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Implications of the Clean Air Act and Other Air-Quality Regulations on Geothermal Development In the United States*

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ABSTRACT

Generation of electricity by geothermal power results in lower emissions of criteria air pollutants than power generation from fossil fuel combustion. This situation suggests that air quality regulations would not impede the development of geothermal energy resources. However, an in-depth study of the Clean Air Act and state air quality regulations has determined that such regulations have constrained geothermal development in the past, based on hydrogen sulfide (H_2S) emissions from geothermal power plants. The "federal enforceability" provision of PSD regulations has caused some geothermal plants with controlled emissions at low levels to undergo PSD review, thus extending the time needed for permit approval. To determine the potential effects of air quality regulations upon future geothermal energy development, Federal PSD and non-attainment regulations are examined. The proximity of known geothermal resource areas to Class I PSD areas and non-attainment areas are determined. Atmospheric modeling of H_2S emissions from a hypothetical geothermal plant finds that if recently available control equipment is installed, H_2S emissions do not constrain geothermal development.

Introduction

The rapid depletion of existing supplies of fossil fuels coupled with increased demand for energy has stimulated increasing national interest in alternative forms of energy, including geothermal (hydrothermal) resources. The rapid commercial development of hydrothermal resources is a prime objective of the Department of Energy's geothermal program.

Before development can proceed, technical, economic, and institutional constraints must be identified and, if possible, mitigated. Federal, state, and local environmental regulations must be met by new geothermal energy facilities. The relative environmental benefits of geothermal resource utilization, in comparison to other forms of energy, could be an important stimulus to more rapid development of geothermal energy.

The Clean Air Act, the Federal legislation that governs air pollution control in the United States, was not drafted in a uniform pattern, but rather at different times, by different people, in response to different pressures. Passage of the legislation was done without careful consideration of potential impacts on the development of domestic energy resources. The impact of air quality legislation on geothermal energy development in particular has received little attention. Air quality regulatory constraints to geothermal development must be identified, and possible mitigation measures proposed, in order to provide adequate background information to decision makers.

This paper identifies the manner in which air quality regulations could constrain or stimulate the development of geothermal power plants in known geothermal resource areas (KGRA's) in the United States. Geothermal technologies and atmospheric emissions are discussed in the second section. The constraints of Federal emission regulations on geothermal development are discussed in the third section. Also in the third section, air quality modeling is used to determine the impact of selected state ambient H_2S standards on geothermal development. The fourth section presents a summary of major findings.

Atmospheric Emissions from Geothermal Power Plants

Geothermal power plants primarily use the binary cycle (a closed cycle) or the flash cycle (an open cycle). Atmospheric emissions are negligible for the binary cycle because the geothermal fluid is reinjected into the ground; the only significant waste production of any kind is heat loss to the atmosphere. Because the closed loop or binary cycle for geothermal power production is characterized by minor air emissions, it is unlikely that its development would be significantly constrained by air quality regulations. Therefore, this report focuses on development using the flash cycle.

In the flash cycle the geothermal fluid is separated into liquid and gaseous (steam) components. The liquid is then flashed a second time to produce more steam at a lower pressure in a second-stage separator[2]. The steam from both flashings is used to drive a turbine to generate electricity. Exhaust steam is condensed and used as makeup water for the cooling tower.

Air pollutant emissions from geothermal power plants are dependent on the concentrations of specific air pollutants in geothermal fluids. A range of potential air pollutants in "typical" geothermal fluids is presented in Fig. 1. Gaseous air pollutant emissions result from operation of the "flash" component of the power plant, and particulate emissions result from cooling tower operation. Noncondensable gases (mainly H_2S and CO_2) represent about 1% of the total vapor fed to the turbines in a geothermal plant[3]. CO_2 is usually not considered to be a pollutant, and therefore H_2S is of primary concern. A range of typical H_2S concentrations is presented in Fig. 1.

Of the volume of gaseous emissions from a geothermal power plant, CO_2 represents 99%, H_2S represents about 1%, NH_3 is emitted in trace amounts of less than 2 ppm (well below the threshold of odor), and Hg has been measured in amounts far below the Occupational Safety and Health Administration's (OSHA) standards. Trace element emissions include arsenic, mercury, boron, and strontium; ammonia has also been detected in geothermal emissions[4]. Based on data collected at the Geysers KGRA in Northern California, a 55 MW geothermal plant without emission controls can emit H_2S at rates ranging from 1 to 35 grams per second (g/s).[5]

Particulate emissions from a geothermal power plant that affect ambient air quality include fugitive dust, which is usually generated during construction of the plant and during well drilling; and cooling-tower drift emissions, which are generated during operation.

