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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

by

MACKAY SCHOOL OF MINES
UNIVERSITY OF NEVADA
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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT

The Norhtern Nevada Region

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Prepared for

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Environmental Sciences Division
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DEDICATION

This volume is considered by our team of researchers to be a tribute to Dean Cornett, who provided us with much of his enthusiasm and talent during the early stages of the project. His utimely death was felt keenly by all. We hope that this volume meets his great expectations.

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PREFACE

The following environmental report on the northern Nevada geothermal region 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 goal of the Geothermal Overview Project is to provide the Department of Energy information on existing environmental data and major environmental issues, and to make recommendations for methods or plans to resolve these issues.

Similar reports are being prepared, or have been prepared for other states and regions with a potential for commercial development of geothermal energy. The primary purpose of these reports is to assist the Assistant Secretary for Environment of the U.S. Department of Energy in planning and decision making. We hope that this report will also provide preliminary information that will be of use to other governmental agencies, to the public, and to those engaged in developing this industry in such a manner that future development can be accomplished in an environmentally sound manner.

Our basic definition of environment is the natural setting and its effect on man's exploration development and production of the geothermal resources, and the converse, the effect of man's search for and use of the geothermal resources on the environment.

During the early stages of preparation of this report, many representatives of local, State, and Federal government, industry, research organizations, consultants, universities, organizations with environmental interest, and the general public were contacted to obtain an input that reflects perceived and real issues that must be considered for development of geothermal resources in this region.

We are especially grateful for the advisory committee who met frequently and provided a wide range of viewpoints that were useful in determining the scope and general direction for research by the project staff. Their intensive effort aided the conduct of our research and the planning and scope of the workshop.

We benefited from the generous and timely assistance provided by Dean Cornett, Neil Crow and Paul Phelps of the Lawrence Livermore Laboratory. Loretta Sabini supervised the editing, formatting, and text editing of the preliminary and final manuscripts. Her contributions greatly improved the organization and clarity of the manuscripts.

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Introduction

Increasing exploration for geothermal resources in northern Nevada indicates that development and use of these resources is imminent. This may have environmental impacts on and near the sites used. If the impacts were severe, development might be unacceptable. To assess the potential significance of environmental impacts and to identify work needed for proper evaluation, the Assistant Secretary for the Environment sponsored the Geothermal Environmental Overview Project, and delegated technical management to Lawrence Livermore Laboratory. This report presents the results of a study of northern Nevada.

Environmental overview studies for geothermal resource exploration and development generally include a review of the impacts and issues that relate to air quality, archeology and cultural resources, ecosystems quality, environmental geology, noise effects, seismicity potential for inducing earthquakes, and socioeconomic effects and water quality (Phelps and others, 1978). The special geologic, economic and governmental setting for Nevada has produced a different set of priorities and issues than is typical of similar studies for other areas. These factors include a combination of low population density, a fragile desert setting, an arid to semi-arid climate, and a unique archeological and historic legacy. In addition, the Federal government has plans to place in reserve, many large, specialized defense installations that embrace large areas, including valley or basin areas, which are generally the prime areas for geothermal development. Moreover, environmental, conservation, and historical organizations have requested that large tracts of land be withdrawn from conventional development to preserve some of the unique natural or historical areas of the State of Nevada.

One of our first steps was to form a steering committee, which consisted of appropriate representatives of various governmental organizations, historical and archeological interests, industry, planners, and environmental or conservation groups (Appendix A). This group formed a valuable resource of qualified individuals to spearhead the preparation of various parts of this report. The steering committee and staff prepared a preliminary list of issues, an inventory of the data base, and an assessment of background knowledge for each of the major topics listed above. A public workshop was held in October, 1979 to present the nucleus of this information and to involve the public, reseachers, governmental officials, environmentalists-conservationists, and industry in a discussion of these issues. The workshop was designed to identify the maximum number of issues for consideration in this report and to obtain outside viewpoints to assist in the preparation of this report.

Issues of environmental concern associated with geothermal exploration and development have been identified in each subject area of this report. Several issues may have significant impact on geothermal exploration, development, or both. The relative importance of each issue was determined by considering the following questions:

1. Does the issue have a high probability of adverse impact?
2. Will this impact be potentially severe, widespread, or of long duration?
3. Is the issue one that currently affects the region or likely to develop in the future?
4. Is the issue of sufficient importance for regulatory agencies to provide for legal means of control?
5. Does the issue represent an impediment to geothermal development?

The ordering of priorities followed the public meeting.

Blocking Issues

No issues that could prove to be serious barriers to over-all geothermal development in northern Nevada were identified in the workshop sessions, in relation to the presently defined KGRAs. There are, however, a number of promising geothermal prospects that are within, or very near, areas being considered for Federal land withdrawal. Two such areas of special interest are the proposed withdrawal for wilderness area of an extensive portion in the Black Rock Desert region, and the withdrawal of an area for the same purpose in the northern Stillwater Range, next to the Dixie Valley KGRA. Federal land withdrawals in these areas could either limit the development of the resource itself, or affect the feasibility of such necessities as transmission lines, making the development of resource economically unattractive.

Other potential "fatal flaw" issues include the possible presence of rare and endangered species (Chapter VII), historic-archeological values, outstanding scenic areas and ecologically unique lands. For example, a rare and endangered species, <u>Astagalus lentiginosus</u> , listed on the Federal Register of 1975 and present in the Soda Lake area, is of particular concern. Both the issue of rare and endangered species and land withdrawal need clarification and further study.

The Bureau of Land Management has started a program for oil, gas and geothermal leases (Bureau of Land Management Environmental Action Report No. 27-020-4-103). Cooperative work by Federal and Nevada State agencies could identify public lands not suitable for development at the present time.

High Priority Issues Involving Long-Term Data Acquisition

Some environmental issues require a long lead time for data gathering. The following are particularly important:

1. Hydrologic (primarily groundwater) parameters of basins;

2. Climate and air quality data in remote areas;

3. Regional seismicity, microseismicity, and strong motion records.

Water is always an important issue in arid Nevada. Anything that affects it's quality or quantity will be regulated by the governmental agencies. Little data exists concerning the interrelationship between geothermal and near-surface groundwater reservoirs. The data base on water quality, particularly geothermal fluids, is also poor. A regional data bank and coordinated research effort is necessary to quantify regional, basin, and geothermal hydrology.

The remote areas of Nevada, where most geothermal energy development is likely, have not been monitored for climate and air quality data. Climatological data are necessary to develop new air quality models and an air quality baseline data are necessary to assess the effect of geothermal emissions on present air quality. A long-term collection of data, on a regional basis, would be more useful than short-term, site-specific measurements.

The potential for earthquakes in Nevada is very high. An excellent seismic network exists but several gaps or "holes" exist, which make the resolution of smaller seismic events difficult, if not impossible. It is also necessary to extend coverage into the northern and eastern parts of the state. Strong motion information is critical to proper engineering design and to acquire the necessary data, strong motion instruments must be in place when a major earthquake occurs. This type of data is almost nonexistent for normal faults, the type that is characteristic in most of Nevada.

Issues by Specialty

Many other issues have been identified by the study teams. Some of the issues are of general importance, concern Federal and State agencies directly, and should receive general action, study and evaluation. Other issues are more site-specific and will require action by developers. A brief review by general topic follows. The text of each chapter should be consulted for a more complete discussion and analysis.

- Environmental Geology (Chapter III) and Seismicity of northern Nevada (Chapter IV).

  Active faulting . The data base is fairly good but needs revision using state-of-the-art methods to determine regional patterns, types of faults, recurrence intervals, and rates. Expansion of existing seismic networks and placement of strong motion instruments to monitor seismicity is necessary. Important issue.

  Induced seismicity . The potential effects of fluid withdrawal and reinjection in the very active tectonic setting of northern Nevada is not well known. Moderately important issue.

  Liquefaction . The data base for northern Nevada is very poor. A regional assessment is moderately important.

  Subsidence . Baseline information and evaluation should be site-specific. This is a low priority regional issue but a high priority item for a given producing field.

  Slope stability . The data base is poor, more detailed information near KGRAs is necessary. An issue of low priority.

  Flash floods . Data can be accumulated for each site. A low priority issue.

  Erosion . The information available for remote areas is very limited. A low priority issue.

  Volcanic hazards . A good data base is available. No action is recommended.

- Hydrology and Water Quality (Chapter V).

  Resource ownership . The issue of ownership, Federal vs. State, and a definition of the resource needs clarification. High priority.

  Baseline data on hydrology, geothermal hydrology, and water quality . This is a very important issue as previously discussed in this chapter. High priority.

Centralized data bank on hydrology, water quality and geothermal resources . Establishing a data bank including the coordination of effort by different agencies is a high priority need.

Enforcement of existing regulations . A problem involving the enforcement of existing regulations may evolve in the future. Low to moderate priority issue.

Communication . Better communication is needed among industry, government, and academic institutions. Low to moderate priority.

- Air Quality (Chapter VI).

Climate data . The data base for northern Nevada is very poor and must be upgraded for air quality modeling. See previous discussion in this chapter. High priority issue.

Air quality data . Similar to above, high priority.

Visibility . In general, the data base on visibility limits and line-of-site visibility is poor and needs upgrading. High priority.

Modeling . Mathematical models to describe dispersion of pollutants is necessary for the basins of Nevada. High priority.

Regulations . The State of Nevada should establish regulations to provide consistency among air quality control agencies. High priority.

Data bank . A data bank of atmospheric, climatic and pollutant information is needed for easy access by different agencies and institutions. Low-moderate priority.

Cooling tower drift . Information is needed on meteorological conditions in Nevada. Low priority.

Emission data . Information is needed on the types, amounts, and rates of substances that will be emitted by a geothermal power plant. High priority.

<u>Geothermal energy conversion cycles</u> . What type of energy conversion process will be used? The type of process used at a particular site will affect the priority of issues

<u>Transformation of H_2S to SO_2 and SO_4</u> . Information is needed for conditions typical for northern Nevada. Low priority.

<u>Effects on vegetation</u> . The effect of emissions on desert fauna, flora, and agriculture is needed. Low priority.

- Nevada Ecosystems (Chapter VII).

<u>Lack of biological inventories</u> . The biological data base is not adequate in most geothermal areas. A regional data bank is also necessary. High priority.

<u>Extent of damage to flora and fauna</u> . This issue is related to the inadequate data base. Are rare and endangered species, critical habitats or ecosystems involved? High priority.

<u>Effect of improved access on present habitat</u> . Geothermal energy development may lead to increased human impacts on sensitive ecosystems. Low-moderate priority.

<u>Lack of adequate pre-planning</u> . Coordination of exploration and development activities among users could minimize impact on ecosystems. Low-moderate priority.

- Noise Effects (Chapter VIII).

<u>Noise levels</u> . A data base of actual noise levels for liquid-dominated wells under operational conditions need to be established. Low-moderate priority.

<u>Effects on local communities</u> . The potential adverse impact of construction and operation noise levels in habitated areas should be assessed on a site-specific basis. Low-moderate priority.

<u>Effects on wildlife and domestic animals</u> . Will there be demonstrable effects? Data base may be sufficient. Low priority.

New regulations and/or special technologies . Will new regulations or central technologies be necessary? Previous studies indicate a minimal need. Low priority.

- Socio-economic Impacts and Considerations (Chapter IX).

Legal water rights . The legal definition of geothermal fluids needs clarification. High priority.

Water and air pollution regulations . Regulations by the State of Nevada covering water and air pollution should be clarified. Moderate priority.

Tax structure . Tax structure considerations, water rights, property rights, and water and air pollution standards should be addressed by the Nevada State Legislature in the near future. The philosophy behind any new legislation dealing with geothermal resources should adhere to the following principles:

1. Tax revenues should be at least adequate to cover the public expenditures required at various levels of government by the undertaking of a geothermal project;

2. Property rights and mitigation measures should be adequately defined so that parties damaged by geothermal resource development have adequate and efficient recourse to redress;

3. Air and water quality standards should have adequate flexibility to take into consideration the actual costs of air and water pollution at specific sites, and be able to adequately balance pollution costs and production benefits; and

4. Property rights, water rights, and tax policies should be established in such a manner that exploration and production are encouraged, as long as the above principles are met.

- Cultural Resources and Archeological Values (Chapter X).

Data base . The data base concerning the distribution of cultural resources in northern Nevada is poor. No priority assigned.

Adverse impact on cultural resources . Geothermal exploration and development, as a ground disturbing activity, is likely to have an adverse impact. Impact will probably be high and mitigation measures are required for Federal land. High priority.

Cooperation of Native Americans . The local Native American community should be consulted prior to exploration and development. Important issue.

Few recommendations have been included in this summary. Each investigator or study team has classified the issues and made specific recommendations concerning these issues. See Chapters III-X of this report.

AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter II

INTRODUCTION

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INTRODUCTION

INTRODUCTION

General Statement

This report studies regional environmental problems and issues associated with geothermal development in northern Nevada. The study is planned to facilitate environmental assessment of potential geothermal resources. The promising outlook for development of geothermal energy in northern Nevada is the result of an unique combination of geologic factors which in turn generate a large number of issues spanning a great variety of disciplines. The various issues are discussed in detail in Chapters III through X of this report and briefly in the paragraphs that follow.

Geologic Setting

The potential for geothermal development in northern Nevada is controlled by complex geologic structures (Chapter III). There are currently over 30 promising localities, mainly in the designated Known Geothermal Resource Areas (KGRAs). Several of these areas show a potential for commercial electric power generation, and many others are suitable for lower temperature applications. The resource is controlled by vigorous deformation within many major, complex fault blocks, and is accompanied by high seismic activity. These blocks include up-faulted mountain blocks (horsts), tilted mountain blocks, and down-faulted valley blocks (grabens). Failure occurs by brittle fracture on normal faults to depth of about 12 to 15 km. The faults vary from simple breaks to complex swarms and constitute shattered zones that can control the deep circulation of heated ground water and provide preferred avenues for upward migration of molten rock. The KGRAs are located primarily along active range front fault zones that dip beneath the valley floors. There are some geothermal areas in mid-valley fault systems (e.g., Soda Lake-Stillwater areas) and, more rarely, in the horst or mountain blocks (e.g., Desert Peak and perhaps the Steamboat Hot Springs area). The complex geologic history of northern Nevada, with a wide variety of rock and fault types, as well as topographic, hydrologic and climatic variations, provides a broad range of environmental situations. The data base for the geologic, tectonic and seismologic setting is incomplete, and preliminary assessment of the environmental geology issues in this report is provisional and will require continuing reassessment.

The origin of Basin-and-Range faults is a matter of continuing debate and the structural setting and the definition of seismotectonic factors that control geologically young geothermal deposits is theoretical. The general depth and nature of geothermal resources is thus unknown although economic considerations generally limit drilling to 10,000 feet (3000m) or less. Current data suggest that most reservoirs are in topographically low and relatively gentle terrains. Accordingly, the major slope stability problems that accompany much of the exploration and development in the well-known Geysers area in California, will not occur in the northern Nevada region. The high earthquake frequency, and the capability of faults in the region for producing earthquakes of magnitudes 7 to 8 indicate a site-specific hazard of rockfalls, earthflows and liquefaction for many or all of the KGRAs.

Seismologic Setting

The seismologic setting (discussed in Chapter IV and to a lesser extent in Chapter III) indicates geothermal resources are generally in close proximity to active faulting and zones of high seismicity, and probably are genetically related to zones of highly active tectonism and deep crustal fracturing. The zones of highest activity branch northward from the major fault systems of coastal and southern California, along the Ventura-Winnemucca zone as defined by historic activity, and along the eastern Sierra Nevada frontal fault system, a zone of high earthquake potential. The presence of these zones indicate most geothermal resource areas will have to be developed with consideration of active faulting, high seismic risk, and possible strong ground motion. In addition to the natural seismicity present in northern Nevada, improper procedures of fluid injection at geothermal sites may produce the risk of induced earthquakes, possibly of high magnitude, accompanied by surface rupture and strong ground motion.

Public concern with seismic safety mandates a program of adequate, long-term monitoring of natural seismicity, and the definition of its character, including the kinds of strong ground motion to be expected from normal slip faults characteristic of the region. An inadequate data base, both world wide and regionally, on the kinds of strong motion to be expected from this type of earthquake make it important to acquire a data base from future earthquakes, particularly in this classic area of normal faulting.

High quality research is being conducted in parts of northern Nevada, but the inadequate distribution of seismographic stations provides insufficient data for the assessment of regional seismicity. High quality data is now being acquired for most of the west-central part of the province, but no local seismographic coverage exists along the northern edge and eastern half of the study area.

Hydrology and Water Quality

The background of data on the water resources of northern Nevada is outlined in Chapter V of this report. Nevada is the driest State in the Union. The arid climate provides only limited surface runoff. In addition, the extensive use of shallow ground water resources, mainly for Nevada's agricultural economy, and the unusual chemical character of geothermal solutions, many of which contain potentially harmful amounts of toxic substances, provide a special situation that will require evaluation during any future development of geothermal resources.

The present surface water resources include six major perennial standing bodies of water, four major perennial streams, and numerous ephemeral streams. Most of the usable water in northern Nevada exists as shallow ground water, mainly in the basin-fill sediments of the valleys (grabens). These basins form many local hydrologic systems with some inter-basin flow in parts of the area.

The quality of the ground water is highly variable and can be high in total dissolved solids (TDS). The high TDS levels may include unacceptably high levels of toxic elements, such as arsenic and boron. These high levels may represent natural pollution from geothermal sources, for example, near the Steamboat Hot Springs, Soda Lake, and Stillwater KGRAs. The interrelationships of shallow ground water and deeper geothermal reservoirs must be assessed if decisions on water use are to be made in the best interest of the environment, the geothermal industry, agriculture, and domestic needs.

Still at issue in Nevada is ownership and regulation of geothermal fluids. Exploration and development will proceed more smoothly once these two issues, water resources and regulation, are clarified, although considerable potential for extended litigation and delay exists.

Air Quality Setting

The problems associated with the release of steam, possibly accompanied by toxic substances, have been evaluated for many geothermal areas outside of Nevada and much of the basic data obtained is useful for evaluating air quality issues in Nevada.

The present data base on the meteorology of northern Nevada is accumulated from a few, perhaps nonrepresentative, stations in the region. Several factors make the limited meteorological data base inadequate to evaluate the impact of future geothermal development in Nevada. These factors include the arid climate and a unique series of topographically closed basins, which have long periods of strong temperature inversions with stagnant air during certain parts of the year. The emission of odorous and toxic substances combined with visibility-limiting aerosols are also important environmental issues of geothermal energy production. The chemical nature of the various geothermal fluids likely to be produced in the future is not well known. One KGRA, Steamboat Hot Springs, is close to an urbanized area where local air quality is an important issue. The heterogeneous geographic setting is likely to provide major problems in assessing the issues related to each future development site in the region.

Ecosystem Setting

The fauna and flora setting, both regionally and for specific KGRAs, is summarized in Chapter VII of this report. There are many research papers published on the flora, fauna, and ecology of the northern Great Basin, although the data base is incomplete for the KGRAs evaluated in this report. Ecological inventories are generally incomplete and are widely scattered, with no complete collection of background data available.

The present data show a number of endangered species within the region and at some of the KGRAs. The region is divided by topographic and climatic factors into a number of distinct ecosystems and zones, where long-term geographic isolation has allowed the development of many distinct, locally defined distributions of species. Those on rare and endangered bird, fish, mammal, and plant species lists prepared by the U.S. Fish and Wildlife Service, the State of Nevada, and private groups are presented in Chapter VII of this report and are described for preliminary planning purposes for some of the individual KGRAs. These compilations are based on the limited data available at this time.

Noise Effects

The nature and scope of noise from production of the geothermal energy is well known and studied for many producing areas (see Chapter VIII). Continuing development of noise control technology is expected to minimize this factor. The remote setting of most of the Nevada geothermal areas and the sparse human and wildlife population will reduce the importance of noise emissions relative to many other geothermal areas.

Socio-Economic Setting

The socio-economic setting is reviewed in Chapter IX of this report. The geothermal development is likely to most affect the agricultural areas of the state when competition for land use occurs. Impacts will vary in nature during the exploration, development and production stages of development, depending on the site. The development will be partially controlled by the economic factors that influence the competitiveness of energy production with other methods of producing energy, but will also be affected by the legal and institutional relationships that define property rights over the resources, surrounding lands, and other affected entities. Present and future tax policies will also affect the manner and rate of development in this industry.

Cultural Resources and Archeological Values Setting

Chapter X summarizes the probable interaction and potential conflicts between geothermal resource development of archeological and historical values in northern Nevada. The prehistoric use of geothermal areas by Native American Indians is well established. Little baseline data is available on the extent of utilization of these areas, with the exception of Steamboat Hot Springs. It is not known what impact geothermal development will have on these archeological and historical sites. Standard methods of study have been developed for assessing the impact from development in other industries. Since development of the geothermal industry does not appear to be uniquely different from other types, the previously formulated methods of assessment may be applicable. There is no indication of any special problems associated with geothermal development that are not common to other, well studied, ground disturbance activities.

The data base concerning the distribution of cultural resources in northern Nevada is poor and addresses only small, widely scattered areas. The compilation of information on each potential geothermal area is difficult and must include collection of additional data. In addition, cooperation with the Native American population, and an assessment of their feelings and beliefs, is necessary to avoid an adverse impact on their society and culture.

AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter III

ENVIRONMENTAL GEOLOGY

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GEOLOGY

Introduction

The regional geology of northern Nevada sets the stage for any discussion of geothermal resources and has a direct bearing on some environmental problems. Overviews of the nature of the resource in northern Nevada and discussions of potential environmental problems can be found on p. III-11 to III-13 and p. III-13 to III-27 .

Geologic History and Structure

General Statement

The geology of northern Nevada is extremely complex with multiple periods of deposition, deformation, metamorphism and intrusion of plutons during the Paleozoic and Mesozoic eras. The Tertiary geologic history is also complex being dominated by a variable pattern of volcanic eruption and sedimentation during the development of Basin-and-Range fault related structures. In view of this complex geological framework, each geothermal area should be studied separately. Published documentation varies from relatively complete, as with the Steamboat Hot Springs area, to generalized reconnaissance reports for most of the Known Geothermal Resource Areas (KGRAs).

Regional Syntheses and Maps

Summaries of regional geology include Roberts and others (1978), Langenheim and Larson (1973 and 1976), Burchfiel and Davis (1975), and Stewart (1980). The county reports of the Nevada Bureau of Mines and Geology contain excellent summaries of the regional geology of each county in northern Nevada; these are listed in Table 1 for the counties shown in Figure 1. The lithologic types of igneous rocks and their ages are compiled in Smith and others (1971), Noble (1972), Armstrong and Suppe (1973), and Christiansen and McKee (1978). Regional geologic maps include King and Beikman (1974) and Stewart and Carlson (1977 and 1978). Tectonic maps include Cohee (1961), Bailey and Muehlberger (1968) and King (1969). Maps of active or geologically young faults are compiled in Slemmons (1966) and Howard and others (1977). Four maps with a brief description of distribution, lithology, age and centers of volcanism are in Stewart and Carlson (1976).

Precambrian and Paleozoic Rocks and Structures

Outcrops of Precambrian rocks are virtually absent in northern Nevada. Thick sequences of Paleozic rocks are exposed in many of the ranges of northern Nevada (Roberts and others 1958; Silberling and Roberts 1962). Paleozoic rocks in eastern and western Nevada are of different lithologies or facies. The western part of the state is

TABLE 1.

COUNTY REPORTS PUBLISHED BY THE NEVADA BUREAU OF MINES AND GEOLOGY

COUNTY	BULLETIN NO.	DATE	AUTHOR(S)
Pershing	89	1977	Johnson, M. G.
Lander	88	1977	Stewart, J. H., McKee, E. H., and Stager, H. K.
White Pine	85	1976	Hose, R. K., Blake, M. C., and Smith, R.M.
Chruchill	83	1974	Willden, R., and Speed, R. C.
Esmeralda	78	1972	Albers, J. P., and Stewart, J. H.
Nye (southern)	77	1972	Cornwall, H. R.
Lyon, Douglas, and Ormsby	75	1969	Moore, J. G.
Lincoln	73	1970	Tschanz, C. M., and Pampeyan, E. H.
Washoe and Storey	70	1969	Bonham, H. F., and Papke, K. G.
Eureka	64	1967	Roberts, R. J., Montgomery, K. M., and Lehner, R. E.
Clark	62	1965	Longwell, C. R., Pampeyan, E. H., Bowyer, B., and Roberts, R. J.
Humboldt	59	1964	Willden, R.
Mineral	58	1961	Ross, D. C.
Elko	54	1957	Granger, A. E., Bell, M. M., Simmons, G.C., and Lee, F.

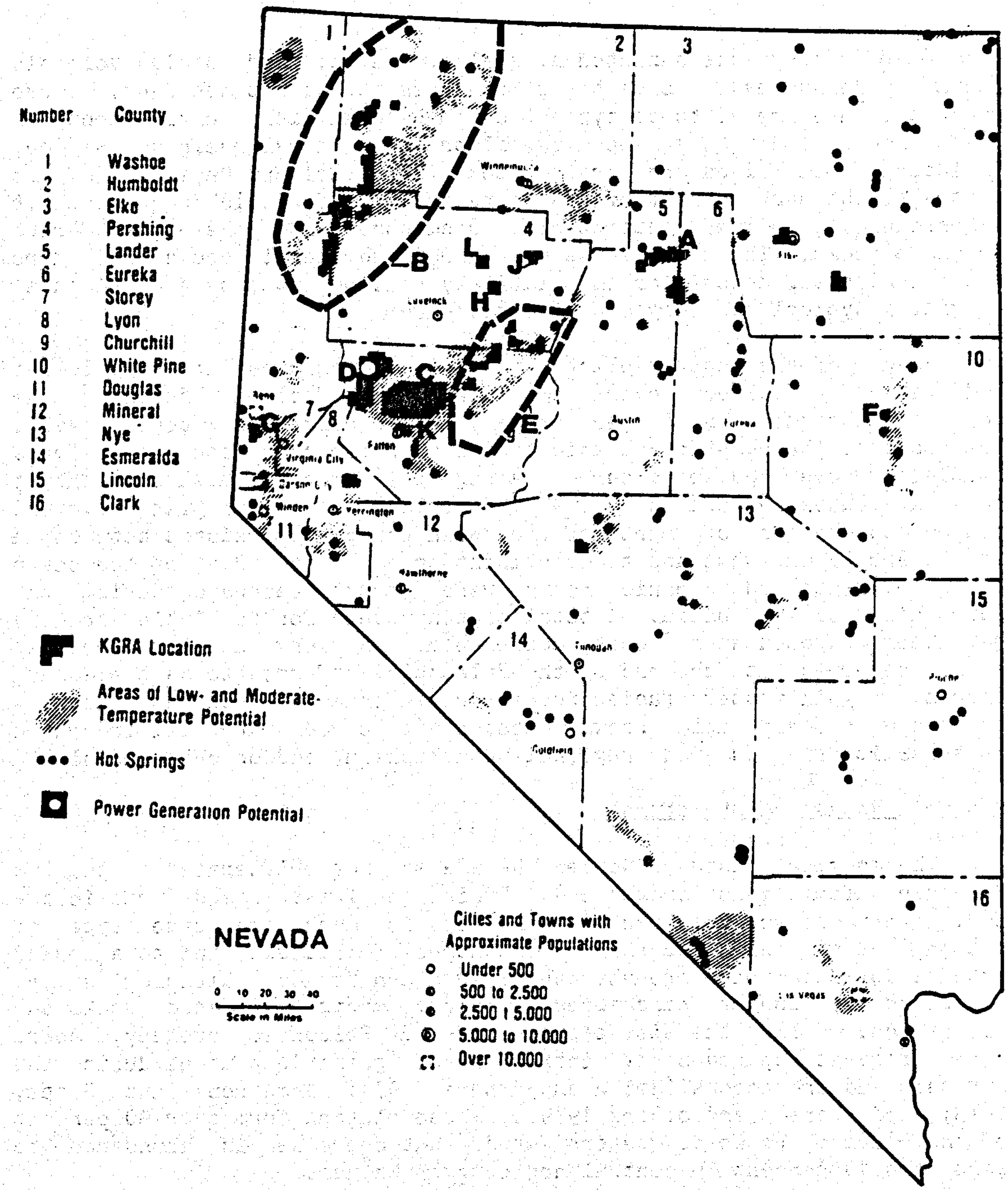


Figure 1. Potential geothermal areas in northern Nevada. Known Geothermal Resource Areas (KGRAs) discussed in this report are labled as follows: (A) Beowawe; (B) Black Rock Desert area; (C) Desert Peak; (D) Brady-Hazen; (E) Dixie Valley area; (F) Monte Neva; (G) Steamboat; (H) Kyle Hot Springs; (J) Leach Hot Springs; (K) Carson Desert (Stillwater-Soda Lake); (L) Rye Patch (Humboldt House). (modified from EG&G Idaho, Inc., 1979)

dominated by greywacke sandstones, shales, cherts, and basic volcanic rocks (greenstones). Limestones are present but not abundant. These rocks are interpreted to be typical of a eugeosynclinal environment of deposition including the deep ocean floor and marginal basin deposition, including some island arc derived rocks (Burchfiel and Davis 1975). In contrast, the eastern part of the state is known for thick sequences of limestones, dolomites, quartz-rich sandstones and shales, with rare volcanic rocks. These carbonate and associated clastic rocks are more typical of shelf deposition in relatively shallow water on a continental margin; a typical miogeosynclinal environment.

Rocks of the western clastic-volcanic facies were intensely folded and thrust faulted over the eastern facies during the Devonian-Mississippian Antler orogeny (Silberling and Roberts, 1962). Transport of the clastic-volcanic facies over the carbonate facies for a distance of over 100 km occurred along the Roberts Mountain thrust complex. Burchfiel and Davis (1975) speculate that major plate movement caused subduction of part of the ocean basin that existed between an island arc to the west and the continent to the east. Part of the ocean floor sediments and volcanic rocks were thrust eastward during the shortening of the basin. A total of ten models for the Antler orogeny have been proposed at a recent conference. A very similar tectonic event occurred at the end of the Paleozoic, referred to as the Sonoma orogeny. Again western facies rocks were deformed and thrust eastward over the eastern facies rocks. Most of these rocks are well indurated as a result of a low grade regional metamorphism, and/or deep burial.

Mesozoic Rocks and Structures

The marginal basin of western Nevada was not obliterated in the two Paleozic deformations (orogenies). During the Triassic and Jurassic the sedimentary and volcanic rocks accumulated in much the same type of setting as the Paleozoic rocks. Exposures of Triassic, and to a lesser extent, Jurassic rocks are abundant in western Nevada. Lithologies are dominated by impure sandstones, shales, marine volcanic rocks and limestones. Unlike the situation during the Paleozoic orogeny, there were frequent episodes of intrusion of granitic plutons during the Jurassic and Cretaceous (Smith and others 1971; Armstrong and Suppe, 1973; and Larson and others 1979). These plutons form over 90 percent of the basement rocks of western Nevada, but decrease in abundance to less than 10 percent in central and eastern Nevada.

Mesozoic rocks of northern Nevada were involved in another major orogeny, the Nevadan orogeny, from late Jurassic through Cretaceous time. Folding and thrust faulting occurred and numerous plutons were implaced, generally after folding and thrust faulting (Armstrong and Suppe 1973). Interpretations of the Nevadan orogeny involve a postulated underthrusting of oceanic rocks beneath the western part of North America and growth of an Andean (continental) volcanic arc in what is now western Nevada. Metamorphism was generally weak, except for contact zones and local areas of high grade regional metamorphism (e.g., the Ruby Mountains).

Cenozoic Rocks and Structures

Rocks of early Tertiary age are rare in northern Nevada but a few localities are mentioned in the literature (Willden 1964). An abundance of volcanic and related rocks began to accumulate during and after the Eocene. Non-marine basin sediments are locally preserved but the Cenozoic rocks are dominated by volcanics. A wide spectrum of lithologies is present but andesitic rocks of the early Tertiary gave way to mostly basalt and rhyolite in the later Tertiary (Stewart and Carlson 1976). Rhyolite, often associated with geothermal energy, has not erupted in northern Nevada during the last 10 million years with the exception of the Steamboat Hot Springs and nearby areas (fig. 1). Overall, volcanism began to wane about 12 million years ago (Christiansen and McKee 1978) and volcanic rocks of less than 6 million years age form relatively thin and widely separated patches in northern Nevada. Basalts predominate during this period with minor andesite and rare rhyolite.

The last period of intense deformation began, locally, during the Miocene (about 17 million years ago) and continues today (Noble 1972; Christiansen and McKee 1978). This period of deformation has been characterized by extension and rifting rather than compression and has produced the fault-bounded basins and ranges so typical of northern Nevada. Outpourings of volcanic rocks accompanied faulting or preceeded it (Stewart 1978), but faulting has continued without associated volcanism over much of northern Nevada. Some small plutonic bodies were emplaced in the Cenozoic but these are rare and with the one possible exception of ryholite at Steamboat Hot Springs, are too old to be a source of heat for active geothermal systems.

The late Cenozoic episode of deformation has produced horst and graben structures (Stewart 1971) with mountain blocks (horsts) separated from basins (grabens) mainly along range-front faults. Intrabasin faults are common as well (Thompson and Burke 1974). Relief on bedrock surfaces may be of the order of thousands of meters (Thompson and Burke 1974) which indicates the presence of thick alluvial fill in some valleys. Late Cenozic faults are associated with hot springs (Slemmons, 1956) and with geothermal reservoirs in northern Nevada (Hose and Taylor 1974).

Topography

Virtually all of northern Nevada is in the Basin and Range physiographic province (fig. 2), with a small salient of the Owyhee Plateau curving into north-central Nevada (Stewart 1978). The Basin and Range in Nevada consists of NNE-SSW to NS trending, fault-bounded mountain ranges (horsts) of bedrock separated by valleys (graben) of basin fill sediments (fig. 3). The NNE-SSW to NS trend is most conspicuous in the central part of the state in the region northeast of

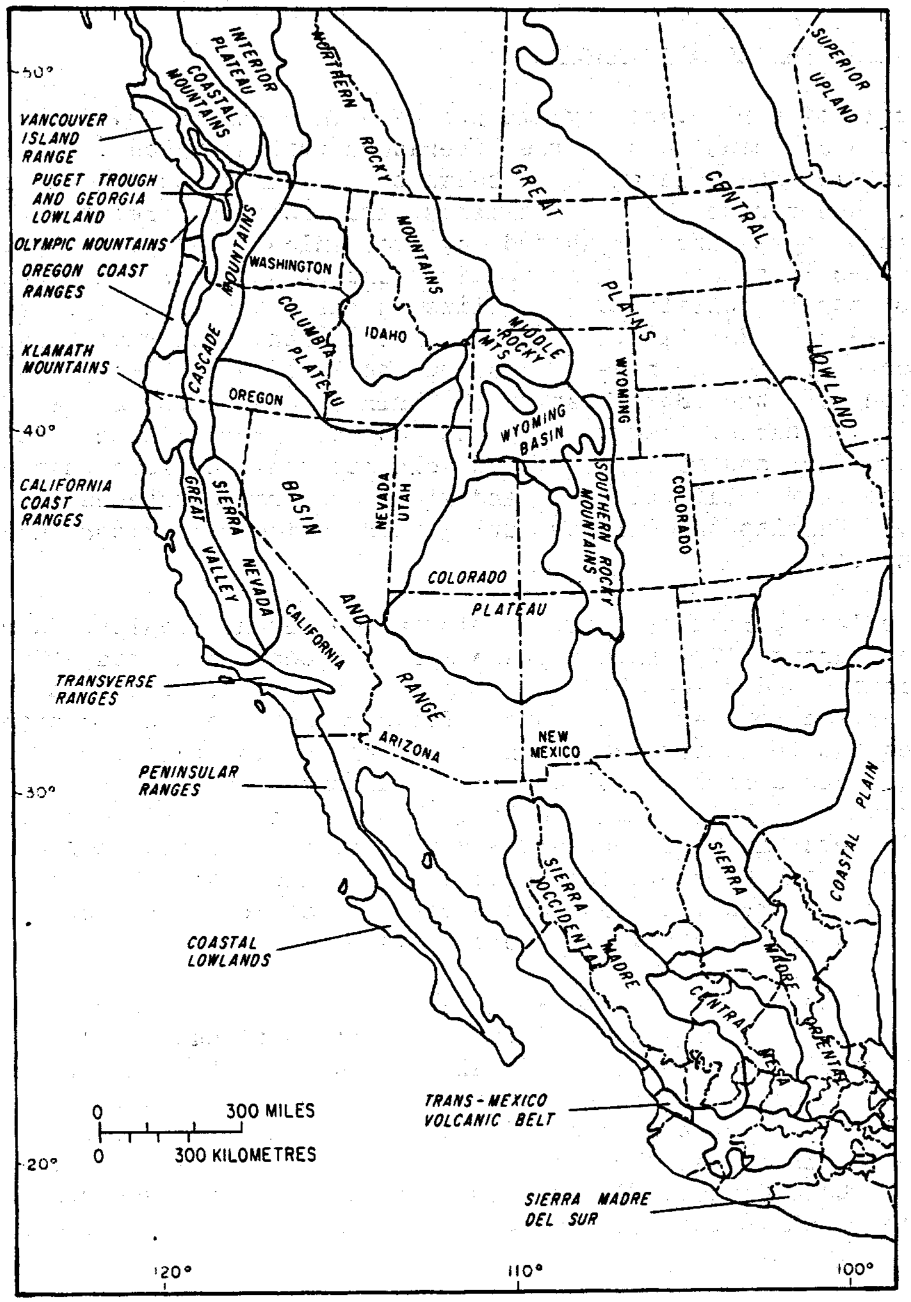


Figure 2. Geomorphic provinces map of the western United States (Stewart, 1978).

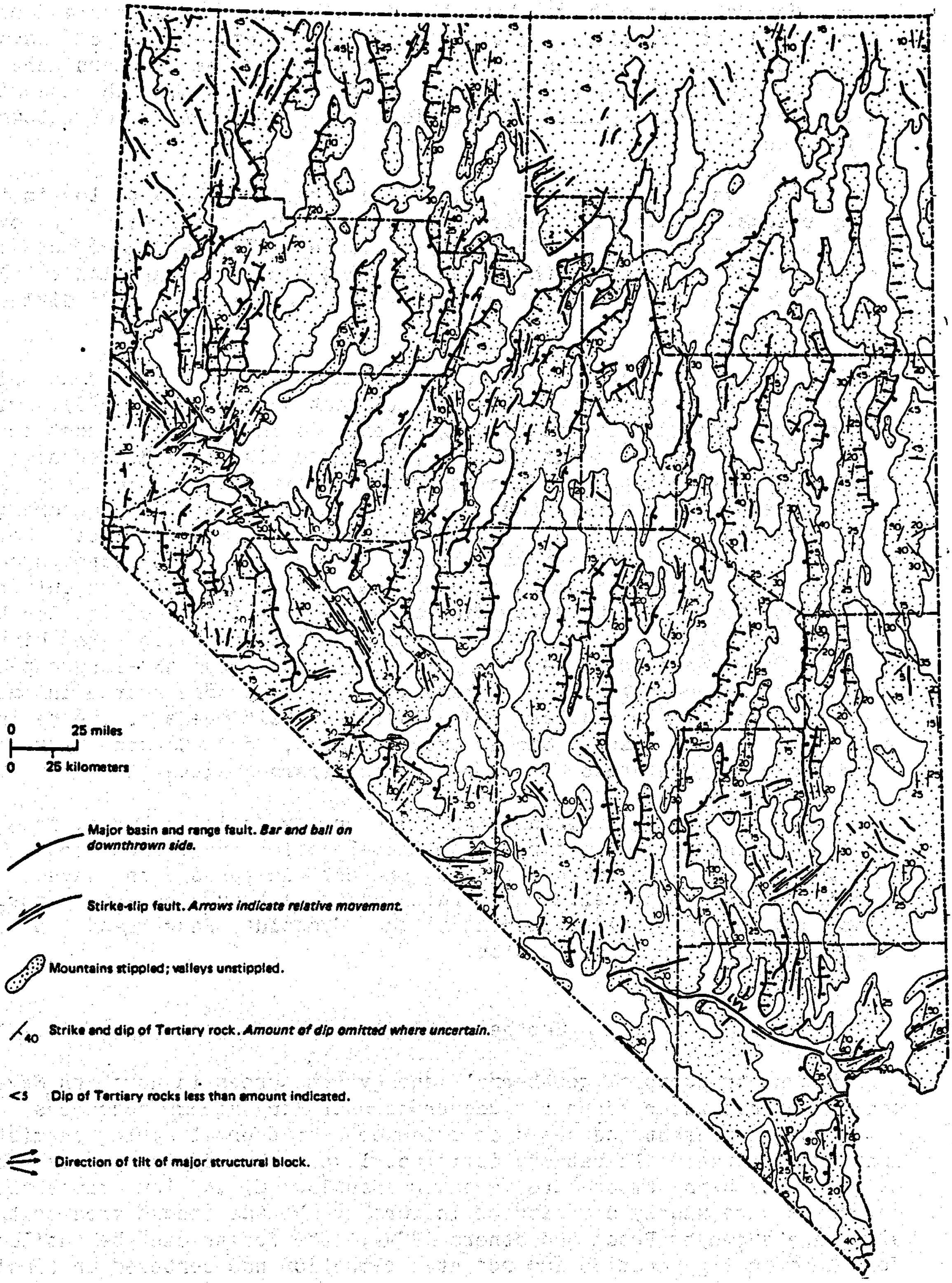


Figure 3. Map of Nevada showing mountains (bedrock), valleys (alluvium), major Basin and Range faults, and tilt of Tertiary rocks (Stewart, 1980).

the Walker Lane zone of NW trending faults (fig. 4). Between the Sierra Nevada and the Walker Lane the fault blocks are shorter and more irregular in outline (figs. 3 and 4). The northwest corner of Nevada is characterized by lower relief. In general, the northern part of Nevada is more plateau-like than the region to the south, with extensive flows of basalt and deposits of silicic tuffs (Map Sheet 3 of Stewart and Carlson 1976).

Relief varies from high within the mountain blocks to low in the valley blocks. Basin fill varies from a few hundred meters to over 3,000 m (10,000 feet) see Thompson and Burke (1974), and a recent U.S. Geological Survey study in the Black Rock Desert (in preparation). All of northern Nevada has internal drainage, and many of the individual valleys are closed basins.

The Basin and Range province, with the exception of some high elevation areas is arid to semi-arid (Houghton and others 1975). with an average annual precipitation of less than 16 in (40 cm) in most areas (fig. 5). Soil development is highly variable with many different soil types present within the province or within a given area. For example, 53 different soil series were mapped in the Reno 15 minute quadrangle (Nevada Bureau of Mines Reno Quadrangle of the Environmental Folio Series). Soil maps are available for many parts of the state through the U.S. Soil Conservation Service of the Department of Agriculture. Vegetation types which have adapted to areas of low precipitation and alkaline conditions are relatively sparse. Erosion rates are highly variable in northern Nevada. This gives the mountain landscapes a stark, high topographic relief. Vegetation is even more sparse in most of the playa lake, salt flat, and alluvial deposit areas of the basins. The Black Rock Desert, Smoke Creek Desert, and Carson Sink are exceptionally large areas of low relief and sparse vegetation.

Most of the geothermal areas are on low relief alluvial fans or aprons adjacent to mountain ranges. The elevations vary from about 1200 m (4000 ft) to 1500 m (5000 ft). At present no prospects have been identified in high relief mountain areas, although some warm spring areas have been identified such as in the Humboldt Range and in the Virginia Range near Virginia City.

Geothermal Resources

Known producible geothermal energy resources in northern Nevada consist of hot water systems. Occurrences of "dry steam" resources are not known at present and based on evidence from thermal spring chemistry and hydrothermal alteration, it is not likely that dry steam resources exist. Both high temperature (greater than 150° C) and low temperature resources are widely distributed in northern Nevada (those greater than 90 °C are shown by Brook and others 1979). The former can be utilized for electrical generation and recent exploration has centered on finding high temperature reservoirs. Garside and Schilling (1979) summarize data on thermal waters of Nevada. Areas with potential for direct use

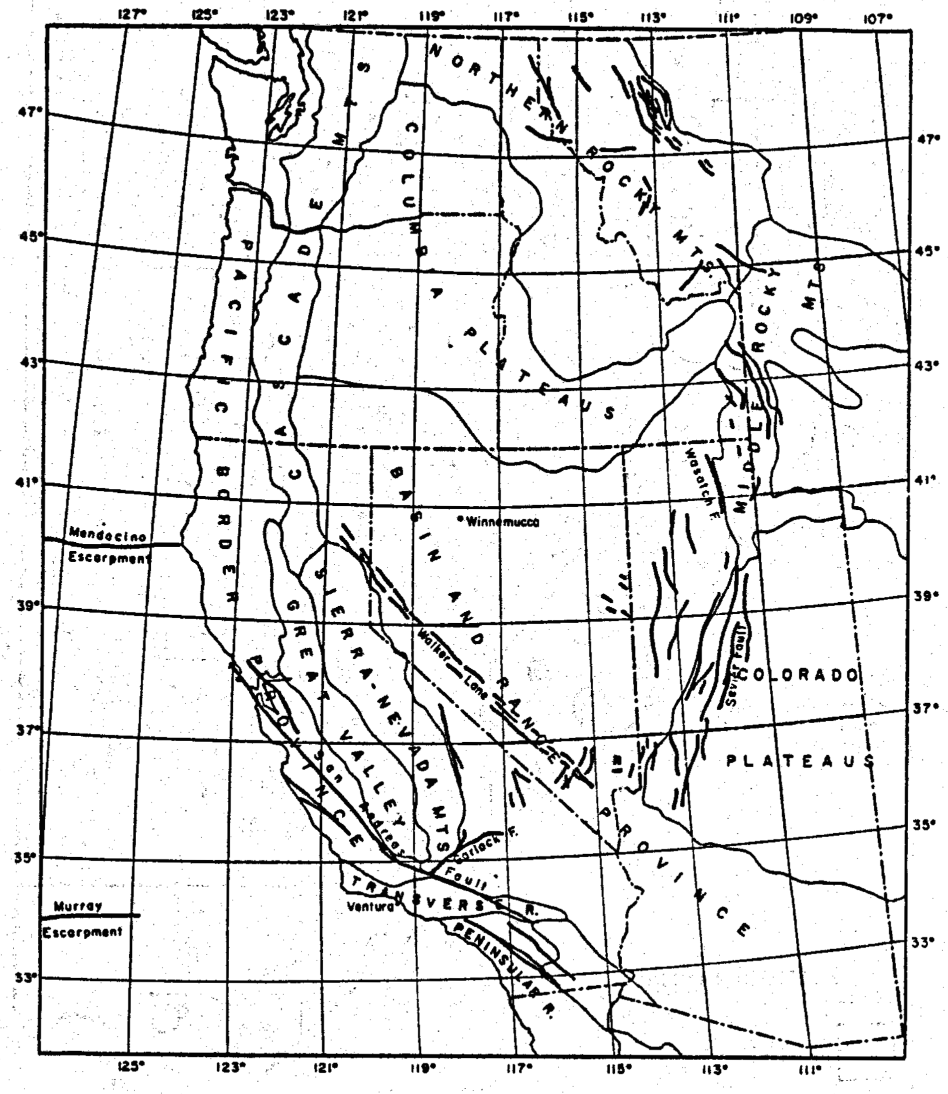
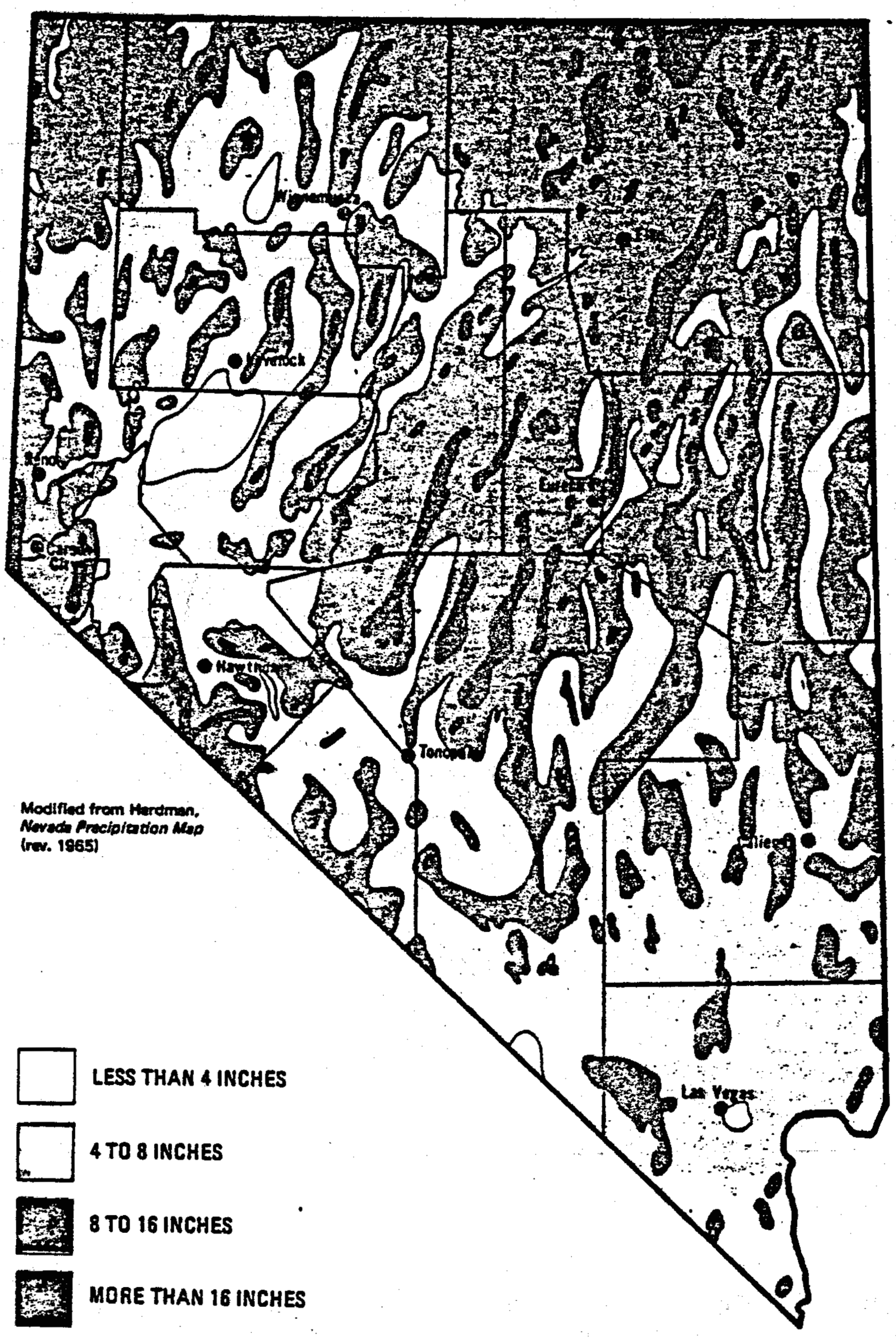


Figure 4. Map of the western United States showing physiographic provinces and major fault zones (Slemmons, 1967).



