 1) (Mason and Irwin, 1955).

Some lignite beds occur in the Mascall Formation near the John Day River, but these beds are irregular in thickness and contain so many partings of impurities that they are of little value. Coal development in the John Day River basin seems unlikely.

Additional Coal Occurrences

Other small areas of coal-bearing rocks in Oregon have been described, for the most part, by Diller (1914). The potential for commercial development of these low-grade deposits is unknown but is likely to be quite small.

In northwestern Oregon, subbituminous coal has been found in Marion, Clackamas, Lincoln, Columbia, Yamhill, Clatsop, and Tillamook Counties. The largest area in this part of the State that is known to contain coal includes about 20 mi^2 in the upper part of Nehalem River basin in Columbia County. Coal beds in that area are known as Vernonia coals and are from 1 to 10 ft thick. The thicker beds consist mostly of carbonaceous shale.

Coal occurs in about 10 mi^2 in the Yaquina area of west-central Lincoln County. The thickest known bed contains only 3 ft of impure coal. Coal also occurs in southern Clatsop County and northern Tillamook County in the lower Nehalem River area, but no bed thicker than 22 in. has been reported.

Other areas in which very small tonnages of coal have been or could be developed include the Wilhoit area of Clackamas County and the Waldo Hills and Black Diamond areas of Marion County. At present, a small deposit in the Wilhoit area is being mined underground by the Madronnes Mining Co. for sale as a soil conditioner.

In southwestern Oregon, near Comstock in the north-central part of Douglas County, thin impure coal beds occur in the Spencer Formation of late Eocene age. Small outcrops of subbituminous coal also occur in the Lookingglass and Camas Valley areas, and near Cavitt Creek, all in Douglas County.

Recent coal exploration by Utah International, Inc., in the Flora area of Wallowa County has reportedly identified lignite on private land. Quality and tonnage of lignite are not yet known, nor is the potential for development (Wallowa County Chieftain, 1980).

Potential Hydrologic Impacts

Hydrologic impacts of coal mining are highly variable depending on methods of mining, terrain, and climate. Most previous production in Oregon has been from underground mining in the Coos Bay coal field.

Hydrologic impacts from earlier underground coal mining in Oregon generally were not recorded. Historical descriptions of mining indicate that mines in the Coos Bay area had no significant drainage problem and that a generally adequate supply of surface water was available for washing coal at the mine sites. The rocks of the region are relatively impervious, so that pumps in the mines were able to control seepage in a few hours' operation each day. Even in the deep Beaver Hill mine beneath Beaver Slough, water was only a minor problem. Faults exposed in the mine workings were generally sealed with impervious clays (Allen and Baldwin, 1944).

Postulated hydrologic impacts from underground coal mining in the Coos Bay and Eden Ridge coal fields may include subsidence which would result in disrupting normal ground-water movement and altering the local occurrence and availability of ground and surface waters. Other impacts could include increased erosion, sedimentation, and stream turbidity from mining activities, such as road construction, removal of vegetation, and disposal of slag on the surface; degradation of surface-water quality; and the use of water for mining and processing the coal.

Because of geologic conditions, mining in Oregon's major coal fields probably will be almost entirely by underground methods, and strip mining likely will be used only for small-scale commercial production. Small surface mines in areas of minor occurrence also could produce coal for residential use. Newton and Mason (1973) indicated that only about 55 acres out of a 15,100 total mineable acreage in the Coos Bay coal field is suitable for strip mining.

Adverse hydrologic impacts associated with underground and surface coal mining are discussed briefly below (Knight and Newton, 1976; U.S. Geological Survey and Montana Department of State Lands, 1976). Most of these impacts can be alleviated or prevented by following proper mining practices, by using acceptable control measures, and by adherence to surface-mining regulations and requirements of the Clean Water Act.

Hydrologic impacts that may be associated with both surface and underground mines include:

1. Degradation of water quality.--In surface mining, surface water is subject to increases in dissolved-mineral content if soluble minerals are exposed in mining or in the spoil piles left after mining. At an underground mine, soluble minerals from the coal and associated rocks may enter local streams and degrade the water quality. By its nature, a mine provides easy access for air that is essential for the oxidation of sulfide minerals that occur in the coals. If the sulfides are dissolved by water that is pumped or drains from the mine opening, the result is acidic water (low pH) containing excessive quantities of iron and other minerals. However, no acid mine-water drainage has been reported from coal mining in Oregon.

   Surface mining also may result in local degradation of ground-water quality by the infiltration of mineralized water into replaced spoil and coal refuse. As water accumulates in the spoil, soluble minerals, such as pyrite, are leached from the mine rubble. If this mineralized water enters local aquifers, it can significantly alter the quality of the local ground water.

2. Disruption or removal of aquifers.--Aquifers overlying the coal beds would be removed during surface mining. As a result, the flow of ground water across the mine area would be disrupted. In addition, ground-water levels in those aquifers would be lowered at various distances from the mine, depending largely on the geohydrologic characteristics of the aquifers. Effects from underground mining would be less severe and would result largely from the pumping out of seepage water from the mine workings. The history of mining in Coos County indicates that effects from underground mining would be minor to insignificant.

3. Erosion and sedimentation.--Activities that contribute to erosion problems include removal of vegetation to construct the mine and mine facilities, building of roads, and creation of spoil or waste-rock piles. Because surface mining affects a larger area than does underground mining and requires a network of haul roads, potential impacts are greatest for that form of mining. However, surface-mining regulations do not permit the discharge of sediment from surface mines.