Particulate emissions from cooling tower operation consist primarily of salts, which remain after evaporation. The concentration of salts in ambient air is dependent on the concentration of dissolved solids that are present in the makeup water used for the cooling towers. Salt levels in water (usually expressed as total dissolved solids or TDS) are site-specific for each KGRA. Some KGRA's are in arid regions with poor water quality where high TDS concentrations are common, increasing the potential for a significant quantity of particulate emissions. In some arid areas, agricultural runoff that is also high in salts may be used for cooling-tower makeup water, which again could result in significant particulate emissions.

Although the total dissolved solids (TDS) content of geothermal fluid may vary considerably among geothermal resources, where controlled its effect on TSP emissions from the cooling tower is minimal. Known TDS concentrations range from an extreme of 200,000 ppm and higher in the Salton Sea KGRA to as low as 2,000 ppm in the East Mesa KGRA in California.

When a flash system is used, the geothermal fluid becomes exposed to the atmosphere, and its steam component is condensed and used as a cooling-tower makeup. In these ways, the opportunity for emission of suspended particulates occurs. However, when the geothermal fluid has been flashed, the steam leaving the fluid leaves behind much of the TDS in the liquid component of the geothermal fluid. This fluid is now more highly concentrated in TDS and is reinjected into the ground. The flashed steam portion contains very little particulate matter and is further cleansed by cyclonic action as it is gathered for the turbine. After the turbine, the steam is condensed into water, and is then used in the cooling tower. Therefore, due to the low TDS content of the condensed steam, the variability of the TDS content in the geothermal fluid has little effect on the emissions of TSP from the cooling tower.

For extremely high levels of TDS (200,000 ppm), present technology of the flash cycle does not provide sufficiently clean steam to avoid heavy corrosion on the turbine blades. When TDS is extremely high (as in the Sultan Sea KGRA), the flash process is not practical, and a binary system will most likely be used to avoid these corrosive effects. TSP emissions from cooling towers in a binary system are most strongly affected by the TDS of the cooling-tower makeup water. This water comes from local streams or local groundwater systems, and the TDS content may range up to 4300 ppm, as in the Imperial Valley in California. These TDS particles are subject to dispersion from the cooling tower. Drift eliminators are necessary on these towers to reduce the tower's particulate emissions to a minimum. High-efficiency drift elimintors are designed to reduce drift losses to extremely low levels, about 0.005% of the water circulation rate. As a result, a recently constructed geothermal power plant of the 55-MW(e) size used as a standard in this report (in the Geysers-Calistoga KGRA in California) has particulate emissions from its cooling tower of less than 5 ton/year[6]. Because cooling towers are now designed with drift eliminators as a standard practice, the effect of geothermal plants on ambient TSP concentrations should be minimal.

Impacts of Federal and State Air Quality Regulations on Geothermal Development

Geothermal power plants, which are of smaller generating capacity and emit fewer air pollutants than modern coal-fired power plants, have often been subject to the same air pollution control regulatory processes, and corresponding time delays for permit approval, as coal-fired plants. While the delays caused by the regulatory process can be burdensome to most industries, they can be especially troublesome for a small and growing industry such as geothermal power production. Many geothermal developers have insufficient financial, legal, and technical resources that are at times needed to obtain

obtain permits in a minimum amount of time. Small developers in particular may be constrained by the regulatory process.

Federal Regulations

Major Source Definition. The current Federal approach to air pollution control in the United States is to subject only major pollution sources and major modifications to the full regulatory process. Thus, principal causes of regulatory problems with geothermal plants are the scenarios under which geothermal plants can be classified as major sources; three such scenarios will now be discussed.