Modified from Hardman, *Nevada Precipitation Map* (rev. 1965)

Figure 5. Average annual precipitation in Nevada (Houghton and others, 1975).

of geothermal fluids, including low temperature water, have been outlined by Trexler and others (1979).

Estimates of the resource base are still highly speculative. A methodology for calculating reserves and a preliminary assessment is given in U.S. Geological Survey Circular 790 (Muffler, editor, 1979). Nevada does not have a producing field as of 1980 but exploration, including drilling is proceeding. There are 29 Known Geothermal Resource Areas (KGRAs) in northern Nevada (table 1 and figure 1). Exploratory work is proceeding at most of them with large bore drill holes at Steamboat Hot Springs, Dixie Valley, Beowawe, Rye Patch, and Brady Hot Springs.

Origin

The source of heat that drives the hot water geothermal systems in northern Nevada is speculative. There is agreement that hot fluids migrate up fractures in bedrock and basin fill. The fractures are frequently associated with active faults (fig. 6). Intersections of two or more trends, particularly NS, NW, and NE, are favorable (Trexler and others 1979; Garside and Schilling 1979) but single trends also show geothermal activity (for example, Brady Hot Springs). Most known geothermal areas have thermal springs that issue from faults that cut alluvium at the surface. Reservoirs are usually in fractured bedrock (Benoit, personal communication) where fracture porosity and permeability are critical factors in allowing fluid movement. Basin fills often show effects of hydrothermal mineralization (Beyer and others 1976; Goldstein and others 1976; Noble 1972; Garside and Schilling 1979). Reservoirs may be located in very thick sections in basin fills

Volcanic Model

Unlike most other geothermal areas, those in northern Nevada are rarely associated with surface Quaternary volcanism. Exceptions are Steamboat Hot Springs, Soda Lake-Upsal Hogback and Buffalo Valley Hot Springs. Ryholite domes of Pleistocene age (1.15 - 1.52 m.y.) are associated with Steamboat Hot Springs (Silberman and White 1975) and volcanic and thermal activity in the vicinity may date back to 3 m.y. before present (Silberman and White 1975). Basalt volcanism of late Pleistocene age and phreatic (gas explosion) craters of Holocene age occur in the Soda Lake-Upsal Hogback thermal area. Garside and Schilling (1979), citing a personal communication from Jonathan O. Davis, give evidence of volcanic activity there in the last 30,000 years. The Buffalo Valley Hot Springs occur basinward of a 12 mile long line of basaltic cinder cones and lava flows. Dates of 1.2 to 1.3 m.y. on the basalt are cited in Garside and Schilling (1979).

Deep Circulation Model

The most accepted model of the origin of geothermal fluids in northern Nevada involves very deep circulation of meteoric water down

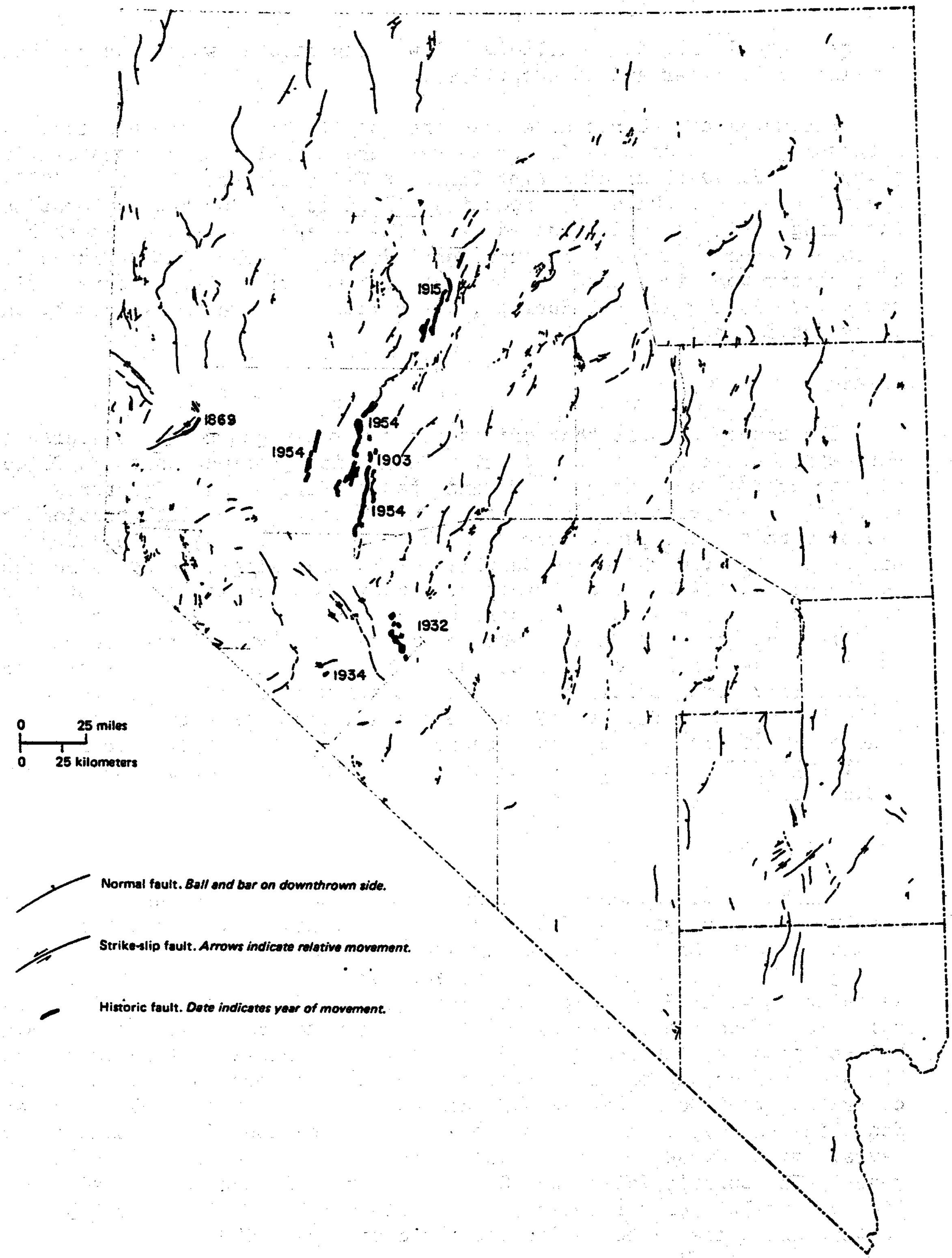


Figure 6. Late Quaternary and historic faults in Nevada (Stewart, 1980).

fractures where it is heated and rises to the surface along fault-related conduits (Hose and Taylor 1974; Olmstead and others 1975). A much higher than normal heat flow and geothermal gradient are characteristic of northern Nevada (Blackwell 1978; Lachenbaruch and Sass 1978) and temperatures in excess of 200 °C should be attainable at depths of 5 kilometers over the regional Battle Mountain High thermal anomaly although economic recovery is not possible at such depths with present technology. Heat may be supplied by a combination of crustal spreading and/or igneous intrusion as discussed by Lachenbruch and Sass (1978). Accordingly, some or many of the geothermal areas may be associated with deep, unexposed magmatic activity.

Character of Northern Nevada Geothermal Resource

The salient points concerning geothermal energy resources in northern Nevada are:

1. Reservoirs contain "hot water", not "dry steam";

2. Most known thermal areas are associated with active faults;

3. Thermal systems are generally not associated with surface expressions of young volcanic activity;

4. Reservoirs are usually in fractured bedrock, but often under alluvial fill.

ENVIRONMENTAL GEOLOGY ISSUES

Introduction

The purpose of this chapter is to identify potential environmental problems related to geology and geological processes. Prior to and during the public workshop on environmental issues that was held on October 11 and 12 1979, the following potential problem areas were identified for discussion:

1. Active Faulting
2. Natural and Induced Seismicity
3. Liquefaction
4. Subsidence

5. Slope Stability

6. Flash Floods

7. Erosion

8. Volcanic Eruptions

Each of these eight topics is addressed within this chapter in relation to the geology of northern Nevada, with an assessment of the current (published) data base, a general description of our knowledge of the problem, and recommendations on the need for future action on each topic. A background of natural and induced seismicity is in Chapter IV of this report. Each topic is assigned a relative priority of importance, from low to high, based on the nature and scope of the problem. Both the potential impact of geothermal development on the environment and the environmental risk that affect geothermal development are considered. Recommendations are made on the action needed to understand, reduce, or mitigate the problems.

Active Faulting

The historic record of larger earthquakes in the western United States has shown a high potential for earthquakes of greater than 5.5 to 6 magnitude. The length of surface fault ruptures are related to the magnitude of the earthquake (fig. 7). These ruptures (fig. 8) show the development of a semi-continuous zone of faulting from Ventura, on the coast of California northward to near Winnemucca, Nevada (Ryall and others 1966; Slemmons 1966). Each succeeding earthquake either has extended the zone or tended to fill gaps in the zone. Earthquakes producing surface faulting along this zone are known for long recurrence intervals (i.e., time between earthquakes). A major seismic event is followed by a dormant period measured in thousands or tens of thousands of years before the next event on the fault segment. Fault activity varies in location and time with a tendency to spread to increase the width or length of the affected rupture zone, or fill gaps between ruptures. Through late Quaternary time, this has produced a widely distributed pattern of ruptures throughout most of the Basin and Range province (fig. 9).

The common association of hot springs and geothermal resources along deep ruptures of recent origin indicates the possibility that future geothermal development must consider the high risk of nearby natural earthquakes of large magnitude, or of fluid injection inducing large earthquakes at or near the geothermal area. The pattern of faulting is a conjugate relationship as noted by Wright (1976), with (1) northwest trending faults of right-slip character, similar to the San Andreas fault, (2) northeast trending faults of left-slip character, similar to the Garlock fault and, (3) north-south faults of normal slip character (fig. 10). This conjugate pattern may be in response to the westward movement of the Sierra Nevada block with respect to the North

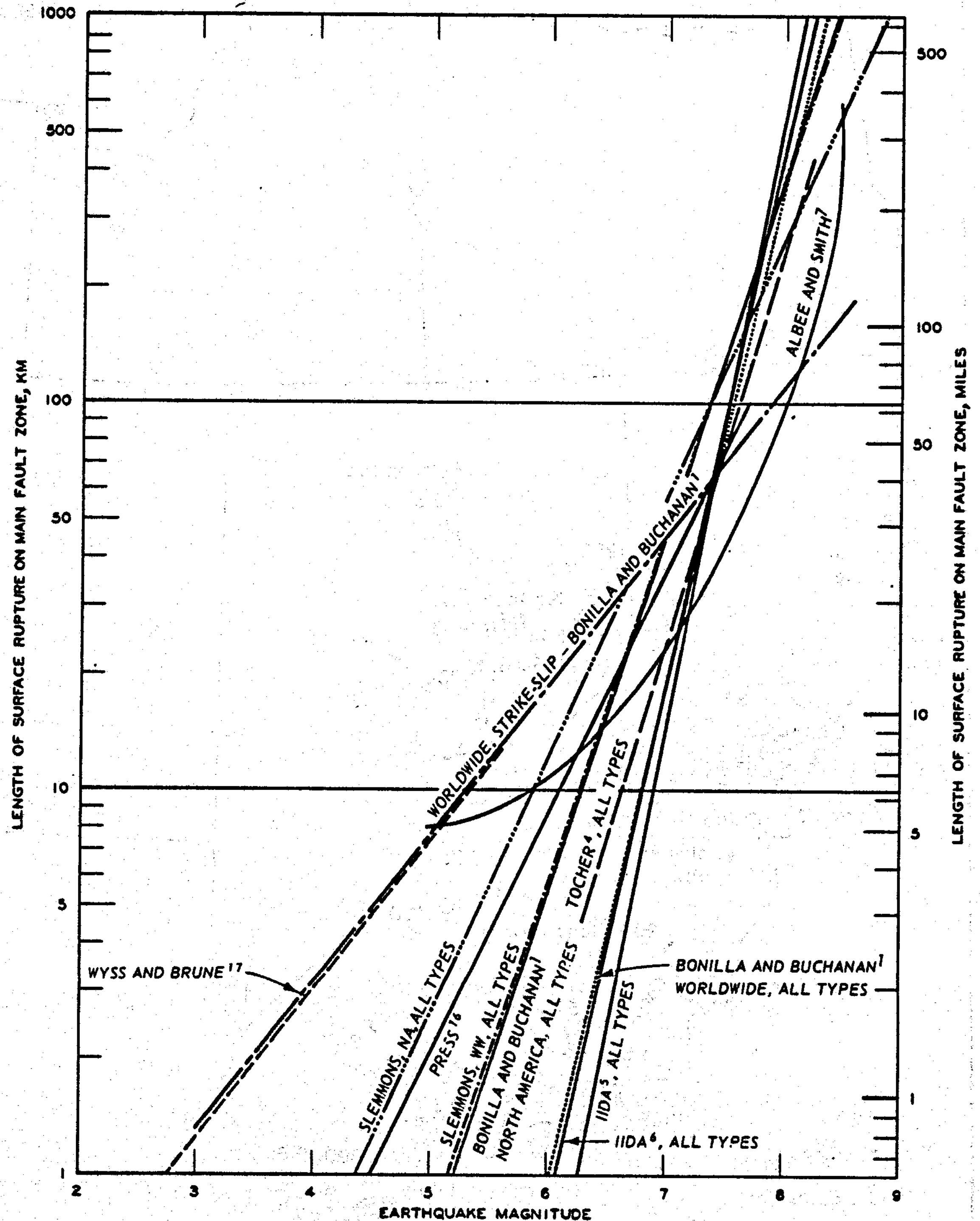


Figure 7. Relation of earthquake magnitude to length of the zone of surface faulting (Slemmons, 1977).

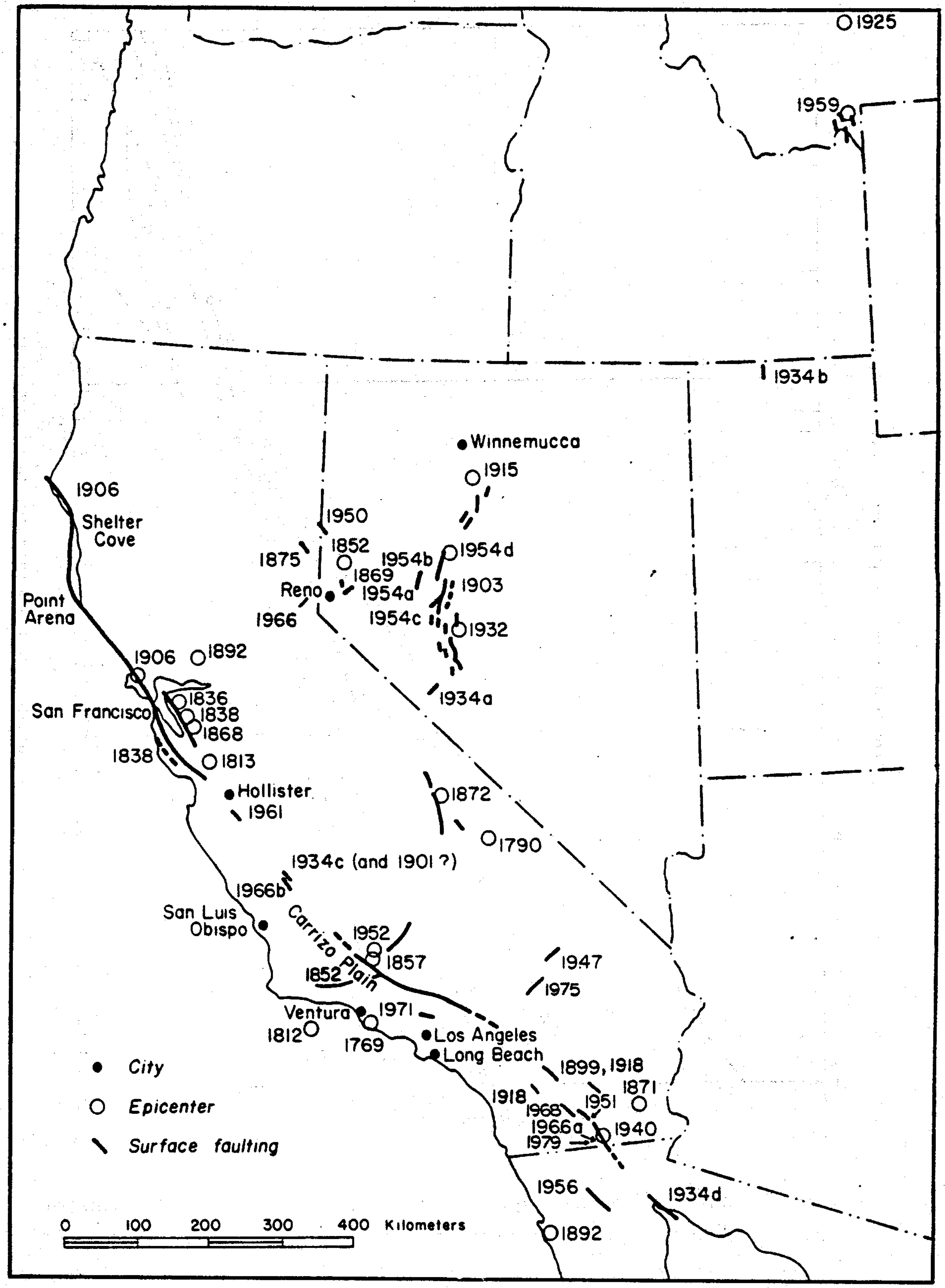


Figure 8. Historic surface faulting in the western United States (modified from Slemmons, 1967).

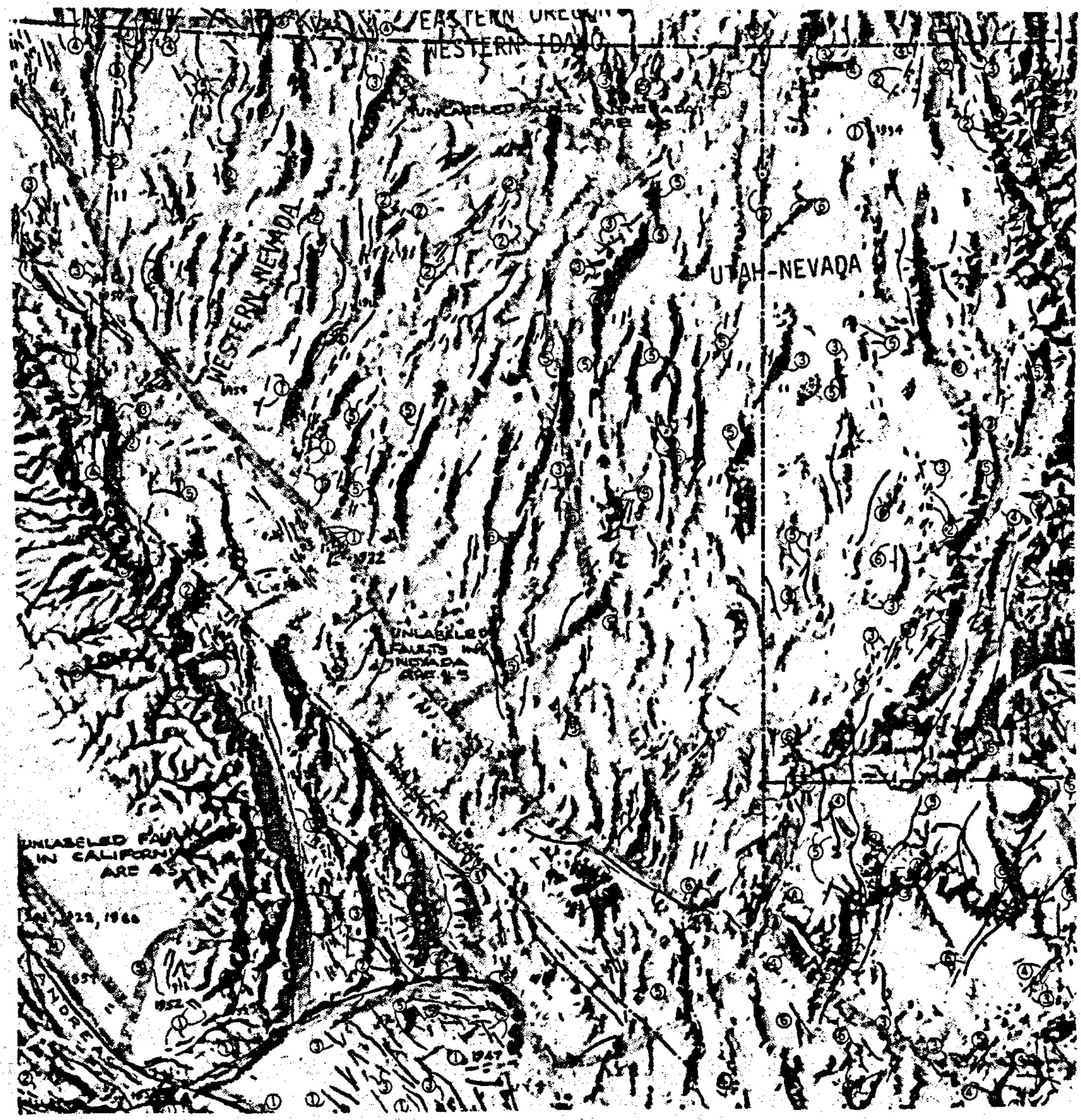


Figure 9. Young faults in the northern Basin and Range province with historic faults denoted by 1, Holocene faults by 2, Late Quaternary faults of approximately the last 500,000 years in age by 3, and Quaternary faults of approximately the last 1.8 million years in age by 4 (Howard and others, 1978).

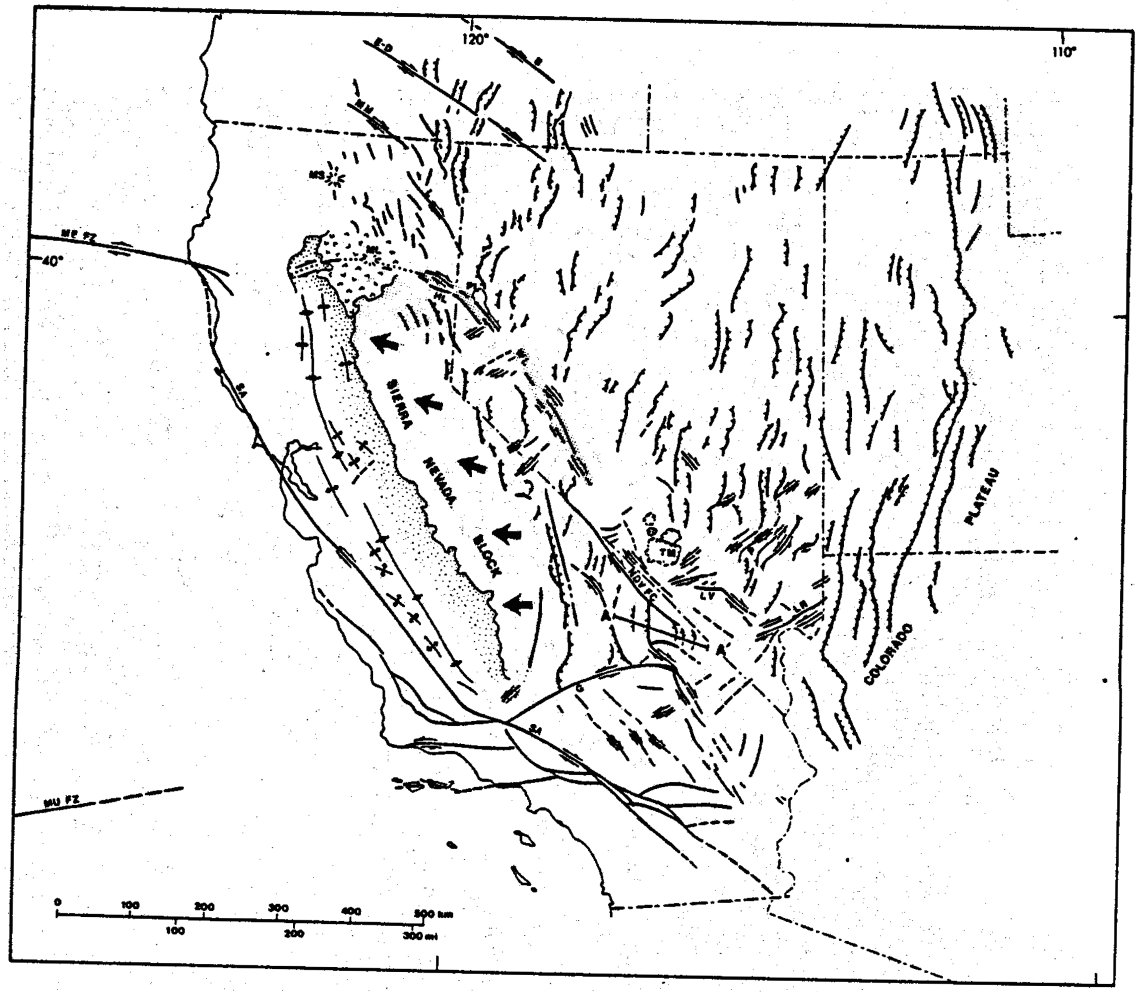


Figure 10. Generalized map of late Cenozoic structural features in the Great Basin and bordering regions showing spatial relationship between Sierra Nevada block and distribution of normal (hachered) and strike-slip faults of Basin and Range province. Lettered features are as follows: (B) Brothers fault zone; (ED) Eugene-Denio fault zone; (G) Garlock fault zone; (HL) Honey Lake and Litchfield faults; (L) Likely fault; (LR) Lime Ridge and associated faults; (LV) Las Vegas shear zone; (ME FZ) Mendocino fracture zone; (ML) Mount Lassen; (MM) Mount McLaughlin fault zone; (MS) Mount Shasta; (MUFZ) Murray fracture zone; (NDV-FC) northern Death Valley-Furnace Creek fault zone; (P) Pahranagat shear system; (PL) Pyramid Lake; (SA) San Andreas fault; (TM) Timber Mountain and related calderas, and (WL) Walker Lane, northern part (Wright, 1976).

American plate (fig. 11).

Data Base and Data Gaps

A fair data base is available for evaluating general risk of surface faulting and the maximum earthquakes that could be generated within northern Nevada (Chapter IV of this report). The characterization of faults as active is described by Cluff and others (1972), Slemmons (1977) and Glass and Slemmons (1978). The criteria may be historic, geomorphic, seismologic, or stratigraphic, including soil-stratigraphic. The faults may be evaluated for their potential maximum earthquake magnitude by means of the methods outlined by Wallace (1970, 1977a 1977b 1978) to establish the number of recent events, and determine the average or maximum displacement and rupture length. Conversion of these values to equivalent magnitudes of causative earthquakes are made by the methods used by Bonilla (1967 and 1970), Bonilla and Buchanan (1970), Mark and Bonilla (1977), and Slemmons (1977). These values are useful for three purposes:

1. As a tool to aid in the exploration for geothermal resource areas.

2. Determine the design earthquakes for faults at or near the geothermal site, or to estimate the potential for surface rupturing within the development area.

3. Estimate the maximum earthquake magnitude or probable amounts of surface rupture on active faults on which earthquakes could be induced from fluid injection at the geothermal site.

Present active fault maps of Nevada (figs. 6 and 9) are inadequate in scale for geothermal development and should be recompiled using new definitions for activity (Slemmons and McKinney 1977) and current state-of-the-art methods of analysis (Glass and Slemmons 1978).

Recommendations

To assist in defining the geothermal resource areas, and to provide a good data base for seismic hazard and risk analysis, a high priority should be assigned to preparing larger scale active fault maps for northern Nevada. This should include state-of-the-art approaches and materials including the use of multi-spectral imagery, multi-scale imagery, multi-date imagery and other new and varied methods (Glass and Slemmons 1978).

A potential problem may exist in determining the nature (i.e., natural or induced) of a seismic event at a developed geothermal site. This problem is amplified as most geothermal areas are in areas of high natural micro-seismicity. Evidence from other geothermal developments

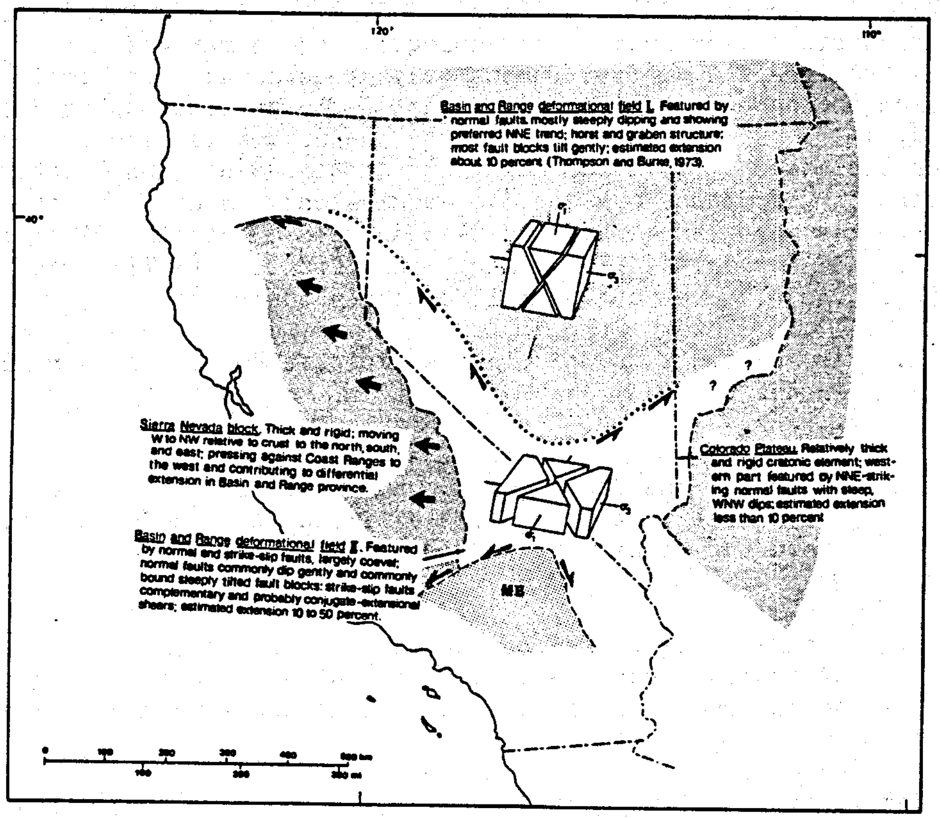


Figure 11. Tectonic model showing: (1) subdivision of the Great Basin into two deformation fields and (2) apparent effect of the westward displacement of the Sierra Nevada block and southward narrowing of the Great Basin. Idealized block diagrams in each field show suggested principal stress orientations; O_1 , maximum principal stress (sigma 1), O_3 , minimum principal stress (sigma 3). MB is Mojave Block (Wright, 1976).

and oil and gas fields suggests induced seismicity is controllable to acceptable levels (Crane 1980). The state-of-the-art of the technology in this subject is poor, and moral and legal issues concerning induced seismicity are possible.

The site-specific, detailed seismic risk analysis should be the responsibility of the developer.

Natural and Induced Seismicity

Northern Nevada is a region with high seismicity. Historically, two zones have higher than average seismicity: the Ventura-Winnemucca Zone and the boundary of the Basin and Range Province with the Sierra Nevada block. Figure 12 is an earthquake epicenter map of Nevada showing earthquakes of magnitudes of about 4.0 and above. Additional discussion of natural seismicity is in Chapter IV.

The possibility of inducing earthquakes through geothermal development has been discussed in many previous studies, and must be investigated for any geothermal resource that is developed. The risk is especially pertinent in regions of high natural seismic activity, such as in northern Nevada. The general effect of withdrawing fluids is to reduce fluid pressures and to delay or modify the slow process of strain accumulation that eventually leads to fault rupturing and earthquake activity. This effect may reduce the near-term potential for earthquake activity. A reduction of seismic potential is reversed if fluid injection is used at or near faults by disturbing the normal stress and strain patterns. This could lead to the induction or "triggering" of earthquakes. This topic is discussed in Chapter IV, Seismicity of Northern Nevada.

Data Base and Data Gaps

The seismic history of Nevada is limited to the period since about 1850, a very short historic record, and modern seismological laboratories were first established in 1962 at the University of Nevada-Reno. A good record of earthquake mechanism and studies of aftershocks are available for many of the larger, recent earthquakes (e.g., Dixie Valley, Adel, Denio, Fairview Peak, Susanville and other areas). There is an excellent seismographic network operated by the Seismology Laboratory of the University of Nevada-Reno for portions of northern Nevada, but many parts of the area are inadequately covered by the present network. Strong motion effects of typical normal fault earthquakes are poorly known from instrumental data. These data gaps require additional information.

The data base for induced seismicity is poor and studies concerning stress accumulation from fluid withdrawal and stress release from fluid injection are indicated.

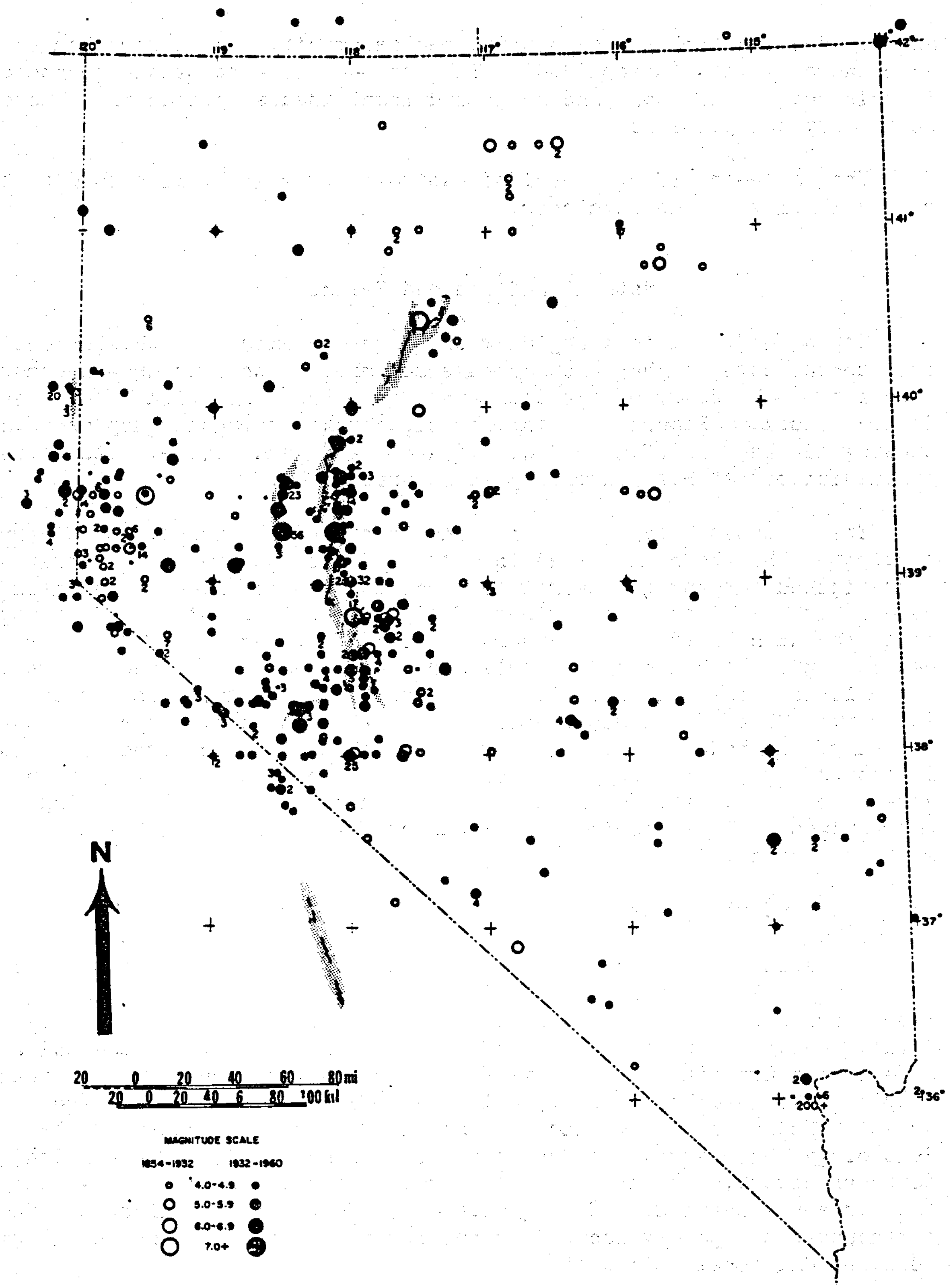


Figure 12. Earthquake epicenter map of Nevada for the period of 1854-1960 (Slemmons and others, 1965).

Recommendations

Prior to the development of any KGRAs, seismographic networks capable of accurate epicentral, hypocentral, and focal mechanism data are needed to monitor induced and natural micro-and macroearthquakes at or near the geothermal resource. The inadequate regional data base for evaluating strong motion effects of normal-slip faulting requires a major regional program of research using strong motion instrumentation, to determine the strong seismic motion effects associated with Nevada earthquakes. This type of study has a high priority and will require a long period of observation with major regional instrumentation. A better understanding of induced seismicity is necessary and has a high priority, but requires development of geothermal resources for obtaining data. The site-specific detailed natural seismic risk analysis and studies of induced seismicity should be the responsibility of the developer.

Liquefaction

Liquefaction is the process of converting a water-saturated, cohesionless soil into a slurry by means of vibrations. Soil is used here in the engineering sense. This process commonly is associated with earthquakes of over 5.5 magnitude and is a larger scale phenomenon, but similar to converting a wet sand into a quicksand by vibrations caused by footsteps. Liquefaction is caused by a small reduction in volume or increase in bulk density of sediment with an associated rise in pore pressure. The result is a loss of shear resistance of the soil. As the soil settles or moves laterally, structures may be damaged. Liquefaction may occur at distances of over 100 km from the source of magnitude 7.5 to 8 earthquakes, the magnitude of the largest historic earthquakes of northern Nevada. The basins of northern Nevada have large areas of such cohesionless, water-saturated silts and sands and this hazard may be widespread.

Methods of testing materials for liquefaction potential (Ferritto and Forest 1978) and the evaluation of faults within a region for maximum vibration effects (Slemmons 1977) are well established. The seismic potential for parts of this region are summarized by Douglas and Ryall (1975), Ryall (1977), and Slemmons (in press). These studies indicate maximum regional earthquakes of 7 to 8 magnitude, and a high potential for many sites to experience sufficiently strong ground motion to cause liquefaction of susceptible materials around an engineered structure with a useful life of 30 to 50 years.

Examples of liquefaction during historic Nevada earthquakes include the extensive liquefaction in the vicinity of Fallon during the 1954 earthquakes centered near Stillwater, Nevada (Tocher 1956), and the more widespread and spectacular effects of the December 16, 1954 earthquakes of Fairview Peak and Dixie Valley. Methods of determining the range of such effects as a function of earthquake magnitude are summarized by

Youd (1975).

Data Base and Data Gaps

No comprehensive studies have been made on the engineering properties and liquefaction potential for northern Nevada, but the technology and methodologies are well established in present state-of-the-art studies (Ferritto and Forest 1978).

Recommendations

Liquefaction hazards in northern Nevada are poorly known and the hazard or risk is high. Baseline studies to evaluate the general hazard are a moderate priority need for this area. Detailed, site specific studies will be required for all future geothermal developments, and should be primarily the responsibility of the developers.

Subsidence

Subsidence of the ground surface over areas of fluid withdrawal are well known. Groundwater and oil field fluid withdrawal have caused most known examples (Poland and Davis 1969; Green 1973). Subsidence is usually less than 2 meters and the amount of subsidence is directly related to the amount of pressure drop in the reservoir. Withdrawal of geothermal fluids has also caused subsidence (Hatten 1970; Stilwell, Hall and Tawhai 1975).

The work of Stilwell and others (1975) has shown that 4.5 meters of subsidence has taken place at Wairakei, New Zealand, in 10 years of geothermal fluid withdrawal. Horizontal movements of up to 1.2 meters were recorded over 8 years of observation. Curiously, at Wairakei the center of subsidence is displaced about 1 kilometer from the main production field. The geology of Wairakei (Grindley 1965) has analogs in Nevada so subsidence is likely in producing geothermal fields in this state if not controlled by injection of fluids back into the reservoir.

Most of the environmental consequences of subsidence in northern Nevada would be of direct concern to design and operating engineers. Pipelines, drainage ditches, and other structures could be adversely affected by major subsidence. The location of most KGRAs on arid alluvial aprons, away from inhabitated areas, irrigation canals, and pipelines means minimal environmental and cultural damage would be associated with subsidence. Injection of fluids has led to stabilization or partial rebound in oil fields (Allen 1973) and careful reinjection of geothermal fluids could minimize subsidence. Injection into active faults or zones with hydraulic connection to active faults could lead to triggering or inducing earthquakes. This potential problem is discussed previously in this chapter and in Chapter IV.

Data Base and Data Gaps

There are no comprehensive studies of subsidence in northern Nevada, although many studies have been completed in the Las Vegas area and elsewhere in the western United States for ground water withdrawal. Most of Nevada has been mapped topographically and there is an excellent data base of both first- and second-order geodetic surveys of most of the potential geothermal areas.

Recommendations

Assessment of the subsidence potential should be completed on a site-specific basis, prior to production. The assessment will be dependent on the extent and type of the development, the geologic setting and the volume of fluids that must be withdrawn. Prior to production by fluid withdrawal, detailed leveling and triangulation surveys should be completed. This is especially critical for development in urbanized or agricultural areas. This task should be carried out by developers and should have a high priority.

The issue of subsidence becomes more important if injection of fluids are required to control subsidence, since secondary effects, i.e., the inducement of earthquakes, may become a major problem. Assessment of injection as a mitigation measure for the control of subsidence must be undertaken well in advance of production for areas of high seismic risk or rate of tectonic deformation.

Slope Stability

The wide variety of rock types present in areas of potential geothermal development, and the contrasting steep mountain slopes and gentle valley floors along range fronts, lead to variable slope stability conditions in northern Nevada. Very little is known about landslides in northern Nevada but large landslides are widely scattered (Stewart and Carlson 1976). Areas of moderate to high landslide potential are shown in a map by Radbrich-Hall, and others (1976). Potential for movement exists in steep terrain of any rock type and in areas of more gentle topography which have undergone hydrothermal alteration and where the bedrock is low strength sedimentary or igneous rocks.

Damage to production equipment, roads and well casings is a potential problem. Present exploration activity is mainly in areas of low relief where the potential for slope stability problems is not high. This situation could change if future exploration and development occurs in the mountain ranges.

Data Base and Data Gaps

No comprehensive studies have been made of slope failure in northern Nevada. Large Quaternary landslides have been mapped as part of the regional mapping program in Nevada (Stewart and Carlson 1976, 1979; Nevada Bureau of Mines and Geology county reports, table 1). The map of Radbruch-Hall and others (1976) shows extensive areas that are susceptible to landsliding.

Recommendations

Assessment of slope stability hazards should be carried out, as necessary, by developers prior to construction activities. Slope stability is considered generally to be a low priority geologic issue in northern Nevada, although it may be very important on a site-specific basis.

Flash Floods

Flash floods are a common occurrence in northern Nevada. Most are from thunderstorms, usually in late spring and summer (Houghton and others, 1975), or from Pacific fronts and tropical storms, mainly during the fall through spring seasons. The combination of heavy rain, sparse vegetation, poor infiltration rates, and steep slopes in the mountain areas cause rapid runoff. Large discharges of water and mud from the mountain fronts create flash floods on the alluvial fans and aprons. These floods can be very destructive. Active channels and evidence of flash floods in the recent past are shown on many of the aerial photographs of the Great Basin and from ground reconnaissance. Damage can be minimized by avoiding areas of potential flooding, or mitigated by proper planning, design, and siting of roads and structures.

Data Base and Data Gaps

Although the prediction of site and time of flash floods is not possible at this time, there are well established and tested methods of predicting the rate of occurrence, size, and character of flash floods in this region. Available information on specific areas, events and situations is largely unpublished but is available through governmental agencies and engineering and geological consultant reports.

Recommendations

Assessment of the hazard from flooding must be conducted by the developer on a site-specific basis, using conventional methods of risk analysis. There is no specific need for special regional studies associated with this hazard and geothermal development.

Erosion

The soils of northern Nevada are highly variable, a response to climate, vegetation, parent material, slopes, time and other soil-forming factors. Erosion rates vary in response to vegetative cover, rainfall intensity, slope angle, the nature of the soil present, and land-use. These factors are highly variable in northern Nevada. On the alluvial fans and aprons, or low relief hills where most geothermal development is likely, vegetation tends to be thin, rainfall sporadic (and less than 30 cm per year) and soils are thin to moderately thick (30 cm to 200 cm).

Disturbance of the surface, either vegetation or natural "pavements", leads to accelerated erosion. The U.S. Soil Conservation Service has a long established methodology for calculating soil loss, the universal soil loss equation.

Except for the mountain areas of northern Nevada, soil erosion of non-disturbed sites is classified as slight to moderate. Virtually any activity that uses wheeled or tracked vehicles, which affect vegetation and natural pavement, can accelerate soil erosion. The total impact can be mitigated by careful layout of roads and work areas and by reclamation of the disturbed area by grading and seeding.

Data Base and Data Gaps

Soil surveys tend to be concentrated in agricultural areas and most geothermal prospects are in remote areas. It is known that exploration and production activities will affect erosion but the impact can not be quantified.

Recommendations

A general statement on soil disturbance in non-agricultural areas needs to be synthesized and published, using the present data base. A low priority has been assigned to this issue.

Volcanic Hazards

Of all the known geothermal prospects in northern Nevada only the Stillwater-Soda Lake area has evidence of volcanism that has occurred in the last 50,000 years (p. III-11). Geothermal areas near Quaternary volcanic centers have been discussed on p. III-11 to III-13. The probability of an eruption in a development area is low.

Data Base and Data Gaps

Sufficient field work has been done in northern Nevada to identify Quaternary eruption centers. Map sheet 4 by Stewart and Carlson (1976) shows the extent of Quaternary volcanism. Most geothermal areas are not associated with young volcanic rocks.

Recommendations

The probability of an eruption, even in the Stillwater-Soda Lake area, is very low. Input of time and material resources to study this hazard in northern Nevada is not warranted.

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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter IV

SEISMICITY OF NORTHERN NEVADA

by

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INTRODUCTION

This report is divided into two sections. The first deals with natural seismicity in northern Nevada and the second section discusses seismicity that may be induced by geothermal power development. The term "seismicity" refers to earthquake activity.

Natural Seismicity

The State of Nevada can be divided into two zones of high seismicity. A continuous zone of high seismicity extends from the coast of southern California, near Ventura, to Winnemucca in north-central Nevada (Ryall and others 1966). The Ventura-Winnemucca zone follows a discontinuous line of major historic faulting. The second highly active seismic zone extends northwest along the transition zone between the Sierra Nevada and the Basin and Range. It is bounded on the west by the Sierra Nevada and on the east by faults of the eastern edge of the Walker Lane (Wright 1976). The Walker Lane is a zone of northwest trending right-lateral faults which extend from Las Vegas to northeastern California. The remainder of Nevada has a lower level of seismicity with earthquakes showing no distinct trends, but occurring throughout the state.

Historic Seismicity

During the historic period since 1840, five large (M 7.0) earthquakes have occurred in Nevada or eastern California. An earthquake in 1852 (?) was reported near Pyramid Lake. Slemmons and others (1965) estimated its magnitude at 7.0. The date and location are based on reports from Paiute Indians of cracks and ground shaking. Ryall (1977) places the epicenter near Stillwater and gives the date as 1845 (?), based on a report in 1869 in the Gold Hill News of intense shaking and a river changing its course in the Carson Sink.

The following large earthquakes are located within the Ventura-Winnemucca seismic zone and are shown in Figure 1. On March 26, 1872, an event with a possible magnitude of 8.0 (Oakeshott et al., 1972) occurred in Owens Valley, California. Faulting associated with this event extended at least 70 km along the eastern side of Owens Valley. An event of magnitude 7.6 (Richter, 1958) took place in Pleasant Valley on October 2, 1915 with faulting along 30 to 40 km of the western flank of the Sonoma Range. On December 20, 1932, an earthquake in the Cedar Mountains had a magnitude of 7.3 (Richter, 1958). Faulting associated with this event was discontinuous throughout a zone roughly 60 km long and 6 to 14 km wide. On December 16, 1954, an event of magnitude 7.1 at Fairview Peak was followed four minutes later by a shock of magnitude 6.8 in Dixie Valley, 55 km to the north (Romney, 1957). The southern rupture zone, associated with the Fairview Peak earthquake, was 50 km long and 10 km wide. The Dixie Valley fault zone was roughly 40 km in length and 5 km wide. The strike-slip faults of the region are shown in Figure 2.

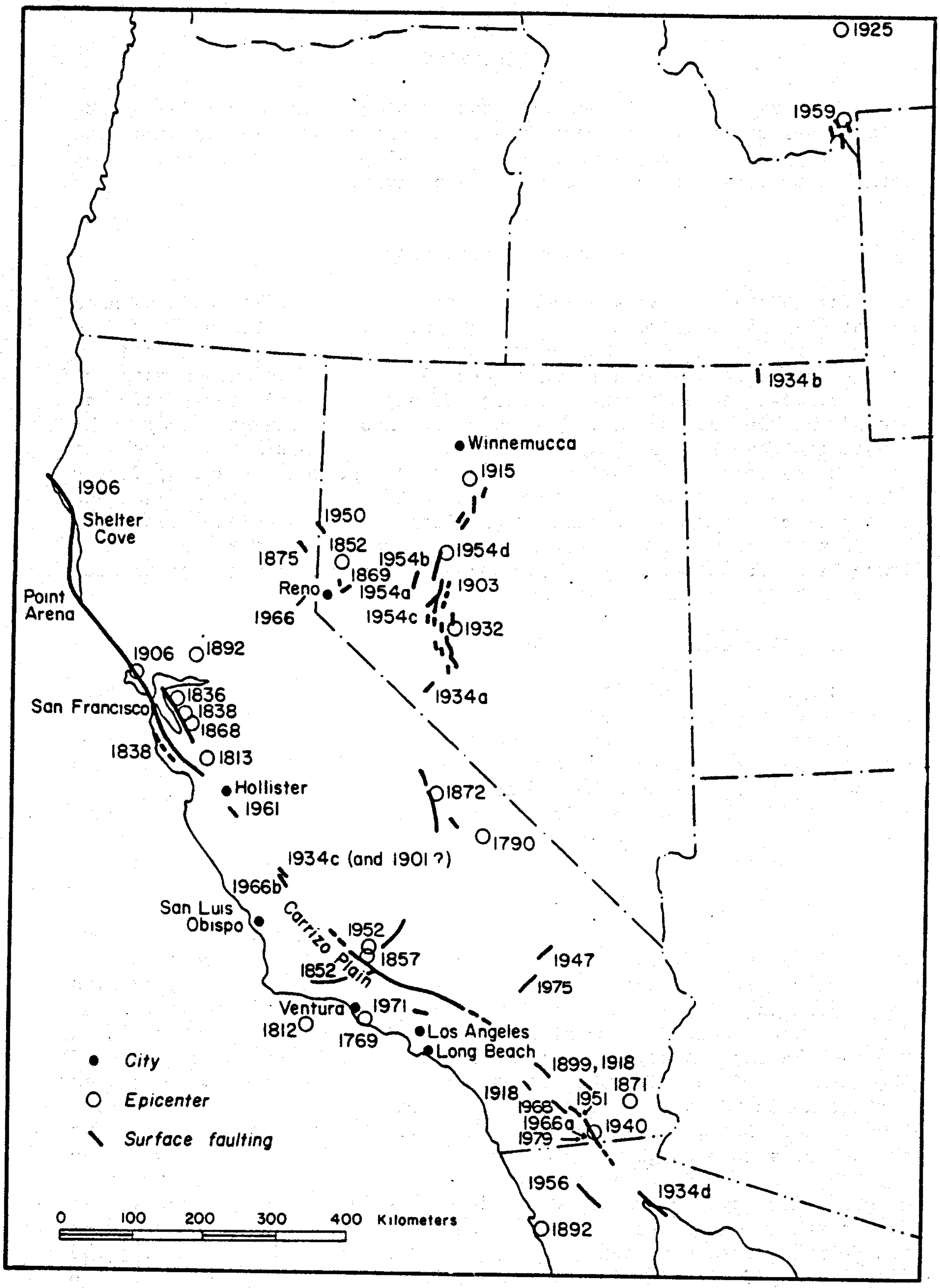

Figure 1. Map of western United States, showing historic surface faulting and epicenters of earthquakes with magnitude greater than about 7 (modified from Slemmons, 1967).