4. Use of water.--The principal use of water is to control dust in the mine. Small quantities of water also are needed for sanitary purposes, upkeep of equipment and facilities, and for processing the coal. Surface mines also require water to control dust on haul roads during dry weather.

   Average water use in coal mining is estimated at 15 gal per ton for underground mining and 4 gal per ton for surface mining, and an additional 8 gal per ton for both methods for waste disposal. The larger water use in underground mining compared to surface mining is attributed to more water needed for dust control underground for health reasons (Davis and Velikanov, 1979).

In addition to the potential impacts discussed above, another impact associated with underground mining is the subsidence of land surface. Where subsidence occurs, the normal occurrence and availability of ground and surface water are disrupted. Subsidence occurs where the roofs of mines are allowed to collapse; for example, where pillars are inadequate to provide support, or where pillars are moved. This is generally associated with mining at shallow depths and is unlikely in Oregon because the dip of the coal beds would carry the beds to considerable depth in a mine of commercial size.

An additional impact associated with surface mining is change in runoff and local streamflow. Streamflow changes include the following:

1. Diversion of runoff from one stream to another.--This would result from the alteration of natural topography by surface mining which commonly diverts small drainageways. Excavations are made across natural boundaries, and, in some areas, overburden is placed in stream channels. Thus, many small tributaries and drainage basins are obliterated or their drainage patterns altered.

2. Reduced runoff.--This would be due to the impoundment of water in the mine area that prevents sediment produced by mining from entering nearby streams. Inasmuch as the drainage area affected would be restricted to a mine area of a few acres, reduced runoff in Oregon would be extremely small.

3. Local increases in storm runoff.--Removal of vegetation for construction of the mine and spoil-storage areas could result in increased runoff during storms. Because expected surface-mined areas in Oregon would be small, increases, if any, would be local.

OIL SHALE

The only known oil-shale deposit in Oregon is the Shale City deposit on private land in sec. 16, T. 38 S., R. 2 E., Jackson County (fig. 2). The Oregon Department of Geology and Mineral Industries estimates that 150,000 tons of high-grade shale occurs in Oligocene-Miocene rhyolitic tuff. Tests indicate a yield of 36 gal of liquid hydrocarbon per ton (V. C. Newton, Oregon Department of Geology and Mineral Industries, written commun., 1980).

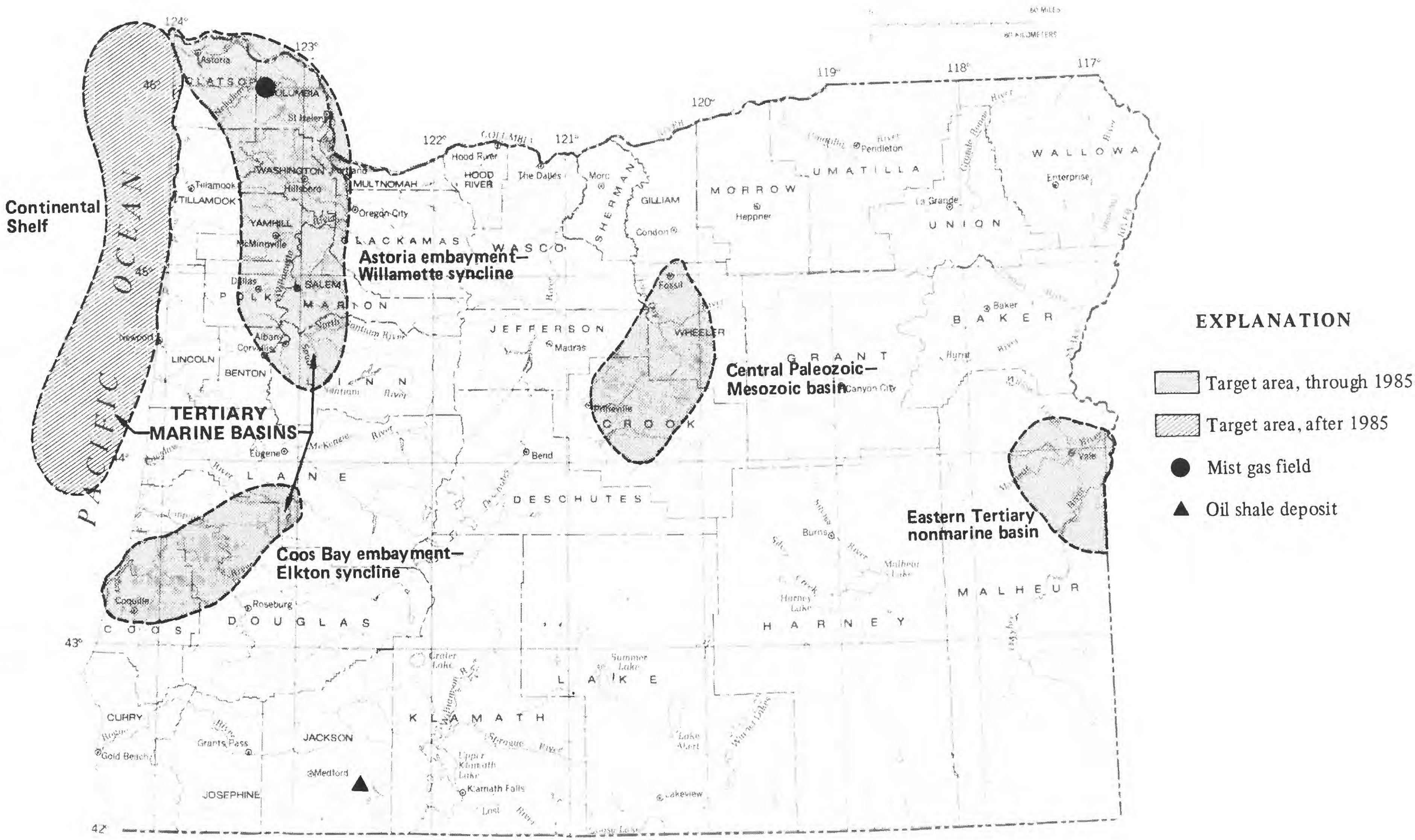

Figure 2. – Target areas for petroleum and natural gas exploration in Oregon. (Source: Newton, 1965, and V.C. Newton, Oregon Department of Geology and Mineral Industries, oral commun., 1980)