The first scenario under which a geothermal plant could be classified as a major source of air pollution is if it emits regulated pollutants at rates exceeding the major source thresholds established by Federal regulations (for geothermal plants, these are 100 tons per year (TPY) in nonattainment areas and 250 TPY in attainment areas). Hydrogen sulfide emissions from power plant operation, and particulate emissions from cooling tower operation, are each regulated air pollutants (40 CFR Part 51). A 55MW(e) plant with 90 percent H_2S abatement would emit H_2S at rates ranging from 4 to 120 TPY and is thus likely to avoid classification as a major source in most instances. If, however, a 55MW(e) geothermal plant had installed H_2S control equipment to meet regulations that are not Federally enforceable, the Environmental Protection Agency would view the plant as being uncontrolled and would thus classify it as a major source (uncontrolled emissions would range from 40 to 1200 TPY). As an example, a 55MW(e) geothermal power plant proposed by the Sacramento Municipal Utility District in Sacramento, California was classified as a source because of the Federal enforceability provisions and was required to apply for a PSD permit. Particulate emissions from cooling tower operation, if not controlled with draft eliminators or similar devices, could also exceed major source thresholds. If particulate emissions exceed the 250 TPY threshold under the attainment area regulations, the full regulatory review would also be required for H_2S emissions if they are in excess of 10 TPY (40 CFR Part 51).

A second scenario under which a geothermal plant could be classified as a major source is as a modification to an existing source. If the geothermal development is in the form of a modification or retrofitting to an existing industry, and is on the list of 28 industries that are subject to the 100 TPY major source cutoff, then the geothermal development, as part of that industry, could be subject to the more stringent cutoff, and the likelihood of being classified as a major source would be greater.

A third scenario that would result in the classification of a geothermal plant as a major source is the classification of a KGRA as one source. According to criteria for source definition found in 45 FR 52676, a KGRA could be classified as a single source if it is developed by the same person, because all geothermal plants are in the same SIC code and they would be located on contiguous or adjacent property. The KGRA would not be considered a major source until one plant results in a cumulative H_2S emission inventory for the KGRA of 250 TPY or greater. Then, only the plant triggering the major source threshold would be subject to the regulations. The bubble concept may be useful in mitigating regulatory problems arising under this scenario.

Nonattainment Area Regulations. Geothermal plants could be located in attainment and nonattainment areas. Although one usually pictures geothermal development in pristine regions, there are instances where geothermal development can occur in nonattainment areas. Attainment status designation is pollutant-specific, i.e., an AQCR can be "attainment" for one pollutant, and "nonattainment" for another. Thus, a new source could be faced with different regulatory procedures for different pollutants. This situation is further complicated for geothermal development because a KGRA may overlap two or more air quality planning regions, and development in different parts of the same KGRA may be subject to different regulations.

A comparison of maps of KGRA locations, as shown in Fig. 2, with maps of nonattainment areas found that some KGRA's are located in non-attainment areas for both particulates and sulfur oxides. This is not surprising, considering that many western areas conducive to geothermal development are often characterized by arid climates in which agricultural activities disturb the dry soil, thus contributing to ambient particulate levels. In addition, high ambient SO_2 concentrations occur in localized areas due to smelting activities in the Southwest.

If subject to nonattainment area emissions regulations, geothermal development could be constrained by the difficulty of defining Lowest Achievable Emission Rate (LAER) and of obtaining pollutant offsets in remote, rural areas. Typically, New Source Performance Standards (NSPS) are used as guidance to define LAER[9]. The lack of a NSPS for geothermal plants could therefore make LAER determination a difficult and time consuming task. Obtaining pollutant offsets in remote areas may be difficult, especially if H_2S emissions must be offset. Another complicating factor with geothermal development under nonattainment area regulations could be the demonstration of air quality improvements (as required in 40CFR 51, App. S) in complex terrain using atmospheric dispersion models.

It should be noted that geothermal emissions with respect to the Federal cutoff for major source definition may have little practical applicability because most, if not all, nonattainment area permitting is done on the state or local level, and these agencies may have lower cutoff values than the Federal 100 TPY value. For example, the Oregon Department of Environmental Quality defines a major air pollution source in terms of pollutant specific thresholds that are as low as 10 TPY for H_2S and 25 TPY for particulate matter[10].

PSD Regulations. PSD regulations can constrain geothermal development, primarily due to the closeness of Class I PSD areas to KGRA's. The potential of Class I areas to constrain geothermal development hinges on whether or not KGRA's are located in or near Class I PSD areas. Because Class I areas are national parks and related areas, development of geothermal energy is precluded within these areas. Industrial development is prohibited in national parks, and soon will be precluded in wilderness areas[11]. Furthermore, the Geothermal Steam Act (P.L. 91-581) expressly forbids the development of geothermal resources in areas with land uses similar to Class I areas (e.g., national recreation areas, wildlife and game ranges, lands reserved for the protection and conservation of fish and wildlife that are threatened with extinction, fish hatcheries, etc.). PSD regulations can still apply to sources located outside Class I areas if their emissions will impact the "air quality related values" (visibility, odor, etc.) of these areas (42 U.S.C. 7475). Thus, a geothermal plant that is considered a major source in a KGRA that is next to a Class I area, must prove that its emissions do not degrade the "air qulity related values" of the Class I area. Demonstrating that a source's impact will not degrade the air quality related values must be done for any pollutant regulated under the CAA. A PSD permit will not be issued if a degradation of air quality related values is demonstrated by the Federal Land Manager to the state, even if the emissions from the source will not cause a PSD increment to be exceeded (42 U.S.C. 7475). The extent of the constraint to geothermal development from this provision of the regulations will depend on the procedure used to demonstrate degradation and on the level of proof required in the demonstration.