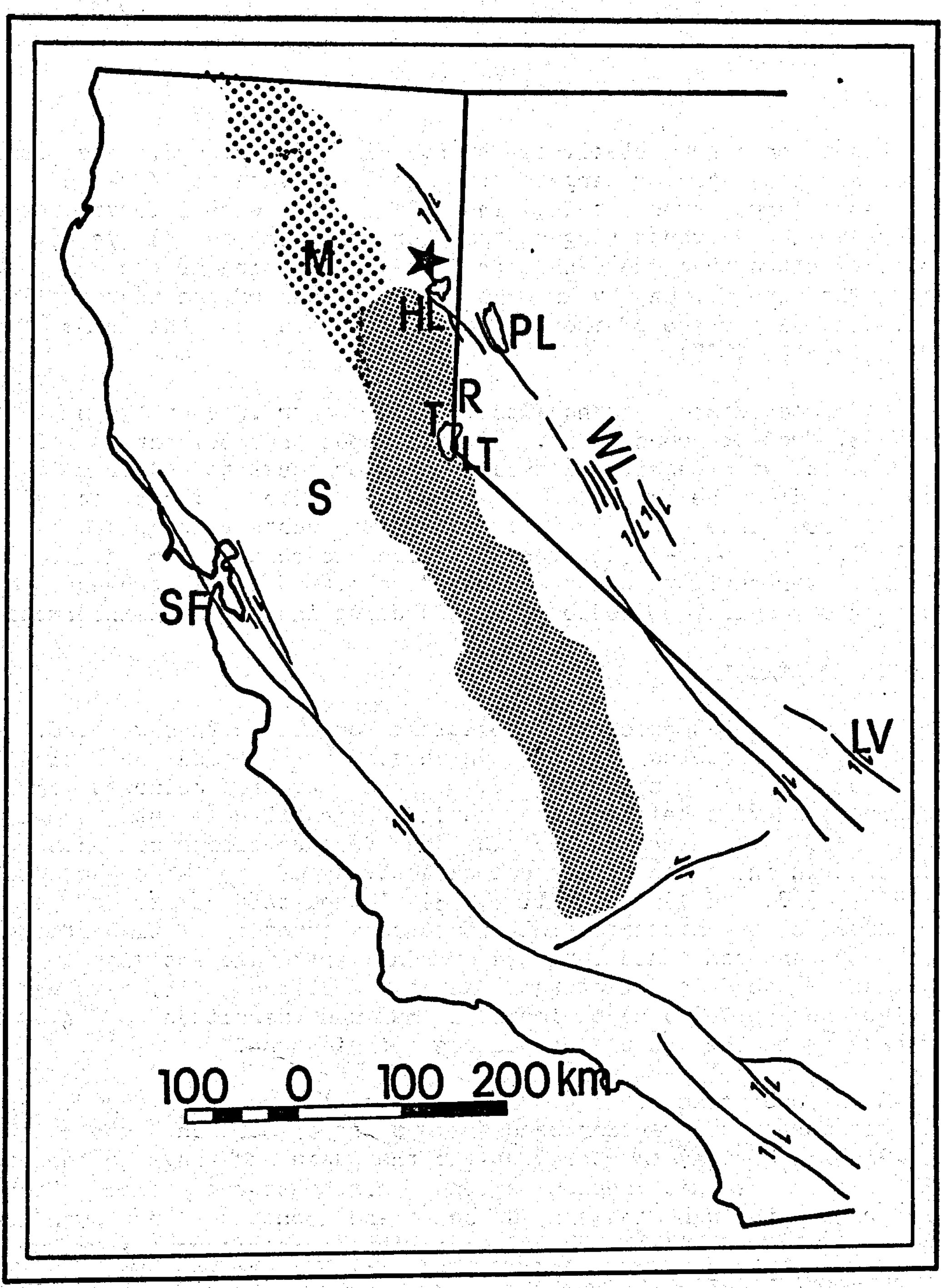

Figure 2. Sierra Nevada-Basin and Range boundary zone showing the Walker Lane-Honey Lake lineament and associated faults. The Sierra Nevada province is indicated by the heavy stippled pattern, the Cascade Range by lighter stippling. The following letters denote features of interest: (HL) Honey Lake; (LT) Lake Tahoe; (LV) Las Vegas; (M) Mineral; (PL) Pyramid Lake; (R) Reno; (S) Sacramento; (SF) San Francisco; (T) Truckee; and (WL) Walker Lane (from Molner, 1979).

Based on the relatively short historic record, the average recurrence interval for large earthquakes in Nevada is 27 years, with the last large event being in 1954. The time interval between successive large events ranges from four minutes to 43 years. It should be noted that one cannot predict the location of the next large earthquake in Nevada by knowing the locations of the previous large events because no two of these events occurred on the same fault system (Ryall, 1977).

Moderate sized earthquakes (M 4.0) occur frequently in Nevada. Figure 3, from Slemmons et al. (1965), shows the epicenters of all earthquakes with magnitudes greater than or equal to 4.0 from 1852 to 1960, including the large events discussed above. These epicenters are divided into two groups: pre-1932 events (designated by open circles), and post-1932 events (closed circles), to distinguish between lower quality epicenters based solely on non-instrumental data and higher quality epicenters located using instrumental information.

Current Seismicity

Figure 4 shows epicentral locations for all earthquakes from 1970 through 1977 located by the University of Nevada Seismological Laboratory. The majority of these events occurred in the Ventura-Winnemucca seismic zone, as did the earlier events shown in Figure 3. The earthquakes in the Ventura-Winnemucca zone are clustered in the areas of aftershock activity of the large earthquakes of 1915, 1932, and 1954. Ryall (1973) plotted the number of events for each of the historic fault zones as a function of time after the main event and concluded that the current earthquake activity in each of these zones is aftershock activity related to the main events. Douglas and Ryall (1975) estimated a maximum magnitude of 7.6 for earthquakes in the Ventura-Winnemucca seismic zone.

A second band of high seismicity is also shown in Figures 3 and 4. This northwest-trending band follows the transition zone between the Sierra Nevada to the west and the Basin and Range to the east. This highly seismic region extends northwestward from Bishop, California, through eastern Nevada, and continues northward past Mineral, California. The seismic activity of this zone is regulated by large vertical fault separations along the Sierra Nevada block. The individual fault segments have lengths of 60 to 200 km and show prehistoric to historic single displacements of up to 6 or 7 meters, which indicates maximum magnitudes of 7.0 to 8.0 (Slemmons, 1977).

Earthquakes with magnitudes greater than or equal to 3.0 which occurred from 1970 to 1979 in or near Known Geothermal Resource Areas (KGRAs) in northern Nevada are shown in Figure 5. Earthquakes of this size are usually felt, at least by persons near the epicenter. Note that none of the KGRAs in western Nevada are more than a few tens of kilometers from a swarm of earthquake epicenters.

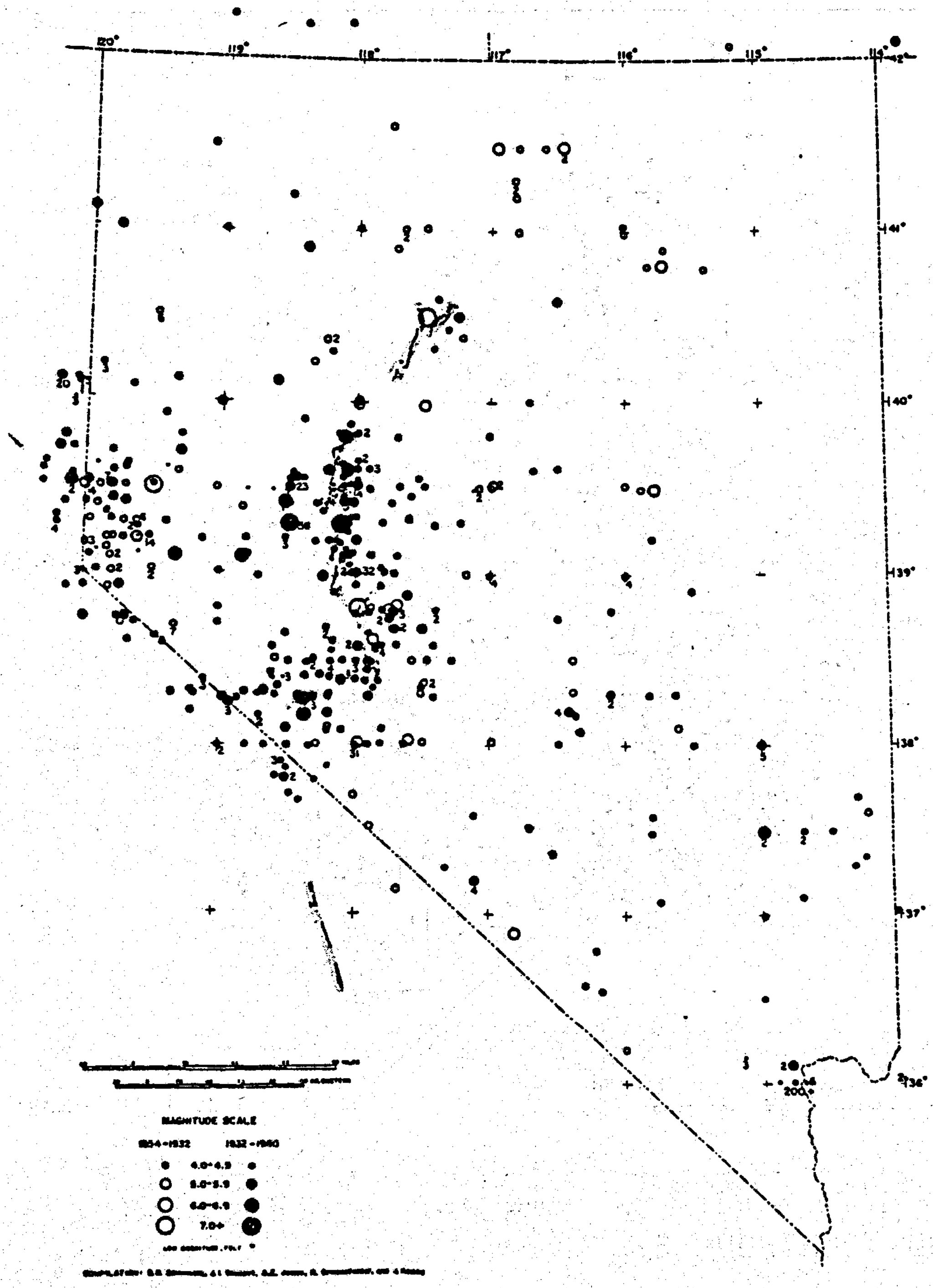

Figure 3. Map of Nevada earthquake epicenters, 1852-1960 (Slemmons, et. al., 1965).

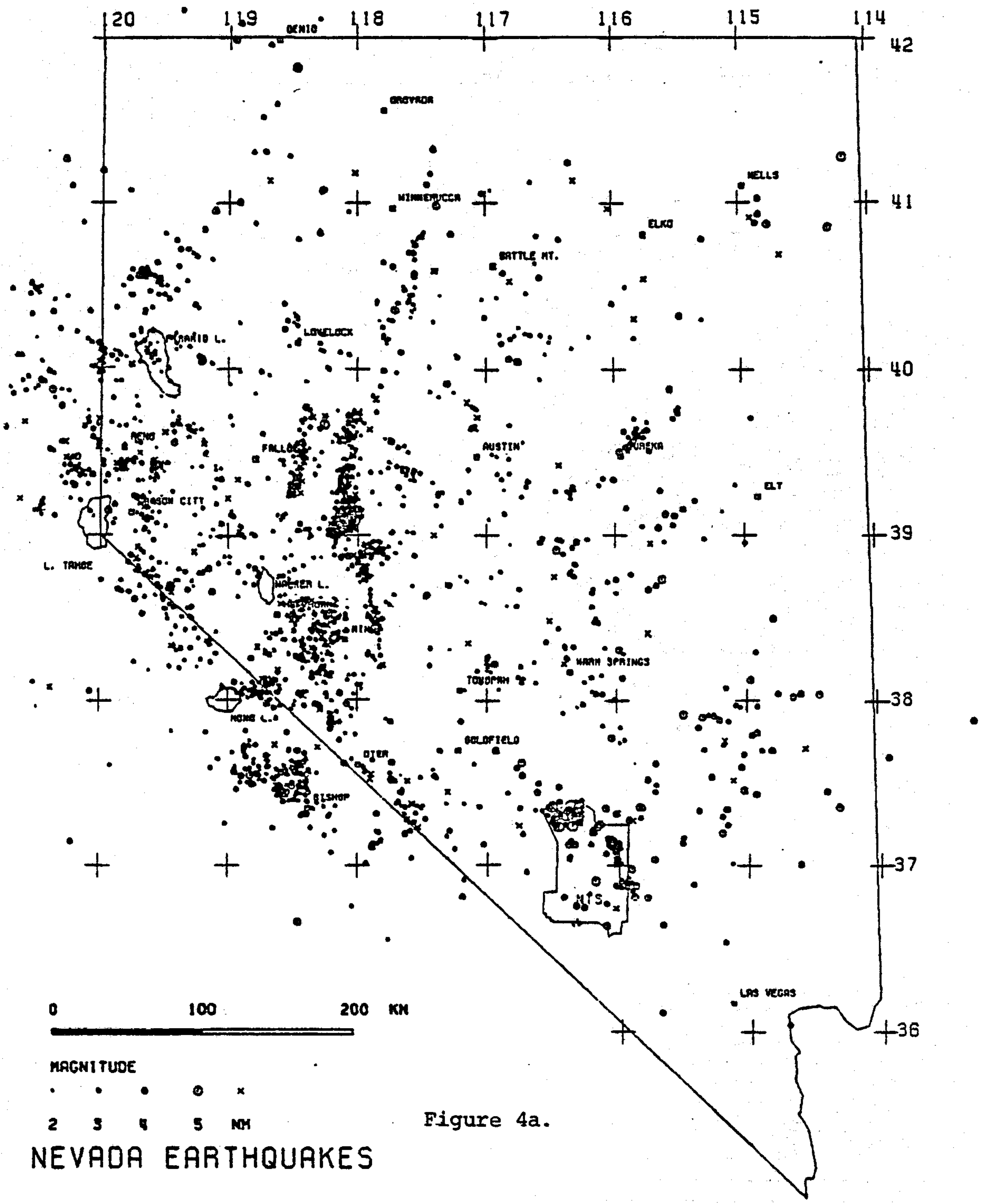

Figure 4a.

Figure 4 (a through i). Epicentral locations for all events from 1970 to 1977 located by the University of Nevada Seismological Laboratory.

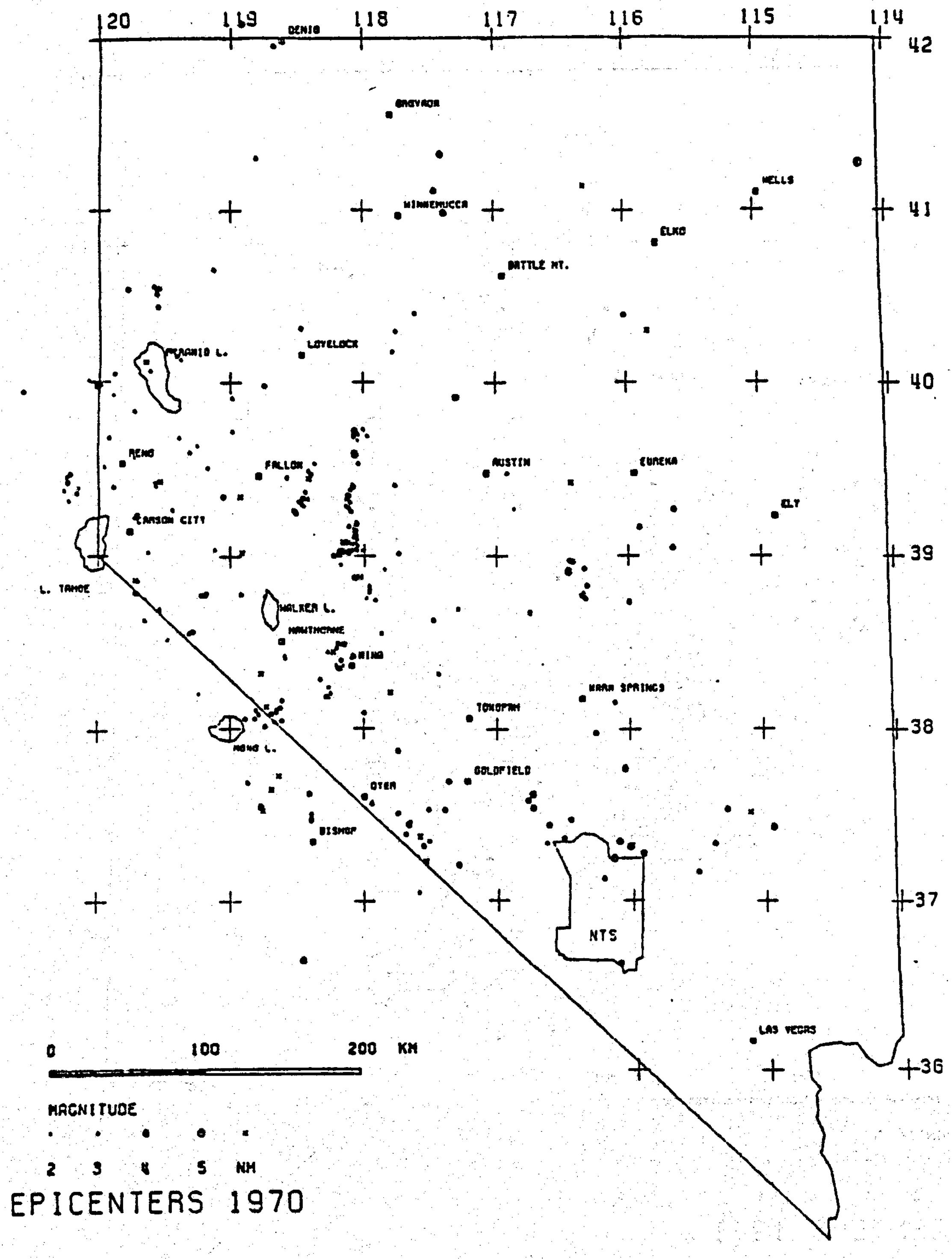
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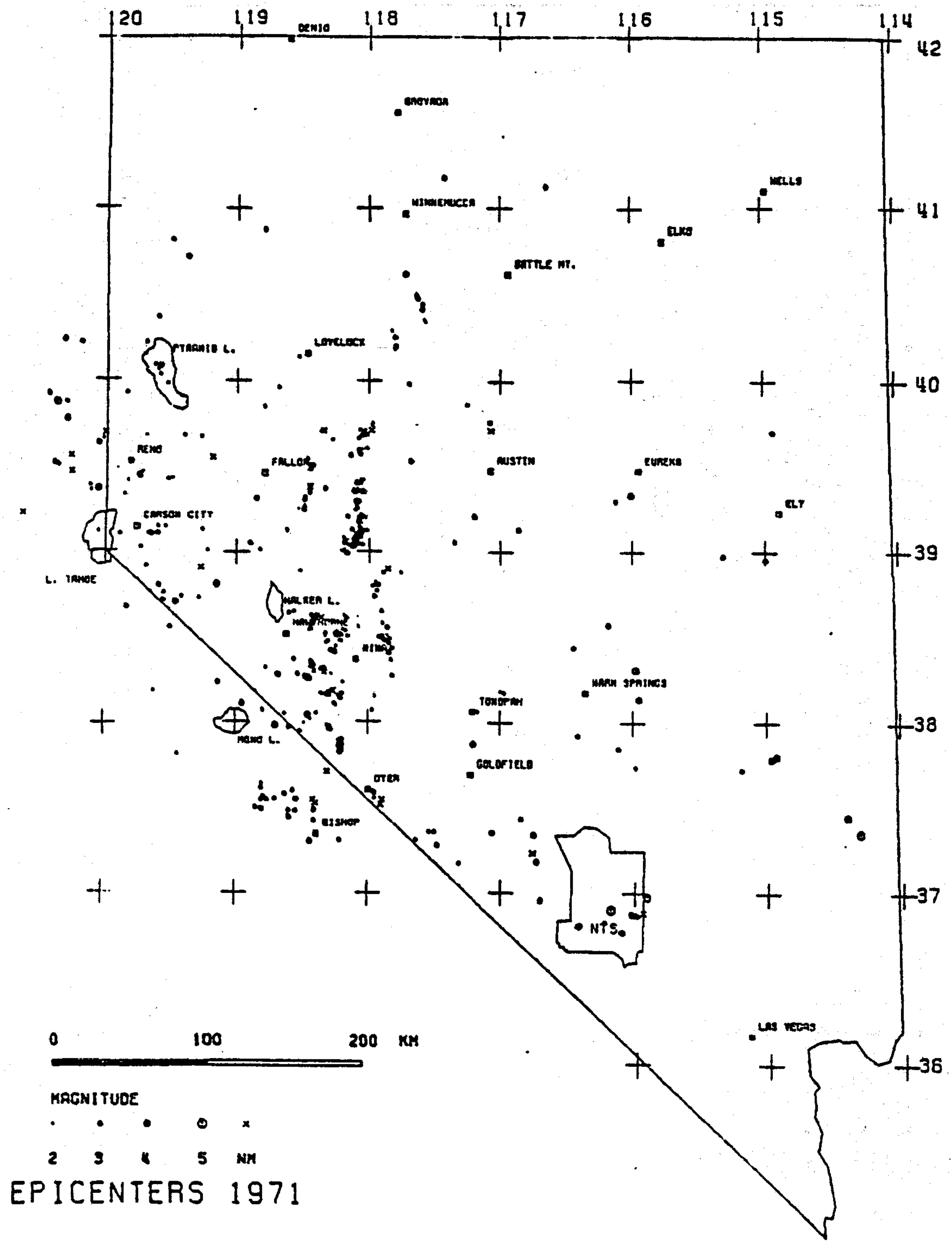
Figure 4b.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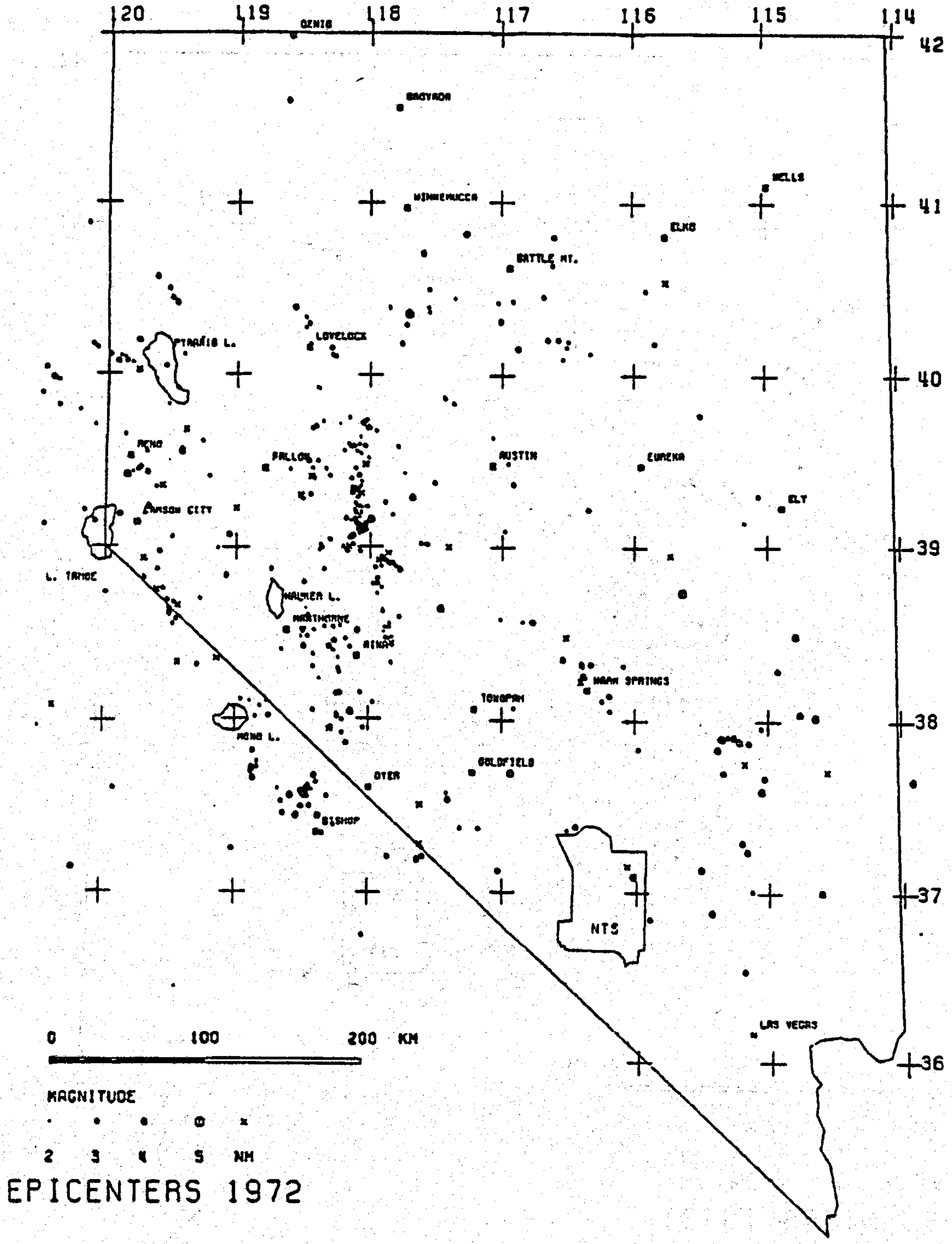
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Figure 4d.

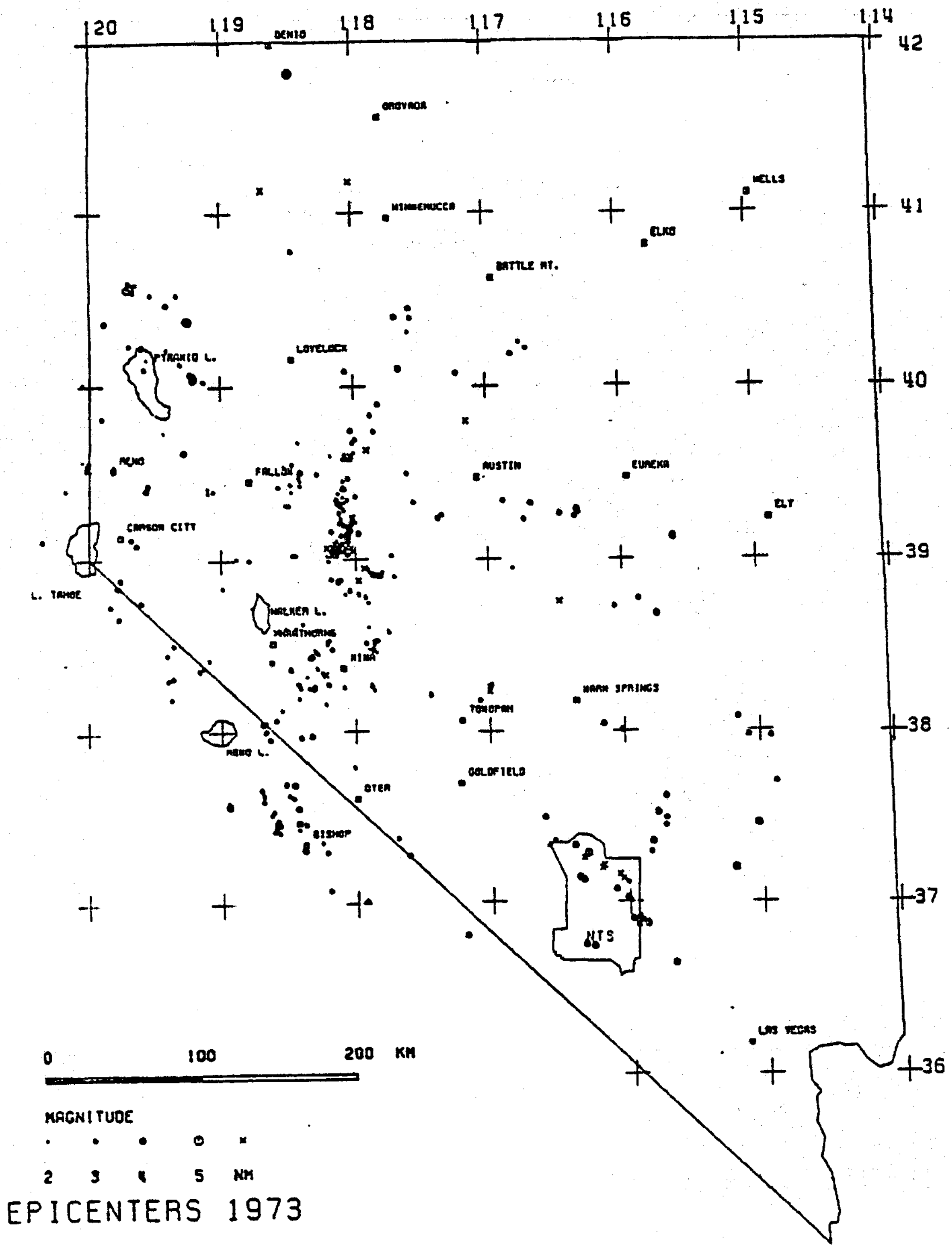
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Figure 4e.

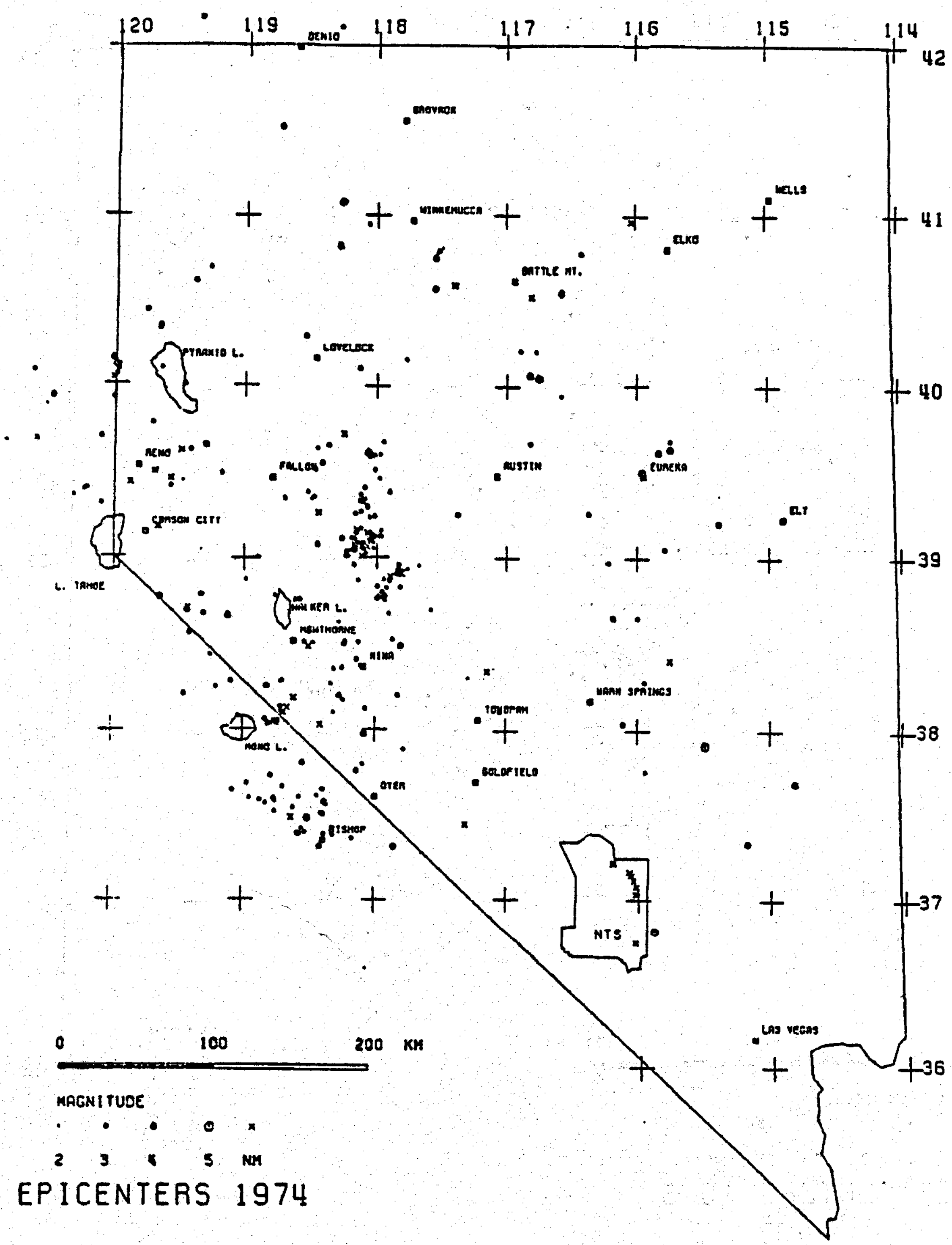
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Figure 4f.

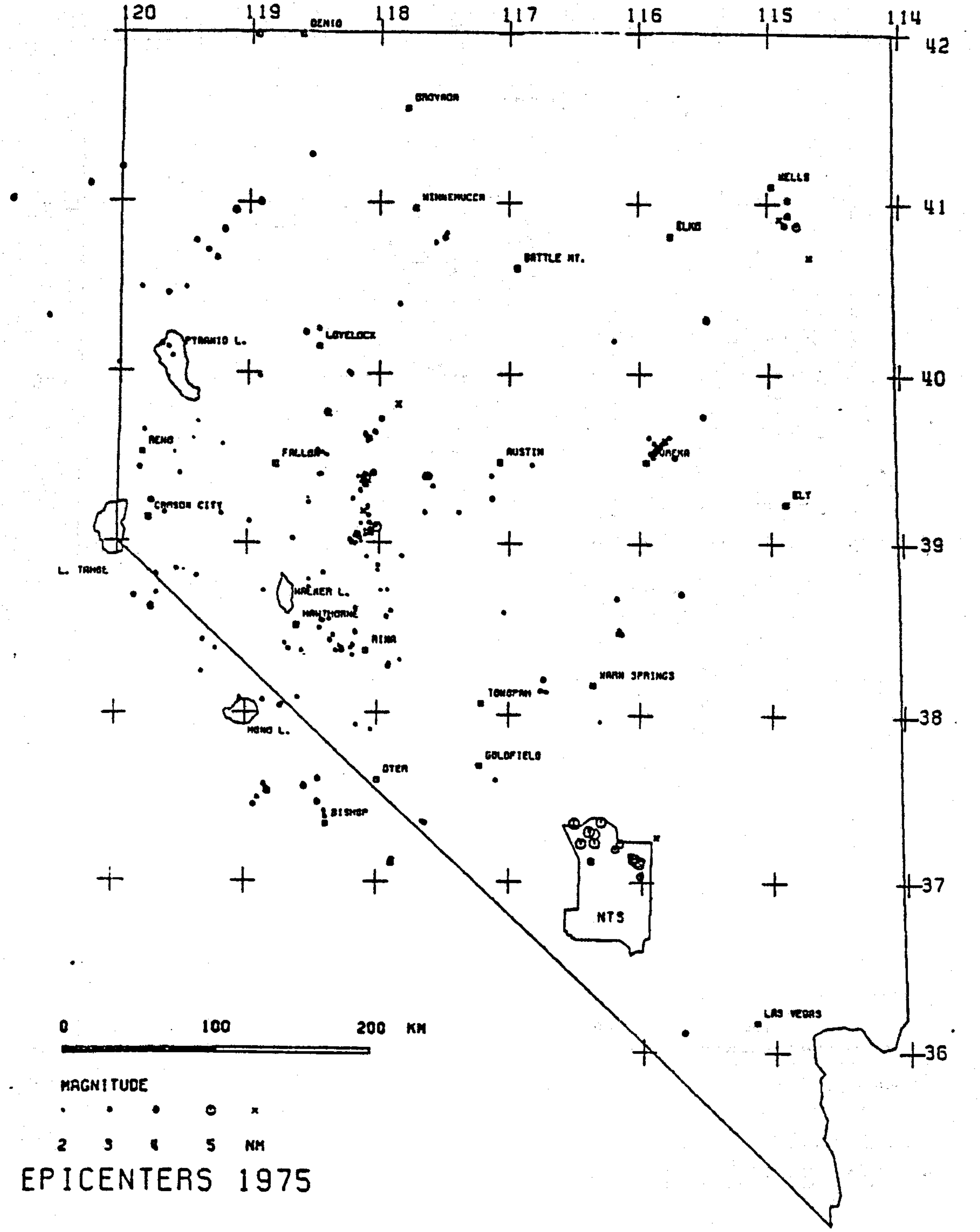
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Figure 4g.

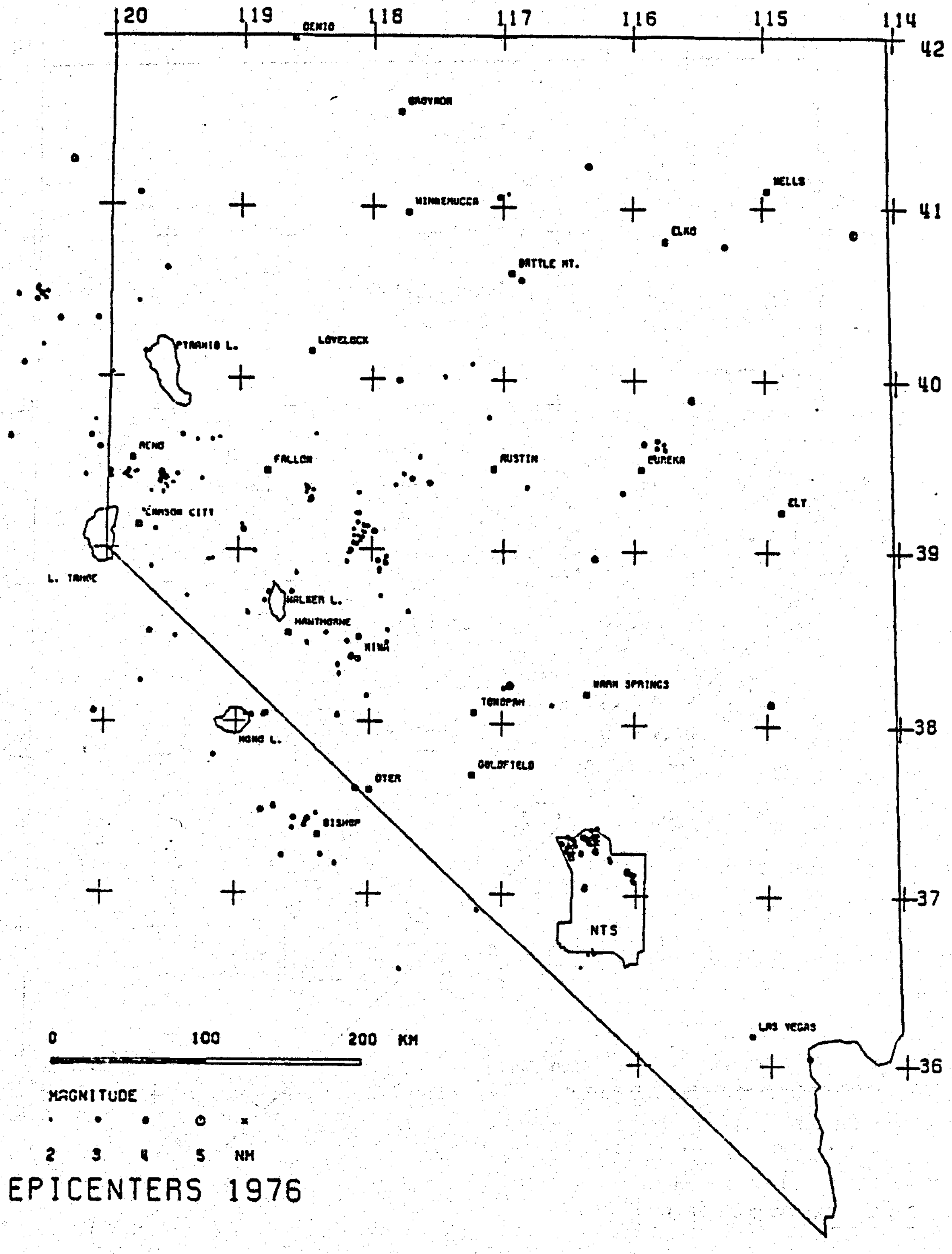
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Figure 4h.

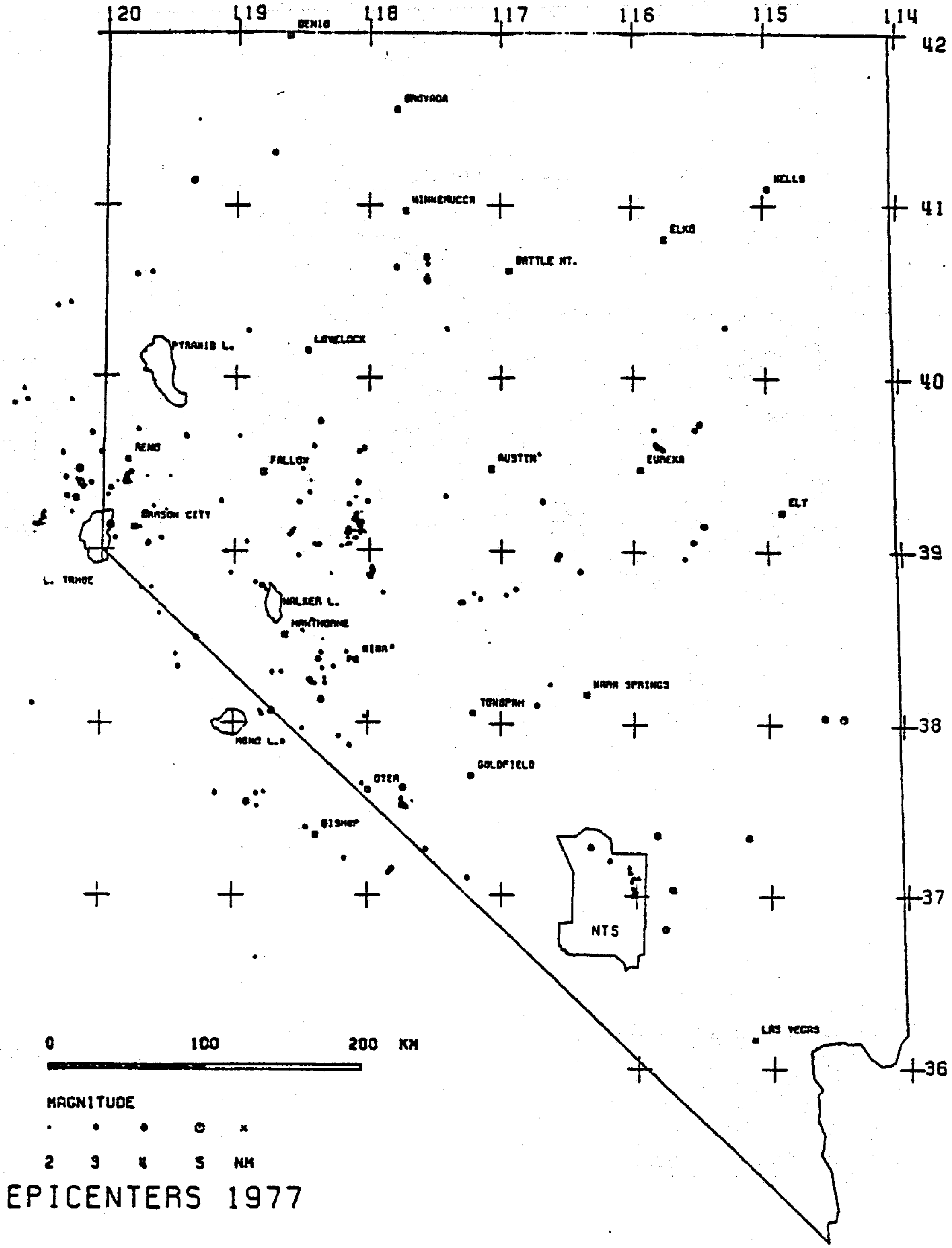
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Figure 4i.

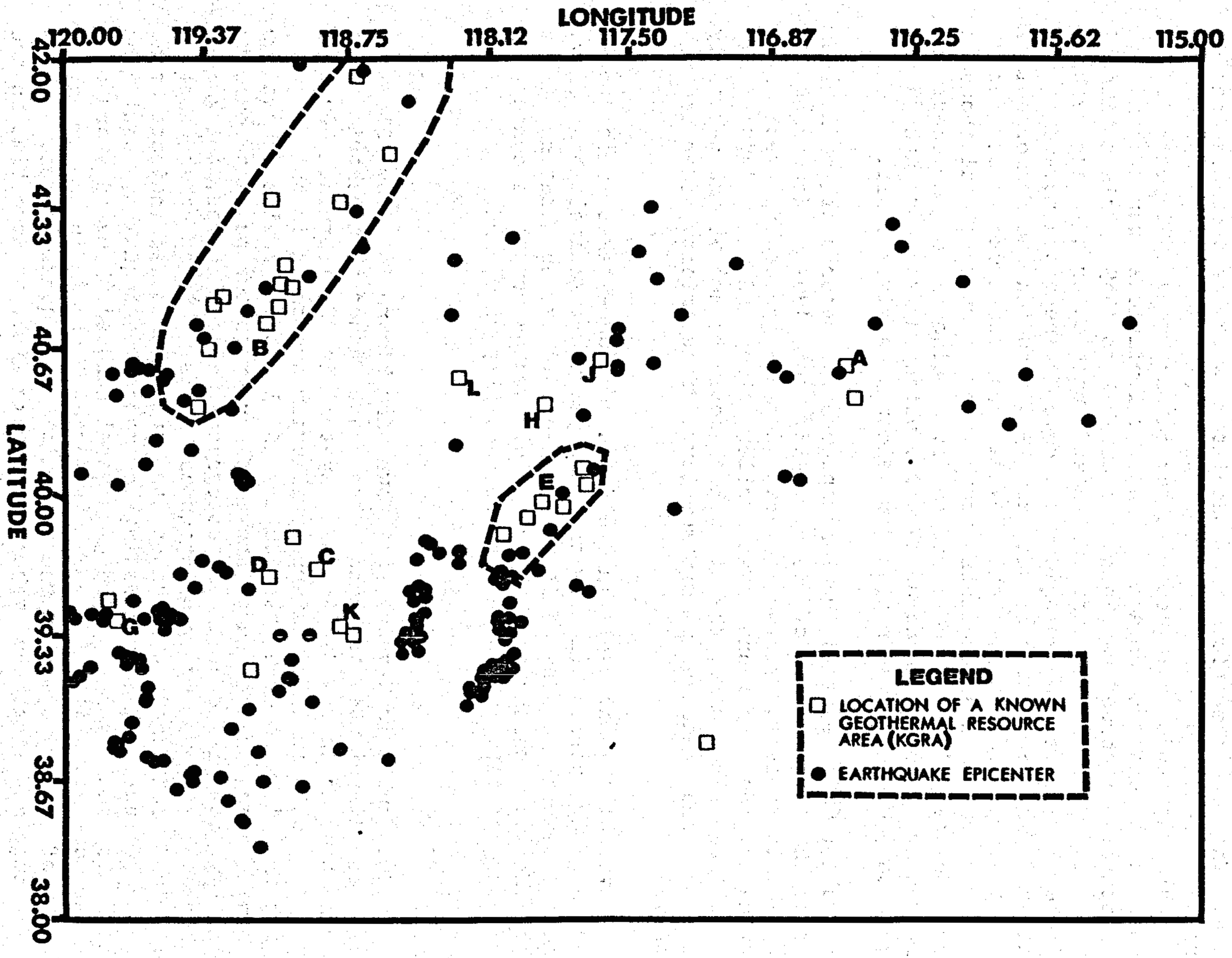


Figure 5. Earthquakes (M 3.0) which occurred from 1970 through 1979 near the Known Geothermal Resource Areas of northern Nevada.

Seismic Cycle

Douglas and Ryall (1975) calculated the expected return period for rock acceleration greater than 0.5 g at a given site in western Nevada. This acceleration is associated with earthquakes having magnitudes greater or equal to 7.0. They estimated a large earthquake with this magnitude would occur approximately every 2000 years at any given site in western Nevada. These calculations were based on instrumentally recorded earthquakes from 1932 to 1969. This estimated return time for large earthquakes at a particular site agrees with estimated time based on geological evidence for repeated movements on a given fault. For example, Wallace (1975) studied the geomorphology of fault scarps in north-central Nevada and concluded that return times for major displacements there are roughly several thousand years. Cordova (1969) found three to five episodes of movement on faults near Reno during Holocene time, which implies a return period of 2000 to 3000 years for repeated movement on a given fault.

Ryall (1977) searched local newspapers for reports of earthquakes prior to the large events of 1915, 1932, and 1954. He found an increase in seismicity for several decades preceding these large earthquakes. He also found in an earlier study (Ryall, 1973) that after a large earthquake, the aftershock activity decays exponentially with time and reaches a minimum level of seismicity after about a century.

A typical seismic cycle in the Basin and Range takes this form: after a long period (a few thousand years) of minimal seismicity, there are several decades of increasing seismicity, culminating in a large (M 7.0) earthquake. This is followed by roughly a century of aftershock activity, which decays exponentially with time.