The thickest shale unit is 3 to 4 ft thick; many thinner shale layers occur in the 30-foot section exposed in a pit on the property. Attempts in the 1920's at commercial exploration of the deposits were not profitable.

PETROLEUM AND NATURAL GAS TARGET AREAS

Approximately one-fifth of the State of Oregon contains sedimentary rocks having geological characteristics (that is, petroleum-generating material, reservoir rocks, and suitable structural or stratigraphic traps) associated elsewhere with the accumulation of commercial quantities of petroleum and natural gas. Until recently, exploratory drilling in Oregon had resulted in no discoveries suitable for commercial development. However, in 1979, commercial quantities of gas were discovered in the Mist area of northwestern Oregon.

The following discussion of the petroleum and natural gas possibilities in the State is directed at potential target exploration areas (fig. 2). On the basis of geologic conditions and leasing information, the Oregon Department of Geology and Mineral Industries (DOGAMI) has identified target areas, including (1) the western Tertiary marine basins, (2) central Paleozoic-Mesozoic basin, and (3) eastern Tertiary nonmarine basin (V. C. Newton, Oregon Department of Geology and Mineral Industries, written commun., 1980).

Western Tertiary Marine Areas

General Geology

Tertiary marine rocks occur in all of western Oregon west of the Cascade Range and north of the Klamath Mountains. In this area of about 15,000 mi^2, marine sedimentary rocks of Tertiary age have an aggregate thickness of more than 25,000 ft (Newton, 1965). Eocene sediments predominate in the western Tertiary marine basins, but thick sections of younger Tertiary rocks occur in northwestern Oregon and on a large part of the Continental Shelf offshore.

On the basis of geologic structures, Tertiary marine areas in Oregon are subdivided into the Willamette syncline, Elkton syncline, the Coast Range uplift (including the coastal embayments at Coos Bay, Newport, Tillamook, and Astoria), and the Continental Shelf. Favorable areas for exploration through 1985 are the Astoria embayment-Willamette syncline and the Coos Bay embayment-Elkton syncline (fig. 2). The Continental Shelf off the northern Oregon coast is a target area for exploration during the post-1985 period, but is not discussed in this report. The first discovery of gas to date, in the Mist area in northwestern Oregon, is discussed in the following section.

Mist Gas Field

The Mist gas field is in the upper Nehalem River basin of Columbia County in northwestern Oregon. Surface ownership is largely private, and mineral rights are county and private. Topographic relief in the upper Nehalem Basin ranges from low to high rugged hills bordering rather narrow, flat lowlands.

Subsurface exploration has greatly increased the knowledge of the stratigraphy of the upper Nehalem River basin. Logs of wells more than 8,000 ft in depth in the Mist area indicate a sequence of marine sediments (Cowlitz Formation) overlying and interbedded with an assemblage of Eocene basaltic submarine lava, breccia, and tuff (Tillamook Volcanics). The gas-producing zone is at a depth of about 3,000 ft in the upper sands of the Eocene Cowlitz Formation. A lower sand unit of the Cowlitz reportedly is a deeper potential gas reservoir (Newton, 1976).

Structurally, the upper Nehalem Basin is part of the lower Columbia River downwarp, which formed prior to extrusion of Miocene lavas. Uplift and arching of the northern Coast Range formed a northward-plunging anticline that projects as a salient into this downwarp. Contacts of sedimentary units bend around the Coast Range cross warp in the upper Nehalem Valley (Newton, 1976). The Mist anticline, an auxiliary cross warp, evidently forms a structural trap in the Mist gas field (Warren and others, 1945).

Exploration for oil and gas first began in the Mist area in 1946, when Texaco, Inc., drilled near this community. Following Texaco's drilling, lands in Columbia County were leased by other major oil companies over a 25-year period. Reichhold Energy Corp., Diamond Shamrock, Northwest Natural Gas Co., and American Quasar Petroleum Co. resumed exploratory drilling in 1977.

The State's first commercial gas field was discovered near Mist in May 1979. Development drilling by Reichhold Energy Corp. is proceeding in the Mist gas field, with a total of five producing wells drilled by December 1980. The Oregon Department of Geology and Mineral Industries has received applications to drill at an additional 24 locations. A map showing locations of holes drilled to date is available from the Oregon Department of Geology and Mineral Industries (Olmstead, 1980).

Total production proved to date (1980) is approximately 17 million ft^3/d, an amount equal to 7 percent of Northwest Natural Gas Co.'s market demands for western Oregon. The gas is about 92 percent methane and has a heating value of 950 Btu/ft^3 (D. L. Olmstead, Oregon Department of Geology and Mineral Industries, written commun., 1980).