Knowledge of the proximity of a particular KGRA to a Class I PSD area is essential to assessing the potential constraints of the PSD regulations to the KGRA in question. Comparing a map of Class I PSD areas (Fig. 3) with the base map of KGRA's (Fig. 2) allows one to evaluate the proximity of KGRA's to Class I areas. Some potential problem areas are in central eastern California, central Oregon, northern Washington, Utah, and Colorado. In these areas geothermal plants could become subject to the Class I PSD regulations.

The PSD regulations could constrain geothermal development through the specification of Best Available Control Technology (BACT). BACT could add considerably to the cost of geothermal plants and could be a prohibitive factor in some proposed geothermal plants that are marginally economical. If a geothermal plant is classified as a major source because of TSP emissions from cooling towers, then PSD review (which includes BACT specification) would be required for H_2S emissions also, if the emissions exceed 10 TPY.

Some states have received authority from the EPA to implement the EPA PSD program, or to implement their own, more stringent, program.

Specific provisions of these state regulations may be different and may offer more of a constraint to geothermal developmet than the Federal regulations.

New Source Performance Standards. The U.S. Environmental Protection Agency has not yet developed a new source performance standard (NSPS) for geothermal power plants because geothermal plants emit few air contaminants and because the industry is new and therefore small. H_2S, the primary emission problem from geothermal plants, frequently is more of a nuisance than a health hazard. To date, NSPS have been developed for less than 30 types of industries, and a variety of industries are on a waiting list for future NSPS development. Little incentive exists for the EPA to develop a NSPS for geothermal power plants because there are numerous "dirtier" industries for which NSPS need to be developed. Considerable growth in the geothermal industry or identification of significant hazardous air pollutant emissions from geothermal power plant operation would be needed to prompt the EPA to develop a NSPS for these facilities. Lack of a NSPS for geothermal power plants can introduce uncertainty into the air quality permitting process[11].

State Regulations

Assessing the impact of state air quality regulations on geothermal development is difficult to do on a generic level because of the wide variety of state regulations. Thus, to simplify the assessment, it was decided to focus on only state ambient H_2S standards, and to select some of the most stringent state H_2S standards in the country. Regulation of geothermal emissions varies from state to state. For these reasons, a range of emissions was modeled for a standard 55-MW(e) geothermal electrical generating plant. The results were then compared with regulatory limitations in the various states containing known KGRAs. This procedure ignored differences in ambient air quality and meteorological data among KGRAs and changes in local terrain at each individual KGRA; however, in evaluating which emission levels might be affected by present regulations, a standardized modeling analysis was considered sufficient.

On the state level, H_2S is a regulated pollutant, because it can create an odor nuisance. At least three states have set 1-hour (1-h) standards based on the odor threshold zone of H_2S: 10 parts per billion (ppb) in New Mexico, 30 ppb in California, and 5 ppb in Montana[13].

The 55-MW(e) power plant (72 MW(e) gross power and 55 MW(e) net power) was used as a model in this study because it is a standard size of those already in operation. Because New Mexico has the most stringent H_2S standard, the standardized 55-MW(e) geothermal plant was modeled with meteorological data from Albuquerque, New Mexico.

Also, the climate of this station is representative of the semi-arid climates of many of the KGRAs which are located in similar terrains. The meteorological input for the model used Albuquerque for both the hourly surface data and the upper air observations.

The CRSTER[14] model was used to predict H_2S concentrations at receptor sites every 10° on ten circles ranging from 0.25 to 5.0 kilometers surrounding the hypothetical geothermal plant site. Emission rates were modeled in a range of values designed to cover the range of controlled and uncontrolled H_2S emissions measured at operating geothermal power plants.