Active Faults

Active faults in Nevada, as shown in Figure 6 from Slemmons (1967) are distributed throughout the state rather than restricted to a single zone as in the San Andreas system in California. Over a thousand faults in late Quaternary alluvium are shown in this figure, ranging from 1 km to more than 100 km in length. Faults shown as continuous over long distances showed clear fresh scarps that could be definitely identified on areal photographs. Older scarps, being more weathered, are shown by discontinuous lines. Since these active faults are scattered throughout the state, this map indicates that large-scale faulting, corresponding to major earthquakes, would be expected to occur over a period of several hundred thousand years over most of Nevada. Almost any spot in the State is in the immediate vicinity of one or more of these potential earthquake sites. Ryall (1977) suggests that "a major earthquake will, at some time in the future, occur within a few tens of kilometers of almost any point in the region."

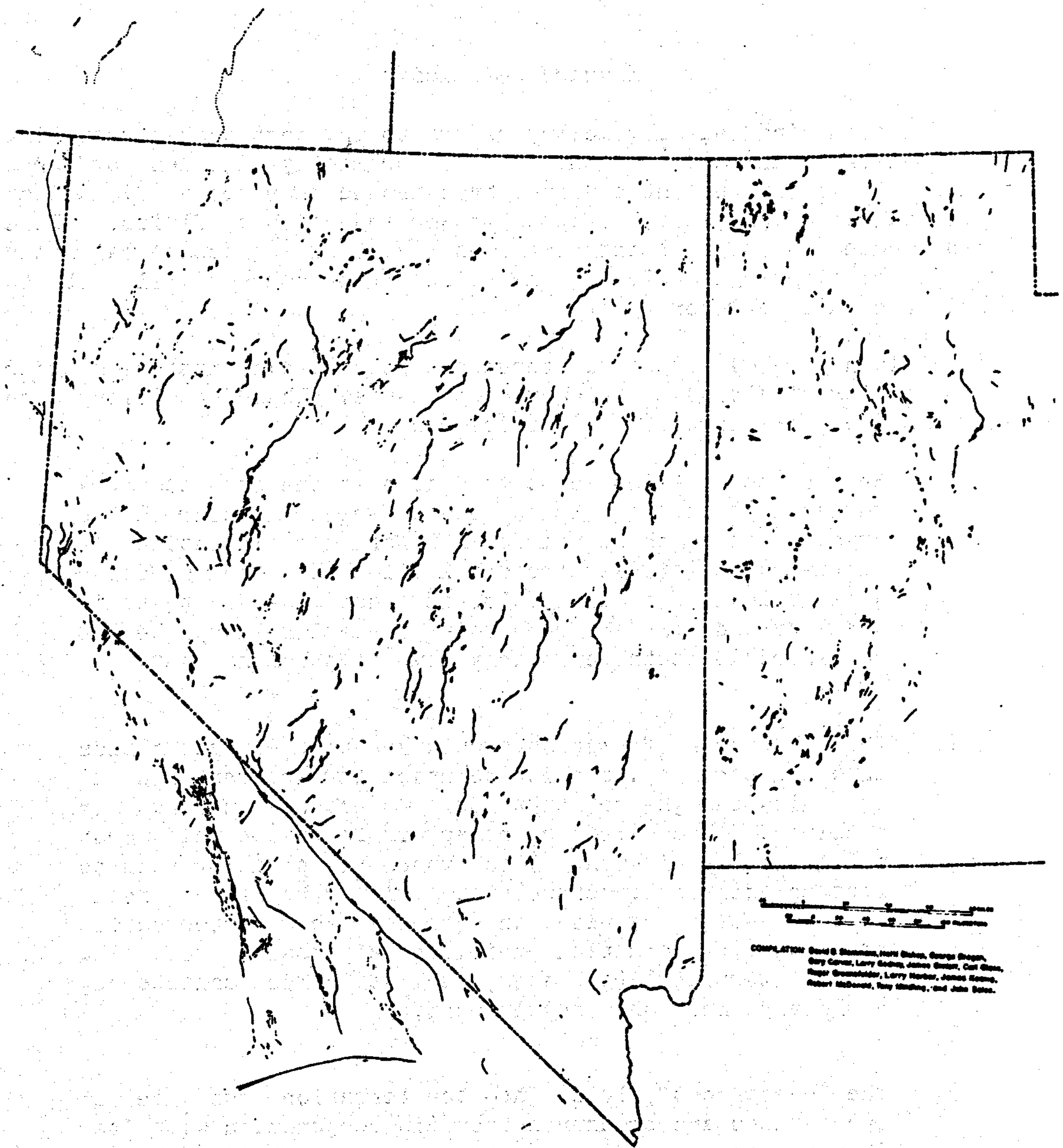


Figure 6. Provisional map of active faults in the Nevada region (from Slemmons, 1966).

Induced Seismicity

The term "induced seismicity" refers to any earthquakes resulting from man-made causes. Seismicity is primarily induced by three actions: 1) impoundment of water by dams and reservoirs, 2) nuclear tests and explosions, and 3) withdrawal or injection of fluids. This third cause is of most interest when investigating geothermal sites and will be discussed below. The first two causes will not be considered in this report.

McClain (1970) suggests three conditions which must be met for the injection of fluids to trigger earthquakes. These conditions are summarized by Kisslinger (1975) as follows:

1. By far the most important condition is the presence of a regional tectonic stress state which is near to the breaking strength of the rocks before the injection is initiated. This requirement implies that the injection well is located in an area of at least moderate tectonic activity and that the reservoir formation must be at considerable depth, certainly several thousand feet.

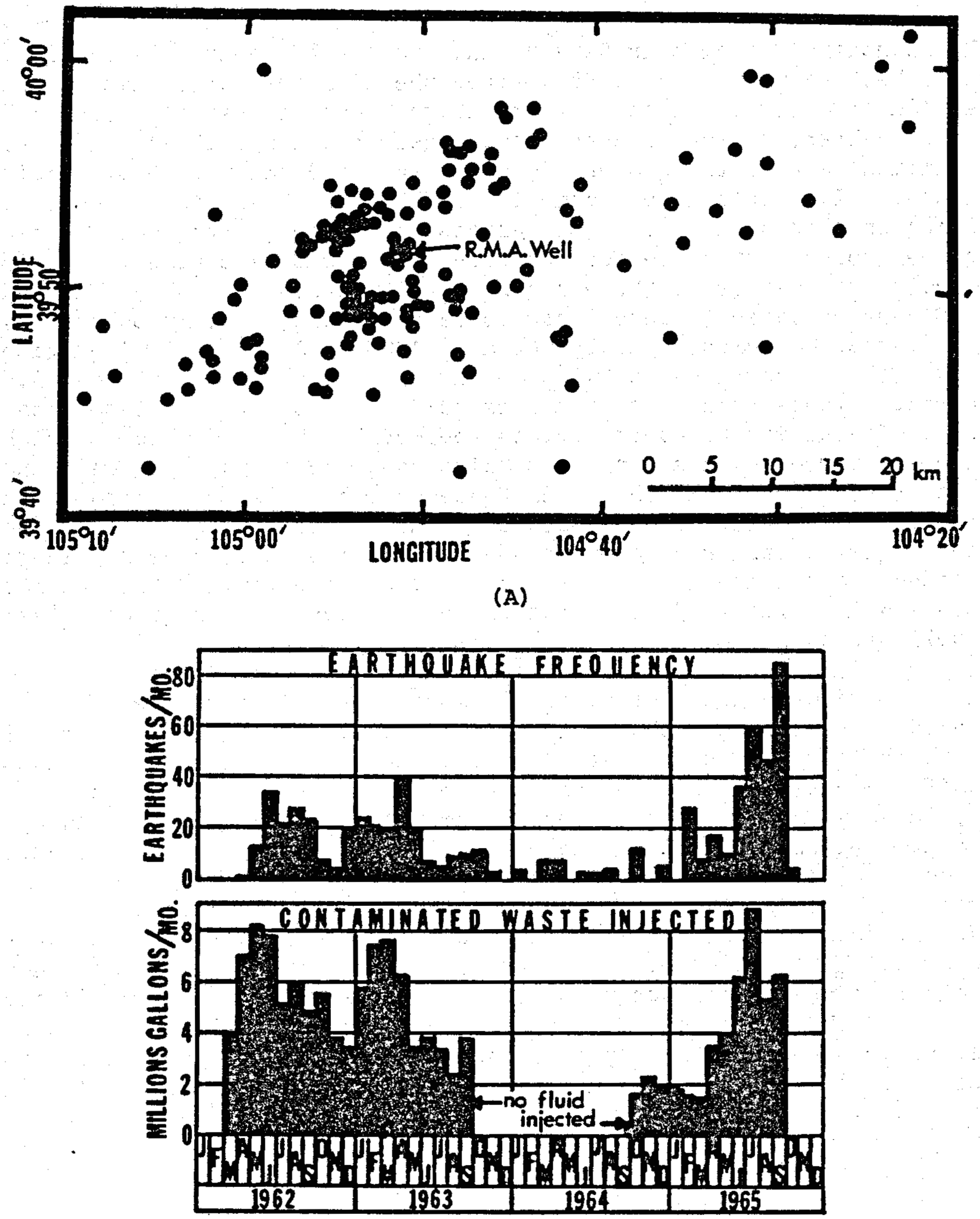
2. The reservoir formation should accept the waste fluids into its porosity, but its permeability apparently needs to be low enough so that pore pressure build-up is possible. The type of reservoir formation which best meets this requirement is one where the porosity results from an existing fracture system in cyrstalline rocks which are otherwise nonporous and impermeable. Presumably, a formation exhibiting a porosity resulting from intergranular spaces, such as in most sandstones, could also meet this requirement.

3. The injection of fluids into the formation must be at such rates and pressures that (in conjunction with item 2 above) the formation pore pressures are significantly increased over a wide area. Based on the Denver situation, apparently flow rates of millions of gallons per month at pressures approaching 1000 psi greater than the original pore pressures are required.

Fluid injection can trigger faulting in the following manner. The injection of fluids increases the pore pressure within the rock unit. This increase in pore pressure decreases the effective stress; in particular, it decreases the effective normal stress across pre-existing fault planes. This is a reduction of the frictional resistance to faulting. At the time of an earthquake, this resistance is overcome and the movement by brittle fracture, in response to local or regional stresses, occurs. There are two documented cases of induced seismicity related to injection in the United States; at the

Rocky Mountain Arsenal near Denver and the oil field at Rangley. Earthquakes began in 1962 shortly after the high pressure, high volume injection of fluid wastes at the Rocky Mountain Arsenal. Figure 7 shows epicenters of earthquakes located near the disposal well and the correlation between the number of earthquakes and the volume of fluid injected. The epicentral zone is parallel to the regional trend of faulting in this area. Focal mechanisms for these earthquakes agree with the geologic evidence for near vertical right-lateral strike-slip faults. The nature of these earthquakes suggests that they released significant tectonic (natural) stress rather than that produced by fluid injection alone (Healy et al., 1968). After fluid injection ceased, three earthquakes with magnitudes between 5.0 and 5.5 occurred. These three earthquakes did not follow the statistical pattern of activity based on events between 1962 and 1966, which predicted three events in this size range in 60 years. Healy and others (1968) explain these earthquakes by large propagating fractures. As the high pressure front moves further from the injection well, larger fractures will be affected, causing large magnitude earthquakes to predominate, even after fluid injection has ceased. While fluid injection continued, shorter fault segments near the well would also be active.

At a geothermal reservoir, removal of water or steam may be balanced by replenishment of cooled water either through forceful reinjection or natural seepage. The available literature suggests that if the rates at which water is removed and reinjected are held approximately equal, the natural seismicity of the region should not be greatly altered. A slight lag in time or a separation in distance between removal and replenishment of fluids may trigger microearthquakes or small earthquakes around the well sites. If a large pressure front is not allowed to build up, large earthquakes should not be triggered by the power plant operation, although they may occur naturally throughout Nevada as discussed previously. In oil fields, if the injection of fluids is kept below normal rock fracture pressures, no environmentally significant seismicity has been known to occur (Crow 1980). Regulations now dictate reinjection pressures in most states.



(A)

(B)

Figure 7. Observations on which Evans (1965) based his theory of the relation between fluid injection and earthquakes at the Rocky Mountain Arsenal, Denver, Colorado (Healy and others, 1968).

(A) Epicenters (solid circles) of earthquakes as calcultaed by Wang using data from the Bergen Park and Regis College stations and from temporary U.S. Geological Survey stations.

(B) Correlations between the number of earthquakes and the volume of fluid injected.

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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter V

HYDROLOGY AND WATER QUALITY

by

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Water Resources Center
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INTRODUCTION

Geothermal development in northern Nevada possesses the potential for adversely impacting the hydrology and water quality of the area undergoing development. Threats to water quality, particularly groundwater quality, generally produce the greatest concern. Ground-water quality degradation is more subtle and pervasive than surface-water degradation and because of the nature of flow through porous media, it is more difficult to mitigate once it occurs. It is therefore, imperative that great care be exercised with regard to potential ground-water quality degradation during all phases of geothermal development. This should not be construed as an attempt to minimize the possible deleterious effects of geothermal development on the quality of surface water. Depending upon the method used to dispose of the geothermal effluent and the surface water, ground water interrelationships in a given area, surface water quality degradation could be a serious problem. Geothermal development can also adversely affect the hydrology of a given region - both surface water and ground-water hydrology. These changes, as with degradation in water quality, can impact a very small or a very large area.

In keeping with the purpose of this study, this chapter will provide a brief synopsis of the possible effects of geothermal development on the hydrology and water quality of northern Nevada. Many of the general effects are expected in all the geothermal areas in northern Nevada; however, site-specific effects in each geothermal area cannot be described quantitatively at this time. In order to accurately assess the effects of geothermal development at a specific site, the following information is required:

1. geothermal fluid chemistry;
2. shallow ground-water chemistry and other water quality parameters;
3. surface water chemistry and other water quality parameters;
4. interrelationships between the geothermal reservoir and the shallow ground-water reservoir;
5. surface water - ground water interrelationships;
6. watershed characteristics (e.g., channel networks, hydraulic and geomorphic properties of the channel network, etc.);
7. characteristics of the shallow ground-water reservoir (e.g.,

number of aquifers and their hydraulic interrelationships, storage, transmissive and dispersive properties, recharge and discharge characteristics, etc.);

8. characteristics of the geothermal reservoir, and

9. general hydrologic information (e.g., precipitation, runoff, evapotranspiration, etc.).

Not all of these data are available for northern Nevada geothermal areas. They will have to be acquired systemtically as geothermal development progresses and more detailed assessments of the environmental impacts are mandated.

GEOTHERMAL IMPACTS

Before proceeding with a discussion of the hydrologic and water quality regimes of northern Nevada geothermal areas, a general list of the various impacts of geothermal development will be given. The location of northern Nevada geothermal areas with respect to the area's major hydrographic basins is shown in Figure 1.

Potential Impacts of Geothermal Development

1. Ground Water

    a. increases/decreases in ground-water storage.
    b. changes in patterns of ground-water discharge, recharge and movement.

2. Surface Water

    a. increases/decreases in streamflow.
    b. increases/decreases in surface water storage.
    c. changes in watershed characteristics.

        (1) rainfall/runoff relationships
        (2) infiltration properties
        (3) hydraulic and geomorphic properties of the channel network

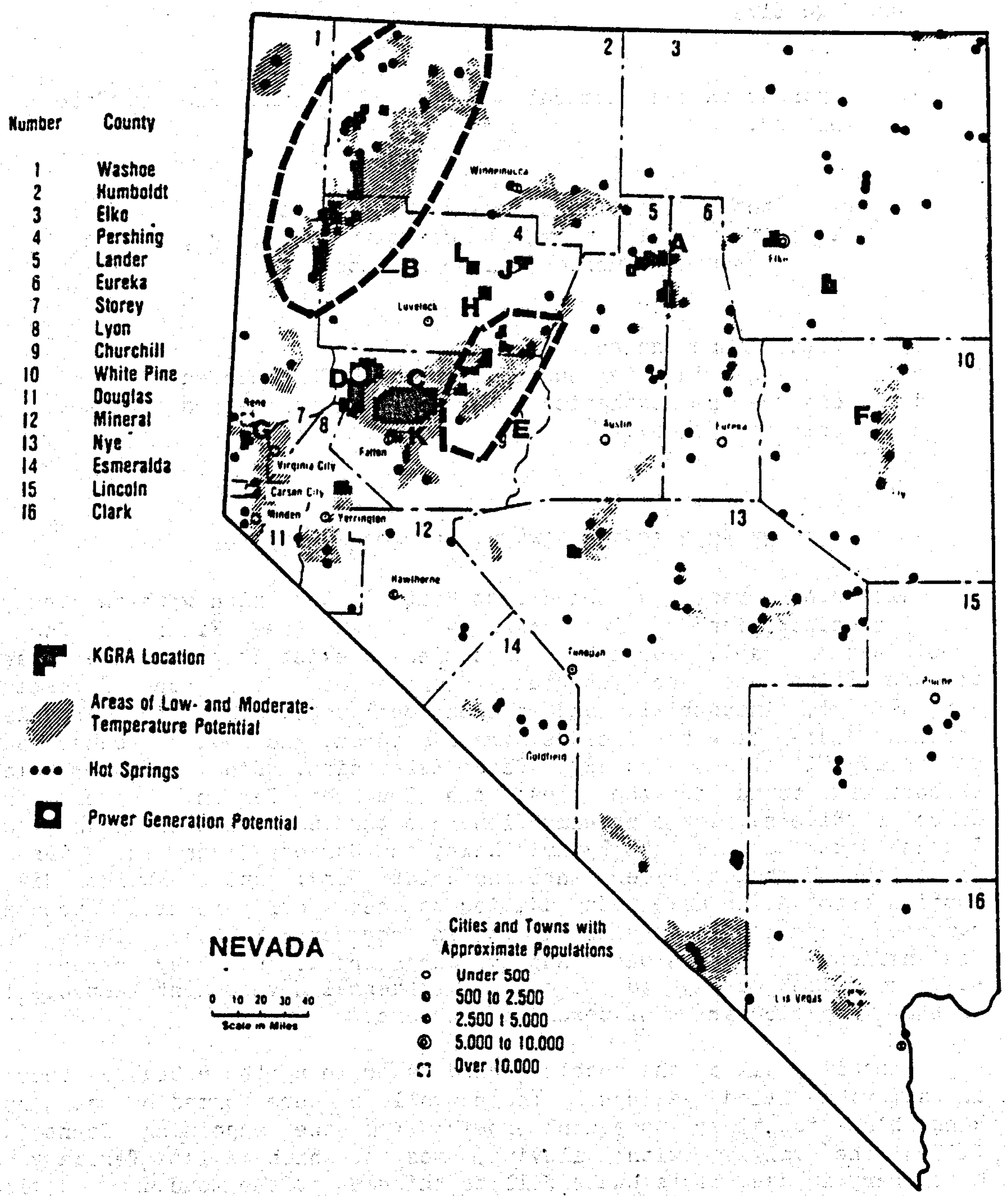


Figure 1. Potential geothermal areas in northern Nevada. Known Geothermal Resource Areas (KGRAs) discussed in this report are labled as follows: (A) Beowawe; (B) Black Rock Desert area; (C) Desert Peak; (D) Brady-Hazen; (E) Dixie Valley area; (F) Monte Neva; (G) Steamboat; (H) Kyle Hot Springs; (J) Leach Hot Springs; (K) Carson Desert (Stillwater-Soda Lake); (L) Rye Patch (Humboldt House). (modified from EG&G Idaho, Inc., 1979)

3. Water Quality

a. changes in the chemical quality of ground and surface waters.

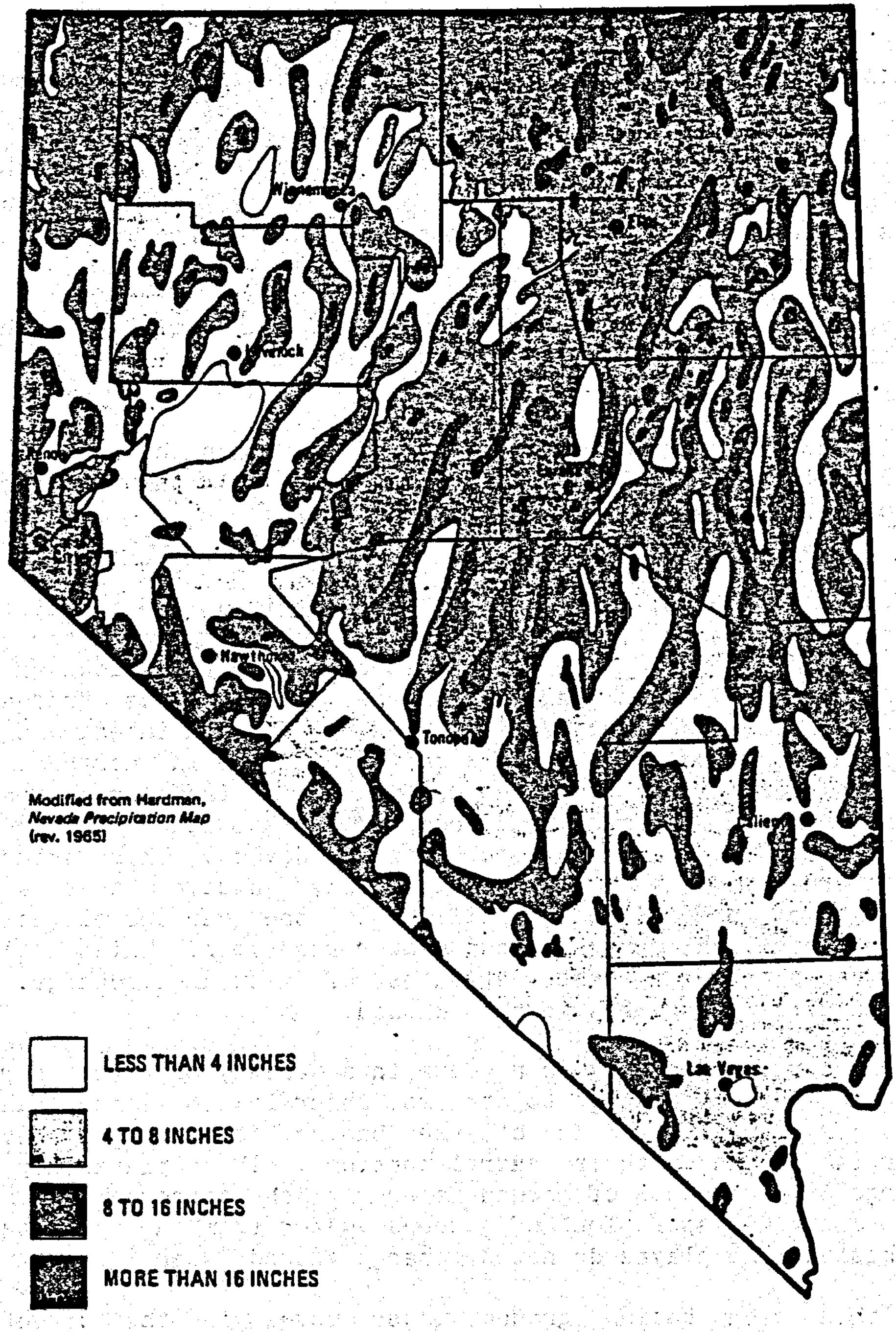
(1) total dissolved solids (TDS) content
(2) individual chemical constituents (e.g., boron, arsenic, fluoride, chloride, etc.)

b. temperature changes
c. increases in total suspended solids (TSS) content
d. changes in "aesthetic" water quality parameters (taste, color and odor).

HYDROLOGIC ENVIRONMENT OF NORTHERN NEVADA

Although Nevada is the driest State in the Union with an average annual precipitation of less than 9 inches (see Figure 2 for a precipitation map), surface water bodies do exist in the northern part of the State and are important sources of water for domestic, agricultural, industrial, and recreational uses. The major perennial standing bodies of water include Pyramid, Topaz, and Walker Lakes and Lahontan, Wildhorse, and Rye Patch Reservoirs. Four major perennial streams are found in the area: the Truckee, Carson, Walker, and Humboldt Rivers. These streams flow into terminal lakes or sinks: the Truckee River empties into Pyramid Lake; the Carson River into Carson Sink; the Humboldt River into Humboldt Sink; and the Walker River empties into Walker Lake. In addition to these four perennial streams, numerous ephemeral streams exist in northern Nevada. These are insignificant as far as water supply is concerned, but they cannot be slighted with respect to effects of geothermal development, especially if they are tributaries of perennial streams.

Virtually all of the usable ground water in northern Nevada occurs in alluvium-filled valleys. These valleys were formed by Basin and Range block faulting; subsequent erosion from the adjoining mountains filled the valleys with alluvium, most of which is late Tertiary or Quaternary in age. This basin fill is thinnest at the mountain margins and is thickest in the central portions of the valleys. Maximum thicknesses of the fill is poorly known but probably exceeds several thousand feet in many basins. The best aquifer material in these basins is the coarse fraction - the sands and gravels. In general, the younger alluvial material possesses more favorable aquifer properties, since it is normally not as consolidated or cemented as the older alluvium. Ground water also occurs in consolidated (sedimentary and igneous) rocks, although these are normally unimportant as aquifers. Locally, they may yield small amounts of water to wells.



Modified from Hardman, *Nevada Precipitation Map* (rev. 1965)

Figure 2. Average annual precipitation in Nevada (Houghton and others, 1975).

Ground water is derived from precipitation in the region. Little ground-water recharge is believed to occur via direct precipitation on the valley floors, since only small amounts of precipitation occur on the valley floors and virtually all of this is evapotranspirated before it can percolate to the water table. Most of the natural recharge results from streamflow infiltration or mountain front recharge, both of which are extremely difficult to quantify. Seepage can occur from both perennial streams (along their losing reaches) and from ephemeral streams during runoff events. Mountain front recharge is a more elusive quantity, although it is believed to occur in two ways:

1. recharge that occurs at the apex of alluvial fans where streams issue forth from the mountains; and

2. via seepage through the fractures or solution channels in the mountain masses which ultimately discharges in the subsurface to the valley fill ground-water reservoir.

Both forms of mountain front recharge are derived from precipitation at the higher elevations. This generally occurs as snow, and the snowmelt either infiltrates in the upland watersheds or flows down as mountain streams. A given basin can also receive subsurface "recharge" or underflow from an adjacent basin. This is known as interbasin flow and is believed to occur on a fairly significant scale in northern Nevada. Non-natural or cultural recharge can be derived from irrigation returns and seepage from man-made impoundments. Estimates of ground-water recharge have been made for each basin in Nevada. These estimates are somewhat crude and have been developed by assuming that a certain percentage of precipitation falling in the various elevation zones within a basin recharges the ground-water reservoir. This estimate is then cross-checked against estimates of natural discharge. Table 1 shows the percentages used in this method.

Ground-water discharge can occur in a variety of ways: springflow, evapotranspiration, seepage to streams, underflow to other basins, or pumpage from wells. Some of the basins in northern Nevada have discharging playas in their central portions. These playas may actively discharge large amounts of ground water via phreatophyte transpiration and/or direct evaporation of ground water from the water table. In other basins, the playas do not discharge ground water.

Within each basin, ground water moves in the direction of decreasing hydraulic head from recharge areas to discharge areas. This generally means that flow in a given basin occurs from the mountain margins to the central (lowest) part of the basin. The pattern of flow, however, is more complex than this simple conceptual model might indicate. The direction of flow also varies with depth as well as laterally, but the this variation of flow with depth is not well quantified in Nevada ground-water basins. Very shallow ground-water flow, not far beneath the water table, commonly is related closely to

TABLE 1.

PERCENTAGES USED TO CONVERT PRECIPITATION TO GROUND-WATER RECHARGE

(after Maxey and Eakin, 1949)

Amount of precipitation in a in a given elevation zone	Percentage of Precipitation in that zone contributing to ground-water recharge
< 8	0
8-12	3
12-15	7
15-20	15
> 20	25

the topography. Unconfined ground-water flow divides and topographic divides are often coincident or nearly so. However, flow in the deeper zones may diverge substantially from the shallow ground-water flow, especially where permeable rocks or permeable zones, such as fracture or solution zones, extend to considerable depth beneath the unconsolidated valley fill ground-water reservoir. Table 2 contains a variety of information on northern Nevada ground-water basins. Figure 3 shows major areas of ground-water recharge and discharge in northern Nevada.

Ground-water quality in northern Nevada is highly variable and can often be quite high in TDS content. High concentrations of sulfate are often present. In northwestern Nevada, parts of which at one time were covered by Lake Lahontan, ground water moving through lacustrine deposits has acquired high levels of dissolved solids. In general, the best quality ground water is found in the vicinity of recharge areas and becomes poorer with increasing flow distance and residence time. Ground-water quality is generally the poorest beneath playas. There are, of course, many exceptions to this general rule. For example, highly mineralized ground water often occurs in the vicinity of the range front faults in some basins (e.g., the Truckee Meadows). These waters can contain unacceptably high levels of such toxic trace elements as arsenic. Table 3 shows the high variability in the chemical quality of northern Nevada shallow ground waters. Reliable data are somewhat scarce; data on the quality of deep ground water are virtually non-existent.

POTENTIAL GEOTHERMAL IMPACTS ON THE HYDROLOGY AND WATER QUALITY OF SEVERAL REPRESENTATIVE AREAS

Because of the large number of geothermal areas in northern Nevada, it is difficult in a report of this nature to give adequate coverage to each Known Geothermal Resource Area (KGRA). Since similar general problems will be common to many northern Nevada geothermal areas, a few representative basins containing KGRAs will be selected for discussion. Not all geothermal impacts will be discussed; for example, many impacts are site-specific (even within a given basin) and cannot be properly addressed without knowing the exact drilling and power plant locations. The assessments of these site-specific impacts must wait for environmental impact assessments and the collection of additional data during resource development.

The organization of this portion of the chapter consist of a general hydrologic discussion of each representative area, which will then be followed by a single section describing potential geothermal impacts on the hydrology and water quality of each area. This format will avoid a great deal of repetition, since similar general impacts will exist in each area.

TABLE 2. GROUND-WATER FLOW SYSTEMS IN NORTHERN NEVADA* (from Mifflin, 1968).

Flow System Name	Prime Source Areas (s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Surprise Valley	Hays Canyon, New Year Lake Range	Surprise Valley	Surprise Valley Warner Valley	[a]2,000		Uncertain hydrologic role of New Year Lake. Ground-water basin mostly in California.
Long Valley	Bald Mountain, Hay Canyon, New Year Lake Range	Long Valley	Long Valley, Mosquito Valley, Boulder Valley, Macy Flat	5,900 700 2,100	[b]7,000 [b]800 ?	Flow in volcanic bedrock probably important.
Massacre Valley	Bald Mountain, Bitner Butte	Massacre Lake Valley	Massacre Lake Valley	3,500	[b]500	Flow in volcanic bedrock probably important.
Warner Valley	surrounding hills	Coleman Valley	Coleman Valley	[a]1,000		Flow in volcanic bedrock probably important.
Badger Creek Catlow Valley	Bald Mountain, Catnip Mountain, Bitner Butte	Swan Lake, Catnip Res. Guano Valley, Stream flow	Guano Valley Swan Lake Valley	[a]7,500		Flow in volcanic bedrock probably important.
Big Spring Res.	Sage Hen Hills, Catnip Mountain, Booch Table	Big Springs Res., stream flow	Virgin Valley Sage Hen Valley	7,000	6,000	Flow in volcanic bedrock probably important.
Virgin Valley	Gooch Table, Blow Out Mountain, Rock Springs Table	Virgin Valley	Virgin Valley			Flow in volcanic bedrock probably important.
Thousand Springs Valley	Pine Forest Range, Rock Spring Table, Pueblo Mtns.	Thousand Creek Valley	Continental Lake V. Gridley Lake Valley	10,900 4,400	10,500 2,000	
Alvord Valley	Pine Forest Range, Pueblo	Pueblo Valley	Pueblo Valley	[a]2,000	1,200	Majority of ground-water basins in Oregon.
Summit Lake	Black Rock Range	Summit Lake	Summit Lake Valley	[c]4,200		Some interbasin flow to NE?
High Rock	Calico Mountains	High Rock lake drainage bottom land	High Rock Lake Valley	13,000	2,000 ave.	Dicharge based on 500 acre area for High Rock Lake. Probable important interbasin flow to Soldier Meadow.

TABLE 2. (Cont.) Ground-Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Duck Flat	Hays Canyon Peak, Granite range	Duck Flat	Duck Lake Valley	9,000	7,000	
Smoke Creek	Buffalo Hills	Smoke Creek Valley	Smoke Creek Desert			
Smoke Creek Desert	Granite Range, Buffalo Hills, Pah Rum Range	Smoke Creek Desert	Smoke Creek Desert			May receive some interbasin flow.
Black Rock Desert	Pine Forest Range, Black Rock Range, Jackson Mtns., Calico Mountains, Granite Range, Selenite Range	Black Rock Desert	Pine Forest Valley	9,700	14,000	May receive interbasin flow; large discharge area probably averages an extremely low rate evapotranspiration.
			Black Rock Desert Mud Meadow	23,900	?	
			Hualapai Flat	4,000	5,000	
Desert Valley King River	Trout Creek Mountains, Jackson Mountains, Slumbering Hills, Eugene Mountains	Kings River Valley Desert Valley	Kings River V. (A+B)	15,000	[g]15,000	Part of southern boundary uncertain
			Desert Valley	5,000	16,000	
Quinn Valley Silver State V.	Trout Creek Mountains, Santa Rosa Range, Slumbering Hills	Quinn River Valley	Quinn River V. (A+B)	74,000	*68,000	*Assumes 5000 acre-ft/yr. surface water outflow ground-water discharge. Note major difference in estimates resulting from two different approaches.
			Silver State V.	[g]24,000	[g]25,000	
Paradise Valley	Humboldt River, Little Humboldt River, Santa Rosa Range, Sonoma Range, East Range	Paradise Valley Grass Valley Humboldt River	Hardscrabble Area			*See Cohen, 1964a, b for budget estimates.
			Paradise Valley	23,000	26,000	
			Winnemucca segment	*	*	
			Grass Valley	18,000	6,800	
Little Humboldt River	Sugar Loaf Hill, Hot Springs Range, Osgood Mountains	Little Humboldt River	Little Humboldt Valley			NE boundary based on small springs; flow in volcanic bedrock may be important in this area.
Owyhee Desert	Capitol Peak, Owyhee Plat. Tuscarora Mtns. Bull Mtns.	South Fork Owyhee River	Little Owyhee River Area, South Fork Owyhee River Area			Large flow system with majority of flux in volcanic bedroc, discharge almost entirely to stream flow.

TABLE 2. (Cont.) Ground-Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Duck Valley	Bull Run Mountains, Jarbridge Mountains	Duck Valley Owyhee River	Owyhee River area			
Wild Horse Res.	Independence Mountains, Jarbridge Mountains	Wild Horse basin	Owyhee River area			
Independence Valley	Independence Mountains, Tuscarora Mountains	Independence Valley South Fork Owyhee River	Independence Valley	10,000	[e]10,000	Terrain at or near ground-water capacity.
Squaw Valley	Tuscarora Mountains	Squaw Valley Rock Creek	Willow Creek Valley			Flow in volcanic rock probably important.
Rock Creek	Tuscarora Mountains, Sheep Creek Range	Rock Creek Valley Rock Creek	Rock Creek Valley			
Little Reese R. Humboldt River	Humboldt River, Owyhee Plateau, Tuscarora Mtns., Osgood Mountains, Battle Mountain, Shoshoe Range	Humboldt River Valley Kelley Creek Valley, Pumpernickel Valley, N. Reese River Valley, Boulder Valley, Humboldt River	Lower Reese River V. M. Reese River V. Boulder Flat Clovers Area Pumpernickel Valley Kelley Creek Area	6,600	3,000	Large amounts of discharge by evapotranspiration present in several areas along the Humboldt.
Maggie Creek	Tuscarora Mountains, Independence Mountains, Adobe Range, Buckskin Mountains	Maggie Creek, Susie Creek, Humboldt River Valley	Elko Segment Susie Creek Area Maggie Creek Area Mary's Creek Area			Important part of discharge may be stream flow.
Tule Valley	Independence Range, Adobe Range, Jarbridge Mtns.	North Fork Humboldt River and tributary valleys	North Fork Area			Majority of terrain at ground-water capacity; important part of discharge is stream flow.
Upper Humboldt River	Jarbridge Mountains, East Humboldt Range, Adobe Range	Humboldt River Valley and tributary valleys	Elko Segment North Fork Area Mary's River Area Starr Valley Area Lamoille Valley			Important part of ground-water discharge is stream flow.
Jarbridge River	Jarbridge Mountains	[a]north flow streams	Bruneau River Area Jarbridge River Area			Discharge mostly stream flow in Nevada.

TABLE 2. (Cont.) Ground-Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
Evans Flat	Jarbridge Mountains	Evans Flat, Bruneau River	Bruneau River Area			Terrain at ground-water capacity
O'Neil Basin Buckthorn Pasture	Jarbridge Mountains	Salmon Falls Creek and tributaries	Salmon Falls Creek Area			Terrain at ground-water capacity.
N. Salmon Falls Creek	Bear Mountain, L&D Mountain, Grassy Mountain	[a]Cottonwood Creek, Salmon Falls Creek	Salmon Falls Creek Area			Discharge by stream flow in Nevada.
Salmon Falls Creek	Granite Range, Antelope Peak Range	Salmon Falls Creek	Salmon Falls Creek			S and E boundaries approximate.
Thousand Creek	Granite Range, Pequop Mountains	Thousand Springs Creek Valley	Thousand Springs Valley (A+B)			
Rock Spring	Granite Range, Round Top	Rock Springs Creek Valley, Thousand Springs Creek Valley	Thousand Springs Valley (B)			
Goose Creek	Gollyer Mountain, Monument Peak Mountains, Bald Mountain	Goose Creek	Goose Creek Area			
18-21 Mile Ranch	Delano Mountains	Thousand Springs Creek Valley	Thousand Springs Valley (C)			
Gamble Ranch	mountains to the north	[a]Gamble Ranch and Montello Area	Thousand Springs Valley (D), Grouse Creek			
West Bonneville	Toana Range, Pilot Range, Goshute Mountains	Great Salt Lake Valley	Great Salt Lake Desert Pilot Creek Valley			
Goshute Valley	Pequop Mountains, Toana Range, Goshute Mountains, Dolly Varden Mountains	Goshute Valley	Goshute Valley Antelope Valley (B) }	10,400 }	[d]10,075	Discharge seems too small in this system, may have incorrect system boundaries.
Clover Independence V.	Pequop Mountains, Wood Hills, East Humboldt Range	Clover Valley, Independence Valley	Clover Valley Independence Valley	20,700 9,300	19,000 9,500	Discharge present derived within Goshute flow system boundaries?

TABLE 2. (Cont.) Ground Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
N. Butte Valley	Spruce Mountain, Cherry Creek Mountains, Medicine Range	northern Butte Valley	Butte Valley (A)			
Ruby Valley	East Humboldt Range, Ruby Mountains, Maverick Springs Range	Ruby Valley	Ruby Valley	68,000	68,000*	*Just Ruby Marsh about 22,000 acres would yield at least 66,000 acre-ft. of discharge if essentially supplied by ground water. Estimates may be low.
Huntington Valley	Ruby Mountains, Sulphur Spring Range, Diamond Mountains	Huntington Creek and tributaries, Huntington Creek Valley and tributaries	Huntington Valley Dixie Creek-Tenmile Creek Area	}	30,000	Has been suggested to be low in ground-water discharge.
Pine Valley	Sulphur Spring Range, Cortez Mountains, Roberts Mountain	Pine Valley, Pine Creek	Pine Valley	46,100	^{e}24,100	27,700 acre-ft. of recharge estimated to occur from precipitation below 7,000 ft. of elevation; may show a basic problem in estimation methods rather than inter-basin flow.
Whirlwind Valley	Tuscarora Mountains	Whirlwind Valley Humboldt River Valley	Whirlwind Valley Crescent Valley Boulder Flat			
Crescent Valley	Cortez Mountains, Shoshone Range	Crescent Valley	Crescent Valley	14,000	12,000+	
Carico Lake Valley	Shoshone Range, Toiyabe Range	Carico Lake Valley	Carico Lake Valley	4,300	3,800	
Buffalo Valley	Tobin Range, Fish Creek Mountain, Battle Mountain, Buffalo Mountain	Buffalo Valley	Buffalo Valley			
Pleasant Valley	East Range, Tobin Range	Pleasant Valley	Pleasant Valley	3,000	2,200	
Buena Vista Valley	Humboldt Range, East Range, Stillwater Range	Buena Vista Valley	Buena Vista Valley	10,000	12,500	

TABLE 2. (Cont.) Ground Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Lower Humboldt Valley	Humboldt Range, Humboldt River irrigation, East Range, Eugene Mountains	Humboldt River, Humboldt River Valley, Lovelock Valley	Winnemucca segment White Plains Lovelock Valley }	[f]24,200 }	23,900	
			Imlay Area	3,800	4,400	
Granite Springs	Seven Troughs Range, Shawaue Mountains	Adobe Flat	Granite Springs Valley			
Kumiva	Selenite Range, Shawaue Mountains	Kumiva Flat	Kumiva Valley			Sparse data in this area.
San Emidio Desert	Pah Rum Peak, Lake Range	San Emidio Desert Granite Creek Desert	San Emidio Desert			
Winnemucca Lake	Lake Range, Selenite Range, Nightingale Mountains	Winnemucca Lake basin	Winnemucca Lake Valley	8,000	8,000	Flow system may not be in equilibrium because of lake desiccation
Lower Truckee R. Pyramid Lake	Lake Range, Virginia Mountains, Pah Rah Range, Truckee River, Virginia Range	Truckee River, Pyramid Lake area	Pyramid Lake Valley Dodge Flat Tracy segment			Evidence of nonequilibrium of flow system near north end of Pyramid Lake because of lake drop.
Henry Lake	[a]Virginia Mountains, Fort Sage Mountain	Honey Lake Valley	Honey Lake Valley Dry Valley Skedaddle Creek Valley			May have received some interbasin flow.
Long Valley	[a]Virginia Mountains, Dogskin Mountain, Seven Lakes Mountain	Dry Valley	Dry Valley Newcomb Lake Valley			
Red Rock Ranch	Petersen Mountain, Dogskin Mountain	Red Rock Valley Bedell Flat	Red Rock Valley Bedell Flat Antelope Valley			Minor interbasin flow from Antelope Valley, probably to Bedell Flat.
Warm Springs Valley	Virginia Mountains, Pah Rah Range, Dogskin Mountain	Warm Springs Valley	Warm Springs Valley			
Cold Springs Valley	Peavine Peak, Petersen Mountain	Cold Spring Valley	Cold Spring Valley			

TABLE 2. (Cont.) Ground Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Lemmon Valley	Peavine Peak	Lemmon Valley	Lemmon Valley (A+B)			
Spanish Springs Valley	Pah Rah Range, irrigation ditches	Spanish Springs Valley	Spanish Springs Valley			
Truckee Meadows	Carson Range, Truckee River irrigation, Virginia Range	Truckee Meadows	Truckee Meadows Pleasant Valley Sun Valley	36,000	33,000+	
Upper Truckee River	[a]Carson Range	Truckee River	Truckee Canyon Segment			
Washoe Valley	Carson Range, Virginia Range	Washoe Valley	Washoe Valley	15,000[1] 33,000[2]	8,500[1] 31,000[2]	1) Estimates do not include surface water relationships 2) Total water budget of valley.
Lake Tahoe	[a]Carson Range	Tahoe Basin	Lake Tahoe Basin			
Eagle Valley	Carson Range, Virginia Range	Eagle Valley	Eagle Valley Dayton Valley	[f]14,400	[e]12,800	
Dayton	Virginia Range, Pine Nut Mountains	Dayton Valley	Dayton Valley			
Corral Springs	Virginia Range, Pine Nut Mountains		Dayton Valley			
Churchill Valley	Pine Nut Mountains, Virginia Range	Churchill Valley	Churchill Valley			
Leets Flat	Truckee Canalirrigation water, Truckee Range	Leets Flat	Bradys Hot Springs Area, Fernley Area Fireball Valley			Majority of discharge from surface water infiltration in Fernley area.
Carson Desert	Irrigation from Truckee and Carson Rivers, Stillwater Range	Carson Desert, Carson Sink, Fourmile-Eightmile Flats	Carson Desert			Local thermal ground-water may relate to late Quaternary volcanism.

TABLE 2. (Cont.) Ground Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2] U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
Dixie Valley	Stillwater Range, Clan Alpine Mountains	Dixie Valley	Dixie Valley	6,000	16,500	Discharge estimate in Dixie Valley seems low to this investigator.
			Fairview Valley	500		
			Jersey Valley	800		
			Stingaree Valley Cowkick Valley	6,000	400	
East Gate Basin	Desatoya Mountains, Clan Alpine Mountains	East Gate Area Dixie Wash	East Gate Valley Area			
Edwards Creek Valley	Clan Alpine Mountains, Desatoya Range	Edwards Creek Valley	Edwards Creek Valley	7,900	7,300	
Smith Creek Valley	Shoshone Mountains, Desatoya Range	Smith Creek Valley	Smith Creek Valley	12,100	6,650	No known evidence for interbasin flow.
Antelope Valley	New Pass Range, Shoshone Mountains, Augusta Mountains, Fish Creek Mountains	Antelope Valley	Antelope Valley	11,300	500	
Reese River Valley	Toiyabe Range, Shoshone Mountains	Reese River Valley	Upper Reese River Valley	36,700	37,000	Discharge estimate seems low to this investigator.
Grass Valley	Toiyabe Range, Simpson Park Range	Grass Valley	Grass Valley	12,600	12,000	May receive minor interbasin from east.
N. Big Smokey Valley	Toiyabe Range, Toquima Range	Big Smoky Valley	Big Smoky Valley(B)			
Monitor Valley Antelope Valley	Simpson Park Range, Roberts Mountains, Fish Creek Range, Antelope Range, Monitor Range, Toquima Range	Bean Flat, Antelope Valley	Kobeh Valley	10,900	14,900	
			Monitor Valley(A)	6,300	2,000	
			Antelope Valley	4,100	4,200	
			Steven Basin	200	0	
Diamond Valley	Fish Creek Range, Diamond Mountains, Sulphur Spring Range, Roberts Mountains	Diamond Valley	Diamond Valley	16,300	[b]23,000+	May receive significant interbasin flow from E or SE.

TABLE 2. (Cont.) Ground Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Newark Valley	Diamond Mountains, White Pine Range, Fish Creek Range, S. Ruby Mountains	Newark Valley	Newark Valley	17,500	[b]16,000+	May receive significant interbasin flow from Long Valley area to E.
Long Valley	S. Ruby Mountains, Butte Mountains, White Pine Range	Newark Valley? Long Valley	Long Valley	10,300	2,200	Significant interbasin flow may leave to W or S.
Butte Valley	Cherry Creek Mountains, Egan Range, Butte Mountains	Butte Valley	Butte Valley (B)			Interbasin flow may leave to E.
Steptoe Valley	Egan Range, Schell Creek Range	Steptoe Valley	Steptoe Valley	85,400	70,000	Discharge estimate seems low to this investigator.
Spring Valley	Schell Creek Range, Snake Range, Antelope Range, Kern Mountains	Spring Valley	Spring Valley Tippett Valley	73,000	57,000	Interbasin flow from Antelope Valley, and some flow to Snake Valley in S.
Spring Valley	Goshute Mountains, Kern Mountains	[a]Spring Creek Valley Deep Creek Valley	Deep Creek Valley			
Snake Valley	[a]Snake Range, Wilson Creek Range	[a]Snake Valley, Pleasant Valley	Snake Valley Hamlin Valley Pleasant Valley	103,000	79,000	
Little Smoky Valley	Antelope Range, Fish Creek Range, Pancake Range	Fish Creek Valley Newark Valley	Little Smoky Valley (A)	4,000	1,900	Interbasin flow in carbonate terrain may be important.
Little Fish Lake Valley	Hot Creek Range, Monitor Range	Little Fish Lake Valley	Little Fish Lake Valley	11,000	9,980	
Monitor Valley	Toquima Range, Monitor Range	Monitor Valley	Monitor Valley (B)	15,000	9,250	No important interbasin flow believed present.
Ione Valley	Shoshone Mountains, Paradise Range, Cedar Mountains	Ione Valley	Ione Valley	8,100	1,300	Under flow to Big Smoky Valley
Gabbs Valley	Paradise Range, Gabbs Valley Range	Gabbs Valley	Gabbs Valley	5,200	[d]4,300	

TABLE 2. (Cont.) Ground Water Flow Systems in Northern Nevada

Flow System Name	Prime Source Areas(s)	Prime Sink Areas(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates		Remarks
				Recharge	Discharge	
Rawhide Flats	none	Rawhide Flats	Rawhide Flats	150	780	Volume of discharge suggests possible interbasin flow from north.
Walker Lake	Wassuk Range, Walker River irrigation	Schurz Area Walker Lake Area	Walker Lake Valley (A+B+C)	6,500	21,000	Whisky Flat system (No. 114) included in estimates. Recharge estimate does not include Walker River irrigation seepage.
East Walker River	Wassuk Range, Pine Grove Hills, East and West Walker River irrigation	Mason Valley East Walker River	Mason Valley Churchill Valley East Walker Area			Majority of flux in Mason Valley from irrigation seepage.
Smith Valley	Pine Nut Mountains, Wellington Hills, W. Walker River irrigation	Smith Valley	Smith Valley			Majority of flux probably related to irrigation seepage.
Carson Valley	Carson Range, Pine Nut Mountains, Carson River irrigation	Carson Valley	Carson Valley			
Upper West Walker River	[a]Pine Nut Mountains, Wellington Hills	Antelope Valley	Antelope Valley			

* Table 2 lists information on Northern Nevada ground water flow systems as given in Mifflin (1968). Flow system names are listed as well as the geographic areas that constitute source (recharge) and sink (discharge) areas for each system. Also listed are hydrographic areas (as published by the Office of the State Engineer) that are partly or entirely involved in each flow system, and the recharge and discharge estimates that have been made for these areas by the U.S. Geological Survey. The discharge estimates, though probably quite variable in accuracy, are believed to be more accurate than the recharge estimates. Discharge estimates, where available, offer indications of the amounts of flux that leave the flow systems in the associated ground water basins.

1 = The hydrographic areas (1968 edition) are not always related to surface water or ground water divides. An attempt has been made to include hydrographic areas partly or entirely involved in the ground water flow system, and also to use the listed hydrographic name. The subdivisions are designated by letter rather than name in this compilation.

2 = An attempt has been made to use the fundamental recharge and discharge estimates in acre-ft/year. In some cases this yields values different than the values favored in the source report. Careful comparison of the methodologies employed indicates judgement has played an important role in many of the estimates, and several different appraches have been used.

a = In the Nevada portion only.

b = Discharge from the phreatic playa not included.