Central Paleozoic-Mesozoic Basin

The central Paleozoic-Mesozoic basin in central Oregon covers an area of 6,000 mi^2 and is believed to be underlain by as much as 30,000 ft of Paleozoic-Mesozoic marine sediments. This basin has prospects for petroleum production and is considered to be a target area for exploratory drilling through 1985. Because of the thick covering of Tertiary volcanic rocks, little exploration has occurred in this area to date. However, minor shows of asphalt, oil, and gas have been reported from Mesozoic rocks in the basin (Baldwin, 1964; Buddenhagen, 1951).

Eastern Tertiary Nonmarine Basin

The eastern Tertiary nonmarine basin area of Oregon (fig. 2) is the extreme western part of the western Snake River Plain of Idaho. At least 10,000 ft of tuffaceous lacustrine, channel debris, and subaerial sediments have been deposited in that basin since late Tertiary time (Newton and Corcoran, 1963). Near Payette, Idaho, several wells intercepted brackish water at depths ranging from 1,000 to 1,500 ft (Kirkham, 1935).

East of the Oregon part of the basin, gas occurs in about 200 wells in the Snake River downwarp region in Idaho. The natural gas contains a high percentage of nitrogen and some hydrogen sulfide along with sparse traces of helium. It also contains, on the average, 10 percent of ethane and heavier petroleum fractions. Heating values range from 940 to 1,490 Btu/ft^3 (Newton and Corcoran, 1963).

The geologic similarities between the Idaho gas field and the Oregon target area indicate that the Oregon area at least warrants further exploration.

Petroleum and Natural Gas Exploration

As a result of the gas discovery near Mist in Columbia County, oil and gas speculation in Oregon has increased dramatically. Information from the U.S. Bureau of Land Management, Oregon State Division of Lands, and Delores Yates of Mineral Leasing Service indicates that oil and gas leasing in Oregon is at an alltime high. Those leases are largely for acreage in the target areas shown in figure 2. The areas of oil and gas leases as of February 1980 were as follows:

Ownership	Total acres
Federal lands (497 leases)	637,239
State lands (37 leases)	119,148
County lands (estimated)	300,000
Private lands (estimated)	930,000
Total (rounded)	2,000,000

Hydrologic Problems

Primary hydrologic impacts of petroleum production relate to saltwater contamination of ground and surface waters and water consumption for flooding operations. Saltwater contamination of ground water can result from poor casing and well-abandonment procedures and the improper disposal of saline water produced with oil (Newton, 1973). One environmentally acceptable solution for disposal of brines is by reinjection into the producing zone. Removal of petroleum from subsurface reservoirs may result in subsidence that could lead to disruption of ground-water flow or surface runoff.

GEOTHERMAL RESOURCES

Oregon has abundant geothermal resources, as indicated by more than 170 hot springs (Bowen and Peterson, 1970) occurring primarily from the Cascades eastward across the State. The U.S. Geological Survey has classified 432,000 acres in 13 areas of the State as Known Geothermal Resource Areas (KGRA's), and other broad areas as Prospective Geothermal Resource Areas (PGRA's). Locations of Oregon's KGRA's and PGRA's are shown in figure 3, and pertinent data for each major region are given in table 1 (at end of this report). Geothermal exploration leasing (as of 1980) is summarized below.

Federal lands1/ (acres)		State lands2/ (acres)	Private lands (acres)	Total (acres)
KGRA leases	Noncompetitive leases			
204,550	48,900	8,934	160,000	(Rounded) 420,000

1/ In addition, 491 lease applications are pending.
2/ In addition, three lease applications are pending.

Cascade Range Geothermal Region

The Cascade PGRA extends over a north-south distance of 150 mi and an east-west distance of 20 to 50 mi. It includes five KGRA's: Mount Hood; and Carey, Breitenbush, Belknap-Foley, and McCredie Hot Springs.

The Oregon Cascade Range is divided into the High Cascades and Western Cascades. The High Cascades lie to the east and are characterized by glaciated Quaternary volcanoes built up on Tertiary rocks equivalent to those of the Western Cascades. The northernmost and highest of these glaciated volcanoes is Mount Hood (11,237 ft), which has several fumaroles near its summit and hot springs on its flanks. Mount Hood is the only KGRA in the High Cascades.

Unlike the young volcanics of the High Cascades, Western Cascades rocks generally show the effects of folding and faulting. The major hot springs of the Western Cascades are alined along the 122° meridian in a relatively narrow zone which Baldwin (1964) has suggested may be fault controlled. These hot springs all flow from structurally deformed volcanic strata of Oligocene to Pliocene age.

Hydrology.--The Mount Hood KGRA lies astride the Cascade Range divide partly in the Sandy River basin and partly in the Hood River basin. The other four Cascade KGRA's are 10 to 20 mi west of the divide, all in basins of streams tributary to the Willamette River. In general, annual runoff is high in the central Cascade Range, being 60 to 90 in. in the Mount Hood, Breitenbush, and Belknap-Foley areas. However, Carey and McCredie Hot Springs are in areas of somewhat lower runoff--only 30 to 60 in. per year.