Results indicate that to meet New Mexico's stringent (10 ppb) standards, the emission rate of H_2S from a 55-MW(e) geothermal power plant must be 0.8 grams per second (g/s) or lower. In order to meet this level, mitigation measures must be employed; the extent of the mitigation depends on the characteristics of the geothermal fluid at that site.

California and Montana have 1-hour average standards for H_2S at 30 ppb and 50 ppb, respectively, designed to keep H_2S concentrations near the general threshold of odor. In these states, a few power plants, such as those in the East Mesa KGRA in California, which have known low H_2S concentrations in the geothermal fluids, might not need controls. For example, in the East Mesa KGRA, H_2S emissions of 0.25 g/s to 1.5 g/s would be expected for 55-MW(e) plants. Modeling predicts emissions of 2.3 g/s and lower are needed to keep the ambient concentration from violating the 1-hour standard in California, so that some 55-MW(e) plants in the East Mesa KGRA might not need H_2S emission controls. Emissions of 3.9 g/s and lower are predicted not to violate the standard in Montana.

The H_2S upper emission limit modeled in this study that will avoid violations of regulations is 3.9 g/s in Montana, 2.3 g/s in California, and 0.8 g/s in New Mexico. This limit applies to any single plant, whether large or small, as a single source with that level of emission would result in the maximum ambient concentration near the standard downwind from the plant. If a 110-MW(e) plant were operated, H_2S emissions would be double; therefore, the plant would be more likely to need controls. Large geothermal power plants [500 MW(e)] are not built because of the difficulty in obtaining sufficient amounts of heat and fluids within effective distance of the plant site to power such large plnts. The result is that several smaller plants are built within a geothermal field. Several plants in a KGRA field have a cumulative effect upon air quality. In order to meet emission standards, this cumulative effect demands a slightly lower level of emissions than has been projected; how much lower the emissions must be depends primarily on the distance between the individual plant sites.

Summary

An analysis of Federal air quality permitting procedures has determined that geothermal power plants, under certain conditions, can be classified as major air pollutant sources and can thus be subject to air pollution regulations. A geothermal plant is most likely to be classified as a major source of particulates if cooling towers are used without drift eliminators, and if the cooling water has high concentrations of dissolved solids. Once classified as a major source in PSD areas, a geothermal plant would need to undergo PSD review for H_2S emissions in excess of 10 TPY/yr, which can occur with a 55MW(e) plant using H_2S abatement device. The air quality analyses and hardware changes (e.g. BACT) that can be required under full PSD review may put many small geothermal developers at an economic disadvantage. Similarly, required air quality analyses and control equipment installation required under nonattainment area permitting procedures may discourage marginally economical geothermal projects from being completed. The Federal enforceability provisions of emission regulations have been responsible for geothermal power plants being subject to the air quality regulatory process. Potential regulatory constraints caused by this provision may be substantially reduced in the future because the Federal enforceability provisions may be changed. The EPA may consider regulations to be Federally enforceable if they can be enforced by Federal, state, or local governments and they are discoverable by the EPA and interested persons.[15] Nonattainment areas pose special problems with defining LAER without NSPS guidance. Also, emission offsets are difficult in remote areas with little industrial development.

Air quality modeling determined that in order to avoid violating the more stringent state H_2S standards in New Mexico, California and Montana of 10ppb, 30ppb and 50ppb respectively, mitigation methods are necessary for the average geothermal plant. Emissions need to be under 0.8 g/s in New Mexico, 2.3 g/s in California, and 3.9 g/s in Montana for a 55MW(e) power plant. In states without H_2S standards, Federal regulations apply. Typically, state standards are enforced as part of a state permitting program, so compliance with the standards may determine whether or not a particular development may proceed. Early identification of air quality regulatory constraints to geothermal development can lead to better planning of geothermal projects and to an effective utilization of this alternative form of energy.

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Figure Captions

Figure 1. A range of potential air pollutants in "typical" geothermal fluids. Wide bars depict ranges within which most of the measurements will probably fall and narrow bars show measured ranges. Source: Ref. 1.

Figure 2. Map of known geothermal resource areas in the western continental United States. Source: Ref. 8.

Figure 3. Map of mandatory Class I PSD areas in the western continental United States. Source: Ref. 12.