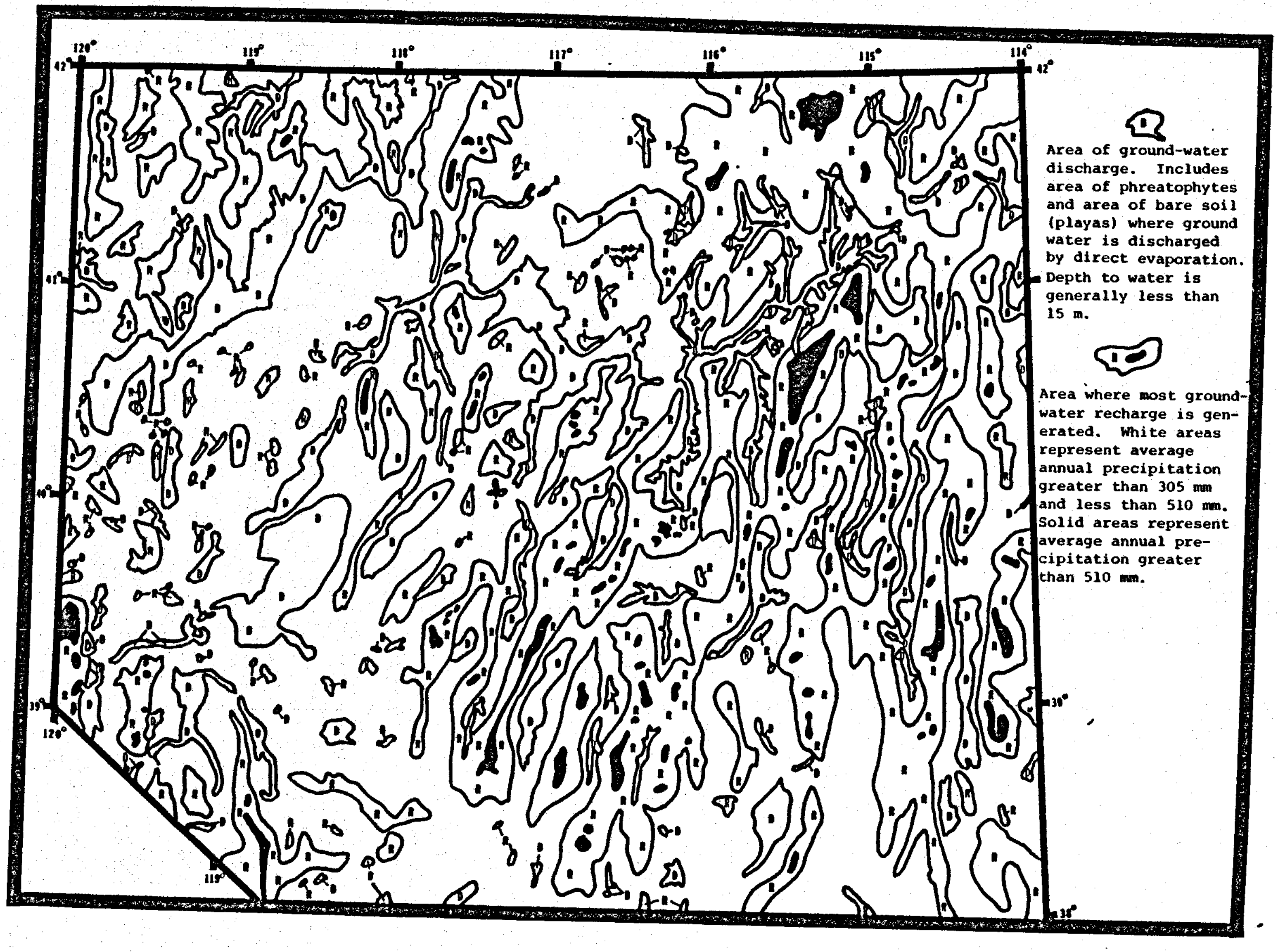
c = Area of recharge estimate and flow system do not approximately coincide.

d = Includes ground water pumpage.

e = Includes stream flow from system or basin.

f = Includes irrigation seepage to ground water system.

g = Early estimate of recharge or discharge.



Area of ground-water discharge. Includes area of phreatophytes and area of bare soil (playas) where ground water is discharged by direct evaporation. Depth to water is generally less than 15 m.

Area where most ground-water recharge is generated. White areas represent average annual precipitation greater than 305 mm and less than 510 mm. Solid areas represent average annual precipitation greater than 510 mm.

Figure 3. Major areas of ground-water discharge and recharge in northern Nevada (after Olmsted, et al., 1975).

TABLE 3.
CHEMICAL QUALITY OF SHALLOW GROUND-WATER IN NORTHERN NEVADA

(concentrations in milligrams per liter)

Location	Na+K	Ca	Mg	HCO_3	SO_4	Cl	NO_3	TDS*	SpC** (µmhos/cm @ 25°C)	pH
Carson Valley	13	21	3.9	90	15	4	3.3	108	--	8.3
Eagle Valley	494	54	20	717	312	272	0	2,700	--	7.9
Datyon Valley	41	79	20	158	204	14	3.5	506	--	7.8
Dayton Valley	52	413	26	154	1,060	16	1.7	1,810	--	7.6
Carson Desert	7,840	1.6	42	1,650	7,750	5,500	30	21,400	--	8.2
Dodge Flat	51.8	27.2	12	125	92	22.8	0.8	368	430	8.03
Dodge Flat	337.8	89	37.8	141	85.2	595	--	--	2,400	7.13
Whirlwind Valley	418	390	110	280	1,200	540	--	2,995	4,130	7.6
Whirlwind Valley	56.9	34.1	8.4	165	42	33	6.6	415	460	7.64
Pleasant Valley (S. of Winnemucca)	108.8	50	19.7	200	78.8	134	--	632	--	7.6
Walker Lake Valley	109.7	215	--	68	854	27	--	1,325	1,721	7.5
Churchill Valley	15	27	10	110	31	10	0	193	--	7.9
Lovelock Valley	1,190	20	11	381	75	1,620	--	--	6,110	7.7
Grass Valley (N. of Austin)	91	47	7.2	331	45	18	--	--	592	7.5
Carico Lake Valley	103	63	21	224	88	137	--	--	953	7.6
Washoe Valley	5	2.2	0	11	3	1.8	--	--	29	5.3
Steptoe Valley	8.7	31	20	174	20	11	--	--	332	8.2
Spanish Springs Valley	125	63	49	144	428	48	--	--	1,150	7.9

TABLE 3 continued.

Chemical quality of shallow ground-water in northern Nevada (concentrations in milligrams per liter)

Location	Na+K	Ca	Mg	HCO_3	SO_4	Cl	NO_3	TDS*	SpC** (umhos/cm @ 25°C)	pH
Desert Valley	628	117	38	235	599	680	0.5	2,230	3,440	7.7
Butte Valley	53	45	28	122	47	138	--	--	629	8.0
Pilot Creek Valley	678	125	52	189	36	1,280	--	2,260	--	7.5
Gabbs Valley	109Na	290	105	510	1,249	66	--	--	3,325	--
Middle Reese River Valley	136	52	7.3	428	62	21	0.8	--	825	7.9
Hualapai Flat	402	18	4.6	336	205	250	0.2	1,342	1,840	9.0
Winnemucca Lake Valley	6,400	54	15	2,050	1,740	7,350	--	17,000	25,400	--
Truckee Meadows	16	26	9	109	37	3	1.4	194	256	7.9
Pyramid Lake Valley	3,600	5	15	270	200	4,600	--	--	15,600	10.0
Fernley Area	214	294	113	204	1,170	198	--	--	3,000	8.1
Duck Lake Valley	1,180	345	122	196	2,070	1,160	1.1	5,160	6,860	7.3
Independence Valley	30Na	29	7.5	132	31	19	0.4	--	329	--
Brady's Hot Spring Area	2,757	165	14	138	--	4,430	--	--	13,200	7.5

* TDS = Total dissolved solids
** SpC = Specific conductance

Data compiled from various sources including unpublished Desert Research Institute data and Nevada Department of Conservation and Natural Resources, Water Resources Reconnaissance Series Reports, numbers 7,8,9,11,17,19,32,37,41,43,49,55,56,57,and 59.

Dixie Valley

Dixie Valley, which contains the Dixie Valley KGRA, is located about 110 miles east of Reno. It is one of seven valleys forming a single closed hydrologic unit. Dixie Valley is topographically the lowest of these valleys; indeed, it contains the lowest point in northern Nevada. The valley is the major ground-water sink for the seven-valley system; it is believed to receive underflow either directly or indirectly from the other six valleys. The ground-water flow into Dixie Valley is southward from Jersey and Pleasant Valleys; westward from Eastgate, Cowkick and Stingaree Valleys into Dixie Valley and then northward to the Humboldt Salt Marsh; and northward from Fairview Valley. In Dixie Valley itself, ground water moves radially from the valley margins toward the Humboldt Salt Marsh.

Ground water occurs under confined (artesian), semi-confined and unconfined (water-table) conditions in the unconsolidated sediments comprising the valley fill. The largest area of artesian conditions lies just south of the Humboldt Salt Marsh in a major ground-water discharge area. Semi-confined ground water occurs in scattered areas throughout the valley. Most of the ground water occurs in and moves through the interstices of the valley-fill sediments. However, a certain amount undoubtedly occurs as fracture-flow in the consolidated rocks. It is believed that the underflow from Pleasant Valley occurs in this manner. This type of flow is more important with respect to the geothermal reservoir than it is to the shallow ground-water reservoir.

Average annual precipitation in Dixie Valley is estimated to be about 456,000 acre-feet. Of this amount, 6,000 acre-feet is believed to reach the ground-water reservoir as recharge. Most of this recharge is believed to originate as precipitation in the mountainous regions: the Stillwater Range and Clan Alpine Mountains. Some of the mountainous regions receive more than 20 inches of precipitation annually, as compared to about 5 inches on the valley floor. In addition, the valley is believed to receive approximately 7,000 acre-feet of recharge annually as subsurface flow from the six surrounding valleys. Average annual natural discharge by evapotranspiration in Dixie Valley is approximately 16,200 acre-feet. The major discharge area is the Humboldt Salt Marsh, where ground water is discharged by transpiration and direct evaporation from the water table. It should be noted that these recharge and discharge estimates from Cohen and Everett (1963) result in an average annual discrepancy of 3,200 acre-feet between discharge (16,200 acre-feet) and total recharge (13,000 acre-feet).

Springs are numerous in the valley; most of them discharge thermal water. In terms of geothermal resources, the most important springs are the three major hot spring systems: Dixie Hot Springs, Hyder Hot Springs and Sou Hot Springs. The Dixie Hot Springs system is comprised of about 35 springs and seeps, which emerge from alluvium over an area of about four square miles. The Hyder Hot Springs system emerges in the middle of the valley where the bedrock is apparently covered by thick alluvium. Travertine deposits up to 100 feet thick have been deposited. The Sou Hot Springs system is found at the northern end of Dixie Valley.

Water quality information for Dixie Valley and surrounding valleys is shown in Table 4. A great deal more data exists, but it is not publically available yet. These unreleased data also include chemical and isotopic information on thermal waters and fluids from deep geothermal exploration wells.

Leach Hot Springs

Leach Hot Springs is located in Grass Va ey, about 30 miles southeast of Winnemucca. An excellent synopsis of the area's hydrology is found in Olmsted, et al (1975), from which most of this discussion is taken. The springs are located at the base of a low fault scarp near the eastern side of the valley. (The springs are comprised of about 29 orifices occupying an area of about 32,000 square feet). The hot springs have a total discharge of approximately 13 liters/second and reach temperatures of 94 C, boiling at their altitude of 4690 feet above mean sea level. The quantity of water discharged by the springs is greater than the quantity of recharge in the drainage area tributary to the hot springs. However, the estimated amount of recharge from the adjoining Sonoma Range is more than sufficient to account for the discharge of the hot springs. Because of the proximity of Leach Hot Springs to the recharge area (Sonoma Range), it is believed that no great lateral movement of ground water is necessary to reach the spring orifices.

Ground water in the immediate vicinity of Leach Hot Springs is present at depths of less than 70 feet below the land surface; elsewhere, the unsaturated zone extends to depths greater than 70 feet. Ground water exists in both the confined and unconfined states throughout the area around the springs. Faults and upwelling thermal water exert a strong control on the movement of shallow ground water; these two agents appear to redirect the flow of non-thermal ground water to the south and east of the springs. Vertical ground-water flow components appear to be small in most of the area. Ground water discharges at the land surface via springflow and evapotranspiration and may leave the area as subsurface flow.

The quality of water issuing from the Leach Hot Springs system is very good. Total dissolved solids content is about 580 mg/1 and is dominated by sodium, bicarbonate and silica. There is some chemical variability from orifice to orifice, although there is no systematic variation in chemistry with either orifice location or discharge temperature.

TABLE 4.

WATER QUALITY DATA FOR DIXIE VALLEY AND SURROUNDING VALLEYS
(from Cohen and Everett, 1963)

(all concentrations are in parts per million)

location (well no.)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH
																	calcium-magnesium	non-carbonate		
16/33-3b1	7-24-63	--	71	--	11	1.8	364	4.7	544	0	179	127	2.6	0.2	1.5	1020	35	0	1570	8.1
16/33-32b1	7-22-63	63	71	0.07	33	4.5	50	6.3	143	0	50	28	.6	3.6	.50	321	101	0	435	7.7
17/35-33c1	7-22-63	63	52	.96	82	7.2	140	4.9	209	0	262	60	2.5	.8	.30	723	234	63	1040	7.5
21/34-36c1	7-22-63	73	54	.01	16	2.2	68	3.0	86	0	80	26	6.0	1.1	.30	297	49	0	435	7.6
21/35-8b1	5- 1-52	61	62	.04	31	3.4	53	4.3	117	0	71	27	1.8	1.4	.16	[a]313	91	0	424	7.8
21/35-18c5	5- 1-52	66	59	.06	23	3.2	63	--	104	0	73	26	4.4	1.1	.13	- -	71	0	- -	8.2
21/35-19a2	7-23-63	67	66	.10	19	1.1	68	4.2	94	0	71	24	5.2	1.4	.30	313	52	0	446	7.6
21/35-20a1	5- 1-52	71	63	.04	12	.9	72	2.0	98	0	60	21	6.9	.9	.08	287	34	0	381	8.2
26/39-29d1	7-23-63	--	58	--	79	17	182	11	407	0	154	127	1.9	1.2	1.1	826	265	0	1290	8.0
27/38-2b1	5- 1-52	70	36	.05	47	19	98	6.5	204	0	71	126	.3	1.1	.20	[a]505	196	28	842	7.6
27/38-2b1	7-24-63	72	39	.04	46	19	101	6.4	205	0	69	124	.5	1.3	.30	503	192	24	853	7.9
28/38-26d2	8-15-61	58	46	--	58	25	130	4.4	308	0	94	132	.3	.0	.30	[a]642	247	0	1070	7.6
30/39-16d1	7-24-63	52	44	--	49	8.9	32	2.8	165	0	35	41	.3	1.5	.10	299	159	24	460	7.7

[a] calculated

Black Rock Desert

The Black Rock Desert area, located about 100 miles north of Reno, contains eight KGRAs: Gerlach, Gerlach Northeast, Fly Ranch, Fly Ranch Northeast, Trego, Double Hot Springs, Pinto Hot Springs and Soldier Meadow. Excellent descriptions of the area's hydrology are found in Olmsted, et al. (1975) and Sinclair (1963), both of which serve as the sources for the discussion contained herein. The Black Rock Desert is one of the major structural basins in Nevada and covers about 2,600 square miles. The desert itself is a large flat playa with several embayments bordered by rugged mountains. The valley floor is about 700 square miles in extent and has an altitude of about 3900 feet above mean sea level. Except for Hualapai Flat, an arm of the Black Rock Desert proper, ground-water development is virtually non-existent. Ground water occurs mainly in the unconsolidated valley fill alluvium.

The estimated average annual ground-water recharge to the entire area is about 44,000 acre-feet. The recharge is derived from precipitation in the surrounding mountains, and occurs via stream flow infiltration and mountain-front recharge. In addition, the area probably receives underflow from the Pine Forest Valley to the north.

No reliable discharge estimates currently exist for the area. Ground-water discharge occurs by springflow, evapotranspiration, and pumpage. No underflow to the Smoke Creek and San Emidio Deserts to the south is believed to occur. Springs are common in the mountains, and hot springs issue forth in some areas of the valley floor. Most of the pumpage in the area is in Hualapai Flat as well as along the mountain margins.

Ground-water chemical quality in the Black Rock Desert Area is highly variable, as indicated by Table 5. Some of the water is of excellent chemical quality (TDS less than 500 mg/l); however, Great Boiling Hot Springs has a TDS content greater than 4,000 mg/l. In general, the poor quality ground water is found beneath the playa. Lacustrine deposits (evaporites) beneath the playa are primarly responsible for the mineralized nature of the water. Better quality water is found in the alluvial slopes near the playa margin.

Carson Desert

The Carson Desert region contains two KGRAs: Stillwater-Soda Lake and Salt Wells Basin. In addition, the Brady-Hazen KGRA is at the far western edge of the area. Much of the discussion in this section is taken from a report by Glancy and Katzer (1975), which covers the entire Carson River Basin. The Carson Desert covers an area of over 2,000 square miles.

Ground water occurs primarily in the valley fill alluvium, which locally exceeds 8,000 feet in thickness and in basalt, which locally (in the Fallon area) yields large amounts of water to wells. In other areas

TABLE 5.
GROUND-WATER QUALITY DATA FOR THE BLACK ROCK DESERT
(from Sinclair, 1963)

(all concentrations are in parts per million)

Well or spring	Date of collection	Temperature °F	Silica (Si)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Hardness as $CaCO_3$		Specific conductance (μmho@25°C)	Dissolved solids residue @ 180°C	pH	Remarks (spring)
															non-carbonate	calcium-magnesium				
42/31-11b1	10- 8-60	75	65	18	2.4	34	4.8	0	104	25	15	0.6	0.8	0.11	0	54	259	244	7.7	
40/24-23	5- 6-61	--	65	2.4	1.5	76	0	0	96	39	21	12	.5	.82	0	12	357	272	7.6	Soldier Meadows
40/27-23b1	5- 3-61	60	79	11	2.4	63	11	0	151	21	28	.4	.8	.17	0	37	376	290	7.8	
40/28-29	?	212	--	--	--	--	--	0	420	126	159	--	--	---	-	--	---	1043	---	Pinto Mtn.
39/17-30d1	5- 6-61	74	34	6.4	.2	55	.6	0	120	15	11	.3	.3	.32	0	17	264	186	8.2	Cain Sp.
37/25-9d1?	6-14-61	--	84	18	6.9	66	5.4	-	148	32	42	1.2	0	---	0	74	451	---	7.3	
37/25-10d1	6-14-61	97	79	9.6	2.8	78	11	-	165	38	28	1.8	0	---	0	35	446	---	7.8	
37/27-8d1	5- 3-61	60	70	11	5.6	786	15	0	1150	95	500	3.9	1.1	7.9	0	50	3280	2070	8.2	
36/26-34b1	5- 3-61	136	62	18	1.9	486	13	0	902	130	155	8.9	.2	2.8	0	52	2050	1330	7.9	Black Rock
35/24-36c1	1-13-62	60	64	3.2	1.2	168	10	19	257	47	58	1.4	.1	.5	0	13	776	499	8.7	
34/25-16d1	5- 3-61	--	58	12	19	1160	15	0	1210	5.8	1170	1.5	1.1	4.5	0	109	5150	3030	7.8	Coyote Sp.
34/30-35c1	6-11-61	60	26	62	14	72	.8	-	166	66	111	.3	.2	---	78	214	767	---	7.3	
33/23-26d1	4- 9-45	--	44	--	---	305	--	48	361	79	160	--	--	---	-	--	---	795	---	
33/25-10b1	9- 2-47	68	101	15	4	272	--	14	88	163	272	--	--	---	-	58	---	880	---	
33/25-10b4	6-12-61	92	94	13	.6	272	8.4	-	93	156	278	2.8	.2	---	0	35	1410	---	7.4	
32/25-15b1	5- 7-40	--	135	102	26	1476	--	0	227	353	2016	--	--	---	-	362	---	4135	---	Great Boiling Sp.

of the Carson Desert, the basalt is untested as a source of ground water. Its extent, source of recharge, and dependability as a water supply are unknown. Ground-water movement in the desert is extremely complex. As in most areas of northern Nevada, very little is known about ground-water flow at depth. The general direction of flow is toward the Carson Sink in the northern part of the desert, which is a major ground-water discharge area as well as the terminus of the Carson River; to Carson Lake in the southern part of the desert; and to Fourmile and Eightmile Flats in the Salt Wells Basin in the southeastern part of the area. Ground-water recharge in the Carson Desert its dominated by human influences. Natural ground-water recharge via underflow from Packard Valley, the Fernley area, and White Plains is about 1,200 acre-feet per year; underflow from Churchill Valley is unknown. Recharge from precipitation within the Carson Desert is about 1,300 acre-feet per year. By far the largest amount of recharge is derived from irrigation, which is prevalent in the southern part of the area. Discharge from the area occurs via subsurface outflow, pumpage, springflow and evapotranspiration. Ground-water outflow is less than 1,000 acre-feet per year, whereas the amount of ground water consumptively used by agriculture, domestic and municipal use and by natural evapotranspiration is probably two orders of magnitude greater than the natural subsurface outflow.

Although ground water in the Carson Desert is abundant, much of it is of poor chemical quality (see Table 6). The poor quality is caused naturally by evapotranspiration and mineralization and by contamination from irrigation waters. Septic tank pollution may also be a contributor to local water quality problems.

POTENTIAL IMPACTS OF GEOTHERMAL DEVELOPMENT

Potential impacts of geothermal development in the four previously-discussed areas will be quite similar (in a general fashion) to those in other northern Nevada basins. The following is a list of the major adverse impacts.

1. Chemical pollution of ground and surface waters. Pollution could be caused by an increase in TDS and/or individual elements such as arsenic, boron, fluoride, manganese, etc. Arsenic and boron could be serious problems - the former is highly toxic and the latter can be highly toxic to plants. Fluoride could also be a serious difficulty. Chemical contamination might be caused by surface disposal of geothermal fluids; improper well design, construction and abandonment practices; and improper reinjection techniques. It should be noted that in some areas, the geothermal fluids may be of better overall (TDS) quality than the shallow ground water. This appears to be the case in the Desert Peak area. However, one must be concerned not only with TDS values but with the individual chemical constituents present, since the geothermal fluid may contain unacceptable levels of some

TABLE 6.

WATER QUALITY DATA FOR THE CARSON DESERT (from Glancy and Katzer, 1975).

(all concentrations are in milligrams per liter)

Location	Source (with well depth where appropriate)	Date sampled	Temperature °F	Temperature °C	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium + Potassium (Na + K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Hardness as ($CaCO_3$)	Specific conductance µmho/cm @ 25°C)	pH
17/31-31ab	Rock Spring	8-19-70	68	20.0	---	---	---	---	394	0	--	1,300	--	--	--	5,340	8.2
18/29-4bac	Kingman Well (776 ft.)	10- ?-58	82	28.0	---	8	1	350	480	12	43	230	--	950	24	1,850	8.0
18/29-23ccc	Truckee-Carson Irrigation Canal	10- 2-56	70	21.0	1.4	21	4.4	---	84	0	29	6.8	1.8	145	70	229	7.1
18/30-12aca	Well	8-15-63	60	15.5	---	6.8	0.5	---	784	47	876	5,420	37	11,200	19	17,500	8.5
18/30-35dc	Well (100 ft.)	8-19-70	--	---	---	----	---	---	---	--	--	1,400	--	--	--	5,680	--
18/31-4da	Well (140 ft.)	8-19-70	66	19.0	---	13	31	2,500	519	0	940	3,000	--	--	160	10,900	7.6
18/31-31ccc	Well (300 ft.)	1961(?)	--	---	3	1	1	---	423	12	495	2,155	--	4,820	6	--	8.7
19/27-12dc	Well (150 ft.)	6-16-71	--	---	---	300	110	1,100	212	0	2700	490	--	--	1,200	6,380	7.7
19/28-7dd	Soda Lake	8-28-58	--	---	.01	7.9	194	---	1,250	1360	6220	7,570	2.2	24,700	822	31,800	9.6
19/28-22daa	Well (41 ft.)	2-25-64	--	---	.01	53	23	117	307	0	144	52	10	605	228	--	8.0
19/28-22dab	Well (1,155+ft.)	12- 9-71	--	---	---	5	1	54	118	4	23	6	--	--	18	276	8.6
19/29-30cdb 1,2	Wells (combined flow; 506 and 521 ft.)	9-29-69	--	---	.01	----	---	---	356	23	164	84	0.6	424	28	--	9.3
19/29-30cdb1	Well (506 ft.)	5- 8-58	68	20.0	.02	2	1.4	---	231	20	75	67	0.8	498	11	821	8.8
19/29-31babc	Well (444 ft.)	12- 9-71	--	---	---	8	1	58	124	0	38	6	--	--	24	316	8.0
19/29-33cbb1	Well (540 ft.)	1-26-67	--	---	137	0.8	1.5	216	283	26	66	94	0.4	580	8	906	9.1
19/30-30ccb	Well (15-19 ft.)	6- 9-69	--	---	.18	35	10	350	237	0	129	420	0	1,110	160	--	8.1
19/30-30ccc	Well (37 ft.)	1-15-69	--	---	.10	1.6	42	7,840	1,650	24	7750	5,500	30	21,400	176	--	8.2
19/31-7dc	Well (204 ft.)	11-23-71	Boiling		---	91	1	1,400	104	0	190	2,080	--	--	230	7,420	7.5
19/31-11a	Well	10- 8-70	65	18.5	---	34	52	2,300	377	0	93	3,500	--	--	300	12,600	7.8
20/28-1bd	Well (627 ft.)	2-26-69	--	---	12	78	24	---	372	0	340	2,720	7	5,320	293	--	8.1
21/30-19cd	Carson River	10-18-71	37	3.0	---	32	10	78	178	0	91	35	--	--	120	615	8.3
21/30-30ac	Well (985 ft.)	10-13-71	63	17.0	---	4	1	600	554	37	100	500	--	--	15	2,930	8.7
21/32-25cbc	Well	10- 8-70	--	---	---	170	33	130	111	0	470	190	--	--	560	1,820	7.6
22/33-15b	Well	10- 8-70	--	---	---	14	4	430	293	44	220	310	--	--	50	2,130	9.0

constituents. Table 7 shows chemical analyses of selected thermal waters of northern Nevada and Table 8 lists the EPA water quality criteria for various constituents.

2. Thermal and "aesthetic" (taste, color, odor) pollution of water. Thermal pollution is perhaps more of a threat to surface water than ground water. Although the taste, color and odor of water does not necessarily indicate that the water is harmful, people will probably be reluctant to consume it.

3. Effects of geothermal fluid withdrawal on ground-water storage, recharge, discharge and movement. This is a very important item, but it is difficult to address at present, since little is known about the movement of ground water at depth much less the hydraulic interrelationships between geothermal reservoirs and ground-water reservoirs in a given basin. These effects will undoubtedly be long-term ones and could have serious ramifications in those areas that depend heavily on ground water for irrigation, domestic and industrial purposes. The effect of geothermal fluid extraction on ground-water recharge is especially critical, since Nevada State law prohibits ground-water mining. Impacts that might be caused by such extraction are numerous: reduction in springflow and baseflow; reduction in streamflow; land subsidence; lowering of ground-water levels; alterations in the flow paths of ground water; changes in recharge; and changes in ground-water leakage relationships. Since some geothermal systems may be regional in nature and some ground-water flow systems are regional, some attention will have to be given to the regional effects of geothermal fluid extraction. It should be noted that ground-water storage could be increased if surface disposal methods are used.

4. Consumptive use of ground water for cooling, operations and reinjection make-up. This is a particular problem in Nevada where competition for ground-water supplies is often keen. Withdrawals of ground water may also be restricted by the State Engineer in certain basins.

5. Changes in watershed/channel network characteristics as a result of exploration, drilling and construction activities. These effects are extremely site-specific and could result in the following: increased erosion and sediment load; exacerbation of flash flood hazards; changes in recharge areas and amounts; and changes in rainfall-runoff-infiltration relationships. These changes could be extremely serious depending upon the specific sites that would be affected.

TABLE 7.

CHEMICAL ANALYSES OF SELECTED THERMAL WATERS IN NORTHERN NEVADA

(concentrations in milligrams per liter)

Location or name	Temp. (°C)	Na	K	Ca	Mg	HCO_3	SO_4	Cl	F	B	SiO_2	TDS*	SpC** (umhos/cm @ 25°C)	pH
Lee Hot Springs	88	450	26	44	0.6	114	470	380	7.9	2.4	180	--	2,430	7.36
Dixie Hot Springs	72	190	6.5	3.6	0.07	111	111	126	16.3	0.89	115	--	914	8.59
Brady's Hot Springs well in S12,T22N, R25E.	--	780	65	53	1.2	162	377	978	7.6	6.8	242	2,600	4,090	7.3
Walley's Hot Spring	61	145	3.6	10	0.01	50	235	44	4.9	1.2	58	--	726	8.77
Sulphur Hot Springs	93	135	8.9	1.0	0.03	244	40	23	17.7	0.2	210	--	601	8.53
Hot Sulphur Springs	90	390	41	49	13	1,180	18	40	7.2	0.77	84	--	1,760	7.0
Beowawe "steam" well	--	250	38	1.3	0.2	505	64	70	.05	2.5	500	--	1,490	9.38
Baltazor Hot Spring	80	180	8.7	8.4	.01	139	220	48	7.1	2.9	160	--	947	8.00
Double Hot Springs	80	180	4.5	4.8	0.1	261	120	59	10	1.8	105	--	902	7.93
Buffalo Valley Hot Springs	49	250	34	45	4.9	813	110	29	4.8	2.3	80	--	1,530	6.53
Wabuska Hot Springs	97	277	15	38	0.2	70	580	46	--	--	115	--	1,550	8.5
Darrough "steam" well	94	110	2.9	1.4	0.1	165	55	12	15	0.24	105	--	499	8.29
Kyle Hot Springs	77	540	80	95	25.5	544	51	770	5.7	3.8	150	--	3,220	6.50
Leach Hot Springs	92	160	13	8.8	0.5	366	53	29	7.8	1.2	135	--	811	7.40
Sou Hot Springs	70	167	26	106	19.8	324	352	77	5.5	--	64	--	1,411	7.3
Western Geothermal Fly Ranch No. 1 well	97	335	13.8	33	4.1	431	186	229	--	--	76	1,667	--	--

TABLE 7 continued.

Chemical analyses of selected thermal waters in northern Nevada (concentrations in milligrams per liter)

Location or name	Temp. (°C)	Na	K	Ca	Mg	HCO_3	SO_4	Cl	F	B	SiO_2	TDS*	SpC** (umhos/cm @ 25°C)	pH
Gerlach Hot Springs	84	1,548	113	89	1.0	91	385	2,238	5.5	--	47	4,596	7,830	8.1
Steamboat Springs	94	680	66	16	0.7	364	73	837	2.1	47	270	--	3,340	7.19
Phillips Petroleum Desert Peak No. 21-2 well	199	--	--	--	--	--	--	--	--	--	--	7,500	--	--
Nevada Thermal No. 2 well (Beowawe)	100	332	30	0.8	0.2	39	90	49	15	2.4	534	1,200	1,130	9.7
Magma Power Wabuska No.3 well	106	276	12	37	8.7	80	566	45	7.6	1.0	100	1,090	1,490	8.0
Western Geothermal Needles No.1 well	67	1,080	31	282	0.1	11.5	338	1,841	3	--	95	3,676	6,072	8.1
Great Boiling Spring	86	1,400	130	68	1.2	83	400	2,200	4.5	9.9	165	--	7,610	8.1
Spencer Hot Springs	72	200	36	43	9.4	672	51	22	4.7	2.6	77	--	1,180	6.49
Magma Power Co. Brady No.4 well	--	813	6	33	--	13	336	986	5	0.3	190	2,440	2,100	8.8

* TDS = Total dissolved solids

** SpC = Specific conductance

Data compiled from Mariner, et.al.(1974); Sanders and Miles (1974); Garside and Schilling (1979); and Trexler et.al.(1979).

TABLE 8.

U.S. ENVIRONMENTAL PROTECTION AGENCY WATER QUALITY CRITERIA FOR SELECTED CONSTITUENTS

Drinking Water Standards

Constituent	Recommended concentration limit* (mg/l)
Total dissolved solids	500
Chloride (Cl)	250
Sulfate (SO_4^{2-})	250
Nitrate (NO_3^-)	45
Iron (Fe)	0.3
Manganese (Mn)	0.05
Copper (Cu)	1.0
Zinc (Zn)	5.0
Boron (B)	1.0
	Maximum permissible concentrations**
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr^{VI})	0.05
Selenuim	0.01
Lead (Pb)	0.05
Mercury (Hg)	0.002
Silver (Ag)	0.05
Fluoride (F)	1.4-2.4

* Recommended limits based primarily upon aesthetic (taste, color, odor, etc.) characteristics.

** Maximum permissible concentrations based on health criteria.

TABLE 8 continued.

U.S. Environmental Protection Agency Water Quality Criteria for Selected Constituents

Standards for Livestock and Irrigation Crop Production

Constituent	Livestock: Recommended Limits (mg/l)	Irrigation Crops: Recommended Limits (mg/l)
Total Dissolved Solids		
Small animals	3000	700
Poultry	5000	
Other animals	7000	
Nitrate	45	--
Arsenic	0.2	0.1
Boron	5	0.75
Cadmium	0.05	0.01
Chromium	1	0.1
Fluoride	2	1
Lead	0.1	5
Mercury	0.01	--
Selenium	0.05	0.02

DATA NEEDS

The following is a list of the data needed for a quantitative assessment of the effects of geothermal development on the hydrology and water quality of northern Nevada.

1. Baseline water quality data (both surface and ground water) for most Nevada basins with geothermal potential.
2. Baseline hydraulic data for most ground-water reservoirs, including information on ground water at depth.
3. Surface water - ground water relationships.
4. Relationships between geothermal reservoirs and shallow ground-water reservoirs.
5. Chemistry of geothermal fluids.
6. Watershed characteristics, especially in those areas targeted for intense exploration, drilling and construction.
7. Characteristics of the ground-water reservoir such as storage, dispersive and transmissive properties, recharge-discharge parameters, relationships to other reservoirs, etc.
8. Geothermal reservoir characteristics such as fluid sources (recharge), boundaries, flow paths and hydraulic properties.

ISSUES

The Hydrology - Water Quality Overview Workshop participants identified the following key issues, which are listed below in order of decreasing priority:

1. Resource ownership. The State and Federal governments will have to resolve the question of geothermal resource ownership. The State also must develop a precise definition of geothermal resources.

2. Baseline data on water quality, quantity and rights are needed. There is also a need for time-series data on certain parameters so that the potential effects of geothermal development can be accurately delineated. The "credibility" of the data will also be a problem. Should the developer or an agent of the developer collect the information? Should a Federal or State agency obtain the information? With respect to time-series data, who decides how long is long enough?

3. A centralized data bank containing all geothermal and related information is desperately needed. At the present time, data are scattered among State and Federal agencies, universities, private corporations and individuals. Because of the lack of a central data location, a great deal of duplication is undoubtedly occurring.

4. Enforcement of existing regulations. In general, there appear to be sufficient existing regulations to protect Nevada's water resources, but they must be properly enforced. One notable exception to existing regulations is the State's lack of geothermal well standards, including drilling, construction and abandonment practices. Standards are needed for production, exploratory, and injection wells. It was noted that the major geothermal companies are doing a very good job with respect to geothermal well drilling, construction and abandonment; standards are needed to protect the State's resources from less competent firms and individuals who may enter the geothermal field as exploration and development increase. The workshop participants also noted that human error will be the biggest problem with regard to protection of the State's water resources.

5. Communications. The Workshop felt that there is a strong need for better communications among those involved in geothermal resources in Nevada - governmental agencies, private firms, individuals, universities, etc. Many problems can easily be solved or avoided by better communications among all those involved in geothermal resources.

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Other Data Sources

In addition to the aforementioned references, the following contain information on the hydrology, water quality and related geothermal aspects of northern Nevada.

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Nevada Bureau of Mines and Geology
Nevada Department of Consdervation and Natural Resources

Desert Research Institute - Water Resources Center
U.S. Geological Survey
U.S. Bureau of Land Management
U.S. Environmental Protection Agency
U.S. Water and Power Resources Service
(formerly U.S. Bureau of Reclamation)
U.S. Department of Agriculture
U.S. Department of Energy
Bureau of Indian Affairs
National Weather Service
U.S. Bureau of Mines
U.S. Fish and Wildlife Service

AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter VI

AIR QUALITY

by

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INTRODUCTION

The State of Nevada is being considered as a potential location for the development of geothermal resources. An important concern resulting from the development and utilization of geothermal resources is the impact on air quality. Many factors need to be considered when assessing air quality impact from geothermal development, e.g., air pollutant emissions levels at specific sites and emission controls.

The purpose of this report is to evaluate air quality problems associated with geothermal development and to recommend areas that need to be investigated to assure that the development of the resource proceeds in an environmentally acceptable manner.

The following sections will 1) identify the potential air quality problems; 2) evaluate data requirements; 3) summarize historical data; and 4) recommend methods to assess potential effects.

IDENTIFY POTENTIAL AIR QUALITY PROBLEMS

There are several air quality concerns associated with the development and utilization of geothermal resources. These are:

A. regulations

B. gaseous and particulate pollutants

C. visibility

D. air quality models.

Regulations

Legislation to protect and enhance the quality of the Nation's air resources is enacted in the Clean Air Act of 1967 and its Amendments of 1970, 1973, 1974, and 1977. This section discusses the regulations pertaining to ambient air quality standards and prevention of significant deterioration.

Ambient Air Quality Standards

The Environmental Protection Agency (EPA) has promulgated ambient standards, National Ambient Air Quality Standards, (NAAQS). but each state as well as local agencies are free to make and enforce their own regulations provided they are more stringent than the federal regulations. The source must then comply with the most stringent of the Federal, State or local standards.

Apart from the State of Nevada there are two local agencies, Clark and Washoe counties, with the legislative authority to regulate air quality within their respective county boundaries. The remaining areas of the state are under the jurisdiction of the State's Department of Conservation and Natural Resources, Division of Environmental Protection. The ambient air quality standards for the Federal, State of Nevada and the two local agencies are presented in Table 1 (Nevada Department of Conservation and Natural Resources, 1979).

Prevention of Significant Air Quality Deterioration

In addition to the ambient concentration limitations, the Prevention of Significant Deterioration (PSD) provisions of the Clean Air Act Amendments of 1977 have limited the amount of air quality degradation allowed in a particular area. For instance, the PSD provisions state that any major pollution source (i.e., 28 specific source categories that have the potential to emit 100 tons per year or more or a source emitting any pollutant in amounts exceeding 250 tons per year) are subject to Prevention of Significant Air Quality Deterioration (PSD) review. This review requires a demonstration that the air quality deterioration resulting from the new source will not be greater than the increments in Table 2. Of course, it must also be shown that the total of background pollution levels and the combination of concentrations from the interaction of existing (if any) and new sources will not violate the NAAQS.

At present, the federal and state air quality regulations for Prevention of Significant Deterioration are in a state of flux. New regulations are being proposed by the EPA (Federal Register, September 5, 1979) and the State of Nevada (Nevada Environmental Commission, 1979). Both sets of proposed regulations are more specific and stringent than the present regulations (Bureau of National Affairs, Inc., 1977). For example, the proposed federal regulations require preconstruction ambient air quality analysis "for each pollutant subject to regulations under the Act". This means that while current PSD regulations require monitoring only for those pollutants for which national ambient air quality standards exist (criteria pollutants), other pollutants regulated under New Source Performance Standards (NSPS) and national emission standards for hazardous pollutants must also be addressed (non-criteria pollutants).

The state's proposed regulations are more stringent in the area of defining a major source. This is "any facility which directly emits or has the potential to emit 100 short tons per year or more of any air contaminant including any source of qualitifiable fugitive emissions of any air contaminant." The portion of the regulations petrtaining to 100 short tons per year and fugitive emissions may pose a problem to geothermal development.

The major sources of air pollutants emitted from geothermal resources vary depending on the systems (open or closed). If it is found that a PSD permit is required, details of the ambient air quality analysis will be carried out on a case-by-case basis (EPA, 1978). Such determinations will be an important consideration for geothermal development in Nevada.

TABLE 1.

NATIONAL AND NEVADA AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging Time	Standard, $\mu g/m^3$ (ppb)	
		National Primary	National Secondary
Sulfur Dioxide	3 Hours	-	1300 (500)
	24 Hours	365 (140)	-
	Annual	80 (30)	-
Particulates	24 Hours	260	150
	Annual Geometric Mean	75	75
Nitrogen Dioxide	Annual	100 (50)	100 (50)
Oxidant (ozone)	1 Hour	235 (120)	235 (120)
Carbon Monoxide (Nevada) above 5,000 feet	1 Hour	40 (mg/m^3)	40 (mg/m^3)
	8 Hours	6.67 (mg/m^3)	6.67 (mg/m^3)
Lead	Quarterly Arithmetic Mean	1.5	1.5
Hydrocarbons (less methane)	3 Hours	160 (240)	160 (240)

TABLE 2.

PSD INCREMENTS FOR SO_2 AND TSP

Pollutant	Class 1, $\mu g/m^3$	Class II, $\mu g/m^3$	Class III, $\mu g/m^3$
Sulfur Dioxide			
Annual Arithmetic Mean	2	20	40
24-hour maximum	5	91	182
3-hour maximum	25	512	700
Particulate Matter			
Annual Geometric Mean	5	19	37
24 hour maximum	10	37	75

* Nevada has only one Class I area, Jarbidge National Wilderness Area located in the northeast corner of the state.

Gaseous and Particulate Pollutants

The types of pollutants most likely to be found from geothermal sources are determined primarily by the chemical composition of the geothermal fluid at each specific site. This composition can vary considerably in different reservoirs, at different wells within the same reservoir, and even within the lifetime of a single well. Thus, the pollutants emitted are variable, a factor that is somewhat different from the gaseous emissions of nuclear or fossil-fuel sources.

Experience at other geothermal power generating facilities have identified a number of gaseous and particulate pollutants. Geothermal steam contains numerous noncondensable gases which can be released to the atmosphere. Of these gases, the primary one of concern is hydrogen sulfide (H_2S). Other potential pollutants are carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitrogen oxides (NO_x), hydrogen (H_2), ethane (C_2H_6), mercury (H_2), arsenic (as) and boron (B).

In addition and included in the above list, the proposed PSD regulations provide de minimis emission rate guidelines for the following pollutants shown in Table 3. Table 4 lists the de minimis ambient air quality impact. These pollutants should be addressed as part of the air quality analysis for geothermal development.

Hydrogen Sulfide

As mentioned earlier, H_2S is the pollutant of most concern because of the quantity emitted from geothermal resources and its toxicity and strong odor. Atmospheric oxidation which produces SO_2 and $SO_4^=$ is also of concern. This pollutant has been the most critical issue at the Geysers-Calistoga KGRA (Known Geothermal Resource Area) in California (Ermak and Phelps, 1978). Odor complaints have been common in that area and because of H_2S odor, development of geothermal resources at the Geysers has been slowed (Rosen and Molenkamp, 1978). Another concern of H_2S is the regional contribution of raising ambient levels of sulfur oxides. Sulfur dioxide (SO_2) is one of the "criteria pollutants" for which EPA sets and enforces National Ambient Air Quality Standards. As implied above, hydrogen sulfide emissions from geothermal sources may also produce acid rain or acid mist by oxidation of H_2S to $SO_4^=$. The latter is also addressed in the proposed PSD regulations as a noncriteria pollutant. However, because of the arid climate of Nevada, both acid rain and acid mist, are not likely to pose a problem in the immediate vicinity of the development. Also for many KGRA in Nevada, H_2S emissions may not be a problem since the sulfur concentration is relatively low.

Cooling Tower Drift

A major point of release of pollutants from geothermal activities is from the cooling tower. Gaseous pollutants such as H_2S and aerosol in the form of droplets will be released into the atmosphere from cooling towers. Certain pollutants such as boron, arsenic and heavy

TABLE 3.

DE MINIMIS EMISSION RATES

Pollutant	Emission Rate
Carbon Monoxide	100 tons per year
Nitrogen Dioxide	10 tons per year
Total Suspended Particulates	10 tons per year
Sulfur Dioxide	10 tons per year
Ozone	10 tons per year of volatile organic compounds
Lead	1 ton per year
Mercury	.2 tons per year
Beryllium	0.004 ton per year
Asbestos	1 ton per year
Fluorides	0.02 ton per year
Sulfuric Acid Mist	1 ton per year
Vinyl chloride	1 ton per year
Total Reduced Sulfur:	
Hydrogen sulfide	1 ton per year
Methyl mercaptan	1 ton per year
Dimethyl sulfide	1 ton per year
Dimethyl disulfide	1 ton per year
Reduced Sulfur Compounds:	
Hydrogen sulfide	1 ton per year
Carbon disulfide	10 tons per year
Carbonyl sulfide	10 tons per year

TABLE 4.

DE MINIMIS AMBIENT AIR QUALITY IMPACTS

Pollutant	Air Quality Impact
Carbon Monoxide	500 $\mu g/m^3$, 8-hour average
Nitrogen Dioxide	1 $\mu g/m^3$, annual
Total Suspended Particulates	5 $\mu g/m^3$, 24-hour
Sulfur Dioxide	5 $\mu g/m^3$, 24-hour
Ozone	*
Lead	.03 $\mu g/m^3$, 3-month
Mercury	0.1 $\mu g/m^3$, 24-hour
Beryllium	.005 $\mu g/m^3$, 24-hour
Asbestos	1 $\mu g/m^3$, 1 hour
Fluorides	.01 $\mu g/m^3$, 24-hour
Sulfuric Acid Mist	1 $\mu g/m^3$, 24-hour
Vinyl chloride	1 $\mu g/m^3$, maximum value
Total Reduced Sulfur:	
Hydrogen sulfide	1 $\mu g/m^3$, 1-hour
Methyl mercaptan	.5 $\mu g/m^3$, 1-hour
Dimethyl sulfide	.5 $\mu g/m^3$, 1-hour
Dimethyl disulfide	2 $\mu g/m^3$, 1-hour
Reduced Sulfur Compounds:	
Hydrogen sulfide	1 $\mu g/m^3$, 1-hour
Carbon disulfide	200 $\mu g/m^3$, 1-hour
Carbonyl sulfide	200 $\mu g/m^3$, 1-hour

* No *de minimis* air quality is proposed for ozone. However, any net increase of 100 tons per year of volatile organic compounds subject to PSD would be required to perform an ambient impact analysis, including the gathering of ambient air quality data.

metals are attached to the drift droplets and will be emitted with the droplets from the cooling towers. The downwind deposition of these pollutants has the potential of producing significant impacts and depends on several variables. These include rate of emissions, height of the release point, exit velocity, water temperature, size and mass distribution of droplets and the ambient meteorological conditions. These variables would be introduced into computer models (discussed in a later section) to evaluate downwind impact of pollutant concentration.

Fugitive Emissions

Perhaps a greater potential air quality problem than H_2S emissions in Nevada is particulate emissions, especially fugitive dust emissions. The State defines fugitive emissions as "any emission including fugitive dust which becomes airborne other than being emitted through a stack or chimney, and is being generated due to activities which are necessary for continued operation of the emitting source or facility" (State of Nevada, 1979). Also present air quality regulations under particulate matter (Article 7) states "No person may disturb or cover 8 hectares (20 acres) or more of land or its topsoil, except for agricultural land until he obtains a registration certificate or operating permit for the purpose of clearing, excavating or leveling such land or an operating permit for the deposit of any foreign material to fill or cover such land." (Nevada Department of Conservation and Natural Resources, 1979). These regulations may pose some difficulties to geothermal development since the arid climate of the state makes construction activities in the desert conducive to significant increases in fugitive dust. The fugitive dust will be exacerbated during the development and testing stages when additional emissions will be generated from the heavy equipment on the site (drilling rigs, generators, trucks, etc.).

Visibility

In the Clean Air Act Amendments of 1977, Congress declared, "as a national goal, the prevention of any future, and the remedy of any existing, impairment of visibility in mandatory Class I Federal Areas which impairment results from manmade air pollution," (Bureau of National Affairs, Inc., 1977). Visibility impairment is defined as reduction in visual range and atmospheric discoloration. There is only one Class I area in the State of Nevada, the Jarbidge Wilderness Area. However, most of the state including the KGRA sites, are within remote areas where visibility is considered excellent. This excellent visibility may pose a problem because geothermal resource development could cause visibility degradation in the immediate area.

As mentioned earlier, when the desert surface is disturbed, wind enhances suspension of dust particles in the atmosphere. This could produce a deterioration in visibility. Also, the transformation of H_2S to SO_2 subsequently to SO_4 Particles, may also lead to deterioration of visibility for some distance downwind of the source.

Air Quality Models

Assessments of air quality impacts from point sources generally involve the utilization of the air quality models of a source in the complex terrain of Nevada. There are several general classifications of models, each with the intent of best relating source emissions to ambient concentrations at receptor sites under various conditions. At present, there is no single acceptable model which can accomplish the task of accurately predicting air quality impact.

Types of Models

There are several types of air quality models. These include: statistical or empirical models, dispersion models based on mass continuity and Gaussian equations, and physical models. However, each type of model, including its derivatives, has advantages and limitations with respect to the applicability to KGRA in Nevada. This is due to the complex topography and meteorological effects which will be discussed in other sections.

Environmental Protection Agency (EPA) Recommended Procedure

The EPA recommends certain modeling procedures and techniques (EPA, 1978), in order for air pollution control agencies, industries and the general public to be consistent in estimating pollutant concentrations. These procedures and recommended models are required in the evaluation of New Source Review programs in order to insure attainment and maintenance of NAAQS as well as comply with PSD. The procedures are summarized in Figure 1 (EPA, 1978).

The figure indicates that a preliminary screening technique should be applied as suggested in a separate EPA publication (EPA, 1977). The purpose is to determine if the sources will cause violations of NAAQS or PSD allowable concentration increments. This will avoid unwarranted expenditure of resources when a refined analysis is not necessary. If the screening analysis indicates that the source may pose an air quality problem, then more refined concentration estimates are required using more sophisticated models. However, if these models are not one of the EPA recommended models then the regulatory group will consider the techniques on a case-by-base basis. Also, there are no acceptable model validation procedures, as required for the non EPA recommended models.

The problem with the EPA recommended models is that they cannot handle the complex meteorology and terrain features of the KGRA in Nevada. This may pose a problem in estimating pollutant concentration and in assessing control strategies for geothermal resources in Nevada.