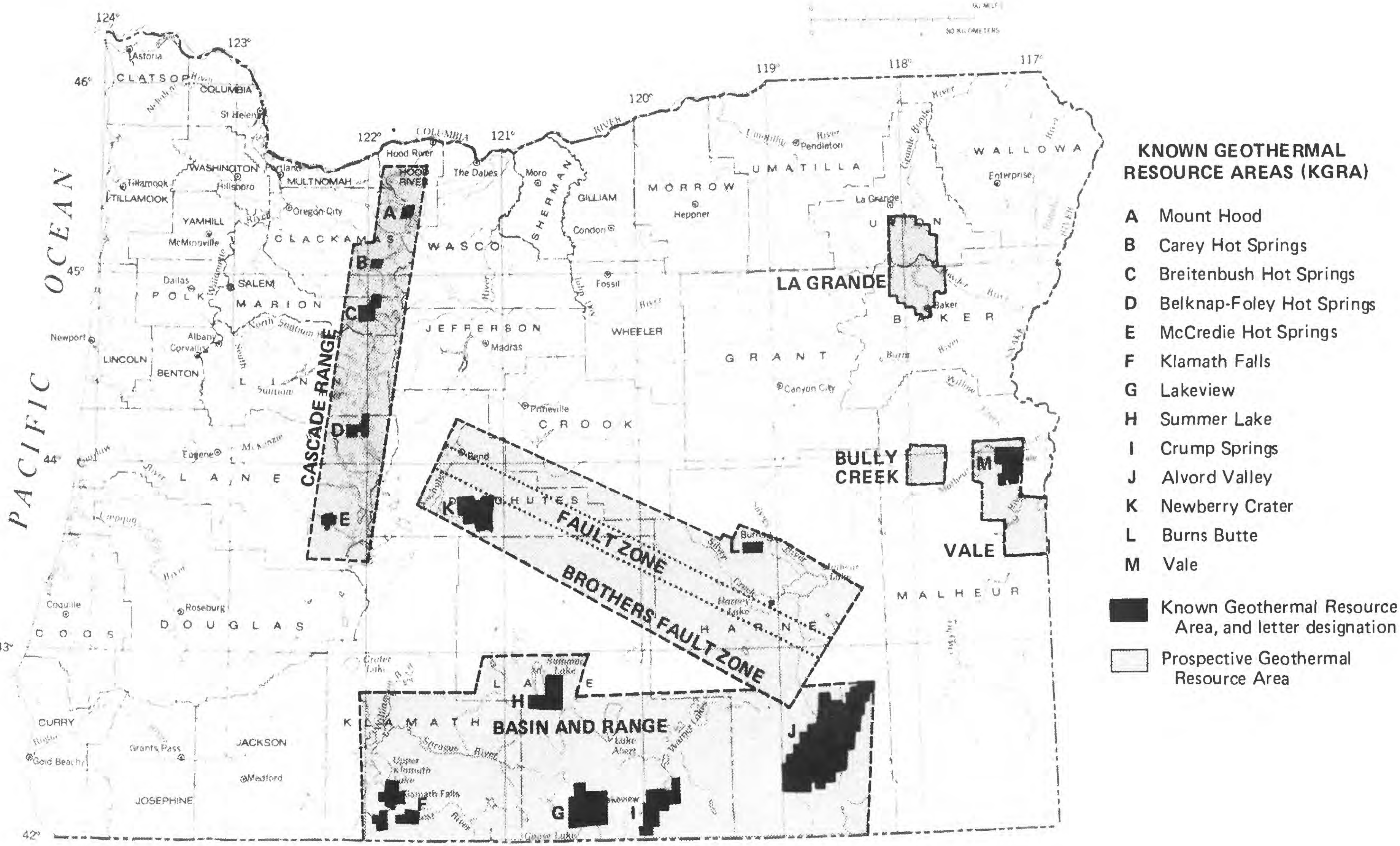

Figure 3. – Geothermal-resource areas in Oregon. (Source: U.S. Geological Survey, 1976)

In all the KGRA's, ground water occurs in volcanic rocks at depths of several hundred feet in topographically high areas and at relatively shallow depths along stream valleys. Alluvial and glacial deposits along valleys are aquifers locally. Yields of wells vary greatly from place to place, but in places a few hundred gallons per minute can be obtained from alluvial deposits or permeable zones in the volcanic rocks.

Basin and Range Geothermal Region

The Basin and Range geothermal region extends across southern Oregon 200 mi eastward from the southern Cascades (fig. 2). It includes five KGRA's: Klamath Falls, Lakeview, Summer Lake, Crump Springs, and Alvord Valley. Each of these KGRA's lies in a structural and topographic basin with associated thermal springs. Information about the KGRA's is given in table 1.

The Basin and Range region in Oregon is dominated by Cenozoic volcanic rocks which are intricately broken by two prominent fault sets--one striking N. 20° to 40° E. and the other N. 20° to 35° W. Large-magnitude displacements of some of these normal faults have resulted in north-trending fault-block basins or grabens bounded by tilted fault blocks. Most of the Basin and Range basin floors are more than 4,000 ft in altitude. The highest mountain block is Steens Mountain, which has an altitude of 9,670 ft.

Hydrology.--The Klamath Falls KGRA lies in the Klamath River basin, but the other four KGRA's are in closed basins that contain shallow playa lakes. Runoff averages less than 5 in. per year and evapotranspiration is high (Pacific Northwest River Basins Commission, 1970). In all the KGRA's, ground water in topographically high areas occurs in volcanic rocks and in the basin areas occurs in continental sediments interbedded with volcanic rocks. Small to moderate yields are obtained from wells in the alluvium, and yields of several hundred gallons per minute can be obtained from wells in the pyroclastic rocks and lavas.

Brothers Fault-Zone Prospective Geothermal Area

The Brothers fault zone PGRA, which includes the Newberry Crater and Burns Butte KGRA's, is a major structural lineament that crosses central Oregon from Steens Mountain through Brothers and possibly extends to the Cascade Range. The Brothers fault zone was described by Peterson and others (1976) as a northwest-trending belt of closely spaced en echelon normal faults. It extends about 200 mi in a general N. 60° W. direction across the High Lava Plains region. Normal faults of the zone are generally 12 to 20 mi long, with numerous horsts and grabens developed between them.