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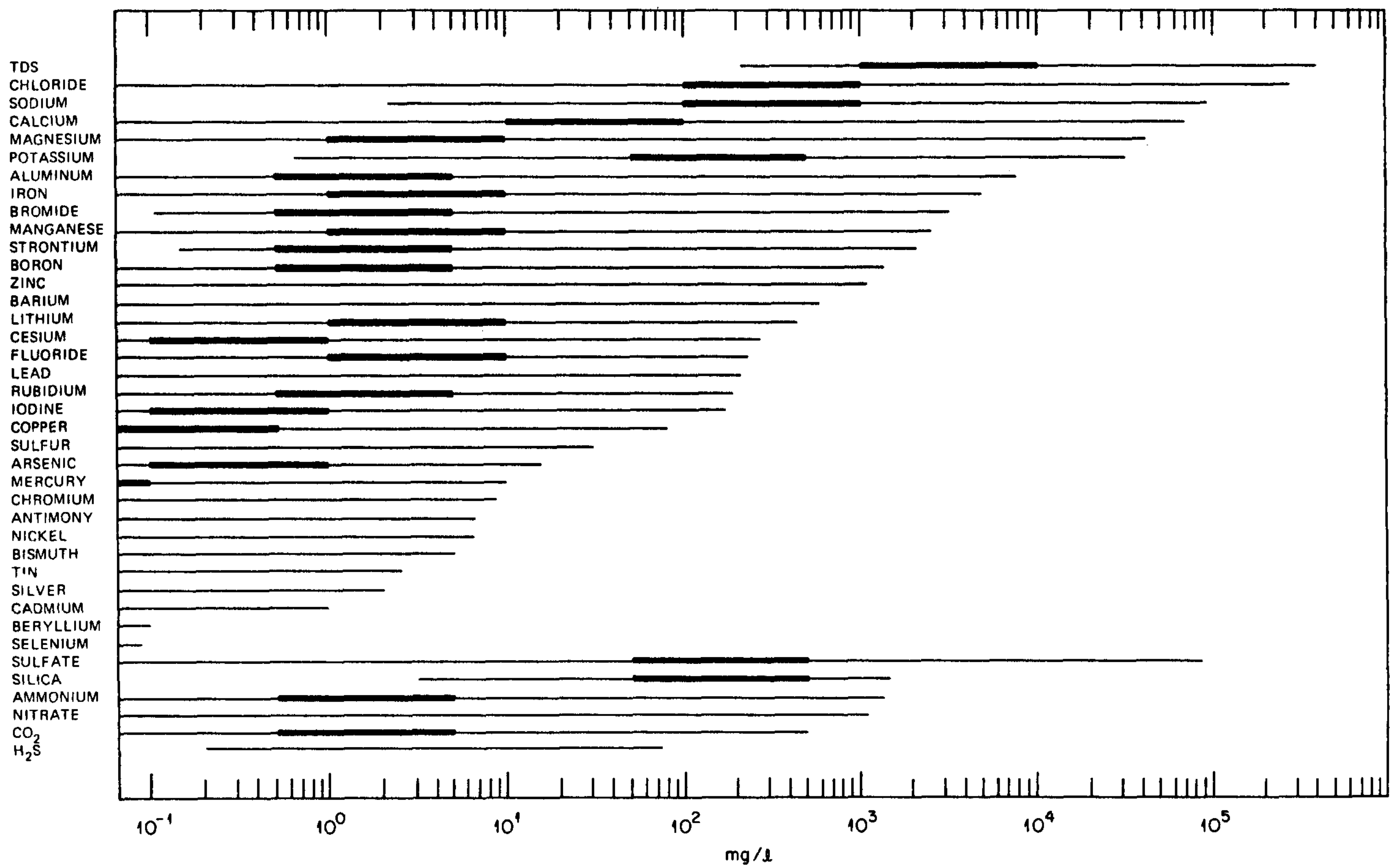