EVALUATE DATA REQUIREMENTS

There are three basic requirements that must be met in order to assess the effect of geothermal development and utilization on air

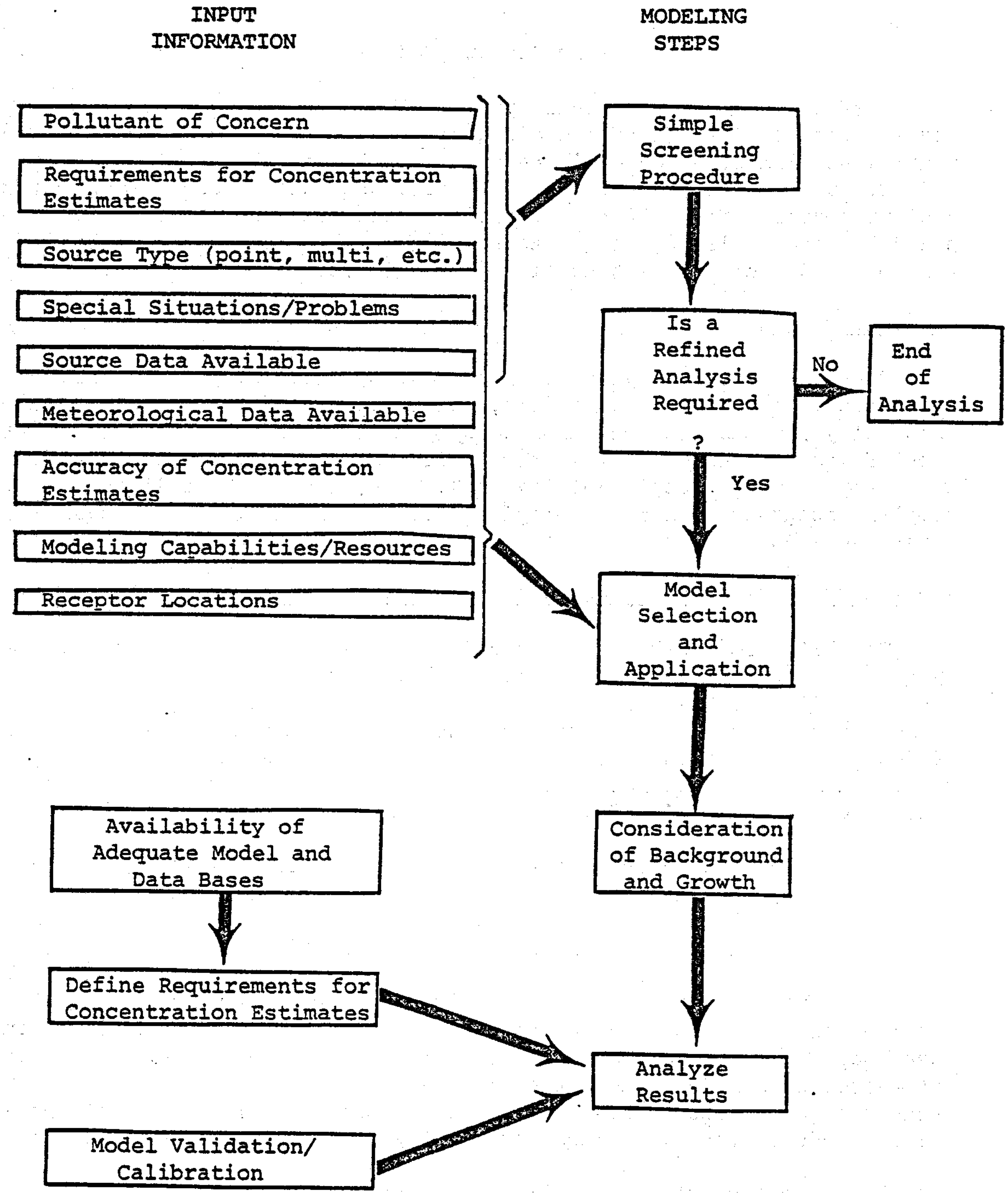

FIGURE 1. The Selection and Application of Air Quality Models (From EPA, 1978).

quality. These are 1) background data base, 2) source or emission inventory, and 3) meteorological data.

Background Data

Background data must be known in order to assess the significance of the air quality impact of an emission source. The background information should include natural sources and manmade sources. For example, most of the KGRAs in Nevada are located in remote areas where typical background concentrations for Total Suspended Particulates (TSP) are 30-40μg/m . However, all the TSP data sites are from areas influenced by human activity. Therefore, background TSP concentration given by the measurements are probably higher than those from the undisturbed KGRAs.

There are two methods of determining background levels of pollutant concentrations - monitoring and modeling. Since there are limitations to modeling calculations, especially with inadequate input data, the preferred method of determining background concentrations is by onsite data collection. Since development of geothermal resources in Nevada has not yet begun (except for isolated test drilling) the opportunity of determining background concentrations for the potential sites of geothermal development is excellent. These data bases will then be compared with post development air quality concentrations to determine the contribution of the geothermal development. This is important since most KGRAs have naturally occurring hot springs or fumaroles which release pollutants into the atmosphere. Therefore, such background data is essential to provide adequate air quality assessment.

If background data is not available, the State Implementation Plan (SIP) accepts values of 25μg/m for TSP and 5μg/m for SO_2.

Source (Emission) Data

Source (emission) data are essential to determine the source impact and to evaluate control strategies. The type of pollutants and concentrations most likely to produce adverse impacts from geothermal development are determined by the chemical composition of the geothermal fluid at each site. This composition varies substantially in different reservoirs and even at the same well. Table 5 compares this composition of noncondensable gases at the Geysers, California and Wairakei, New Zealand, geothermal fields.

As mentioned earlier, the proposed PSD regulation states that all pollutants regulated under the new source performance standards and the national standards for hazardous pollutants (partial list in Table 3) need to be addressed. In addition, the U.S. Department of Interior has published a list which included the following substances: CO_2, H_2S, SO_2, NH_3, As, Ag, B, Bl, Cd, Cr, Cu, Fe, Hg, Mn, Mo, NH_4, Pb, Se, Sr and Zn (Crittenden, 1977).

It must be stressed that the importance of the above substances as

TABLE 5.

COMPARISON OF NONCONDENSABLE GASES IN STEAM FROM WELLS AT TWO GEOTHERMAL POWER PLANTS

GAS	RANGE OF CONCENTRATIONS MEASURES (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; Axtmann, R.C., 1976
(From Resource Planning Associates, 1977).

potential pollutants is not only dependent upon the composition of the geothermal fluid but also as upon the emission characteristics. These emissions also vary because of the power plant operating procedures, viz., 1) type of energy conversion system, 2) cooling tower operating characteristics, and 3) air pollution control technology. Therefore, the emission characteristics and the geothermal fluid composition must be known before the potential air quality impact can be estimated.

Meteorological Data

The transport and dispersion of the pollutants emitted from the geothermal source are determined by the meteorological conditions in vicinity of the source. In order for dispersion models to provide useful and valid results, the meteorological parameters wind speed, wind direction, atmospheric stability, mixing height, temperature and humidity are necessary as model inputs. It is preferable to collect these data in the area of the source for a reasonable time period (at least one year) such that the data are representative of the area and seasons. This is important since the accuracy of the model estimates are directly related to the accuracy of the input data.

In the cases where representative meteorological observations are not available, such as most of the KGRAs in Nevada, EPA recommends a procedure (EPA, 1978), based on reasonable interpretations of climatological data to estimate pollutant concentration. This analysis is based upon "worst case conditions" meaning poor dispersion characteristics. However, PSD regulations state that a minimum of one year of meteorological data (site specific data is preferred) are normally required.

HISTORICAL DATA

Since site-specific data is not available, this section will consider the available data in a broad, regional overview. However, when applicable, KGRAs of Nevada which were identified by the Nevada Geothermal Environmental Overview Committee and discussed at the Geothermal Workshop held at Reno, Nevada on October 12, 1979, will be specifically considered. These KGRAs include Dixie Valley, Desert Peak-Brady Hot Springs, Steamboat Springs, Leach Hot Springs and Beowawe.

Background Air Quality

The State of Nevada and the two local air quality control districts (Clark and Washoe Counties) maintain several air monitoring stations. All of the above identified KGRAs except for Steamboat Springs are located in remote areas with no nearby monitoring stations. Also, the monitoring programs do not include the critical pollutant, H_2S.

The nearest monitoring station to Steamboat Springs is located about 6.5 miles (10.5 km) north and is within a semi-urban area. It was operated with only a high volume sampler. For nine months from June 1979 to March 1980, the geometric mean of the TSP was 56µg/m and the maximum 24-hour concentration during the period was 124µg/m (Sheen, 1979). Both values are within the secondary ambient air quality standards. Continuous monitoring of air pollutants for special studies have been conducted and reported for a proposed coal-fired power plant (Valmy Generating Station) and an existing Copper Smelter (McGill Smelter) (U.S. Department of Interior, 1978 and Nevada Division of Environmental Protection, 1978).

All other available data are summarized in the Nevada Air Quality Report, 1978 (Nevada Division of Environmental Protection, 1979).

Meteorological Data

There is only a small amount of meteorological data available in the KGRAs. This, again, is expected because most KGRAs are in sparsely populated regions.

General Climate

Nevada is the driest of the fifty states. Its aridity results from the fact that the State is positioned in the rain shadow of the Sierra Nevada and Cascade mountain ranges which act as a barrier to the moisture laden Pacific maritime air mass. As a consequence, the average annual precipitation is nine inches.

Other climatic characteristics include large local variation of daily temperature ranges, and infrequent severe storms. These characteristics are perhaps best described in the publication "Nevada's Weather and Climate" by Houghton, et al, 1975.

Surface Winds

An important meteorological parameter which affects air quality dispersion is wind. As mentioned above, there are very few continuous wind monitoring stations in the region. However, the National Weather Service maintains wind sensors at the following locations: Reno, Lovelock, Winnemucca, Elko and Ely, all in northern Nevada (Department of Commerce, 1977). In addition, a 100 meter meteorological tower is located at Valmy, Nevada (Department of Interior, 1978). Current data from this tower is routinely submitted to the Nevada Department of Conservation and Natural Resources at Carson City, Nevada.

Monthly mean speed and prevailing wind direction for Elko, Ely, Reno and Winnemucca, Nevada are presented in Table 6.

Although prevailing winds are useful for general environmental assessment, the diurnal air flow characteristics within each KGRA is probably more important in terms of local dispersion. These local winds are dominated by the nearby terrain features. Even the synoptic winds are modified by the terrain features and in the absence of strong

TABLE 6.

MONTHLY MEAN SPEED (S) AND PREVAILING WIND DIRECTION (D) AT FOUR LOCATIONS IN NEVADA*

MONTH	Elko		Ely		Reno		Winnemucca	
	S	D	S	D	S	D	S	D
JAN	5.5	SW	10.7	S	6.1	S	7.7	NE
FEB	5.8	SW	10.7	S	6.0	S	7.6	S
MAR	6.8	SW	10.9	S	7.5	WNW	8.5	S
APR	7.2	SW	11.1	S	7.9	WNW	8.5	W
MAY	7.0	SW	11.0	S	7.6	WNW	8.5	W
JUN	6.7	SW	10.8	S	7.1	WNW	8.3	W
JUL	6.2	SW	10.4	S	6.5	WNW	8.3	W
AUG	6.0	SW	10.7	S	6.1	WNW	7.8	W
SEP	5.6	SW	10.6	S	5.4	WNW	7.6	W
OCT	5.2	SW	10.5	S	5.3	WNW	7.3	S
NOV	5.1	SW	10.2	S	5.1	S	7.0	S
DEC	5.2	SW	10.3	S	5.1	SW	7.2	S
YEAR	6.0	SW	10.6	S	6.3	WNW	7.9	W

* From Houghton, et al., 1975, reprinting from <u>Local Climatological Data</u>, <u>Annual Summary with Comparative Data</u>, 1971.

synoptic flow, the local winds are controlled by the mountain/valley winds.

Figure 2 shows the wind speed frequencies at Reno, Nevada and is typical of most of the valleys in northern Nevada. In the early morning hours the winds are light and in most cases, the direction will be from the mountain slopes (downslope). By mid-afternoon, the wind speeds are stronger and the direction is upslope.

Temperature

A significant feature of Nevada's climate is the large diurnal temperature range where a difference between day and night of 50°F in the region is not unusual. This diurnal temperature range occurs because of the clear skies and low moisture content of the atmosphere causing intense solar heating of the surface. At night the same clear skies and low moisture permits rapid radiation loss and subsequent rapid cooling. (This rapid cooling leads to a temperature inversion which will be discussed in a later section).

Table 7 presents mean daily temperature ranges and values for 1978 for stations in northern Nevada (Department of Commerce, 1978).

TABLE 7

MEAN DAILY TEMPERATURE RANGES AND
EXTREME VALUES IN 1978 (F)

STATION	MEAN RANGE	MAXIMUM	MINIMUM
Reno	35	102	-7
Fallon	33	100	-4
Lovelock	31	106	-21
Austin	27	97	-8
Winnemucca	32	104	-9
Battle Mountain	33	105	-19
Elko	34	107	-12
Ely	32	96	-16

Air Pollution Potential

Air pollution potential is related to the ability of the ambient atmosphere to disperse pollutants. This potential is governed by various meteorological and topographic characteristics such as the depth above the surface through which pollutants are mixed (mixing depth), wind speed through the mixing layer and synoptic features associated

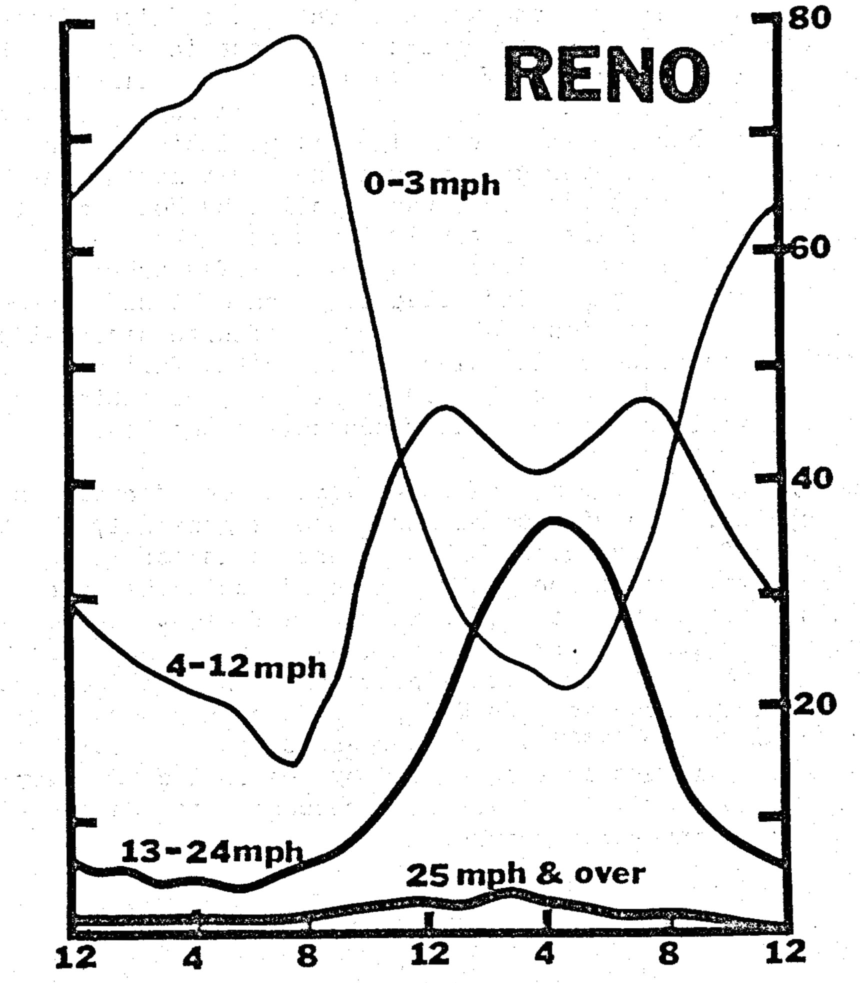

Figure 2. Diurnal frequencies of wind speed at Reno, Nevada (from Houghton, et. al., 1975).

with high pollution potential.

Holzworth (1962, 1964, 1972, and 1974) has evaluated the air pollution potential of the western contiguous United States including this region. He has found that northern Nevada is within the area of the most numerous stagnating air masses. Also, using the indicator of high frequency of low wind speeds as a measure of air pollution potential, he has shown that a high air pollution potential exists in northern Nevada. The average number of days per month that daily wind speeds were 5.0 mph or less was compiled by Holzworth (1962) and is shown in Figure 3. These relatively low wind speeds are confirmed by the data in Table 6. Also, the NOAA STAR program for Winnemucca revealed that the average wind speed of 5 mph or less occurred more than 50% of the time. The figure also shows a definite seasonal pattern with the maximum occurrence of low wind speeds in the fall and winter months. The low winds provide a high air pollution potential during these periods especially since the mixing depths are shallow.

The height of the mixing depth varies considerably on diurnal and seasonal cycles. The minimum mixing depth is generally limited by the nocturnal surface inversion. This inversion is formed when the loss of heat by long wave radiation from the ground cools the air adjacent to it. This radiational transfer is very efficient with clear skies and low atmospheric moisture such as commonly found in northern Nevada. The highest occurrence of low level inversions in the contiguous United States is in the southwestern U.S., including northern Nevada according to a study by Hosler (1961). The percent of total hours of inversion and the maximum inversion frequencies by season and annually is shown in Table 8. The maximum inversion frequency is the percent of nights during which an inversion occurs.

TABLE 8

PERCENT OF TOTAL HOURS OF INVERSION AND MAXIMUM
INVERSION FREQUENCIES BY SEASON/ANNUAL
(From Hosler, 1961)

SEASON	Percent Total Hours (%)	Maximum Inversion Frequencies (%)
Winter	47	85
Spring	40	82
Summer	40	90
Fall	50	90
Annual	45	88

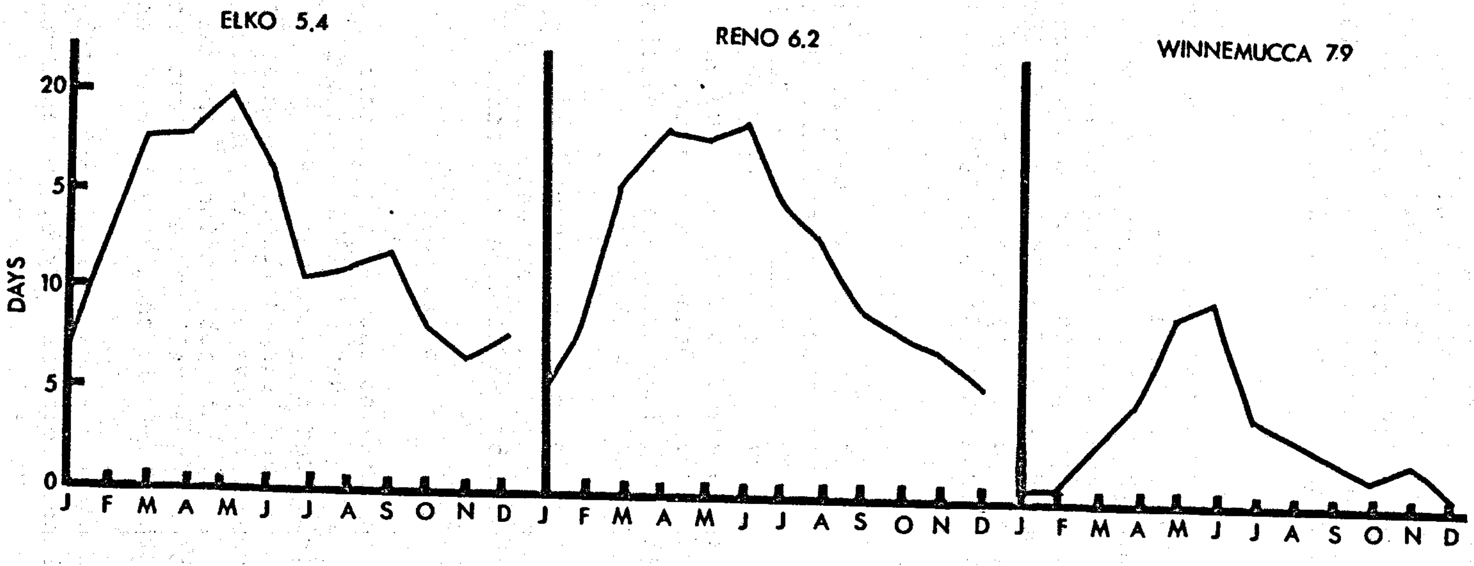

Figure 3. Average number of days per month with average daily wind speeds less than 5.0 mph (Holzworth, 1962).

Holzworth (1964) also estimated the maximum mixing depth for the area. The results show a definite seasonal variation from a maximum of 3600 meters in July to a minimum of 700 meters in December.

The high incidence of inversions in northern Nevada could constrain geothermal development and utilization. However, the corresponding diurnal changes in stability from stable (late night and early morning) to neutral and unstable (transition and early daylight) back to stable would create a situation where cumulative pollution build-up at the lower layer of the atmosphere would be limited.

Precipitation

Precipitation is highly variable in northern Nevada from site to site as well as by time. Annual precipitation for Reno, Nevada during the period 1938 through 1977 varied from a maximum of 11.75 inches to a minimum of 1.55 inches with an average of 7.6 inches. In Winnemucca, Nevada, the annual average precipitation is 8.5 inches and the extremes over the 90 year record ranged from 18.38 to 3.13 inches. More than 50% of the annual precipitation occurs during the winter months, mostly in the form of snow (Department of Commerce 1978).

Data Source

Most of the limited amount of meteorological data has been collected, tabulated and stored by the U.S. Department of Commerce, National Climatic Center, Asheville, North Carolina (Department of Commerce, 1977 and 1978). Another source of climatological data is "Climatological Data Nevada Test Site and Nuclear Rocket Development Station" (Quiring, 1968). Other data sources from various Federal, State and local agencies, industries and universities are available, but these require compilation and evaluation.

The Department of Interior, Bureau of Land Management Nevada is in the process of compiling the above data through a literature search. This information should be useful as a data base.

Source Data

There are essentially no data on the chemical composition of the geothermal fluid in the Nevada KGRAs. This is, in part, due to the early state of development of geothermal energy. Several exploratory wells have been or are being drilled, but most of the data collected relates to the thermal and physical characteristics of the resource. For example, in a recent publication, "Thermal Waters of Nevada", physical descriptions are well-presented but there is minimal information on geothermal fluid chemistry (Garside and Schilling, 1979).

Analyses of water from shallow geothermal wells and hot springs from Beowawe, Gerlach, Golconda, Kyle, Leach, and Needles (Pyramid Lake), Nevada are available and are presented in Table 9 (Sanders and Miles, 1974). This analysis quantifies substances in geothermal fluids

TABLE 9

ANALYSES OF WATER FROM GEOTHERMAL WELLS AND HOT SPRINGS

IN mg/l EXCEPT FOR As, Hg AND se WHICH ARE IN μg/l

(From Sanders and Miles, 1974)

	Beowawe Hot Spring	Gerlach	Golconda	Kyle's	Leach	Needles (Pyramid Lake)
Temp (C)	84	84	43	95.5	71.5	67.2
pH	9.73	8.08	7.03	7.0	7.99	8.1
Sp. Cond	1,006	7,830	942	3,312	807	6,072
TDS (sum)	964	4,596	626	1,968	608	3,676
S_1O_2	345	170	40	155	120	95
HCO_3	0	90.7	528	544	397	11.5
CO_3	152	0	0	0	0	0
Cl	67	2,238	27	775	33	1,841
SO_4	128	385	56.7	47.8	49.7	338
NO_3	< .1	< .7	<.2	<.1	2.2	< .1
F	18.7	5.51	2.9	6.32	9.13	3.0
PO_4	<.1	.2	<.1	<.1	<.1	< .1
Na	229	1,548	159	518	170	1,080
K	14.2	113	24.3	80	12	31.0
Ca	9	89	47	97	16	282
Mg	0.82	.98	7.8	20	.48	.12
NH_4	.5	.6	.8	1.3	.6	.1
Ag	<.02	<.02	<.02	<.02	<.02	<.01
As (μg/l)	2.2	3.3	.9	<.05	<.05	<.5
Ba	<.04	<.04	.46	.46	.20	<.5
Be	<.005	<.005	<.005	<.005	<.005	<.005
Bi	<.1	<.1	<.1	<.1	<.1	<.10
Cd	.01	.01	<.01	<.01	<.01	<.006
Cr	<.02	<.02	<.02	<.02	<.02	<.02
Cs	1.04	4.76	1.12	2.82	1.04	4.17
Cu	<.01	<.01	<.01	<.01	<.01	<.01
Fe	.09	.09	.79	.12	.05	.02
Hg (μg/l)	<.5	.7	<.5	<.5	<.5	<.1
Li	2.59	3.52	.527	5.34	.887	.76
Mc	.014	.018	.096	.034	.046	.01
Nb	—	—	—	—	—	—
Ni	.05	.05	.06	<.02	<.02	<.02
Pb	.06	.06	.02	.05	<.02	<.02
Rb	.266	1.73	.198	1.60	.168	.80
Sb	<.1	.3	<.1	<.1	<.1	<.1
Se (μg/l)	<1	<1	<1	<1	<1	<1
Sn	.05	<.05	<.05	<.05	<.05	<.02
Sr	.015	.408	.227	.160	.038	4.2
Ta	—	—	—	—	—	—
Zn	2.32	.135	.068	.050	.130	.015

which can be useful for determining background concentration. Other analyses, shown in Table 10, presents the average chemical composition of thermal ground water in the Truckee Meadows, Nevada.

Table 11 shows the difference in the chemical quality between thermal and non-thermal ground water (Bateman and Scheibach, 1975). This difference in chemical quality stresses the importance of requiring site specific data for geothermal fluids. It must also be emphasized that the analysis of the geothermal fluid by itself is not adequate in determining the severity of potential atmospheric emissions. However, analysis of the fluid must be initially done to quantify the potential problems and to explain the naturally occurring background air quality.

CONCLUSIONS AND RECOMMENDATIONS

The foregoing discussion leads to the conclusion that the lack of adequate aerometric meteorological and air quality data impedes the necessary air quality assessment for geothermal resource development in Nevada. This inadequate data base, combined with a nonexistent source emission data base, makes only crude estimates of the resulting air quality pacts possible. This general lack of data is a common problem for other western States including Oregon, Utah and California (Freeman and Slinn, 1979; White, 1979; and Rosen and Molenkamp, 1978).

The following discussion will identify the key issues and recommend methods to address the issues.

Data Requirements

It is obvious that the top priority issue is the gathering of specific data necessary to assess the air quality impact of geothermal resource development. The first four issues are considered critical and should be given high priority.

Source Data

The limited amount of data on the composition of geothermal fluid presented in this report applied to shallow surface geothermal sources. However, plans for commercial geothermal development include deep wells (greater than 5,000 feet) where the fluid chemistry is probably substantially different than from surface sources.

Recommendation : Chemical characterization of geothermal fluid, steam and noncondensable gases should be a requirement for each producing well. Substances that could produce environmental impact should be monitored continuously.

Air Quality Data

The only air quality measurement near an identified KGRA (by overview committee) is Total Suspended Particulates (TSP) at Steamboat,

TABLE 10

AVERAGE CHEMICAL QUALITY OF THERMAL GROUND WATER IN THE TRUCKEE MEADOWS

Parameter	Average Value	Range	Average Ionic Ratio (%)
Temp. (^{o}C)	62.2	30. - 145.	—
pH	7.85	6.7 - 9.0	—
SEC	1419.	194. - 3661.	—
TDS (mg/l)	1130.	162. - 3352.	—
HCO_3 (mg/l)	200.	78. - 461.)	35.
CO_3 (mg/l)	6.2	0 - 104.)	
Cl (mg/l)	226.	2.6 - 999.	31.
SO_4 (mg/l)	245.	2.3 - 1959.	34.
Na (mg/l)	282.	5.8 - 770.)	75.
K (mg/l)	24.	2.6 - 71.)	
Ca (mg/l)	34.	1.4 - 336.	17.
Mg (mg/l)	10.	0.1 - 112.	8.
SiO_2 (mg/l)	121.	4.7 - 317.	—

(from Bateman and Scheibach, 1975).

TABLE 11

COMPARISONS OF THE CHEMICAL QUALITY OF STEAMBOAT SPRINGS MOANA, AND NON-THERMAL GROUND WATERS

Name	Spring 8, Steamboat Springs		Thermal Well, Moana area		Sierra Pacific Power Co. Well No. 6	
Location	18N 20E 33AB		19N 19E 26ADDD		19N 20E 8BDD	
Sample no.	30-27		30-131		20-31	
Collection date	Aug. 9, 1949[1]		Mar. 27, 1974[2]		Aug. 24, 1959[3]	
	mg/l	epm	mg/l	epm	mg/l	epm
HCO_3	305	5.00	85	1.39	116	1.90
CO_3	0	—	0	—	0	—
Cl	865	24.39	50	1.41	7	0.20
SO_4	100	2.08	457	9.51	57	1.19
F	1.8	0.09	4.8	0.25	0.2	0.01
Br	0.2	—	<0.1	—	—	—
I	0.1	—	0.2	—	—	—
H_2S	4.7	—	0.2	—	—	—
B	49	—	2.0	—	—	—
Total anions	1,326	31.6	599	12.6	180	3.3
Na	653	28.41	243	10.58	43	1.87
K	71	1.82	7.4	0.19	—	—
Ca	5.0	0.25	23	1.15	22	1.10
Mg	0.8	0.06	0.2	0.02	3.9	0.32
Al	0.5	—	<0.04	—	—	—
As	2.7	—	0.10	—	—	—
Fe	0.05	—	0.02	—	0.05	—
Hg	—	—	<0.0005	—	—	—
Li	7.6	1.10	0.19	—	—	—
Mn	0.05	—	0.01	—	0.02	—
Sb	0.4	—	<0.01	—	—	—
Se	—	—	<0.005	—	—	—
Sr	0.5	—	0.5	—	—	—
Total cations	742	31.6	274	11.9	69	3.3
SiO_2	293		102		39	
SEC[4]	3,210		1,367		325	
TDS	2,361		975		288	
pH	7.9		8.3		8.0	
Temp. (°C)	89.2		89.9		23.3	
Depth (ft.)	—		150		752	

[1] Analysis by U.S. Geological Survey

[2] Analysis by Desert Research Institute

[3] Analyst unknown

[4] Specific Electrical Conductance (µmhos/cm @ 25°C)

(From Bateman and Scheibach, 1975)

Nevada. At present, this data base is inadequate to determine the background air quality. There have been no published measurements on H_2S and no continuous measurements of other important pollutants in northern Nevada.

Recommendation : A survey of natural emissions and ambient concentrations should be carried out to determine the background air quality. This baseline data should include, at a minimum, H_2S and all other potential harmful pollutants from geothermal sources.

Meteorological Data

The general lack of meteorological data in the northern Nevada is not surprising because the area is sparsely populated.

Recommendation : A network of surface stations should be installed to measure the following meteorological parameters: wind speed, wind direction, temperature, humidity, wind variation (turbulence) and mixing height. The stations must be located to measure the representative meteorological conditions for each KGRA with high potential for development. This data is required in order to determine the air quality impacts from development of the KGRAs.

Regulations

At present, there are no regulations specifically pertaining to geothermal development in Nevada. The Nevada Division of Environmental Protection is contemplating drafting regulations specifically for geothermal resource development.

The EPA also intends to establish standards for geothermal pollutants within the New Source Performance Standards (NSPS) provisions in their regulations. These standards will probably include an emission limitation for H_2S.

Recommendation : The State of Nevada should establish regulations governing geothermal resource development to provide consistency among control agencies, developers and the general public for estimating pollutant concentrations, assessing control strategies, and specifying emission limits.

Modeling

Dispersion models are necessary tools to assess air quality impact from geothermal development. Although the EPA has established guidelines (EPA, 1978) for the application of air quality modeling techniques and for the utilization of air quality models, the terrain in northern Nevada is so complex that the approved models do not adequately simulate the transport and dispersion conditions of the area. In general, current EPA models including "Valley" for complex terrain have very poor predictive capabilities.

Recommendation : Since simple models are inadequate to assess the air quality impact of geothermal sources in complex terrain, development of complex terrain models should proceed. As these models become available, they should be validated with data from the Nevada KGRAs.

Additional Recommendations

Additional research and information are required in the following areas in order to more completely address air quality impacts from geothermal resource development.

1. Data Bank

It is recommended that a central data bank be established to compile and eventually evaluate data from various agencies and organizations. This data bank should have a standardized data format so as to provide easy, cost effective access to the information.

2. Cooling Tower Drift

Since cooling towers are a primary emission source, studies should be conducted under the meteorological conditions found in the Nevada KGRAs. Studies will be required to evaluate the impact of cooling tower plumes including for example, surface deposition and visibility.

3. Emission Rates

Realistic estimates of emission rates and emission chemical components are required to assess the air quality impact of geothermal development. Without this knowledge, air quality assessment cannot be adequately carried out.

4. Geothermal Energy Conversion Process

More information is needed on the characteristics of the various geothermal energy conversion processes. This includes energy conversion cycles and waste heat rejection systems.

5. Transformation of H_2S

Studies on the transformation of H_2S to SO_2 and $SO_4^=$ for conditions found in the northern Nevada are required, e.g., conversion mechanisms and reaction rates.

6. Effects on Vegetation

The potential effects of pollutants found in geothermal fluids on native plants in the vicinity are required. Research efforts should include the effects of exposure on the vegetation, i.e., tolerance as a function of dosage and time.

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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter VII

NEVADA ECOSYSTEMS

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SUMMARY

There is considerable potential for geothermal development at a number of sites in Nevada. Many of these sites are quite isolated and essentially undisturbed at the present time; development carries with it the risk of irreparably damaging unique ecosystems. Other sites have ecosystems that are already stressed by present land uses and geothermal development could add sufficient stress to destroy them. The purpose of this report is to identify potential environmental issues of geothermal development that could impact ecosystems sufficiently to cause damage. We have assessed the relative importance of these issues. An inventory of available data about the ecosystems likely to be affected by geothermal development has been made, and it is shown that very few of the essential data are now available. We conclude that to accurately assess some of the potential environmental problems, it will be necessary to collect certain kinds of data for each site at the time development is considered. For other issues, it is possible to make a generalized evaluation. We propose a number of kinds of studies to provide the necessary information on Known Geothermal Resource Areas.

The techniques used in preparing this report include research, field work, and the use of a public workshop to obtain the widest possible input to our evaluation of the relative importance of the environmental issues. This workshop was held as part of the Nevada Overview on October 12, 1979.

Environmental Issues

While some of the environmental issues listed are of general concern, others are important only at some specific areas. Additionally, the importance of each issue varies from area to area. For these reasons, we have prepared a display (Table 1) to show the variations in importance of the environmental issues.

Endangered Plants : It is possible that endangered species will be found at many potential geothermal sites. For example, *Castilleja salsuginosa* is found at Monte Neva. Perhaps the greatest potential environmental significance is the presence of unique plant assemblages at hot spring areas that would be significantly affected if the hot springs are altered by geothermal development. The aquatic plant community in these areas include the desert spring and riparian community along the streams produced by the springs. Little is known about these communities or the flora that occurs within the hot springs themselves.

Endangered Animals : It is possible that endangered animals will be found near one or more of the KGRAs. Unfortunately, there is very little information available on this subject at this time. It is anticipated that any effects on the fauna from geothermal development will be secondary in nature. For example, if undesirable water from the Steamboat KGRA were to be discharged into Steamboat Ditch, which

TABLE 1.

SUMMARY OF ENVIRONMENTAL CONCERNS BY KGRA

KGRA **Concern**	Black Rock	Kyle, Leach Dixie Valley	Steamboat, Reno	Soda Lake, Hazen-Brady, Desert Peak Stillwater	Beowawe	Rye Patch	Monte Neva	Other
Existing Residences	0	2	4	0	1	2	0	?
Endangered Plants	4	?	?	4	?	4	4	?
Endangered Animals	3	?	?	3-4	4	3-4	0	?
Local Noise Pollution	0	1	3	0	1	3	0	?
Local Air Pollution	0	3	1	2	3	4	0	?
Present use/ Value conflict	4	3	1	1	3	3	1	?
Population Influx effect	4	3	1	3	3	2	3	?
Visual Pollution	4	0	1	0	0	3	3	?
Habitat Damage	4	3	4	3	4	4	1	?
Improved Access	4	3	0	1	2	0	0	?

Scale/Score:
0 = No problem
1 = Easily }
2 = Solvable }
3 = Difficult
4 = No solution seen
? = Unknown

eventually becomes a part of the Truckee River system, we would have a potential threat on the endangered Cui-ui and Lahontan cutthroat trout.

Local Noise Pollution : This includes an assessment of the potential problems caused by interposing a drill rig/power station on the existing environment.

If high levels of noise as a result of geothermal operations were to occur at Steamboat or Rye Patch, significant environmental effects would be likely. This subject is considered in Chapter VIII of this report.

Local Air Pollution : The potential effect on the local flora and fauna of the pollutants common to geothermal development should be considered.

This we see to be a major concern only at Rye Patch where an unusual air flow pattern would drive any fumes directly up a canyon or to a mountain range which contains many unusual and potentially rare and endangered plant and animal species.

Present use/Value Conflict : Here we have tried to assess potential conflicts with current use or potential use. We have included factors such as damage to or removal of grazing lands, farm lands, wilderness areas, migratory bird areas, and interference with historic sites and trails.

We believe that the potential for such conflict is highest at Black Rock, and almost as high at Dixie Valley and adjacent areas as well as at Beowawe and Rye Patch. The situation is most difficult with respect to the Black Rock Desert as the area is being considered for wilderness classification.

Lack of Biological Inventories : Most of the northern Great Basin KGRAs are located in remote areas and have been little studied by biologists. Biological inventories simply do not exist. Consequently, the potential for problems in these areas is unknown, but may be quite high if sensitive habitats or endangered species are present.

Critical Habitat Damage : Potential damage to both terrestrial and aquatic ecosystems is considered in this category. These examples range from the pollution of a nearby river system at Beowawe, or damage to a unique desert ecosystem and historic trails at the Black Rock Desert. This is the most important environmental factor with respect to the northern Great Basin. The importance is clear, since in a desert, water is the limiting factor, and where it is found, one also finds people, historic trails, and unusual flora and fauna.

Improved Access to the Areas near KGRAs : This factor we only consider to be a problem when increased access to KGRAs will increase the recreational use of fragile or unusual areas which are now relatively inaccessible. Increased human access brought about by the establishment of secondary roads may disrupt the surrounding natural ecosystems and can bring about increased soil erosion and habitat destruction by off-road vehicle enthusiasts testing their four-wheel drives and dirt bikes on the surrounding steeper hillsides. In urban areas or where improved roads presently exist, further access is not an important issue.

Available Data

The data base is not sufficient to evaluate the present state of the ecosystems of the KGRAs in northern Nevada. While there is considerable literature about the ecosystems of the region, much of which is discussed in this report, there is little or no site-specific information on KGRAs.

Data Gaps

While it is possible to generally characterize the regions near specific KGRAs, there is an insufficient data base for confident assessment of the potential impact of varying kinds of geothermal development. The biological information necessary includes inventories of flora and fauna in the locality and the variations with the seasons of the year, an analysis of the potential impacts on them of the particular geothermal development proposed, and the general affects of development on the surrounding area.

Recommended Studies

Proper ecosystem analysis of KGRAs must be at least a two-part effort. The basic part of any study should follow a conventional sampling plan, with transects crossing the area in a random pattern. If, as is usually the case, there are thermal springs, a special study must be made of the vicinity because of the discrete ecosystem associated with hot springs and should include inventory transects radiating out from the spring. There is also need for hydrologic studies to determine interconnections between the prospective geothermal reservoir and the hot springs. If there are cold springs present, they also need special study. Maps of the baseline condition of the ecosystem should be made, including vegetation communities, and wildlife habitats. Any critical areas such as hot springs should be carefully described.

INTRODUCTION

The Northern Great Basin Desert can be considered as a geographic unit. However, once so done, an ecological consideration of the area presents several problems. The land mass so defined is comprised of a number of ecosystems. These differences are brought about largely by variances in abiotic factors such as temperature, latitude, elevation, rainfall, and geological history. As a consequence, numerous local exceptions can be found to any classification system. Examples of such are described by Vreeland, P., et al . (1978) and many others. Local conditions such as overgrazing (Young, et al . 1976) may cause community change over relatively short periods of time. An example is some of the shadscale/sagebrush boundaries Billings (1951) considered have been altered by the interventions of man. The desert is a vulnerable land area with respect to external disturbances. People, through community growth, overgrazing, mining and other activities, have already altered the Great Basin. Some efforts are presently being made to document the current status of the flora and fauna (Vreeland, P., et al . 1978; Vreeland, H., et al . 1979; and Lugaski, et al . 1980).

These classifications are, in general, consistent with and follow the guidelines of Billings (1951). The modifications herein are further detailed in Lugaski and Vreeland (in preparation). It is important to note that except in a few rare instances there are no sharp dividing lines between or among the various categories. The labeling of each segment of the Northern Great Basin is a subjective attempt to segregate areas based on what seems to be the most important type of phytosociological association or geographic feature present. Most taxonomic references are in accordance with Intermountain Flora (Cronquist, et al . 1972). When there is substantial disagreement in the literature as to the proper scientific name or when there has been a recent change in nomenclature, the alternate or old name is shown in parentheses. In similar manner, the first time a dominant genus and species is mentioned, a common name is given in parentheses.

During the past one hundred plus years, many botanists and ecologists have worked on areas of the Great Basin Desert. Many of these workers are cited in the text.

In recent years, there has been increasing concern relative to endangered plant species in the Great Basin Desert. The members of the Northern Nevada Native Plant Society have been most active in researching this subject and in compiling lists of suggested species. Dr. Hugh Mozingo and Margaret Williams are currently funded by the Portland office of the U.S. Fish and Wildlife Service to prepare a book on the rare and endangered plant species in Nevada.

Development of geothermal energy in Nevada carries with it the potential for environmental impacts on the ecosystem. There are two important factors in judging the significance of such impacts: the kind of geothermal installation contemplated and the environmental sensitivity of the specific site under consideration. For example, development of large-scale geothermal power production involving the construction of multiple powerhouses, transformer yards, and cross-country transmission lines has the potential for a large-scale disruption of the local ecosystem. On the other hand, construction of a single greenhouse to be heated from a geothermal well using a downhole heat exchanger, or of single-house residential heating in the same fashion, clearly has a much smaller potential for environmental impact. Most potential projects fall somewhere between the two extremes cited.

Similarly, localities with extremely sensitive ecosystems--many endangered species and a high potential for alteration of unique hot springs systems--are more likely to suffer significant environmental impact than localities with fewer sensitive features.

These considerations point out the site- and project-specificity of geothermal developments. The usual approach is to assume a "worst-case" situation, and to evaluate the impacts of this. Many potential developments are small in scope and would therefore, have a relatively smaller potential for significant environmental impact than the "worst-case" evaluation made. In Nevada, the available data base is not sufficient to allow prediction of potential adverse impacts. Until an adequate data base is collected, the "worst-case" scenario is assumed.

A major portion of any ecological overview study is an assessment of the currently available data base relative to the area being considered. There is no baseline data available relative to the flora and fauna for any of the Known Geothermal Resource Areas (KGRAs) considered in this report.

Portions of the Great Basin have been examined thoroughly with respect to a particular plant or animal species and some general surveys of flora and fauna have been made (Tidestrom 1925; Linsdale 1936, 1938; Hall 1946; Billings 1949; La Rivers 1962; Beatley 1975 and others). Unfortunately, none of these efforts are relative to northern Nevada. Current biological inventories for the Northern Great Basin must be considered to be nonexistent for all practical purposes.

It is important to note that a full scale environmental assessment of each KGRA is not necessary at this time. While such would be most interesting from a scientific point of view, it is not financially feasible. However, at least a basic inventory must be conducted prior to any alteration of the habitat, including new access roads around any KGRA under consideration for development.

OVERVIEW OF VEGETATION

The overview of vegetation includes those areas in which geothermal development is currently occurring and those areas of potential development. This includes areas of the mountain tops and the possible northernmost extension of the southern desert shrubs in the northern Nevada geothermal areas. Numerous other shrub communities are present in southern Nevada but are not presented here.

Climatic differences from desert to mountain range within the Great Basin are intensified by the topographic features. Factors such as air and soil temperatures, wind movement, precipitation, evaporation and length of growing season vary as greatly as the plant community composition at the extremes of these gradients. In the Alpine Ecosystem, for example, a frost-free growing season seldom exceeds 90 days (Sampson 1925). Table 2 lists the various vegetation associations found in the Great Basin. Table 3 lists all known rare and endangered plant species for Nevada.

Alpine Ecosystem

Although known as the "timberless zone" (Sampson 1925), Billings (1978) stresses the fallacy of considering the location of Alpine Ecosystems above the timberline for frequently alpine flora can be found in pockets at lower elevations. The Alpine Ecosystems within the Great Basin are confined to the highest peaks. Shallow soil and few frost-free nights make this zone unsuitable for all but the hardiest tree species. Those which occur are stunted and prostrate.

Sierra Alpine Zone

This zone is found beyond the timberline of the Sierra Nevada, often around permanent snowbanks. Temperatures within this zone are generally warmer than on many of the Great Basin ranges at a comparable altitude. Precipitation, mostly in the form of snow, is high. Soil is poor and shallow, covered mostly by summit screes and alpine fell-fields. Shrub associations are well developed, occupying open areas above the red fir stands (Smith 1973), however, perennial herbaceous vegetation is generally dominant.

Basin Range Alpine Zone

The shrub-covered desert valleys which separate approximately 200 mountain ranges in the Great Basin have created "alpine islands" (Billings 1978), unlike floristically as well as ecologically. Many species occurring here are endemic to a particular peak, therefore, it is difficult to classify individual synusia. However, for simplification, two communities shall be considered representative of this zone: the limber pine-bristlecone pine community and the alpine tundra community.

Moisture and temperature are two key environmental factors affecting the Basin Range Alpine Zone. Pacific storms have been relieved of most of their moisture when crossing the Sierra Nevada, leaving the Great Basin ranges largely dependent upon convectional summer rains. Some peaks of the Great Basin ranges are sufficiently high to also catch moisture from Pacific storm tracks. Winter temperatures characteristic of many Great Basin ranges are colder than

TABLE 2.

LIST OF GREAT BASIN VEGETATION ASSOCIATIONS

I. ALPINE ECOSYSTEM

- A. Sierra Alpine Zone
- B. Basin Range Alpine Zone
  1. Limber Pine -Bristlecone Pine Community
  2. Alpine Tundra Community

II. WESTERN PINE - SPRUCE - FIR - DECIDUOUS - FOREST ECOSYSTEM

- A. Wasatch Zone
  1. Pine - Deciduous Community
  2. White Fir - Douglas Fir - Blue Spruce Community
  3. Englemann Spruce - Subalpine Fir Community
- B. Basin Range Zone
  1. Mountain Mahogany Community
  2. Upper Sagebrush Community
- C. Sierran Zone
  1. Pine - Fir Community
  2. Red Fir Community
  3. Lodgepole - Pine - Mountain Hemlock Community
  4. White Bark Pine Community

III. PINYON - JUNIPER ECOSYSTEM

- A. Pinyon - Juniper Zone
  1. Pinyon - Juniper Community

IV. DESERT SHRUB ECOSYSTEM

- A. Northern Desert Shrub Zone
  1. Sagebrush Community
  2. Rabbitbrush Community
  3. Shadscale Community
  4. Winter Fat Community
  5. Hog Sage - Coleogyne Community
  6. Mat Saltbush Community
  7. Gray Molly Community

TABLE 2. (Continued)

List of Great Basin Vegetation Associations

- B. Salt Desert Shrub Zone
    1. Greasewood Community
    2. Greasewood - Shadscale Community
    3. Saline - Alkaline Community
    4. Rabbitbrush Community

- C. Southern Desert Shrub Zone
    1. Desert Saltbrush Community
    2. Creosote Bush Community
    3. Joshua Tree Community
    4. Mesquite Community

- D. Transition Desert Shrub Zone
    1. Creosote Bush - Boxthorn Community
    2. Hop Sage - Boxthorn Community
    3. Boxthorn - Atriplex Community
    4. Artemisia Community

V. HYDRIC AND ANHYDRIC ECOSYSTEM

- A. Hydric and Aquatic Zone
    1. Desert Spring and Marsh Community
    2. Stream Riparian Community
    3. Stream Community
    4. Lake Community

- B. Playa and/or Dry Lake Zone

TABLE 3.

A LIST OF THE THREATENED AND/OR ENDANGERED PLANT SPECIES FOR NEVADA

(From "Threatened/Endangered Plant Atlas for Nevada" distributed through the Nevada State Museum, Carson City, Nevada, 1978).

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1. Agave utahensis var. eborispina
2. Angelica scabrida
3. Antennaria arcuata
4. Antennaria soliceps
5. Arabis dispar
6. Arctomecon californica
7. Arctomecon merriamii
8. Arenaria kingii var. rosea
9. Arenaria stenormeres
10. Asclepias eastwoodiana
11. Astragalus aequalis
12. Astragalus alvordensis
13. Astragalus beatleyae
14. Astragalus callithrix
15. Astragalus calycosus var. monophyllidius
16. Astragalus funereus
17. Astragalus geyeri var. triquetrus
18. Astragalus lentiginosus var. latus
19. Astragalus lentiginosus var. sesquimetralis
20. Astragalus mohavensis var. hemigyrus
21. Astragalus musimonum
22. Astragalus nyensis

TABLE 3. (Continued)

A List of the Threatened and/or Endangered Plant Species for Nevada

23. Astragalus oophorus var. clokeyanus
24. Astragalus phoenix
25. Astragalus porrectus
26. Astragalus pseudiodanthus
27. Astragalus pterocarpus
28. Astragalus robbinsii var. occidentalis
29. Astragalus serenoi var. sordescens
30. Astragalus toquimanus
31. Astragalus unicalus
32. Calcochortus striatus
33. Camissonia megalantha
34. Camissonia nevadensis
35. Castellja salsuginosa
36. Centaurium namophilum
37. Cirsium clokeyi
38. Cordylanthus tecopensis
39. Coryphantha vivipara var. rosea
40. Croton wigginsii
41. Cryptantha hoffmanni
42. Cryptantha insolita
43. Cyrptantha interrupta
44. Cryptantha tumulosa
45. Cymopterus nivalis
46. Ditaxis diversiflora

TABLE 3. (Continued)

A List of the Threatened and/or Endangered Plant Species for Nevada

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47. Draba arida
48. Draba asterophora var. asterophora
49. Draba crassifolia var. nevadensis
50. Draba jaegeri
51. Draba lemmonii var. incrassata
52. Draba paucifructa
53. Draba stenoloba var. ramosa
54. Elodea nevadensis
55. Enceliopsis nudicaulis var. corrugata
56. Epilobium nevadensis
57. Erigeron ovinus
58. Erigeron uncialis var. conjugans
59. Eriogonum anemophilum
60. Eriogonum argophyllum
61. Eriogonum bifurcatum
62. Eriogonum darrovii
63. Eriogonum holmgrenii
64. Eriogonum lemmonii
65. Eriogonum lobbii var. robustius
66. Eriogonum viscidulum
67. Forsellesia pungens
68. Frasera gypsicola
69. Frasera pahutensis
70. Fraxinus cuspidata var. macropetala

TABLE 3. (Continued)

A List of the Threatened and/or Endangered Plant Species for Nevada

71. Galium hilendiae ssp. kingstonense
72. Geranium toquimense
73. Gila ripleyi
74. Grindelia fraxino-pratensis
75. Haplopappus watsonii
76. Heuchera duranii
77. Isoetes bolanderi var. pygmaea
78. Ivesia cryptocaulis
79. Ivesia eremica
80. Lathyrus hitchcockianus
81. Lesquerella hitchockii
82. Lewisia maguirei
83. Lupins malacophyllus
84. Lupinus montigenus
85. Machaeranthera leucanthemifolia
86. Mentzelia leucophylla
87. Mertensia toiyabensis
88. Mimulus washensis
89. Mirabilis pudica
90. Opuntia pulchella
91. Pountia whipplei var. multigenculata
92. Oryctes nevadensis
93. Oxytheca watsonii
94. Penstemon arenarius
95. Penstemon bicolor ssp. bicolor

TABLE 3. (Continued)

A List of the Threatened and/or Endangered Plant Species for Nevada

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96. Penstemon biocolor ssp. roseus
97. Penstemon francisci-pennellii
98. Penstemon fruticiformis ssp. amargosae
99. Penstemon keckii
100. Penstemon nanus
101. Penstemon pahutensis
102. Penstemon procerus var. modestus
103. Penstemon pudicus
104. Penstemon rubicundus
105. Penstemon theompsoniae ssp. jaegeri
106. Penstemon thurberi var. anestius
107. Phacelia anelsonii
108. Phacelia beatleyae
109. Phacelia glaberrima
110. Phacelia inconspicua
111. Phacelia parishii
112. Polygala subspinosa var. heterorhyncha
113. Polemonium nevadensae
114. Primula capillaries
115. Primula nevadensis
116. Psorothamnus kingii
117. Rorippa subumbellata
118. Salvia funerea
119. Sclerocactus polyancistrus

TABLE 3. (Continued)

A List of the Threatened and/or Endangered Plant Species for Nevada

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120. Sclerocactus publispinus
121. Selaginella utahensis
122. Silene clokeyi
123. Silene scoposa var. lobata
124. melowskia holmgrenii
125. Sphaeralcea caespitosa
126. Sphaeromeria compacta
127. Synthyris ranunculina
128. Thelypodium laxiflorum
129. Thelypodium sagittatum var. ovalifolium
130. Townsendia jonesii var. tumulosa
131. Trifolium andersonii ssp. beatleyae
132. Trifolium lemmonii
133. Viola purpurea var. charlestonensis
134. Streptanthus oliganthus
135. Haplopappus aberrans
136. Hackelia ophiobia

the Sierra Nevada.