As described by Hull and others (1977), the zone contains an interlayered sequence of volcanic and sedimentary rocks ranging in age from Miocene to Holocene. Walker (1974) and MacLeod and others (1975) noted a general progressive decrease in age of silicic volcanic vents from east to west along the Brothers fault zone. The farthest western eruptive center of the zone is Newberry Crater, containing silicic rocks dated at 1,300 years before present (Peterson and Groh, 1969).

The hydrologic characteristics of the Brothers fault zone PGRA are similar to those of the closed basins of the Basin and Range geothermal region.

Vale Prospective Geothermal Area

The Vale PGRA is in the Snake River structural basin in eastern Oregon. It includes the Vale KGRA and the nearby Bully Creek PGRA.

The dominant structural feature of the area is the Snake River downwarp, a large structural trough extending from Yellowstone National Park across southern Idaho into eastern Oregon. Vale Hot Springs in the Vale KGRA is at the intersection of the Willow Creek and Malheur River faults in an assemblage of interbedded Tertiary volcanic and sedimentary rocks.

The Vale PGRA is in the lower part of Malheur River basin, where annual runoff is less than 3 in. Wells tapping consolidated rocks generally yield only a few gallons per minute, whereas wells tapping alluvial deposits may yield as much as 50 or 60 gal/min. Arsenic concentrations in water from some wells in the Vale area exceed Environmental Protection Agency drinking-water standards.

La Grande Prospective Geothermal Area

The La Grande PGRA is in the Upper Grande Ronde Valley of northeastern Oregon. The Grande Ronde Valley is a graben associated with complex faulting of upper Tertiary and pre-Tertiary rocks (Hampton and Brown, 1964). Thermal springs seem to be controlled by northwest-trending faults that mark the margins of the valley.

Wells in the valley that tap the Tertiary basalt and alluvial-fan deposits supply water for irrigation.

Hydrologic Problems

Geothermal fluids, if released into surface- or ground-water bodies, potentially can cause chemical or thermal pollution. Other potential impacts of geothermal development are consumptive use of water, subsidence of land, and increased seismicity.

Water-quality degradation may be caused by dissolved constituents in geothermal waters, including arsenic, boron, carbon dioxide, chloride, fluoride, hydrogen sulfide, mercury, and sulfate. Excessive quantities of dissolved constituents may raise salinity to an unacceptable level, and some constituents may produce undesirable pH levels in water (Ellis and Mahon, 1977). More importantly, high concentrations of arsenic, boron, mercury, and other metals in geothermal fluids can render the water into which the fluids are discharged unusable for drinking, stock use, and other purposes. Hydrologic problems are more likely from a hot-water geothermal source than from a vapor-dominated source. These problems result from the greater volume of water brought to the surface in developing a hot-water system than a vapor-dominated system.

The only water-quality problem that has been identified to date due to geothermal development in Oregon is the discharge of heated water into local streams in the Klamath Falls KGRA. Some of the geothermal water withdrawn for space heating in that area has a high sodium concentration and low potassium concentration. The dissolved-solids content may be as high as 4,000 mg/L, but the average is about 900 mg/L and the water is potable. The water characteristically has a pH in the basic range, with values of 7.5 to 8.5 (Lund, 1978; Sammel, 1980).

CONCLUSIONS

No significant hydrologic problems have been identified to date from previous coal mining, from recent exploration of coal and petroleum resources, or from the development of the Mist gas field. One of the more likely causes of hydrologic problems associated with geoenergy exploration and development is the discharge of warm or mineralized water into bodies of fresh, potable water. Improperly sealed exploratory wells can allow poor-quality water to discharge at the surface or into freshwater aquifers. State regulations require freshwater zones to be cased and sealed off during test drilling. Procedures for abandoning exploratory wells also require preventive measures designed to protect freshwater aquifers.

At present, no new programs nor expansion of the Oregon hydrologic-data programs seems necessary to monitor hydrologic changes or potential problems associated with future development of geoenergy resources. However, continued and accelerated exploration of Oregon's geoenergy resources is likely, as indicated by the large acreages leased for coal, petroleum and natural gas, and geothermal resources.

This study should be updated in about 3 years with particular attention to:

1. Ongoing exploration of coal resources in Coos and Wallowa Counties.
2. Establishing a water-quality monitoring program in any area where coal mining is expected within 2 or 3 years.
3. Reviewing the hydrology of the Mist gas-field area with respect to potential hydrologic and other problems, especially water-quality problems.
4. Developing detailed background hydrologic and other data for any areas where geothermal resources are being developed or where development is imminent.

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Table 1.--Data for Known and Prospective Geothermal Resource Areas of Oregon

[Location and ownership data from Bureau of Land Management files; surface temperature, flow, pH, and dissolved-solids values from U.S. Geological Survey geothermal file and Mariner and others (1974). Subsurface temperatures and reservoir volume and energy from Muffler (1978) and White and Williams (1975)]