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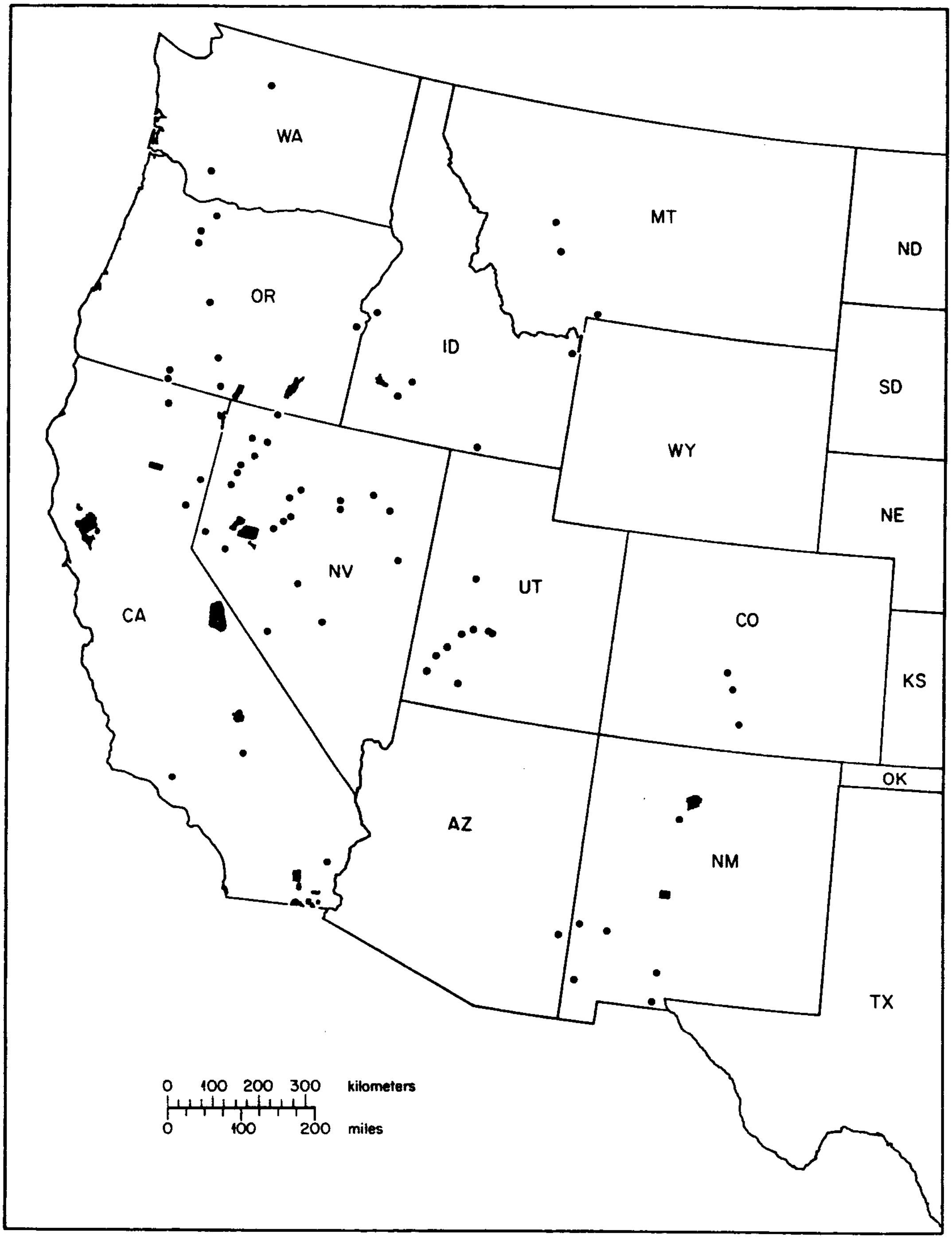
KNOWN GEOTHERMAL RESOURCES AREAS



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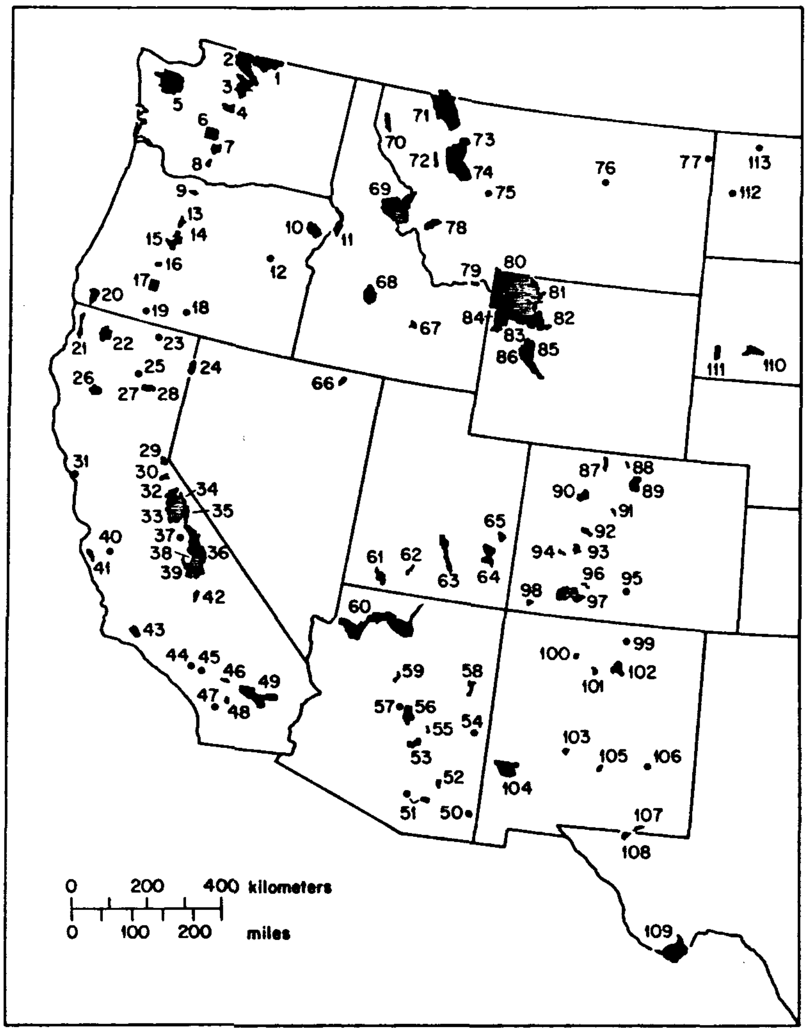
MANDATORY CLASS I PSD AREAS