Wasatch Alpine Zone

Separated from each other by low-lying deserts, islands of alpine tundra can be found on high mountain peaks of the Wasatch region. This zone contains few endemic species, in contrast to the many endemics found in the Basin Range Alpine Zone (Cronquist, et al . 1972). Alpine tundra can be found in the Basin Range Alpine Zone and at elevations above 10,500 feet in the Wasatch Mountains, above 12,000 feet in the Utah Plateaus, and at over 13,000 feet in elevation in the LaSal Range in southeastern Utah. Short growing season, freezing night temperatures and poor, shallow soils render this an unfavorable environment for trees. Low-growing shrubs, forbs, and grasses are the principal components of the Wasatch Alpine Zone. In general, Wasatch Alpine flora is similar to the alpine tundra of the central Rocky Mountains (Billings 1951).

Western Pine - Spruce - Fir - Deciduous Forest Ecosystem

This ecosystem is present on the Wasatch and Sierra Nevada mountain ranges marking, respectively, the eastern and western boundaries of the Great Basin. The ecosystem is also present on many of the Great Basin ranges which lie between. These highlands receive considerably more precipitation and colder temperatures than the communities of the Desert Shrub Ecosystem. Although there are three separate zones in this ecosystem, there is considerable species overlap between and among them. Occasionally two zones may occur on the same range, especially toward the extreme eastern and western limits of the Great Basin. For example, both Basin Range and Sierra zones can be found on the Carson Range, located just east of the Sierra Nevada.

Wasatch Zone

Floristically, this zone is similar to synusia of the Rocky Mountains. Three community types are representative of this zone: (1) Pine, Deciduous, (2) White Fir, Douglas Fir, Blue Spruce, and (3) Englemann Spruce, Sub-alpine Fir Communities. General altitudinal ranges vary depending on slope direction. Geographically, the Wasatch Zone can be found along the eastern boundary of the Great Basin, on the Wasatch Range and the Wasatch Plateau although partial community extensions occur on neighboring mountains.

Basin Range Zone

Eastward from the Sierran Zone, a series of north-south trending mountains, ranging in elevation from 5,000 to over 11,000 feet, extend across the Great Basin to west-central Utah. In conjunction with other environmental factors, these ranges receive less precipitation than the Sierra Nevada and consequently, support different vegetation communities. However, certain coniferous species do occur which are also found in the Sierra Zone, namely, *Pinus jeffreyi* , *P* . *ponderosa* , *P* . *contorta* , *P* . *monticola* and *Abies concolor* (Billings 1954; Little 1956). Two community types are associated with the Basin Range Zone: Mountain Mahogany and Upper Sagebrush Communities.

Sierran Zone

The Sierran Zone of the Western Pine-Spruce-Fir-Deciduous Forest Ecosystem marks the western boundary of the Great Basin. This ecosystem is located along the eastern slopes of the Sierra Nevada and the nearby Carson Range. It is over these ranges that moisture laden Pacific storm fronts must pass, dropping most precipitation in the form of snow at higher elevations. The rain shadow created by this barrier is responsible for the arid and semi-arid conditions throughout most of the Great Basin. Four major community types can be found within this zone. Species overlap is not uncommon, not only with trees but also shrubs and forbs. One such species for example, *Sarcodes sanguinea* occurs in three of the four communities within this zone (Vreeland, P., *et al* . 1976), resulting perhaps from the overlap of its associated autotrophic species.

Yellow Pine - White Fir Community

This community extends from about 5,000 to 7,500 feet and is characterized by *Pinus ponderosa* , *P* . *jeffreyi* (both considered yellow pine), and *Abies concolor* (White Fir) as principal dominants with *P* . *lambertiana* and *Calocedrus decurrens* commonly associated tree species. *Ceanothus* , *arctostaphylos* and *Quercus* (i.e., understory shrubs) are found in this community. Ponderosa Pine, considered by Billings (1954) to be the most important western timber tree, is widely distributed from Canada to Mexico. It can be found in eastern, southern, and western Canada to Mexico. It is found in eastern, southern, and western Nevada at elevations ranging from 8,000 to 9,000 feet. Areas of hydrothermally altered rock in the Carson Range to the east of Steamboat KGRA are often occupied soley by *Pinus ponderosa* with no understory present (Billings 1950).

Once considered to be a variety of the Ponderosa pine, Heller (1912) points out that the Jeffrey pine is a separate and distinct species. *Pinus jeffreyi* is the predominant yellow pine in western Nevada. The range of the Jeffrey pine is not as extensive as Ponderosa pine; Jeffrey extends only from southern Oregon to lower California (Billings 1954). In Nevada, it is confined to the western portion of the state from southern Washoe to Mineral counties at elevations from 5,000 to 7,800 feet.

The *Pinus washoensis* (Washoe pine) bears a close resemblance to both the Ponderosa and the Jeffrey pines and is considered to be a possible hybrid of the two (Billings 1954). The type specimen was located on Mount Rose in the Sierra Nevada in 1938 by Mason and Stockwell (1945) in a small grove, elevation approximately 8,000 feet.

The range of the White Fir, one of the most common trees in mixed coniferous forests of the Sierra Nevada, is from southern Oregon to Mexico. Abies concolor occurs at 6,000 to 8,500 feet elevation in eastern and western Nevada. The eastern trees are characterized by shorter needles than those found in the Sierra Nevada (Billings 1954).

Pinyon - Juniper Ecosystem

This ecosystem is considered the dominant forest type with respect to area in the Intermountain Region (Cronquist, et al . 1972 and West, et al . 1978). Elevation ranges from 5,000 to 8,000 feet for the Pinyon - Juniper Ecosystem although these limits vary greatly. Precipitation is generally in excess of 12 inches per year. Only one zone is representative of this ecosystem type in the Great Basin, however, species diversity is considerable (Harner and Harper 1976). Various external factors may have had a substantial effect on the distribution of this ecosystem in Nevada such as fire and grazing patterns (Blackburn and Tueller 1970). The topography in which this community occurs is varied, ranging from gentle rolling hills to steep mountain slopes, rocky canyons and narrow ridges. Soil is usually well-drained sandy loam.

Pinyon - Juniper Zone

This zone occupies major portions of the Great Basin area and is found in Utah, Arizona, and Nevada (Odum 1971). In general, the elevation of this zone is highest in the west-central portion of the Great Basin and declines both westward toward the Sierra Nevada and eastward to the Wasatch Front - High Plateaus (West, et al . 1978). The northern limit of this zone is generally considered to be south of the Humboldt River in Nevada although east of the Nevada-Utah border it extends north to the Raft River Mountains and southern Idaho (Critchfield and Allenbaugh 1969). West, et al . (1978) attribute the absence of this zone from northwestern Nevada to be largely a factor of unstable temperature inversions over this area due to Pacific frontal systems. Approximately twenty percent of the state of Utah and northern Arizona foothills are covered by the Pinyon - Juniper Zone (Woodbury 1947). One phytocoenosis, the Pinyon - Juniper Community, comprises this zone.

Pinyon - Juniper Community

Considered "pigmy conifers" by Woodbury (1947), this community consists of open stands of low, scrubby conifers dominated by Pinus monophylla (Pinyon) and several species of Juniperus (Juniper). Both pinyon and juniper are commonly present in this association. Juniper is usually more abundant at lower elevations while pinyon becomes more numerous as elevation increases. Cercocarpus ledifolius can be frequently associated in higher elevations while Betula occidentalis , Salix sp., and Populus sp. occur in wetter areas of this community type. Artemisia tridentata is the dominant shrub in this community throughout much of the Great Basin although other important shrubs include the genera Chrysothamnus, Ephedra, Ribes, Purshia, Ceanothus, Tetradymia, Sambucus and Symphoricarpos. Many species of forbs and grass are also present. The lower limit of this community is generally around 5,000 feet. Disturbance by fire can cause the occurrence of Cowania mexicana, Falugia paradoxia, Quercus gambelli, Q. turbinella, Ameanchier utahensis, Prunus faciculata and Arctostaphylos pugens (Bradley and Deacon 1965). Juniperus has been said to invade sagebrush communities in lower elevations as a result of overgrazing (Cottam and Stewart 1940). Pinyon-Juniper vegetation is considered unimportant economically but provides erosion protection, wood for fencing and fuel, and pine nuts, a major component of the diet of some western Indian tribes.

Desert Shrub Ecosystem

Whittaker (1970) divides deserts into categories based on a number of environmental factors including temperature, precipitation, latitude, altitude, and the resulting different vegetational groupings. The Desert Shrub Ecosystem is the category describing the overall physiognomy of much of the Great Basin Desert. Based largely upon geographic location, four zones within this ecosystem are present in the Great Basin: Northern Desert Shrub Zone, Salt Desert Shrub Zone, Southern Desert Shrub Zone, and Transition Desert Shrub Zone.

Northern Desert Shrub Zone

This zone consists of seven distinct community types based upon the dominant species: Sagebrush, Rabbitbrush, Shadscale, Winter fat, Hop Sage-Coloegyne, Mat Saltbrush, and Gray Molly. Clements (1920) finds most of the dominant shrubs in this zone belong to the families Asteraceae and Chenopodiaceae. This northern desert can be considered "cool-temperature desert scrub" or "semi-desert" (Whittaker 1970). Precipitation is generally greater than the other zones within the Desert Shrub Ecosystem. Temperature ranges between 115° F in summer to -43° F in winter with diurnal fluctuations frequently between 40 to 50 degrees (Billings 1951). Topography of this zone is dominated by many relatively small basins separated from each other by fault-block mountain ranges in the northern portion of the Great Basin. The seven community types found in this zone frequently overlap and dove-tail as environmental factors vary, resulting in a mosaic of synusia.

Overgrazing has been a major factor affecting species composition in many communities within this zone. Bunch grass, once a major non-woody component throughout much of this area, has been replaced by less palatable grasses and shrubs, a result of grazing. Robertson (1947), Tueller (1973), and others offer solutions for restitution of this valuable range land.

Salt Desert Shrub Zone

This zone differs from the other geographically distinguished zones of the Desert Shrub Ecosystem in that its differentiation is based on a high salt concentration in the soil. Many interior drainage areas within the Great Basin collect run off from the surrounding hills, where it evaporates leaving behind deposits of soluble salts (Shantz 1925). According to Stalfelt (1960), soils in large areas of Utah contain excessive amounts of chlorides, sulfates, carbonates, and bicarbonates of sodium, potassium, calcium and magnesium with a high concentration of sodium chloride. Crystalline deposits of chlorides and sulfates of sodium, calcium and magnesium comprise "white alkali" while those of sodium carbonate cause a dark soil coloration, thus, the name "black alkali" (Shantz 1925). The latter is considered more harmful to vegetation. The pH of these soils varies depending on the proportion of salts, ranging from weakly to strongly alkaline. In areas of extreme alkalinity, no vegetation occurs on the salt encrusted soil.

The Salt Desert Shrub Zone consists of five community types: Greasewood, Shadscale, Greasewood-Shadscale, Saline-Alkaline, and Rabbitbrush communities. These plant associations are relatively bright green in color when compared with the sage, gray-green characteristic of the Northern Desert Shrub Zone. Generally, vegetation in the Salt Desert Shrub Zone receives adequate moisture since the water table is usually 12-24 inches below the soil surface (Shantz 1925). Vegetation communities of the Salt Desert Shrub Zone present in northern Nevada KGRAs are described below.

Greasewood Community

Sarcobatus vermiculatus (greasewood) occurs on soil which contains high concentrations of salts and where the water table is high at least part of the year. These shrubs are evenly spaced from 4 to 7 feet apart with expanses of bare ground between. Sarcobatus roots often extend to depths of 10 to 15 feet and this shrub is considered to be a good indicator of subsurface ground water (Flowers 1934). Chenopodiaceae is the dominant plant family in the Greasewood Community (Flowers 1934).

Shadscale Community

Atriplex confertifolia (shadscale) is the dominant shrub in this community which occupies many valley bottoms in western Nevada and Utah, perhaps because of this species' high salt tolerance and low moisture requirements (Billings 1949). According to Billings (1949) the largest shadscale community extends from the Carson Desert region of west-central Nevada south and east to the mountains of Death Valley and southern Nevada. Another large shadscale area can be found in western Utah with many smaller communities extending into eastern Oregon and southern Idaho. Other shrubs which occur in conjunction with Atriplex confertifolia are Atriplex spinescens , Chrysothamnus vicidiflorus , *Ephedra nevadensis* , *Ceratoides* (*Eurotia*) *lanata* , *Sarcobatus baileyi*, *Tetradymis glabrata* , *Gutierrezia sarothrae* , *Grayia spinosa* and several other species of *Atriplex* . These low, gray-green shrubs are generally spiny and cover less than 10 percent of the ground area (Cronquist, *et al* . 1972). Forbs and grasses, both annual and perennial, are few and appear only after sufficient precipitation which averages 4.5 inches annually in Nevada and almost 8 inches annually in Utah for this community (Billings 1951). *Halogeton glomeratus* is an intoduced weed common in this community which is poisonous to sheep and spreads rapidly in disturbed areas. Many of the palatable grasses have been replaced by shrubs as a result of overgrazing.

Although of questionable fertility according to Shantz (1925), soils in the Shadscale Community can be reclaimed for agriculture. These efforts have gone on for many years. What was once described as "...one of the most desolate and arid spots on this continent..." (Blanchard 1907) is now a productive agricultural community surrounding Fallon, Nevada. Water for this reclamation was diverted approximately 40 miles from the Truckee River to provide irrigation. Although complicated by high salt concentrations in the soil, the area now produces many hay and food crops and supports a sizeable community.

Billings (1949) points out the difficulty in classifying the shadscale communities because of the discontinuity of associated species in various areas due to environmental variations. However, he does consider shadscale to be a recognizable community type in that it is a natural area with marked biological characteristics.

Greasewood-Shadscale Community

Sarcobatus vermiculatus (greasewood) forms communities with *Atriplex confertifolia* (shadscale) at higher elevations from the Greasewood Community. This vegetation association often marks a transition between the Northern Desert and Salt Desert Shrub zones. The two species are quite different morphologically, *S* . *vermiculatus* having a bright green color and somewhat taller than the gray-green, low hemispheric *A* . *confertifolia* . Both species also have different moisture requirements. Shantz (1925) explains this unusual association by differences in root structure. *S* . *vermiculatus* is deeper rooted and is able to utilize ground water found below the dry, alkaline soil inhabited by more shallow root systems of *A* . *confertifolia* . Some associated shrubs in the Carson Desert Greasewood-Shadscale Community are *Artemisia spinescens* , *Ceratoides* (*Eurotia*) *lanata* , and *Lycium cooperi* . Although often lacking in this community, herbaceous flora may include *Oryzopsis hymenoides* , *Sphaeralcea ambigua* and *Hermidium alipes* along with annuals of the genera *Cryptantha* , *Coldenia* , *Gilia* , *Eriogonum* , and *Glyptopleura* (Billings 1945).

According to Stutz (1978), *Atriplex* , is able to invade playas formed by the recession of inland seas such as Lake Bonneville and Lake Lahontan because of this species' ability to hybridize rapidly. These hybrids are able to tolerate extremely high salt concentrations and the resulting physiological drought in such habitats. Not only is Atriplex hybridizing with other species of the same genus but Stutz (1978) reports interspecific hybridization with Artemisia tridentata in western Utah and northern Nevada. The resulting seeds produce viable offspring with characteristics of both parents. Thus, it can be summarized that this hostile environment seems conducive to the rapid evolution of species.

Southern Desert Shrub Zone

This zone occurs in southwestern Utah and low, warm valleys south of the thirty-seventh parallel in Nevada (Shantz 1925). Cacti, yucca, and green shrubs characterize this zone in contrast to the gray-green shrubs of the Northern Desert Shrub Zone. Some species, such as Atriplex , overlap the two zones. Maximum temperatures of 120° F have been reported with frost-free periods exceeding 120 days (Shantz 1925). Annual precipitation ranges from as little as 2 inches in Utah to as much as 5-10 inches in parts of Nevada.

Transition Desert Shrub Zone

Meyer (1978) defines a floristic transition zone as one where "...a high proportion of indigneous plant species reach a distributional limit...". Species found in the Mojave Desert do not normally occupy the Transition Desert Shrub Zone, largely due to cold air accumulations in the lowlands at night. However, it is possible for a species with a wide range of tolerances and sufficient genetic variability to migrate into a favorable micro-environment and consequently, form an island in an otherwise hostile element (Meyer 1978). The higher mountains within this zone are considered by West, et al . (1978) to be the areas of greatest environmental and floristic diversity.

According to Beatley (1975), transition communities in the southern Great Basin characterize the change in vegetational composition between the southern, lower Mojave Desert and the more northern Great Basin Desert which lies at a higher elevation. This transition is further influenced by the close proximity of the Sonoran Desert.

The Nevada Test Site is perhaps the most studied area with respect to floral composition within the Transition Desert Shrub Zone. Beatley (1976c) has compiled several check lists on plant distribution, biotic studies have been conducted by Allred, et al . (1963), ecological aspects have been considered (O'Farrell and Emery 1976) and effects of underground detonation have been studied by Tueller, et al . (1974) and Tueller and Clark (1976). However, many areas remain scientifically unexplored within this zone which contains numerous endemic, endangered and relic species (Clokey 1951; Bradley 1967; Beatley 1976a, 1976b, 1976c).

Classification of communities within the Transition Desert Shrub Zone is based upon topographical position, species composition and the open or closed drainage pattern of the basin. Four communities are characteristic of this zone: (1) Creosote bush-boxthorn, (2) Hop sage-boxthorn, (3) Boxthorn-Shadscale, and (4) Sagebrush.

Communities of the Transition Desert Shrub Zone is present in northern Nevada KGRAs and is dominated by Artemisia tridentata (big sagebrush). This community is considered the climatic climax of desert areas with annual precipitation in excess of 7 inches (Cronquist, et al 1972). This community replaces the Shadscale Community as elevation increases above 4,500 feet in the north and 5,000 feet in the southern areas. Artemisia tridentata is less drought resistant and salt tolerant than Shadscale Community vegetation (Billings 1951). As a result, the Sagebrush Community stretches over vast expanses of the northern Great Basin, covering both valleys and mountain ranges. According to Beetle (1960), A . tridentata communities cover approximately 150 million acres in the western United States. This community occupies more area within the Great Basin than any other vegetation type (Billings 1951).

The typical Sagebrush Community consists of non-spiny shrubs from one to six feet high, perennial and annual grasses and forbs. In addition to Artemisia , woody genera present include Chrysothamnus , Ephedra , Purshia , Ribes , Symphoricarpos and Tetradymia . Shrubs account for approximately 20% of the ground cover in this community (Billings 1951).

Precipitation averages 8.8 inches in the northern Nevada extensions of this community type, mainly as snow in winter. An important community component, perennial grasses, includes Agropyron , Oryzopsis , Poa , Sitanion , and Stipa . Numerous studies have shown that overgrazing has greatly reduced the percent cover of bunchgrass and increased that of Artemisia tridentata in portions of this community (Robertson 1947; Cottam 1961; Christensen and Johnson 1964; Driscoll 1964). The alien annual, Bromus tectorum , has invaded overgrazed areas. This less palatable grass has prevented the establishment of more desirable species (Cronquist, et al . 1972).

Sagebrush is important winter forage for cattle, sheep, big game animals, and game birds. Grazing is known to increase the density of sagebrush often at the expense of perennial grasses. The use of fire and herbacides to control the intrusion of sagebrush onto desert range lands is cautioned against by Beetle (1960). The author points out that both grasses and sagebrush are important dietary components of many livestock and game animals who browse on either or both on winter ranges.

Upper Sagebrush Community

This community is dominated by shrubs and herbs giving many mountain peaks a bald appearance throughout the Basin Range Zone. Whether caused by climatic shifts (Billings and Mark 1957) or drying trends (Vasek 1966), this phenomenon has resulted in an absence of trees from these areas. Artemisia tridentata subsp. vaseyana (sagebrush) and other shrubs extend to elevations of over 10,000 feet, exhibiting a greater range of elevational tolerances than many species of trees. Climate at these elevations is much colder than that of the low-lying desert sagebrush communities. Precipitation is generally two to three times the amount received in lower elevations (Billings 1951). Vegetation in the Upper Sagebrush Communities is generally more dense than in Sagebrush Communities found at lower elevations. Associated woody species include *Holodiscus dumosus* , *Symphoricarpos* sp., and *Cerocarpus ledifolius* (Billings 1951). Occasionally, *Populus tremuloides* may be found in wet areas of this community along with many species of perennial forbs and grasses.

Hydric and Anhydric Ecosystem

Hydric and Aquatic Zone

Throughout the Great Basin there are a number of different hydric and aquatic community types. These include: (1) the desert spring and marsh community, (2) the stream riparian community, (3) the stream community, and (4) the lake community. Although these four communities are listed as being separate, they are often contiguous. An example is the Humboldt River system which has its origins in the mountains of northeastern Nevada. In this area, we find springs and stream communities that contribute water to the river system and associated with these communities one often finds marshes and small lakes. As the Humboldt River proceeds on its meanderings to the lowlands, the river maintains a distinct stream and riparian community, each with its own distinctive flora and fauna. Along the way, other streams and springs add water, flora and fauna to the system. Eventually, as the Humboldt River approaches its terminus, the river broadens into a shallow lake, Humboldt Lake, then this turns into Humboldt Marsh and finally the water disappears into the desert at Humboldt Sink; in this way the system incorporates all communities within the hydric, aquatic and anhydric ecosystems.

In many other areas of the Great Basin this is not the case. Many of the springs, seeps, and streams simply disappear into the desert soil or evaporate into the desert air, and are isolated from other systems.

Playa and Dry Lake Zone

In this land of interior drainage, valleys between the mountain ranges of the Great Basin often form collecting basins for ephemeral streams formed by run off from the surrounding high lands. Dry lake beds or playas mark the retreating shores of prehistoric lakes which once covered large portions of the Great Basin. As they evaporated, these bodies of water left behind large alkali deposits which support virtually nothing living, plant or animal. One of these, the Great American Desert, is an area approximately 50 by 100 miles vacated by the regression of the Great Salt Lake. Wind and alkali "...render this area one of the most forbidding deserts on this continent..." (Flowers 1934).

Further westward, the Smoke Creek and Black Rock Deserts mark the retreat of prehistoric Lake Lahontan, which once covered more than 8,000 square miles, mostly within Nevada (Wheeler 1978). These deserts became known to pioneers of the 1850's (who chose to traverse them) as the "death route." The alternate trail westward crossed the dreaded Forty-mile Desert, a sink formed by the terminus of the Carson River. These alkali-encrusted playas, because of the intense heat, lack of shade, forage for the livestock and absence of water, resulted in untold hardships for early pioneers journeying westward. An early traveler, Israel Russell, wrote in 1881 of his experience,

> "The scenery on the larger playas is peculiar, and usually desolate in the extreme, but yet is not without its charms. In crossing these wastes, the traveler may ride for miles over a perfectly level floor, with an unbroken skyline before him and not an object in sight to cast a shadow on the ocean-like expanse." (Wheeler 1978).

William Wallace, a correspondent for a San Francisco newspaper, writes of his journey across the Forty-mile Desert in 1858,

> "The road there is hard and smooth for the greater portion of the way, but the plain around for thousands of acres together is leafless and lifeless, white arid plains without water, upon which the sun glares. I never saw a desert before and I do not wish to see another." (Wheeler 1978).

Shreve (1942) notes the absence of plants on the playa formed by Lake Bonneville, the largest dry lake bed in the Great Basin.

Soils are saline to great depths; frequently this salt is relatively pure and is mined as table salt. Most of the Great American Desert is barren but _Allenrolfea occidentalis_ (pickleweed) occupies widely scattered hummocks along the borders and occasionally appears further interior (Flowers 1934). _Salcornia_ sp., _Distichlis spicata_, and _Suaeda_ sp., are frequently occurring herbaceous species found around the edges along with _Sarcobatus_ (greasewood) and _Atriplex_ (shadscale) shrubs as distance increases.

Playa and Dry Lake Community

Botanically speaking, these areas are a wasteland. An early account typical of this community is taken from Haskill (1872) who states in his account of the agricultural resources of Nevada to the U.S. Geological Survey, "Black Rock Valley, forty miles west of Humboldt City, contains 350,000 acres of sagebrush and alkali flats, and volcanic matter lines the outskirts. This valley is almost entirely destitute of vegetation."

OVERVIEW OF FAUNA/ANIMAL COMMUNITIES OF NORTHERN NEVADA

The data available on the fauna/animal communities is limited in a number of respects: (1) Those analysis that have been done are few and far between, (2) most are likely to be in areas not concerned with geothermal development as it is presently being explored, and (3) all of the data available is found in major monographs such as E.R. Hall's "Mammals of Nevada" and I. La Rivers "Fishes and Fisheries of Nevada."

The recent native fishes of the western portion of the Great Basin which includes mainly the Lake Lahontan drainage basin and adjacent areas have been reviewed by Snyder (1917), Hubbs and Miller (1948), La Rivers (1952, 1962), Hubbs, Miller, and Hubbs (1974), and Smith (1978). The known forms of native fishes include 5 families, 10 genera, 13 species and some 30 subspecies from the Lahontan drainage basin and adjacent areas (Hubbs and Miller 1948; La Rivers 1962). Most of the major geothermal development areas are in areas that do not contain native fishes, however, a number of potential areas of development in the Black Rock Desert area, Dixie Valley, Big Smoky Valley, Diamond Valley, Newark Valley, and Steptoe Valley contain unique native fishes.

The amphibian and reptiles of the Northern Great Basin are relatively well known. This herpetofauna has most recently been reviewed by Linsdale (1938, 1940), La Rivers (1942), Stebbins (1951, 1954, 1966), and Banta (1961, 1963, 1965a, 1965b, 1967). Banta (1965a, 1965b) published an annotated bibliography of the herpetology of the State of Nevada. There are few endemic amphibian and reptile species in the Northern Great Basin and all of the known species that occur in northern Nevada geothermal areas are found through the State of Nevada and adjacent areas. There are probably numerous undescribed subspecies of amphibians and reptiles in the Great Basin. A recent example is the description of a lizard Crotaphytus wislizeni macuosus from the Lahontan Basin (Tanner and Banta 1977).

The avian fauna of the Northern Great Basin has been reviewed by Linsdale (1936, 1951), Behle (1978), Johnson (1965, 1970, 1973, 1974, 1975, 1978), and others. The Great Basin avifauna is closely related to the Cascade-Sierra Nevada and Rocky Mountain-Great Plains avifauna elements of the Mojave and Sonora Desert avifauna. Those rare and endangered birds that occur in Nevada have been reviewed by Nappe and Klebenow (1973) and will be listed later.

The mammal fauna of the Northern Great Basin has been worked on extensively by Hall (1946) and Larrison (1967). Hall has divided the mammals of Nevada into five faunal areas: (1) Sierra Nevada, (2) Northern Great Basin, (3) Central Rocky Mountain, (4) Lower Sonora-Lahontan Lake Basin, and (5) Bonneville Basin with numerous centers of differentiation. Most of the mammal species listed by Hall (1946) are found throughout the existing northern Nevada KGRAs.

The aquatic communities of the Northern Great Basin inhabit a number of areas that will be effected by geothermal development. Any aquatic area within the desert is by itself and its nature, unique. This uniqueness is due in part to isolation and in many cases not having been completely disturbed by man. A number of studies on these areas have been completed, including those by Brues (1927, 1928, 1932), La Rivers (1978), Nyquist (1963), Billings (1945), and others. With the exception of Brues, La Rivers, and Nyquist, most of these areas studied are not in potential geothermal development areas.

Rare and Endangered Animal Species

Those fish species from northern Nevada that are listed on the Federal rare and endangered species list include the Cui-ui (*Chasmistes cujus*) and the Lahontan cutthroat trout (*Salmo clarki henshawii*). The Cui-ui occurs only in Pyramid Lake, Nevada, completely within a Paiute Indian Reservation and not likely to be a center of geothermal development. The Lahontan cutthroat trout occurs at Summit Lake in the Black Rock Desert area and in certain areas of the Humboldt, Truckee, Carson, and Walker River systems of northern Nevada. Development along these areas may affect the habitat of this trout although most of the known areas of occurrence of the cutthroat are well outside the geothermal areas. In addition to the Cui-ui, the State of Nevada recognizes the Desert Dace (*Eremichtyhys acros*) and the Steptoe Dace (*Relictus solitarius*) as rare and endangered fish species. The Desert Dace occurs in the Black Rock Desert region at Soldier Meadow and the Steptoe Dace occurs in Steptoe Valley near Monte Neva Hot Springs and several other valleys on the eastern side of the State.

None of the amphibian and reptile species known to occur in northern Nevada are on the Federal-State of Nevada rare and endangered list.

Those bird species in Nevada that are considered rare, endangered or protected are listed in Table 4. This list includes those bird species protected under Federal laws in accordance with the Migratory Bird Treaty Act of 1918 and the Eagle Act of 1940. In addition, the State of Nevada lists the Southern Bald Eagle (*Haliaeetus leucocephalus leucocephalus*) and the Peregrine Falcon (*Falco peregrinus*) as endangered species. Nappe and Klebenow (1973) list the rare and endangered birds of Nevada as follows: White Pelican (*Pelecanus erythronhynchos*), White-faced Ibis (*Plegadis chihi*), Goshawk (*Accipiter gentilis atricapillus*), Bald Eagle (*Haliaeetus leucocephalus*) Ferruginous Hawk (*Buteo regalis*), Osprey (*Pandion haliaetus carolinensis*), Prairie Falcon (*Falco mexicanus*), American Peregrine Falcon (*Falco peregrinus anatum*), Sharp-tailed Grouse (*Pedioecetes phasianeclus columbianus*), Greater Sandhill Crane (*Grus canadensis tabida*), and the Western Yellow-billed Cuckoo (*Coceyzus americanus occidentalis*).

The only mammal in Nevada classified as rare is the Spotted-Bat (*Euderma maculatum*), however, the Mountain Beaver (*Aplodontia rufa*), Pika (*Ochotona princeps*), Douglas squirrel (*Tamiasciurus* sp.),

TABLE 4.

FISH, BIRD, AND MAMMAL SPECIES LISTED ON VARIOUS STATE, FEDERAL OR PRIVATE ENDANGERED SPECIES LIST

(There are no known reptile or amphibian, rare, threatened or endangered species in northern Nevada).

Species	Governmental Designation*		
MAMMALS	FEDERAL	STATE OF NEVADA	
1. SPOTTED BAT (*Euderma maculatum*)		R	
2. MOUNTAIN BEAVER (*Aplodontia rufa*)		P	
3. PIKA (*Ochotona princeps*)		P	
4. DOUGLAS SQUIRREL (*Tamiasciurus* sp.)		P	
5. FLYING SQUIRREL (*Glaucomys* sp.)		P	
6. GRAY SQUIRREL (*Sciurus* sp.)		P	
BIRDS	FEDERAL	STATE OF NEVADA	NAPPE AND KLEBENOW
1. SOUTHERN BALD EAGLE (*Haliaeetus leucocephalus leucocephalus*	E	P	E
2. GOLDEN EAGLE (*Aquila chrysaetos*)	1	P	
3. PIGEON HAWK (*Falco columbarius*)	1	P	R
4. PRAIRIE FALCON (*Falco mexicanus*)	1	P	D
5. SPARROW HAWK (*Falco sparverius*)	1	P	
6. PEREGRINE FALCON (*Falco peregrinus*)	E	E	E
7. COOPER'S HAWK (*Accipiter cooperii*)	1	P	
8. FERRUGINOUS HAWK (*Buteo regalis*)	1	P	D
9. GOSHAWK (*Accipiter gentilis*)	1	P	D
10. HARRIS HAWK (*Parabuteo unicinctus*)	1	P	
11. MARSH HAWK (*Circus cyaneus*)	1	P	
12. RED-TAILED HAWK (*Buteo jamaicensis*)	1	P	

TABLE 4 (Continued)

Fish, Bird, and Mammal Species Listed on Various State, Federal or Private Endangered Species List

Species	Governmental Designation*		
BIRDS (Cont.)	FEDERAL	STATE OF NEVADA	NAPPE AND KLEBENOW
13. ROUGH-LEGGED HAWK (Buteo lagopus)	1	P	
14. SHARP-SHINNED (Accipiter striatus)	1	P	
15. SWAINSON'S HAWK (Buteo swainsoni)	1	P	
16. WHITE-FACED GLOSSY IBIS (Plegadis chihi)	1	P	D
17. KING FISHER (Megaceryle alcyon)	1	P	
18. NIGHT HAWK (Chordeiles sp.)	1	P	
19. OSPREY (Pandion haliaetus)	1	P	R
20. BARN OWL (Tyto alba)	1	P	
21. BURROWING OWL (Speotyto cunicularia)	1	P	
22. GREAT HORNED OWL (Bubo virginianus)	1	P	
23. LONG-EARED OWL (Asio otus)	1	P	
24. SHORT-EARED OWL (Asio flammeus)	1	P	
25. BROWN PELICAN (Pelecanus occidentalis)	1 E	P	
26. TURKEY VULTURE (Cathartes aura)	1	P	
27. SHARP-TAILED GROUSE (Pedioecetes phasianellus columbianus)			E
28. GREATER SANDHILL CRANE (Grus canadensis tibida)			D
29. WHITE PELICAN (Pelecanus erythrorhynchos)	1	P	D

TABLE 4 (Continued)

Fish, Bird, and Mammal Species Listed on Various State, Federal or Private Endangered Species List

Species	Governmental Designation*		
FISH	FEDERAL	STATE OF NEVADA	DEACON ET AL.
1. DESERT DACE (*Eremichthys acros*)		R	T
2. STEPTOE DACE (*Relictus solitarus*)		R	SC
3. CUI-UI (*Chasmistes cujus*)	E	E	E
4. LAHONTAN CUTTHROAT TROUT (Salmo *clarki henshawi*)	T		T
5. LAHONTAN TUI-CHUB (*Gila bicolor obesa*)			SC
6. ALVORD CHUB (*Gila alvordensis*)			SC
7. FISH CREEK SPRINGS TUI-CHUB (*Gila bicolor euchila*)			E
8. INDEPENDENCE VALLEY TUI-CHUB (*Gila bicolor isolata*)			T
9. NEWARK VALLEY TUI-CHUB (*Gila bicolor newarkensis*)			SC
10. INDEPENDENCE VALLEY SPECKLED DACE (*Rhinichthys osculus lethoporus*)			E
11. CLOVER VALLEY SPECKLED DACE (*Rhinichthys osculus oligoporus*)			E

* P = Protected
R = Rare
T = Threatened
E = Endangered
D = Decreasing
SC = Special Concern
1 = Protected under Federal law - Migratory Bird Treaty and Eagle Act.

Flying Squirrel (Glaucomys sp.) and Gray Squirrel (Sciurus sp.) are listed as protected.

INDIVIDUAL KGRAs

In this section, several KGRAs shall be considered by vegetational community type and the related faunal populations. The grouping of KGRAs in this section was done in consultation with and at the direction of LLL personnel. Table 5 lists threatened and endangered plant species.

Rye Patch KGRA

In the area of the Rye Patch KGRA, two distinct vegetational communities are found. The Shadscale Community of the Salt Desert Shrub Zone and the Upper Sagebrush Community of the Transition Desert Shrub Zone.

Those plant species from the Rye Patch area that are listed in the Nevada Threatened and Endangered Plant Book include: Astragalus pterocarpus , Eriogonum anemophilum , Opuntia pulchella , Malchaeranthera leucanthemifolia , Phacelia inconspicua , Astragalus porrectus and Oryctes nevadensis .

The fauna of the Rye Patch KGRA includes the typical desert mammals, birds, amphibians, and reptiles as described by Hall (1946), Linsdale (1938, 1940), and Stebbins (1954, 1966). The composition of the animal communities will vary with the previously described plant communities. Of special concern in the Rye Patch area will be the Rye Patch Reservoir flora and fauna. The fauna is a typical warm water fisheries which includes various types of catfish, bass, sunfishes, and northern pike. The addition of brines from close-by geothermal developments could have a detrimental effect on the Reservoir. To the east of the Rye Patch geothermal area is the West Humboldt Range which is a relatively good upland and large game habitat area. Development in the area may not have a direct impact on these areas but the recreational use of the area by workers and their families could be detrimental to the wildlife habitat. Little is known as to the exact composition of these wildlife areas in and near Rye Patch.

Black Rock KGRA

In the area of the Black Rock KGRA, the dominant vegetational type is the Playa and Dry Lake Community of the Playa and Dry Lake Zone.

The plant species from the Black Rock area that are listed in the Nevada Threatened and Endangered Plant Book include: Astragalus alvordensis , Astragalus pterocarpus , Trifolium andersonii , Hackelia ophiobia , Silene scaposa var. lobata and Opuntia pulchella . In addition, Rogers and Tiehm (1979) have listed the following plant

TABLE 5.

THREATENED AND/OR ENDANGERED PLANT SPECIES BY KGRA

A. Black Rock Desert

   1. _Astragalus alvordensis_
   2. _Astragalus pterocarpus_
   3. _Hackelia ophiobia_
   4. _Trifolium andersonii beatleyae_
   5. _Opuntia pulchella_
   6. _Silene scaposa_ var. _lobata_
   7. _Dimeresia howellii_
   8. _Draba douglasii_ var. _douglasii_
   9. _Eriogonum desertorum_
   10. _Eriogonum rubricaule_
   11. _Nemacladus rigidus_

B. Kyle, Leach, and Dixie Valley

   1. None

C. Steamboat

   1. None

D. Rye Patch

   1. _Astragalus pterocarpus_
   2. _Astragalus porrectus_
   3. _Eriogonum anemophilum_
   4. _Opuntia pulchella_
   5. _Machaeranthera leucanthemifilia_
   6. _Phacelia inconspicua_
   7. _Oryctes nevadensis_

TABLE 5. (Continued)

Threatened and/or Endangered Plant Species by KGRA

E. Desert Peak, Stillwater-Soda Lake, Brady Hazen

1. *Astragalus porrectus*
2. *Camissonia nevadensis*
3. *Penstemon arenarius*
4. *Opuntia pulchella*
5. *Psorothamnus kingii*
6. *Oryctes nevadensis*
7. *Elodea nevadensis*
8. *Eriogonum lemmonii*
9. *Trifolium andersonii beatleyae*

F. Beowawe

1. None

G. Monte Neva

1. *Castillega salsuginosa*
2. *Haplopappus watsonii*
3. *Silene scaposa* var. *lobata*

species as candidate threatened, proposed endangered, recommended and sensitive species from the Charles Sheldon National Wildlife Refuge area: *Dimeresia howellii* , *Draba douglasii* var. *douglasii* , *Eriogonum desertorum* var. undescribed, *Eriogonum rubricaule* , *Nemacladus rigidus* and *Trifolium andersonii beatleyae* .

The fauna of the Black Rock geothermal area includes the typical desert mammal, birds, amphibians, and reptiles as described by Hall (1946), Linsdale (1938, 1940) and Stebbins (1954, 1966). In several of the warm water and cool water springs in the Black Rock area there occur unique populations of desert fishes. The Desert Dace, *Eremichthys acros* is found in Soldier Meadow, Humboldt County, Nevada; the Alvord chub, *Bila alvordensis* , in a number of springs and streams in the Sheldon Antelope Range area, Nevada, and the Lahontan cutthroat trout, *Salmo clarki henshawii* at Summit Lake, Humboldt County, Nevada. Little is known about other faunal communities in this area.

Beowawe KGRA

In the area of the Beowawe KGRA the dominant vegetational type is the Sagebrush Community of the Transition Desert Shrub Zone.

There are no known species of rare, endangered or threatened plants currently listed as occurring in the Beowawe area.

The fauna of the Beowawe KGRA includes the typical desert and mountain mammal, birds, amphibian and reptile species as described by Hall (1946), Linsdale (1938, 1940), and Stebbins (1954, 1966). Little is known about the fauna communities in and around Beowawe. The Humboldt River system occurs nearby and the effects of geothermal water discharge upon its ecosystem is of special concern for little is known about the river ecosystem along its entire length.

Steamboat KGRA

In the area of the Steamboat KGRA, two distinct areas of vegetational communities occur. To the west on the Sierra Nevada front is the Yellow Pine - White Fir Community of the Sierran Zone. To the east occurs a Pinyon-Juniper Community of the Pinyon Juniper Zone.

There are no known rare, endangered, or threatened plant species from the Steamboat area, however, there are numerous plant species listed from the Sierran Zone to the west.

The Steamboat KGRA has the typical desert and montane faunal species. In addition, a very large human population has developed in and around the Steamboat KGRA. The effects of geothermal development on this population is of special concern. In addition, any discharge from the geothermal area into Steamboat Creek would eventually affect the Truckee River, Pyramid Lake and the Truckee-Carson irrigation district near Fallon, Churchill County, Nevada. The Truckee River system contains the endangered Cui-ui (Chasmistes cujus) and the threatened Lahontan cutthroat trout (Salmo clarki henshawii). Little other scientific knowledge exist about the Steamboat KGRA.

Soda Lake, Hazen, Desert Peak, Stillwater, Brady KGRAs

In the area of the Soda Lakes, Hazen, Desert Peak, Stillwater and Brady KGRAs, the Greasewood-Shadscale Community of the Salt Desert Shrub Zone is the dominant vegetational type.

The following plant species are listed in the Nevada Threatened and Endangered Plant Book as occurring in the Desert Peak, Stillwater, Soda Lake, Hazen, and Brady KGRAs: Astragalus porrectus , Camissonia nevadensis Opuntia pulchella , Penstemon arenarius , Psorothamnus Kingii Oryctes nevadensis , Elodea nevadensis , Eriogonum lemmonii and Trifolium andersonii beatleyae.

The composition of the faunal communities in the Soda Lake, Hazen, Desert Peak, Brady, and Stillwater areas is typical of the plant desert and montane communities. In addition, there is an extensive agricultural district and wetlands wildlife habitat in the Soda Lake-Stillwater areas. The environmental concerns for this area are mainly the effects the various geothermal pollutants (boron, mercury, hydrogen sulfide, etc.) on the faunal communities in the agricultural and wildlife areas. This region is used by numerous upland game and migratory game and non-game species, in addition to numerous predator species, especially eagles, hawks, and owls. The effects of mercury is of special concern because various amounts of mercury have been reported from the Carson River drainage (Richins 1973) due to the residues dumped into the river system during the early mining days in Nevada.

Kyle, Leach, and Dixie Valley KGRAs

In the area of the Kyle, Leach, and Dixie Valley KGRAs, the Greasewood Community of the Salt Desert Shrub Zone is the dominant vegetational type.

The faunal communities for Kyle, Leach, and Dixie Valley KGRAs includes the typical desert species. Although no unusual species of birds or mammals are known from most of these areas, the wetlands habitat created by the outflow of the numerous springs in these areas provides numerous nesting and hunting areas for birds of prey and mammal predators. The freshwater areas also provide water and food for numerous desert species.

In Dixie Valley, the cool water springs provide a habitat for an undescribed subspecies of chub (Gila bicolor). In the summer of 1979, a young white-faced ibis was living in a pond on the Lamb Ranch. This species, once plentiful in the nearby Stillwater area, is now rare because of environmental changes. Further habitat disturbance could endanger the existence of this unusual bird.

Monte Neva KGRA

In the area of the Monte Neva KGRA, three distinct vegetational types are found. The Shadscale Community, the Greasewood-Shadscale Community of the Salt Desert Shrub Zone, and the Sagebrush Community of the Transition Shrub Zone.

Those rare, endangered or threatened plant species that occur in the Monte Neva KGRA include: Castilleja salsuginosa , Haplopappus watsonii and Silene scaposa var. lobata .

The animal communities in and around the Monte Neva KGRA are typical desert and montane mammal, bird, amphibian, and reptile species. Currently, the area around the hot spring is used as a hunting area for numerous species of birds of prey. The only animal species that is currently classified as rare by the State of Nevada is the Steptoe Dace, Relictus solitarus .

ENVIRONMENTAL PROBLEMS BY KGRA

Since the grouping of KGRAs under the "Individual KGRAs" section was not based upon ecological considerations. This section is based on those ecological considerations and potential problems, and separates many of those groupings, previously mentioned, into individual KGRAs.

The present data base for northern Nevada KGRAs is poor to non-existent. Until the necessary data base is assembled, it is difficult to predict the true nature and extent of environmental damages. Assuming interference of ecosystems will occur with development of geothermal resources, "worst-case" predictions are assumed.

Desert Peak

Problems : This KGRA has little standing water resulting in a few animal species present. There is one spring with a high boron content which may result in unusual plant communities in the vicinity but a major data gap exists relative to species inventories.

One plant, Penstemon arenarius , which is on the Nevada list of threatened and endangered species, is reported as occurring at Desert Peak.

Of major concern is the influx of off-road vehicles and subsequent disturbance of the area following development and improved access to the area.

Dixie Valley-Kyle-Leach KGRAs

Problems : Portions of the Dixe Valley KGRA are presently used for agriculture. Crops and cattle are raised in areas of the valley where there is sufficient water. Rare fish species are known to occur in several cold water ponds formed by the high water table. Unusual and endangered bird species were observed near areas of geothermal exploration. The marsh area of Dixie Valley which is used for grazing may provide winter habitat for migrating water fowl. Data on endangered plants from this area are lacking. Potential effects of population influx, damage to critical habitats, and land use conflicts with ranchers are considered major concerns along with the effects of improvement of access to the area.

Kyle and Leach KGRAs are north of Dixie Valley. The same concerns apply to these areas as well.

Black Rock KGRAs

Problems : Included in this evaluation are KGRAs located at Baltaza, Pinto, Double Boiling Spring, Gerlach, and Soldier Meadow, all located in or near the proposed Black Rock Wilderness Area. Development of these KGRAs would present a potential visual pollution source to the historic trail route which crosses the Black Rock Desert. According to proponents for establishing the trail as a historic monument, all areas visible from the actual trail are to be considered part of the historic area. On this alkali playa nothing blocks the view of the horizon in any direction. Any development would almost certainly be visible from the trail. Many of these hot and warm springs contain rare or unusual fish species. Geothermal exploration could alter the springs sufficiently to further endanger these populations. One such species known to occur in Soldier Meadow was removed from the Federal Register. Use of water from the habitat has again reduced the number of fish to the point of extinction. Unusual plants have been collected from several geothermal areas but baseline inventories of both flora and fauna are lacking. Access to the more remote portions of this area resulting from geothermal explorations is another major concern. Population influx on the tiny towns of Gerlach and Denio would present a major problem.

Stillwater-Soda Lake KGRAs

Problems : These KGRAs are situated in an agricultural valley. Runoff from irrigated lands together with the flows from the Carson and Truckee

River (via the Newlands Project) forms an important habitat for migrating waterfowl. This area is used both as a wildlife preserve and hunting area. Geothermal development may alter this critical habitat. Other potential problems are the land use conflicts with ranchers and sportsmen, population influx, and the resulting disturbances and air pollution effects from cooling tower drift on crops.

Of particular concern at Soda Lake KGRA is the effect of geothermal discharges into the Carson River. In additon to possible aquatic habitat damage resulting from dissolved minerals in the thermal water, the Carson River has a high mercury residue left from the Comstock mining and milling efforts nearly a century ago. Although most of this mercury is now in a bound form, added discharge could disturb this mercury sufficiently so that it would again become a serious environmental concern.

Astragalus lentiginosus recently removed from the Federal Register of Threatened or Endangered Flora is known to occur in the Soda Lake area. Recent reports indicate that although distribution of the species is limited to this area, the population is of substantial size. However, geothermal development at this KGRA could further endanger this unusual plant.

Brady-Hazen KGRAs

Problems : These KGRAs are located in areas already heavily disturbed by man. No plant or animal baseline inventories exist for these areas. Because of their non-pristine state, it is believed that no rare or unusual species occur. Direct uses of geothermal energy such as mineral baths, greenhouses, and food dehydrating plants have been attempted at Brady and Hazen. Adverse effects resulting from a relatively large population influx is perhaps of major concern here.

Rye Patch KGRA

Problems : The Rye Patch KGRA, located at Humboldt House, is situated near major electric transmission lines, a railroad, and an interstate highway. Of major concern is critical habitat damage to both terrestrial and aquatic ecosystems. The effects of geothermal waste discharge into the nearby recreation and fishery areas of the Humboldt River must be considered. The Humboldt Range, a few miles to the east of the KGRA, is an unusual and biologically little known area which may be critically affected by improved access and air pollution resulting from geothermal development. Baseline data for flora and fauna in this area are limited.

Monte Neva KGRA

Problems : This KGRA is a highly disturbed area. However, a plant which has been proposed for endangered species status in he Federal Register, Castilleja salsuginosa , is known from "a plot of ground no larger than a hectare" (Holmgren 1973) near Monte Neva Hot Springs.

Beowawe KGRA

Problems : The Beowawe area is presently used for ranching and mining. Emigrant trail routes transect the KGRA. Present land uses together with the increases in local populations comprise major problems to geothermal development of this site. However, of primary concern is the potential for habitat disturbance resulting from geothermal discharge into the Humboldt River, a few miles down the valley from the KGRA.

The Humboldt River downstream from Beowawe is used for agriculture, ranching, boating, and fishing. It flows through Battle Mountain, Winnemucca, and Lovelock, in addition to the recreation area at Rye Patch Reservoir. Possible alteration of this aquatic ecosystem must be investigated prior to development. Although no floral or faunal inventories exist for this area, unusual vegetation occurrences have been reported.