Geothermal area[1/]	Latitude longitude	Location	Size (acres) and ownership	Reservoir temperature (°C) Surface	Reservoir temperature (°C) Subsurface	Flow rate (gal/min)	pH (units)	Dissolved solids (mg/L)	Mean reservoir volume (mi^3)	Mean reservoir thermal energy (10^{15} Btu)	Remarks
CASCADE RANGE GEOTHERMAL REGION											
Mount Hood KGRA	45°22'5" N.; 121°42'5" W.	Secs.16-22, 27-33, T.2 S., R.9 E.	8,671 (Federal)	--	122±12	--	--	--	0.79±0.05	0.91±0.28	Reservoir temperatures speculative; may be small vapor-dominated system.
(Swim Warm Springs)	45°17'42" N.; 121°44'18" W.	Sec.24, T.3 S., R.8½ E.	--	90	--	25	7.3	988	--	--	
Carey Hot Springs	45°01'12" N.; 122°0'36" W.	SE. part T.6 S., R.6 E.; SW. part T.6 S., R.7 E.	7,419 (Federal) 160 (private)	--	104±8	250	--	--	0.79±0.2	0.76±0.23	Sulfate-water isotope geothermometer indicates 181°C.
(Hot Springs)	45°01'18" N.; 122°0'30" W.	Sec.30, T.6 S., R.7 E.	--	86	--	--	7.63	1,030	--	--	Also called Austin Hot Springs.
Breitenbush Hot Springs KGRA	44°46'9" N.; 121°58'5" W.	SE. part T.9 S., R.7 E.; Secs.4 and 23, T.8 S., R.7 E.	13,445 (Federal) 2.917 (private)	--	125±10	--	--	--	0.79±0.2	0.94±0.28	Sulfate-water isotope geothermometer indicates 195°C.
(Hot Springs)	44°46'52" N.; 121°58'32" W.	Sec.20, T.9 S., R.7 E.	--	92	--	900	7.31	2,440	--	--	
Belknap-Foley Hot Springs KGRA	44°46'9" N.; 121°58'5" W.	SE. part T.9 S., R.7 E.; secs.4 and 23, T.8 S., R.7 E.	5,066 (Federal)	--	--	--	--	--	--	--	These two areas are 6 km apart. The two subsurface reservoirs may converge.
(Belknap Hot Springs)	44°11'40" N.; 122°02'54" W.	Sec.11, T.16 S., R.6 E.	--	71	113±14	80	7.62	2,540	0.79±0.2	0.83±0.27	Three springs.
(Foley Hot Springs)	44°09'12" N.; 122°05'50" W.	Sec.28, T.16 S., R.6 E.	--	81	99±7	60	8	3,333	0.79±0.2	0.72±0.21	Four springs.
McCredie Hot Springs KGRA	--	Mostly in SE. part T.21 S., R.4 E.	3,659 (Federal)	--	91±4	--	--	--	0.79±0.2	0.65±0.18	Chemical constituents are higher than for other hot springs in the Western Cascades. A hot-water-dominated hydrothermal convection system is indicated.
(McCredie Springs)	43°42'21" N.; 122°17'13"	Sec.36, T.21 S., R.4 E.	--	73	--	20	7.3	4,400	--	--	
BASIN AND RANGE GEOTHERMAL REGION											
Klamath Falls KGRA	42°14' N.; 121°46' W.	Parts of Tps. 38-39, Rs. 9-10 E.	50,300 (Est. 30 percent private)	--	111±7	25-400	7.5-8.5	900	27.4±0.13	28±14	Several wells ranging in depth from 100 to 1,800 ft used for space heating.

See footnotes at end of table.

Table 1.--Data for Known and Prospective Geothermal Resource Areas of Oregon--Continued

Geothermal area[1]	Latitude-longitude	Location	Size (acres) and ownership	Reservoir temperature (°C) Surface	Reservoir temperature (°C) Subsurface	Flow rate (gal/min)	pH (units)	Dissolved solids (mg/L)	Mean reservoir volume (mi^3)	Mean reservoir thermal energy (10^{15} Btu)	Remarks
BASIN AND RANGE GEOTHERMAL REGION--Continued											
Klamath Falls KGRA--Continued											
(Olene Gap Hot Springs)	42°10'27" N.; 121°36'54" W.	Sec.14, T.39 S., R.10 E.	--	74	--	50	7.68	826	--	--	
(O.I.T. well 6)[2]	42°14'54" N.; 121°46'50" W.	Sec.20, T.38 S., R.9 E.	--	--	88	250	8.2	740	--	--	Depth 1,800 ft.
Klamath Hills area	42°03' N.; 121°44'30" W.	Part of Tps. 40-41 S., Rs. 9-10 E.	--	--	124±7	Up to 5,000	--	--	2.54±0.91	2.9±1.0	
(O. H. Osborn well)[2]	42°03'18" N.; 121°44'42" W.	Sec.27, T.40 S., R.9 E.	--	--	90	450	9.5	655	--	--	Depth 417 ft.
Lakeview KGRA	42°12' N.; 120°21'36" W.	Secs.32, 33, T.38 S., R.20 E., and central part of T. S., R.20 E.	12,165 (private)	--	150±3	--	--	--	3.67±1.3	5.3±1.9	Travertine and sinter abundant around spring orifices. Several shallow wells used for space heating.
(Hunters Hot Springs)	42°13'19" N.; 120°22'5" W.	Sec.4, T.39 S., R.20 E.	--	96	--	600	7.8	806	--	--	
Summer Lake KGRA	42°43' N.; 120°38' W.	E. part of T.33 S., R.17 E., and NW. part of T.33 S., R.18 E.	11,460 (Federal) 2,171 (private)	43	118±6	--	--	--	1.9±0.67	2.1±0.76	Sulfate-water isotope geothermometer indicates about 190°C.
(Summer Lake Hot Springs)	42°43'32" N.; 120°38'45" W.	Sec.12, T.33 S., R.17 E.	--	46.7	--	20	8.5	1,120	--	--	
Crump Springs KGRA	42°15' N.; 119°53' W.	Part of Tps. 38-39 S., Rs. 24-25 E.; T.40 S., Rs.23-24 E., and T.41 S., R.24 E.	13,023 (Federal) 1,280 (State) 71,360 (private)	--	167±9	--	--	--	1.7±0.67	2.8±1.1	Several hot springs, seeps, and one geysering well.
(Crump Spring)	42°13'36" N.; 119°52'47" W.	Sec.34, T.38 S., R.24 E.	--	78	--	50	7.26	1,030	--	--	
(Crump Geyser)	43°13'36" N.; 119°52'52" W.	Sec.34, T.38 S., R.24 E.	--	99	--	1,000	8.7	1,130	--	--	Well depth 1,810 ft; artesian jet 160-210 ft high.
Alvord KGRA	--	Parts of Tps.32-37 S., Rs.33-36 E.	106,438 (Federal) 5,360 (State) 64,575 (private)	--	--	--	--	--	--	--	

See footnotes at end of table.