MANDATORY CLASS I AREAS

1. Pasoyten W
2. North Cascades NP
3. Glacier Peak W
4. Alpine Lakes W
5. Olympic NP
6. Mount Rainier NP
7. Goat Rocks W
8. Mount Adams W
9. Mount Hood W
10. Eagle Cap W
11. Hells Canyon W
12. Strawberry Mountain W
13. Mount Jefferson W
14. Mount Washington W
15. Three Sisters W
16. Diamond Peak W
17. Crater Lake NP
18. Gearhart Mountain W
19. Mountain Lakes W
20. Kalmiopsis W
21. Redwood NP
22. Marble Mountain W
23. Lava Beds W
24. South Warner W
25. Thousand Lakes W
26. Yolla-Bolly-Middle-Eel W
27. Lassen Volcanic NP
28. Caribou W
29. Desolation W
30. Makelumne W
31. Point Reyes W
32. Emigrant W
33. Yosemite NP
34. Hoover W
35. Mingrets W
36. John Muir W
37. Kaiser W
38. Kings Canyon NP
39. Sequoia NP
40. Pinnacles W
41. Ventana W
42. Dome Land W
43. San Rafael W
44. San Gabriel W
45. Cucamonga W
46. San Gorgonio W
47. Aqua Tibia W
48. San Jacinto W
49. Joshua Tree W
50. Chiricahua National Monument W (Chiricahua W)
51. Saguaro W
52. Galiuro W
53. Superstitition W
54. Mount Baldy W
55. Sierra Ancha W
56. Mazatzal W
57. Pine Mountain W
58. Petrified Forest NP
59. Sycamore Canyon W
60. Grand Canyon NP
61. Zion NP
62. Bryce Canyon NP
63. Capitol Reef NP
64. Canyonlands NP
65. Arches NP
66. Jarbridge W
67. Craters of the Moon W
68. Sawtooth W
69. Selway Bitterroot W
70. Cabinet Mountains W
71. Glacier NP
72. Mission Mountains W
73. Bob Marshall W
74. Scapegoat W
75. Gates of the Mountain W
76. U.L. Bend W
77. Medicine Lake W
78. Anaconda-Pintlar W
79. Red Rock Lakes W
80. Yellowstone NP
81. North Absaraka W
82. Washakie W
83. Teton W
84. Grand Teton NP
85. Fitzpatrick W
86. Bridger W
87. Mount Zirkel W
88. Rawah W
89. Rocky Mountain NP
90. Flat Tops W
91. Eagles Nest W
92. Maroon-Bells Snowmass W
93. West Elk W
94. Black Canyon of the Gunnison W
95. Great Sand Dunes W
96. La Garita W
97. Weminuche W
98. Mesa Verde NP
99. Wheeler Peak W
100. San Pedro Parks W
101. Bandelier W
102. Pecos W
103. Bosque del Apache W
104. Gila W
105. White Mountain W
106. Salt Creek W
107. Carlsbad Caverns NP
108. Guadalupe Mountains NP
109. Big Bend NP
110. Badlands W
111. Wind Cave NP
112. Theodore Roosevelt NMP
113. Lostwood W