Table 1.--Data for Known and Prospective Geothermal Resource Areas of Oregon--Continued

Geothermal area[1/]	Latitude-longitude	Location	Size (acres) and ownership	Reservoir temperature (°C) Surface	Reservoir temperature (°C) Subsurface	Flow rate (gal/min)	pH (units)	Dissolved solids (mg/L)	Mean reservoir volume (mi^3)	Mean reservoir thermal energy (10^{15} Btu)	Remarks
BASIN AND RANGE GEOTHERMAL REGION--Continued											
Alvord KGRA--Continued											
(Alvord Hot Spring)	42°32'36" N.; 118°31'36" W.	Sec.32, T.34 S., R.34 E.	--	76	181±18	130	6.73	2,805	1.2±0.5	2.1±0.95	Several springs.
(Hot Borax Lake)	42°20' N.; 118°36' W.	Sec.14, T.37 S., R.33 E.	--	96	191±14	900	7.3	1,625	2.0±0.84	3.8±1.6	Several springs, a large pool, sinter.
(Mickey Hot Spring)	42°40'30" N.;	Sec.13, T.33 S., R.35 E.	--	73	205±10	25	8.05	1,684	3.07±1.6	6.2±3.3	Extensive sinter.
(Trout Creek area)	42°11' N.; 118°23' W.	Sec.16, T.39 S., R.37 E.	--	52	154±9	50	8.3	869	0.79±0.2	1.19±0.34	Sulfate-water isotope geothermometer indicates 235°C.
BROTHERS FAULT ZONE GEOTHERMAL REGION											
Newberry Crater KGRA	43°44' N.; 121°14' W.	Parts of Tps. 21-22 S., Rs. 12-13 E.	31,284 (Federal)	21	230±20	--	--	--	11±1.7	26±9.5	Hot springs that issue along the shores of East and Paulina Lakes appear to be drowned fumeroles.
(East Lake Hot Springs)	43°43'6" N.; 121°12'12" W.	Sec.29, T.21 S., R.13 E.	--	62	--	--	6.49	278	--	--	
(Paulina Hot Springs)	43°43'42" N.; 121°45'0" W.	Sec.26, T.21 S., R.12 E.	--	--	--	--	6.82	914	--	--	
Burns Butte KGRA	43°36' N.; 119°08' W.	Sec.28, T.23 S., R.30 E.	640 (Federal)	--	--	--	--	--	--	--	
Harney Basin PGRA											
(Harney Lake area)	43°10'36" N.; 119°03'36" W.	Sec.36, T.27 S., R.29½ E.	--	68	114±7	150	7.26	1,810	0.79±0.2	0.84±0.25	Unnamed hot springs near Harney Lake.
(Crane Hot Springs)	43°26'27" N.; 118°38'18" W.	Sec.34, T.24 S. R.33 E.	--	78	117±6	150	8.1	550	0.79±0.2	0.86±0.26	

See footnotes at end of table.

Table 1.--Data for Known and Prospective Geothermal Resource Areas of Oregon--Continued

Geothermal area1/	Latitude-longitude	Location	Size (acres) and owner-ship	Reservoir temperature (°C) Sur-face	Subsur-face				Mean reservoir volume (mi^3)	Mean reser-voir thermal energy (10^{15} Btu)	Remarks
				VALE GEOTHERMAL REGION							
Vale KGRA	43°57' N.; 117°12' W.	Parts of Tps. 18-19 S., R.45 E., and secs.19 and 30, T.19 S., R.46 E.	14,565 (Federal) 8,433 (private)	--	157 ± 2	--	--	--	28.1 ± 1.2	43 ± 20	Larger area suggested by audiomagnetotelluric survey and heat-flow anomaly. Sulfate-water isotope geothermometer indicates 200°C.
(Vale Hot Springs)	43°58'58" N.; 117°13'59" W.	Sec.20, T.18 S., R.45 E.	--	73	--	20	7.47	1,025	--	--	
				NORTHEASTERN OREGON GEOTHERMAL REGION							
La Grande PGRA	45°10' N.; 117°50' W.	Parts of Tps.4-6 S., Rs.39-41 E.	Undetermined acreage (private)	--	30-80	--	--	200-900	--	--	Referred to as Craig Mountain - Cove by Muffler (1979, p. 118-119). Na-K-Ca geothermometer indicates 89°C.
(Medical Hot Springs)	45°01'5" N.; 117°37'29" W.	Sec.25, T.6 S., R.41 E.	--	60	96 ± 12	--	8.23	845	0.79 ± 0.2	0.69 ± 0.22	Two groups of springs; total discharge 50 gal/min.

1/ Specific springs or wells, shown in parentheses, are typical hot springs in KGRA or PGRA for which data are listed.

2/ Data from Sammel (1980).