Beowawe is a favorite hunting area for upland game birds. The effect of geothermal development on the abundance of these species must be evaluated.

Steamboat KGRA

Problems : The Steamboat KGRA is located in a highly disturbed urban area. Runoff from present hot springs is discharged into Steamboat Creek which flows through several ranges and urban areas on its way to the Truckee River. The pollutants from present hot springs (including 4 mg/1 arsenic) are diluted by existing flow in the creek. Additional discharge from geothermal development could effect downstream users which includes the Pyramid Lake Indian Reservation, Pyramid Lake (home of the endangered Cui-ui and Lahontan cutthroat trout), and the residents of Fallon who obtain their drinking water from the Truckee River.

Visual and air pollution as well as effects of additional population influx are concerns of lesser importance. No rare and endangered species are known except for those previously mentioned in affected habitats. Because the area has been severely altered by man's activities for many years, it is unlikely that any unusual species, plant or animal, could be found in the immediate vicinity of the KGRA.

Other KGRAs

Problems : Other KGRAs located in northern Nevada present many of the same problems as the ones previously detailed but have not been considered here on an individual basis. The greatest problem is a lack of baseline flora and fauna inventories for most of the state, resulting in difficulty of assessing potential environmental damage as well as identification of threatened and endangered species.

ECOSYSTEM ISSUES AND RECOMMENDATIONS

This section is based upon discussions by participants in the Geothermal Overview Workshop. The comments and suggestions have been categorized and presented but do not necessarily reflect priorities.

1. In general, issues have to be considered as being specific to each KGRA. This is unfortunate but because of the number of KGRAs in northern Nevada and the vast geographical area over which they are found, there are a number of different ecosystems involved. Each has its own problems.

2. To a certain extent the issues may be grouped. Such a grouping is set forth below.

   a. A general lack of adequate biological inventories for the areas involved. This is particularly difficult since the least is known about the areas where development interest is greatest.

A solution to this issue would permit an adequate assessment of the next issue.

   b. What flora and fauna will be damaged by development and how critical are the ecosystems involved? What will the habitat loss be?

Once these two issues are answered we feel that the third can be considered.

   c. What will be the effects of improved access to development of these largely remote areas?

A consideration of the three issues above will permit an evaluation of what we see to be the fourth and final issue.

   d. What is the extent of the local direct and indirect effects and what are the cost/benefit tradeoffs?

An evaluation of this must consider but not be limited to items as:

1. Water discharge or seepage into local water systems.
2. Downwind drift of gases.
3. Effects of population influx on the existing community.
4. Effects of establishing new communities.

These "costs" must then be compared with the "value" of the resource to be recovered and the potential "gain" through its use.

Recommendations:

1. The need for long-term quantitative data with respect to flora and fauna prior to disturbance is of primary importance. This baseline information will be useful for determining the presence of any rare and endangered species as well as provide a data base against which post development monitoring can be compared.

2. The establishment of a centralized ecology data base for the entire state to identify gaps in information and provide a baseline prior to development. Input should come from all agencies and developers, and be accessible to the general public. This joint effort would save individual developers time, money and duplication of effort in addition to providing more extensive information than lies within the scope of any single developers goals. The information collected should be an accurate and impartial reporting of the ecosystem useful to each geothermal contractor and governmental monitoring agency. Joint funding for such a project should come from various governmental agencies, universities, and private enterprise and not be the responsibility of any one contractor or developer.

3. Adequate pre-planning is necessary prior to all exploration or development. Such action would minimize the cumulative impacts of all projects within an area. For example, the construction of one road which could be used by geothermal developers, miners, ranchers, etc. would have less impact than several roads, each taking a different route to essentially the same place.

4. Where possible, an "energy park" or centralized location should be established where several geothermal developments and/or other energy projects are grouped into one area. This would lessen the impact and endanger fewer habitats than if these projects were spread out. Possible locations for such a "park" are the Humboldt

House, Dixie Valley, Kyle, or Leach KGRAs.

5. The assessment of waste water quality and method of discharge is necessary prior to development. Many of the concerns previously outlined could be eliminated if geothermal waste were disposed of in such a manner to minimize the impact on an existing water source. However, if the water quality of the discharge is sufficiently high, the existing habitat could actually be improved by direct disposal. These assessments should be made before initiation of development.

6. If, following exploration, a geothermal site is to be abandoned, restoration of the site to its original condition is highly recommended. This requires baseline information of the ecosystem prior to disturbance. The use of ecological conscience in disturbing as small an area as possible and housekeeping prior to abandonment would lessen the impact of development and eliminate many potential concerns.

GUIDELINES FOR ECOSYSTEM ANALYSIS AT KGRAs

KGRAs present two problems which require that conventional desert ecosystem analysis be modified.

1. Normally, there is a source of ground water nearby, thereby creating a mini-ecosystem separate from the surrounding area.

2. There is no assurance that the actual habitat disturbance will be that close to the ground water, i.e., the actual drilling may be done hundreds of meters away in a neighboring ecosystem.

As a consequence, it is suggested that proper ecosystem analysis of a KGRA is at least a two part effort. The first should treat the "problem" as a point source around the ground water (if present). This is best done if the transects for both flora and fauna analysis radiate from the point source. The second part is done in a conventional manner with the lines going through the surrounding area in a random pattern. If there is close by cold ground water, this must be treated as a second point source since it represents a completely different ecosystem.

Conventional data relative to presence and number of all flora and fauna should be taken. Particular attention must be taken to collect and/or photo-record the plants and animals on the presumption that development of the KGRA will, to an as yet unknown extent, change the ecosystem. For the same reason, a map of the study area must be prepared and the area should be carefully observed for any unusual circumstances.

An appropriate level of effort for this task is 1500 m of line intercept and 1500 trap nights for mmammals. In addition, there would be plant collecting, invertebrate and reptile sampling, and the fishes analysis if any are present.

Such analysis must be done once during the May-August period for each area and should be done through several seasons to record variations. Once the baseline data is collected, the effort must be repeated in a developed KGRA for a period of years in order to record changes.

The level of effort suggested is not as difficult or as costly as it may sound. With optimum conditions, three investigators with six assistants could easily collect and do the preliminary analysis for a single area in a two week period.

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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter VIII

NOISE EFFECTS

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INTRODUCTION

The development and utilization of geothermal energy resources, like many other industrial operations, can be a source of unwanted sound. Geothermal industry noise emissions have become a significant environmental issue at The Geysers-Calistoga Known Geothermal Resource Area in northern California (Leitner, 1976). In this KGRA, major geothermal development projects have been constructed or proposed in proximity to a number of small residential communities. Some local residents who have chosen The Geysers area for its recreational and retirement values object to increased noise levels resulting from the truck traffic, the drilling of geothermal wells, and the venting of large quantities of superheated steam.

Therefore, it is important to evaluate the potential for environmental noise problems prior to large-scale geothermal development in northern Nevada. This chapter will identify key issues relating to noise effects. It will describe existing data that may be useful in resolving these issues: ambient noise conditions within the region, geothermal noise sources to be expected, types of sensitive noise receptors, and any applicable regulations or standards. Finally, it will outline the additional information needed to help ensure that geothermal development can proceed without creating unacceptable noise impacts.

KEY ISSUES

The development and utilization of vapor-dominated geothermal resource areas such as The Geysers field is likely to be accompanied by high noise levels from steam releases (Whitescarver, 1978). Noise emissions are expected to be of only moderate intensity in liquid-dominated fields because of the absence of unmuffled steam venting (Shinn, 1976). Thus far, geological evidence and exploratory drilling indicate that all known geothermal reservoirs in northern Nevada are of the liquid-dominated type. Furthermore, many of the promising geothermal resource areas are sparsely populated and remote from noise-sensitive receptor sites. For these reasons it seems unlikely that noise will be a serious environmental problem at most geothermal development sites in northern Nevada. Nevertheless, the following issues can be identified and may be significant at certain locations:

1. What noise levels are likely to be associated with the various stages of the geothermal development process in northern Nevada?

2. What will be the effects on local communities and sensitive land-uses?

3. What will be the effects on wildlife and domestic animals?

4. Are new noise regulations or special noise control technologies required?

EXISTING DATA BASE

The information needed to adequately address these issues includes quantitative data on geothermal noise sources and baseline noise conditions, the locations of proposed facilities and existing receptors, and noise propagation models appropriate to the terrain and meteorological properties of the area. With these data, it is possible to predict the impacts that geothermal projects will have on the noise environment at particular receptor sites and to make recommendations for such noise control measures and other mitigations as may be required.

Geothermal Noise Sources

Although no published noise information is available for geothermal industry operations in northern Nevada, extensive studies of noise emissions have been carried out at The Geysers-Calistoga KGRA in northern California (Atlantis Scientific, 1975, 1976, Bush, 1976, 1977; ECOVIEW Environmental Consultants, 1977; Environmental Impact Planning Corporation, 1977; and Sociotechnical Systems, Inc., 1977). Wells drilled into the vapor-dominated reservoir at The Geysers produce superheated steam at high pressure. The jet noise that results when there is large-scale venting to atmosphere has been the source of the majority of community complaints (Illingworth, 1976 and Leitner, 1976). Sound pressure levels (SPL) over 120 dB(A)* have been recorded at 15.2 m (50 ft) from well-venting operations and the noise can be heard at distances of 3.2 - 4.8 km (2-3 mi) (Illingworth, 1976). Noise abatement measures have been successful in reducing the frequency of venting episodes and in effectively silencing certain venting procedures, but additional work is needed to bring all sources under acceptable control (Leitner, 1976 and Whitescarver, 1978).

If, as expected, the geothermal reservoirs in northern Nevada are of the liquid-dominated type, no unmuffled venting of superheated steam should occur. Wells could be completely shut-in when not producing, eliminating the need to release geothermal fluids.

*dB(A), A-weighted sound level, is the SPL in decibels measured using a sound level meter with a weighting network (filter) approximating the frequency sensitivity of the human ear.

Furthermore, no venting should be necessary when wells are put back into production. Liquid-dominated geothermal fields can therefore be developed and operated without the problem of very high noise emissions. Major noise sources should not exceed 95 dB(A) at 15.2 m (50 ft) when treated with noise control techniques currently available.

A summary of noise sources expected to accompany geothermal resource development in the northern Nevada area is given below, along with typical SPL ranges.

1. Road and Site Preparation. -- Especially during the exploration and field development stages, heavy earth-moving equipment is used to prepare roads, drill pads, sumps, and sites for power plants and other facilities. Data from the EPA document PB 206 717 suggest a SPL range of 70-95 dB(A) at 15.2 m (50 ft) (U.S. Environmental Protection Agency, 1971).

2. Well Drilling. -- Drilling operations begin with exploration and continue through the field development stage. In addition, make-up wells must be drilled periodically during the production stage to replace original wells whose yield has declined. The dominant noise sources associated with drilling are the large diesel engines which power the rotary rig and mud pumps. Typical SPL during drilling when mud is used as the circulating medium ranges from 75 to 85 dB(A) at 15.2 m (50 ft) (Whitescarver, 1978).

   Compressed air is routinely used as a circulation medium in the final phase of drilling at The Geysers; the large compressors and the release of the air to atmosphere can be troublesome noise sources with SPL up to 5 dB(A) above that recorded for mud drilling (Whitescarver, 1978). Compressed air drilling will probably not be used in northern Nevada.

3. Production Testing. -- The process of flowing geothermal wells to test production capability begins in the exploration stage and will occur periodically for the life of the field as new make-up wells are drilled. Although there are no published data on SPL's during production testing at Nevada geothermal wells, this operation can be a significant source of noise. It is likely that SPL's exceed 95 dB(A) at 15.2 m (50 ft). Fortunately, relatively inexpensive and effective noise reduction techniques are available if needed (Dick Benoit, personal communication).

4. Facilities Construction. -- Construction of a power plant, pipelines, and transmission lines involves the use of many standard pieces of heavy motorized equipment. The resulting SPL can be estimated at 70-95 dB(A) at 15.2 m (50 ft) by reference to the EPA document PB 206 717 (U.S. Environmental Protection Agency, 1971).

5. Operation of Geothermal Field and Power Plant. -- The noise emission characteristics of geothermal power plants, including turbine building, cooling tower, and steam jet ejector system, are well-documented and adequate data are readily available. SPL of 75-85 dB(A) are typical at 15.2 m (50 ft) from the cooling tower, the dominant noise source (Bush, 1977 and Pacific Gas and Electric Company, 1977). Other potential noise sources are the flash units in which a portion of the geothermal fluid is allowed to flash to steam. These units may be located at the wellheads or near the turbine building, although the exact design will depend on the electric generation technology used. SPL at 15.2 m (50 ft) from a flash unit undergoing testing in Imperial Valley was measured at 85 dB(A) (P. Leitner, unpublished data). Any downhole pumps required to produce the geothermal fluid and reinjection pumps used to dispose of residual liquids should be powered by electric motors; these motors are not expected to be significant noise sources.

6. Vehicular Traffic. -- Auto and truck traffic is an important source of noise throughout the life of any geothermal project, with maximum SPL ranging from 70-95 dB(A) at 15.2 m (50 ft) depending on the type of vehicle (U.S. Environmental Protection Agency, 1971).

Existing Noise Environment

Most geothermal areas in northern Nevada are sparsely populated and much of the land is administered by public agencies. Major land uses are livestock grazing, watershed, outdoor recreation, and wildlife habitat. There are mineral extraction activities in the vicinity of some geothermal areas and farming is carried out in the irrigated valleys.

Quantitative data on ambient noise conditions are essentially nonexistent for northern Nevada. However, in the absence of activity by aircraft or motorized vehicles, it can be assumed that the environment is generally very quiet. A large series of measurements at similar remote sites in the California desert indicate that ambient SPL's may be as low as 14 dB(A) under windstill conditions when there are no bird or insect sounds (Bondello and Brattstrom, 1978). A summary of the results of this study showed that 82.6% of all ambient SPL's measured in the desert environment under natural conditions were below 35.5 dB(A). Wind and rain could result in significant increases in SPL, with values as high as 53 dB(A) recorded in wind velocities up to 25 kilometers per hour (16 mph). The range of ambient SPL's should be quite similar at most geothermal resource areas in northern Nevada under natural conditions.

At the present time, intrusive man-made noise sources are most likely to be associated with the transportation corridors that cross northern Nevada. A number of geothermal areas are located near Interstate Highway 80, while others are adjacent to the Western Pacific and Southern Pacific railroad lines. Several commercial airline routes also pass over various geothermal prospects. In addition to aircraft and motor vehicles, machinery used in mining and farming can be a source of noise in several areas. In most cases, noise emissions associated with pre-existing human activity probably do not significantly increase ambient levels above the natural background.

Noise Receptor Sites

Any analysis of the potential for noise impacts must consider the types and locations of noise receptors in the vicinity of a project site. Residences, schools, and healthcare facilities are particularly sensitive to noise intrusion and require special consideration to guard against unacceptable impacts. In certain parts of the Truckee Meadows near Reno and perhaps at some other sites, geothermal development may occur in the future within 1.6 km (1 mi) of sizeable urban communities. Because of the concentration of residential receptors, these areas may be very sensitive to noise impacts. Since many geothermal fields in northern Nevada are remote from population centers, such receptors will often not be of concern. However, it should not be assumed that even very small rural communities or isolated ranch homes can be subjected to noise impacts without adverse reaction. Other noise receptor sites that should be considered are outdoor recreation areas, designated wilderness lands, and critical wildlife habitats such as raptor nesting cliffs, waterfowl concentration areas, and water sources. The locations of sensitive receptors in a given geothermal resource area can almost always be readily determined by consultation with local, State, and Federal agency staff.

Noise Propagation Models

Once noise sources have been identified and characterized and the location of sensitive receptors has been determined, an adequate noise propagation model will allow accurate prediction of SPL and frequency spectra at the receptor. Methods that are currently in use at The Geysers-Calistoga KGRA in northern California seem to give reasonable results and can probably be adapted for use in northern Nevada (Bush, 1977; Pacific Gas and Electric Company, 1977; and Timmons and Whitescarver, 1978). These field-tested noise propagation models indicate that an attenuation of at least 40 dB can be expected over a distance of 0.8 km (0.5 mi). This suggests that the loudest geothermal noise sources expected with the development of a liquid-dominated reservoir would be attenuated to about 55 dB(A) at that distance.

Noise Criteria and Standards

Community Noise

The so-called "Levels Document" published by the EPA identifies environmental noise levels which, according to the best available scientific studies, appear to protect against community annoyance and activity interference (U.S. Environmental Protection Agency, 1974). The criterion proposed in this document for residential areas, schools, and hospitals is an outdoor day-night equivalent sound level (L_{dn})* of 55 dB. This level provides useful guidance in judging the acceptability of noise intrusion, but in no way represents a Federal standard. The document does not consider the economic or technological feasibility of attaining such a level, nor does it consider local needs and attitudes. For example, this criterion may not be adequate in some rural areas because of low existing ambient noise levels. Under these conditions, geothermal industry operations may be audible at considerable distances and could lead to annoyance even at noise levels well below an L_{dn} of 55 dB.

There are no State standards or regulations governing community noise levels in Nevada. Industrial noise emissions are subject to regulation only insofar as they may affect the occupational health of workers. The Nevada Industrial Commission requires that noise exposure in the workplace be subject to the same limits set forth by the Federal Occupational Safety and Health Act of 1973.

There are no local ordinances in Nevada relating to noise control. City and County governments have statutory authority to control noise emissions, whatever the source, if they can be shown to constitute a public nuisance. In order to apply this control, however, there must be a demonstration of bodily injury or property damage; annoyance is not a valid reason for requiring noise abatement.

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*L_{dn} day-night equivalent sound level, is the 24-hour A-weighted sound level that contains the same total acoustic energy as the actual time-varying sound, with a 10 dB penalty applied to the levels from 10:00 p.m. to 7:00 a.m.

The only published environmental noise criterion which would specifically apply to geothermal industry operations is that contained in the U.S.G.S. Geothermal Resources Operational Order No. 4 (USDI Geological Survey, 1975). This document states that geothermal-related activities on Federal leases shall not exceed a noise level of 65 dB(A) at the lease boundary or at 0.8 km (0.5 mi) from the source, whichever is greater. No such criteria exist for geothermal operations on land leased from the State or from private owners.

Domestic Livestock and Wildlife

There are no generally accepted criteria which would apply to the prevention of adverse noise effects on animals. It must be assumed, in the absence of definitive studies, that application of the criteria suggested for humans in the EPA "Levels Document" will serve to protect animals against behavioral disruption and physiological damage from noise (U.S. Environmental Protection Agency, 1974).

RECOMMENDATIONS

In general, adequate information is available to assess the potential for environmental noise impacts from geothermal resource development in northern Nevada. Although it does not appear that noise will be a significant problem, additional data of certain kinds would be very useful in future impact analyses.

Source Term Measurements

Sound pressure levels and frequency spectra are not available for some geothermal operations that may be important noise sources. These activities include (1) test flowing of full-scale fluid production from individual wells and (2) the operation of flash units at the wellhead or near the power plant to separate steam from residual hot water. Noise emissions data for these processes should be collected in the near future through field measurements at appropriate locations in the Imperial Valley, at Roosevelt Hot Springs in Utah, and in Nevada.

Ambient Noise Measurements

Existing environmental noise conditions should be documented prior to development at all sites where commercial use of geothermal resources is proposed. Measurements should be made in general conformance with the guidelines of the Geothermal Environmental Advisory Panel (1976). Sampling would normally be carried out at key locations within the geothermal leasehold unit, at its boundaries, and at nearby receptor sites; a map of these monitoring locations would be prepared. It is desirable to measure both A-weighted and C-weighted * SPL. The results should be expressed as equivalent SPL (L_{eq})**, as day/night equivalent SPL (L_{dn}), and as the statistical descriptors L_{10}, L_{50}, L_{90}***. In addition, a description of existing noise sources at each monitoring location should be provided.

Noise Receptor Sites

A map should be prepared that shows the location of sensitive noise receptors in the vicinity of a proposed geothermal development area. These receptor sites should include:

1. Residences
2. Hospitals
3. Schools
4. Recreation Sites
5. Wilderness Areas
6. Sensitive Wildlife Areas

The mapping effort should be extended up to 6.4 km (4mi) beyond the sites of proposed geothermal development activities.

Noise Criteria and Standards

Noise emissions are expected to be of moderate intensity during the development and operation of geothermal facilities in northern Nevada. There should be little difficulty in meeting the standard of 65 dB(A) at 0.8 km (0.5 mi) from the source set by the U.S. Geological Survey (USDI Geological Survey, 1975). However, if sensitive receptors or land uses exist within 3.2-4.8 km (2-3 mi) of a project site, it would be well to consider the need for a noise standard lower than 65 dB(A) or even below an L_{dn} of 55 to avoid annoyance and activity interference. For example, special consideration might be given to noise regulation for development and

* C-weighted SPL or dB(C) is the sound level in decibels measured using a sound level meter with a weighting network (filter) that does not de-emphasize the lower and higher frequencies as much as the A-weighted network, but approximates the overall SPL.

** equivalent sound level, is the constant A-weighted sound level that, for a given period, contains the same total acoustic energy as the actual time-varying sound.

*** L_{10}, L_{50}, and L_{90} are the A-weighted sound levels that are equaled or exceeded 10, 50, and 90 percent, respectively, of the time.

activities at Steamboat Hot Springs south of Reno, which is in close proximity to residential areas. At more remote geothermal fields, noise from such sources as unmuffled production testiong may be audible at distances in excess of 4.8 km (3 mi) because of low ambient sound levels. Noise reduction measures could be warranted if there is a likelihood of adverse community reaction. In most cases, a careful analysis of the expected source levels and available noise control strategies should indicate economically feasible ways of avoiding significant impacts.

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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter IX

SOCIO-ECONOMIC IMPACTS

by

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INTRODUCTION

Growing worldwide shortages of fossil fuels along with the rapid petroleum price increases experienced throughout the 1970's have stimulated considerable interest in the development of alternative energy sources. One of these alternatives, the use of geothermally heated water for the production of electricity and for commercial and residential applications of space heating, has come under recent investigation in a number of Western States because of the known presence of geysers, hot springs, and other geothermal activity. Nevada is one of these states.

The purpose of this study is to examine the potential for socioeconomic impacts that would result from the development of geothermal resources in northern Nevada. The first section examines some of the basic economic considerations in determining the feasibility of developing a particular geothermal resource. The second section relates those considerations to the areas in northern Nevada that have been cited as having the greatest potential for development. The third section sets out a model for estimating the economic impact that geothermal development will have in nearby towns or cities; most of Nevada's geothermal sites are in very rural settings, so a model is developed to address this particular situation. The final section offers some policy suggestions which are likely to improve the economic environment for development of geothermal resources and minimize the negative effects development may have on local or regional communities.

ECONOMIC CONSIDERATIONS FOR GEOTHERMAL DEVELOPMENT IN NEVADA

Nevada has considerable potential for geothermal resource development because of the widespread presence of hot springs and geyser activity; altogether, over 600,000 acres of land in Nevada have been designated as Known Geothermal Resource Areas (KGRAs) by the U.S. Geological Survey, most of them in the northern half of the State (see Figure 1).

Nevada's geothermal resources have only been developed in minor ways in the past, mainly for space heating, water heating, or the heating of swimming pools or commercial mineral spas. Most of these applications have occurred in the Reno-Sparks area of Washoe County (Garside and Shilling, 1979). Outside of the Reno-Sparks area, even more limited uses of space and water heating by geothermal heat can be found, but there are a few commercial applications that have been made. For example, at Brady Hot Springs, in Churchill County, a hot water well is used by Geothermal Food Processors, Inc., to operate a vegetable dehydration plant, and at Wabuska in Lyon County and Wally's Hot Springs in Douglas County, geothermal heat is used in greenhouses for the year-round growing of vegetables. Also, the geothermal waters at Steamboat Springs in Washoe County have been used for the casting of plastic explosives (Mendive, 1976).

The use of geothermal resources for residential heating and small commercial applications may become more common in the years ahead as alternative energy costs increase, but the magnitude of application is limited by the fact that such uses are highly site-specific, and Nevada does not have the population density in the vicinity of its geothermal resources to fully exploit its resources for those purposes.

However, there has been considerable interest in recent years in the use of geothermally heated water or steam for the generation of electrical energy. This particular use in Nevada has not developed in the past for three main reasons, one dealing with the economics of electricity production, a second with the ambiguities and difficulties in leasing procedures on Federal lands, and a third with the relative absence of clean steam geothermal resources. In past years, other sources used in energy production, such as coal, natural gas, hydroelectric, and nuclear, have been inexpensive enough that it was not economically feasible to develop the new technologies and make the capital expenditures necessary to develop geothermally powered electricity production.

The only site in the United States presently using geothermal steam for electricity production is The Geysers, north of San Francisco, and the resource there is pure dry steam which has a low mineral content and remains in vapor form in the production process. Consequently, the resource is readily adaptable to existing technologies and equipment. Nevada's geothermal resources are all highly mineralized and of the hot water type rather than dry steam, so new techniques and equipment would have to be tested and adapted before commercial electricity generation could be undertaken. With the increasing costs of other energy sources in recent years, and with the new substantial interest of the Federal Government in the development of new commercial energy sources, new technologies are being developed and a number of hot water geothermal power plants are under construction in California and New Mexico.

Assuming these new technologies prove to be economically efficient and reliable, then a number of geothermal resource sites in Nevada could be developed for commercial energy production. This would allow Nevada to become less dependent on conventional power production for its own needs and possibly to become a net exporter of energy in the years ahead.

In assessing the potential for economic development of a particular geothermal resource, a number of factors need to be examined. First, in terms of the alternative uses available for the resource, the size, temperature, pollution potential, and location all need to be determined. Residential space heating, for example, would only be feasible if there is a fairly high density of population to service in the immediate vicinity of the resource and there are no serious air or water pollution problems. Since most of Nevada's geothermal resource sites are located miles from population centers, this potential use is not very promising. Commercial space heating applications are not quite so restricted, and will depend to some extent on the ingenuity of the commercial or industrial operation in applying geothermal heat to the production process. Site location would be important only to the extent that it influences the operation's costs of labor and the transporting of materials, and costs of land. Land use conflicts resulting from air or water pollution generated by use of the geothermal resource could also be a constraint. However, to date, commercial or industrial applications have been very limited in scope and size.

It seems then that the critical questions in evaluating a particular geothermal resource deal with whether or not it can be developed as an electricity generating source. Appropriate analysis would encompass two major categories of concern: first, are the natural conditions suitable for the economically feasible production of electricity from the resource, and second, are the beneficial and adverse impacts on the immediate region and surrounding communities such that development of the resource is desirable from a public policy perspective in that particular region. This section examines factors that will be influential in answering the first question; parts of the second question are addressed in the section "Economic Impacts of Potential Geothermal Development."

The examination of economic feasibility can be further subdivided into three categories: factors relating to costs and techniques of production, factors relating to the competitiveness of the final product in comparison to electricity produced by other means, and factors relating to legal and institutional relationships that can influence either cost or revenue streams. The costs of production would initially incorporate the cost of drilling exploratory wells and an *a priori* assessment of the likelihood of the wells resulting in a productive facility. Beyond the exploration state, labor and other construction costs could be site-specific to the extent that wage premiums may be necessary to compensate for high time and money costs of commuting from the nearest community, or to the extent that it is necessary to provide housing in the vicinity of the geothermal resource.

Once a geothermal power plant is in operation, labor costs of operation and maintenance will depend on the degree of mineralization that exists in the hot water or steam from the resource, the technology that is being used to convert the resource into electricity, and the amount of damage the resource does to the capital equipment in the conversion process. Pure dry steam, such as that at The Geysers in California, is not found in Nevada. Consequently, new technologies would have to be adopted into the production process, and this creates uncertainty with respect to both the reliability of continuing power generation operations and the costs and frequency of required maintenance. Other things equal, the cooler and the more mineralized the geothermal water, the more expensive it will be to operate and maintain the power generating facilities.

Power plants that are adaptable to the geothermal resource sites in Nevada would be either or the "binary" or "flash steam" variety (Olson and Breindel, 1976). Both types of plants are highly capital intensive, and both exhibit economies of scale in the 10 megawatt (MW) to 50 MW range (Olson and Breindel, 1976). For example, with a flash steam plant, capacity (capital) costs per kilowatt-hour decrease approximately by half as the plant's capacity is increased from 10 MW to 50 MW. Furthermore, with a flash steam plant, operation and maintenance costs also decline per kilowatt-hour generated as a function of size, though total yearly operating costs are highly sensitive to both the degree of capacity utilized and the brine temperature of the resource (Olson and Breindel, 1976). Also, capital costs are sensitive to the temperature of the brine; using 1975 dollars, Olson and Breindel estimated that the temperature variations from 250° F to 400° F would reduce the capital costs per kilowatt-hour of capacity from $750 to $450 (Olson and Breindel, 1976). For the purpose of this study, it will be assumed that because of the economies of scale characteristics of geothermal resource power plants, plants will be built at a 50 MW capacity.

Other factors that will affect costs, and therefore feasibility, of any particular geothermal resource, would include distance from a population center that could utilize the generated electricity, or alternatively, distance from existing transmission lines that could be linked into by the facility. Other things equal, the greater the distance electricity must be transmitted, the greater are the construction costs of transmission lines and the greater the "leakage" of electricity from the transmission lines.

Another cost consideration is the amount of pollution abatement equipment that would be necessary to mitigate environmental damages to the local air quality and to surface and ground waters. Water pollution damages would depend on the existing quality of surface and ground waters, the mineral composition and content of the brine utilized in the production process, and alternative uses of ground and surface waters, such as residential or agricultural. In sparsely populated rural areas, alternative water uses are likely to be limited, and pollution abatement on water quality and water temperature may only be necessary when the brine contains substances that might adversely affect crops or pose a threat to livestock, such as boron or arsenic. If these are not serious issues, then the brine might be a useful by-product of the production process by increasing the amount of water available for agriculture or by allowing the extraction of economically desirable minerals.

Geothermal resources are often accompanied by the presence of H_2S (hydrogen sulfide) which produces an unpleasant odor and, in great enough concentrations, is noxious. The potential health hazard would be a concern both for workers in the vicinity of the plant and for residents of the area; if concentrations are low enough that only the unpleasant odor is a concern, then this is likely to pose a serious problem only in densely populated areas. Mitigation measures would also be appropriate to meet State and Federal air and water quality standards, regardless of the presence or absence of damages to other affected parties in the region.

How competitive geothermal energy production will be relative to electricity produced by other resources is a broad question requiring assessment of the future availability and cost of the alternative resources, the cost of producing electricity with those resources, including environmental and safety mitigation costs, and projections of future demand for electricity in the Western United States. Casual observation would indicate that electricity production by geothermal energy compares favorably to fossil fuels in the medium and long term because of the rising prices and decreasing availability of fossil fuels, and compares favorably to nuclear resources because of the safety and disposal problems that accompany nuclear power production. However, a detailed analysis of this question is beyond the scope of this overview.

Another set of factors that are important in influencing the perceived economic feasibility of particular geothermal development projects are the legal and institutional relationships that define property rights over the resources, surrounding lands, and other affected entities. These relationships come into play in two ways: first, as long as existing laws and regulations concerning property rights and liabilities are ambiguous, they create uncertainty for the potential developer of the resource; second, if such laws or regulations are altered or clarified, they can affect the revenue and cost streams over the expected life of the power plant. As in most other Western States, Nevada has as of yet done little to define a regulatory structure for the geothermal energy industry or to address areas of potential conflict in property rights, such as conflicting land or water uses, or pollution related problems. Also, the Federal Government has not yet determined land use restrictions for numerous geothermal resource sites that are located on Federal lands and are being considered for restrictive classifications, such as wilderness areas or "desert trails" (McNamara, 1979). The effect of these uncertainties is to discourage even preliminary exploration by potential developers if there is a substantial risk that development will ultimately be blocked by legal or regulatory restrictions.

The second area in which institutional factors can influence feasibility is more amenable to economic analysis: the determination of tax policies and tax rates, which will affect a project's cost and revenue flows in a manner that can be analyzed with other cost and revenue projections. The determination of the tax structure for a new, as of yet undeveloped, and potentially profitable industry should attempt to meet the following objectives. First, tax policies should be structured so that enough revenues are generated to cover the added costs of provision of public services and infrastructure for the localities and regions affected by geothermal development. In general, electricity generated by a geothermal plant would provide benefits to residents outside of the region in which it is generated. However, production will increase employment and possibly population, with resulting increased demands on a region's resources. As a consequence, new costs could be incurred by that region's public sector. The project should be taxed in a manner to adequately cover these costs (Atkinson and others, 1978; Hannah, 1979). Second, tax policies should attempt to minimize the disincentive effects on investment and production. Since any tax policy will reduce the potential profitability of a particular project, the two objectives will be somewhat in conflict with one another.

Given the present tax structure in Nevada, the two major sources of tax revenue from a geothermal power plant would be property taxes and taxes related to the volume and the value of production. Currently in Nevada, property taxes on an electrical generating unit under construction are allocated wholly to the site county. The assessed value is set at 35% of "full cash" value and the local tax rate is applied (Nevada Revised Statutes). Once a unit is completed, it is assessed at 35% of full cash value and allocated among the State's counties according to the local tax rates multiplied by the percentage of total transmission line mileage within each county.

Recent legislation in Nevada may eventually remove geothermal resources from the property tax roles (Senate Joint Resolution 19, 1979). If not taxed as real property, productive geothermal resources would be taxed under the net proceeds of mines tax, while nonproductive geothermal resources would be exempt from taxation (Nevada Legislative Council Bureau, 1978). Basically, the net proceeds tax law allows for the deduction of necessary expenses to mine and refine the product from the gross proceeds in arriving at an assessment value to which is applied an appropriate local tax rate. This method of taxation automatically adjusts the assessed value of the mine to the revenue flow from sale of the resource and the costs involved in extraction and production (Nevada Legislative Council Bureau, 1978). However, for geothermal resources, adequate measures of the value of the resource have not yet been determined, so assessment of productive resources has not yet been undertaken. Specific tax treatment of geothermal resources remains under investigation by the Nevada Department of Taxation.

GEOTHERMAL RESOURCE SITES IN NORTHERN NEVADA

There are a number of areas in northern Nevada that have often been mentioned as possible feasible sites for geothermally powered electrical generating facilities. The six areas that will be covered in this analysis are: Desert Peak (Brady-Hazen), Steamboat Hot Springs, Dixie Valley, Humboldt House, Beowawe, and Gerlach Hot Springs. With the exception of Steamboat, all are located at isolated sites and, with the exception of Gerlach, all have attracted the interest of major geothermal developers. The basic characteristics of each location are discussed below.

Desert Peak is located in Churchill County's north end, about 20 miles from the towns of Fernley and Fallon, and about 50 miles northeast of Reno. Land ownership is about 50% private (mainly Southern Pacific Railroad) and 50% Federal. Major exploration efforts have been undertaken by Phillips Petroleum Company and, should power facilities be constructed, the public utility involved will be Sierra Pacific Power Company (Anderson, 1979). The estimated capacity of Desert Peak is at least as great as any other prospect in northern Nevada; a USGS survey estimates the power potential at 750 MW, with a water temperature of 400° F (U. S. Geological Survey, 1978). There are already four test wells that have been drilled by Phillips Petroleum, and Phillips is presently negotiating with Sierra Pacific for potential power plants.

Steamboat Springs, which is one of the better known geothermal areas in the Western United States, is located in Washoe County about 12 miles south of Reno and 20 miles north of Carson City. It is a hot water reservoir with water temperatures in the 400° F range, and an estimated capacity of 350 MW. Principal potential operators for Steamboat include Phillips Petroleum and Gulf Mineral Resources Company. It lies within the Sierra Pacific service area. Five test wells have been drilled there (by Phillips) from depths of 800 feet to 3,000 feet.

Dixie Valley is located in the northeastern portion of Churchill County and southeastern portion of Pershing County, about 110 miles from Reno. Exploration in the area is fairly recent, so that estimates on water temperature and the capacity of geothermal power plants have not yet been made. However, the one deep well drilled by Sunoco Energy Development Company in 1978 generated results which "...have been very encouraging and have caused the scheduling of drilling by two other operators" (Anderson, 1979). As of December 1979, five deep wells had been completed and another was in process. Access to Dixie Valley is poor, being limited to a dirt road that runs north to Winnemucca (about 60 miles) and south to U.S. Highway 50 (about 40 miles). It, too, falls within the Sierra Pacific Power service area.

Humboldt House is a geothermal area located about 35 miles from Winnemucca and Lovelock and 120 miles from Reno, in Pershing County. It has an estimated water temperature of 360° F and a potential capacity of 47 MW; however, one report indicates "...operator feels that they (sic) have only penetrated a shallow auxiliary reservoir and that the main reservoir exists at depth and will contain water at temperatures of approximately 430° F" (Anderson, 1979). Three wells have been drilled in the area to date, two by Phillips Petroleum and one by Union Oil Company. Humboldt House is within the Sierra Pacific Power Company service area.

Beowawe is located near Interstate 80 about 40 miles east of Battle Mountain and 40 miles west of Elko, in Eureka County. There are a total of six deep wells in existence at Beowawe, and initial exploration there was done by Magma Power Company in the late 1950's. The estimated water temperature for the area's geothermal reservoir is 412° F, and the estimated power plant capacity is 127 MW. At present, both Chevron Oil Company and Getty Oil Company hold geothermal leases in the area, and the area falls within the service area for Sierra Pacific Power Company.

The Gerlach Hot Springs are located just outside of the small town of Gerlach in Washoe County, approximately 100 miles north of Reno. The estimated temperature for the Hot Springs are in the vicinity of 340° F, and the estimated power plant capacity is at 34 MW (U.S. Geological Survey, 1978). One apparently unsuccessful well was drilled by Sunoco in 1979. Gerlach is within the Sierra Pacific Power Company service area.

ECONOMIC IMPACTS OF POTENTIAL GEOTHERMAL DEVELOPMENT

If the firms presently involved in exploration and feasibility studies of Nevada's geothermal resources decide to build full scale power plants in the vicinity of the resources, they will generate numerous effects on the regions and communities close to the sites. The purpose of this section is to outline a simple methodology for evaluating the economic impacts such developments would have in the State and the region and, more specifically, point out those changes affected communities could expect in total employment, expenditures, and population.

It will be assumed, for purposes of making preliminary impact analyses, that each location will be built to its capacity in units of 50 MW plants at a particular site. Drilling will take one year, followed by two years of construction of the facility, and during the last three months of the second year, transmission lines will be built. The plant would begin power production at the end of the third year. At the end of one year of operation (presumably to determine the additional potential for new power plants), drilling for a second plant would begin. The cycle would then repeat itself until enough power plants would have been built to fully utilize the site's estimated capacity for power generation.

It is further assumed that for a particular construction project on a power plant, the drilling operations would employ 75 people for one year, construction would employ 65 people for two years, construction of transmission lines would require 20 persons for three months, and once the plant was in operation, there would be permanent employment of 35 persons as long as the plant continued to operate (Energy Research and Development Administration, 1977). Except for the employees needed for the operation and maintenance of the operating plant, all employment is considered temporary; this will have implications for the type and location of housing by the labor force at each geothermal site. Estimates of employment and number of power plants for each location are provided in Table 1.

Because the geothermal resources are fundamentally nonrenewable, the development to capacity of a resource site could lead to its exhaustion in a fairly short period of time, say 30 to 50 years. If this were to occur, then the closing down of electric generating operations would also have economic ramifications on the immediate area and the surrounding communities. The severity of impact would depend on how quickly operations are closed down, whether or not the remaining geothermal resources are used in any alternative production processes, and the degree of economic dependence of the immediate area and the surrounding communities on incomes generated by the operations. Since employment projections for the electric generating operations are relatively low, it is unlikely that these "pull-out" impacts would have much effect on the surrounding communities. However, the economic base of the immediate area could be completely eliminated if it were totally dependent on the geothermal operation.

It is quite possible that when a resource site is no longer economically feasible for electricity generation, it may still attract alternative users who can effectively exploit the remaining resource. Power plant construction and operation will require the provision of considerable infrastructure into the area, and new operations would be able to take over the existing controllable wells, as well as benefit from the public and private investments that had been undertaken at the site during power plant operations.

Since most of the sites with geothermal power production potential in northern Nevada are located in very isolated areas, it is necessary to come up with a methodology to allocate workers among the various communities in the general vicinity of the plant site. Lacking any empirical data on this problem, the following assumptions are used in order to estimate what proportion of the labor force will remain at the site (for example, in campers or company provided housing) and what proportions will locate at communities some distance from the site and commute in to work. The assumptions are:

1. Other things being equal, a larger proportion of workers will prefer to live in a larger community than a smaller community;

2. the farther a community is from the plant site, the greater the proportion of workers who will live at the site;

3. a greater proportion of temporary workers will live at the site than permanent workers; and

TABLE 1

Geothermal Power Plant Sites and Employment Estimates

Site	MW Capacity	# of Power Plant	Maximum Employment	Years to Buildout
Desert Peak	750 MW	15	575	59**
Steamboat	350 MW	7	295	27**
Dixie Valley*	N/A	N/A	N/A	N/A
Humboldt House	47 MW	1	85	3
Beowawe	127 MW	3	155	11
Gerlach	32 MW	1	85	3

* Assume for Dixie Valley 150 MW and 3 power plants

** If these sites were initially successful and the capacity estimates were accurate, it is highly likely build-out would occur much more rapidly and with larger (i.e., 100 MW) power plants.

4. other things equal, a community close to the site is preferred by more workers to one more distant from the site.

Applying these assumptions to the six potential sites, estimates of the proportions of workers who would reside at the site and in the nearest two communities to each site are presented in Table 2. These figures are naive estimates and could be improved with further study.

In order to estimate the employment impacts of geothermal development on the various communities, the information from Tables 1 and 2 was used in conjunction with 1978 employment estimates to determine the significance of the projects on any particular community's economic base. In effect, as long as unemployment rates in the communities were relatively low, then the amount of expansion in employment would be highly correlated with population growth in the community; this was the case for all affected communities in 1978. Employment impacts are summarized in Table 3.

All the communities, with the exception of Fallon, would be affected by only one geothermal development; Fallon could absorb workers from both the Desert Peak and Dixie Valley projects, according to assumptions. Employment impacts range from insignificant as a percentage of total employment (5% or less) in Reno-Sparks, Carson City, Winnemucca, Lovelock, Battle Mountain and Elko, to moderate at Fallon and Gerlach, to substantial at Fernley. Employment multipliers ranging in value from 1.2 to 2.0 were used to estimate the change in total employment induced by a given change in base employment for the various communities; smaller communities which are characterized by a low level of secondary services provided to local residents were assigned the multiplier value of 1.2, moderate sized communities were assigned a multiplier value of 1.4, and the Reno-Sparks-Carson area was assigned a value of 2.0 (Economic Research Associates, 1976, and Fillo and others, 1978).

The moderate or substantial employment impacts of geothermal development would be due to two factors: the size of the potential project, and the smallness of the community to begin with. For example, Desert Peak is estimated to be the largest potential geothermal area in the State. If it is built out to its full potential and if the employment estimates per plant are accurate, then it would ultimately employ 525 permanent employees. Because the affected communities, Fallon and Fernley, are so small relative to this number of employees, the effects would be noticeable. However, it is likely it would take anywhere from 20 to 60 years for the full development of the resource to occur, so any effects on the communities are likely to be gradual; also, estimates over this long a time frame are not very reliable. Furthermore, Fernley is far more likely to be affected by economic and population growth in the Reno-Sparks area than by geothermal development, so the likely outcome is that geothermal resource development will play a relatively minor

TABLE 2

Allocation of Workers Among Possible Places of Residence (distance from site in parentheses)

Location	% Residing At Site	% Residing At Community #1	% Residing At Community #2
Desert Peak	Site	Fallon (25)	Fernley (20)
Temporary Workers	10%	45%	45%
Permanent Workers	0	50%	50%
Steamboat	Site	Reno (12)	Carson City (20)
Temporary Workers	0	80%	20%
Permanent Workers	0	80%	20%
Dixie Valley	Site	Fallon (50)	Other
Temporary Workers	80%	10%	10%
Permanent Workers	50%	30%	20%
Humboldt House	Site*	Lovelock (35)	Winnemucca (35)
Temporary Workers	40%	25%	35%
Permanent Workers	10%	40%	50%
Beowawe	Site **	Battle Mountain (40)	Elko (40)
Temporary Workers	40%	25%	35%
Permanent Workers	10%	40%	50%
Gerlach	Site	Gerlach (3)	Reno (100)
Temporary Workers	0	100%	0
Permanent Workers	0	100%	0

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* Imlay or Humboldt House

** Beowawe

TABLE 3

Employment Effects of Geothermal Power Plant Construction, by Community

Community (Employment Multiplier in Parentheses	1978 Non-Agricultural Employment	Maximum Direct Employment	Permanent Direct Employment	Total Employment	% of 1978 Employment
Reno-Sparks (2)	104,300	236	196	392	0*
Carson City (2)	13,850	59	49	98	1%
Fallon (1.4)	3,140	314	294	412	13%
Fernley (1.2)#	416	293	262	314	75%
Winnemucca (1.4)	3,170	30	18	25	1%
Lovelock (1.2)	890	21	14	17	2%
Battle Mountain (1.2)**	1,064	49	42	50	5%
Gerlach (1.2)	250	85	35	42	17%
Elko (1.4)##	4,460	65	53	73	2%

* less than 0.5%
\# employment assumed to be 20% of employment in Lyon County
** employment assumed to be 70% of total employment in Lander County.
\#\# employment assumed to be 75% of total employment in Elko County.

and secondary role on the future of the Fernley area.

If a geothermal power plant were to be built in Gerlach, it would have moderate impacts on the community's economy only because the existing employment base and population are so small. Population of the Gerlach-Empire area was less than 600 in 1970, and there has not been much growth since then. The two major employers are U.S. Gypsum and the Western Pacific Railroad, who employ about 150 and 40 workers respectively. Consequently, the creation of even 40 new jobs could have a noticeable impact on the area's economic base.

It is also possible to formulate crude estimates on the amount of spending that could be expected in the various communities as a result of geothermal power plant development. Parallels can be drawn to a 1978 study on the economic impact of the construction of a 400 MW coal-fired power plant in rural Nevada (Seigler, 1978). The technique is to estimate the total amount of spending done by sector by workers who are living within the community and commuting to work, and by workers who are living at the site but commuting on the weekends to the community in question. It should be noted that since the composition of the work force at a power plant site is changing until the site is fully built out, separate estimates should be computed each year until build-out. These estimates could then be compared against the total taxable sales computed from the Department of Taxation tax collection data to determine the magnitude of the impact.

For example, computations for Fallon during the sixth year after the beginning of geothermal development would indicate approximately 36 of the 130 construction workers from the Desert Peak and Dixie Valley geothermal areas would be living in Fallon, with approximately 28 of the 70 operations workers from the two sites living there also. There would also be about 29 on-site construction workers and nine operations workers from the two sites who lived on-site during the week but who commuted to Fallon for the weekend (based on the assumption that 50% of on-site workers would weekend in Fallon and the other half elsewhere, presumably the Reno-Sparks-Carson area).

Using 1978 average earnings for construction workers in Nevada of $22,700 per year, and for utility operations workers of $16,000 per year, total expenditures by sector could be estimated for the community. (It is also assumed that on-site workers will spend 30% of earnings in the community, and residents will spend 100% there). Results of this estimating methodology, along with other assumptions used in the Siegler study, are summarized in Table 4. It is interesting to note that the estimated 64 new residents of Fallon and the 38 commuters from the geothermal sites would spend less than $1 million in 1978 dollars, nearly half of it in the trade sector, and this would increase total county expenditures by about 2%.

Similar methodologies could be used to estimate the effect of the geothermal project developments on a community's housing stock, on its school enrollments, and on other infrastructure needs. This approach

TABLE 4

Expenditure Estimates for Fallon, Sixth Year, by Sector*

Sector	% of Income spent by residents	% of Income spent by week-end commuters	Total direct expenditures	% of 1978 total sales
Printing/ publishing	1.5%		11,300	
Casino	4	40%	88,100	
Service Stations	7	10	67,600	
Eating, drinking, lodging	4	40	88,100	
Transportation	1		7,600	
Communication	1		7,600	
Utilities	5		38,000	
Trade	55	10	431,957	
FIRE	7		53,100	
Personal Business	3		22,800	
Other Services	2.5%		19,000	
Health Services	8		60,700	
			$ 903,534	46,357,900**

* Expenditures are gross income, less taxes, savings, housing expenditures and non-local expenditures. Total (local and non-local expenditures) are assumed to be 60% of gross income.

** Nevada Tax Commission 1977-1978 Annual Report.

could also provide estimates of how much tax collections are going to be increased through property taxes on new homes and sales taxes on retail sales.

CONCLUSION AND RECOMMENDATIONS

The question of the long term economic feasibility of using Nevada's geothermal resources for commercial electric power production is not yet settled, and probably will not be until after several such facilities are in operation. However, the characteristics of this potential industry are generally promising, both from the standpoint of the economic advantages of using geothermal heat as a power source and in terms of its effects, especially relative to other types of power generating facilities, on communities near geothermal sites. Once constructed, geothermal power plants are highly capital intensive, implying that they would place relatively little strain on the public services of affected communities and also that they would expand the community's tax base because of the assessed value of the facilities themselves. Furthermore, because of the low employment needs associated with an operating geothermal power plant, population and growth impacts are minimal in all communities except those with very small initial populations, such as Gerlach.

On the negative side, factors that need to be considered, and in some cases mitigated, relate to legal water rights and air and water pollution. The geothermal sites that are very isolated, such as Dixie Valley and Desert Peak, are least likely to have problems in these areas because there are few alternative uses of local water resources and there is virtually no local population to be affected by air or water pollution. Development at resource sites that are close to population centers, such as Steamboat Springs, are more likely to confront problems with these factors.

As mentioned before, the present lack of a clearly defined regulatory or tax structure for the geothermal industry in Nevada does create some uncertainty for potential resource developers in the State. As these institutional structures are developed, they should be formulated in such a way that economically feasible developments are not unduly discouraged, but also in such a way that affected communties are compensated adequately through increased tax revenues for any public sector costs incurred. From a political standpoint, the latter suggestion would also prevent the formation of broad-based opposition to specific projects because of feared adverse economic impacts. Finally, the issue of the effect of land use restrictions by Federal or State government on the potential for geothermal development will have to be seriously addressed by carefully considering the full costs and benefits of specific alternatives on the residents of the local region, the State, and the Nation.

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AN ENVIRONMENTAL OVERVIEW OF GEOTHERMAL DEVELOPMENT: NORTHERN NEVADA

Chapter X

CULTURAL RESOURCES AND ARCHEOLOGICAL VALUES

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INTRODUCTION

The following is a discussion of the potential for interaction and conflicts between the development and exploitation of geothermal resources and the protection and conservation of cultural resources in northern Nevada. Since many readers will be unfamiliar with cultural resources and the legal requirements for dealing with them, this chapter begins with a discussion of varieties of cultural resources, and goes on to discuss relevant case studies, issues, lists of laws and regulations, and an outline of required mitigation efforts.

VARIETIES OF CULTURAL RESOURCES

Since all human works are cultural by definition, the term "cultural resources" can be very inclusive (Elston 1980). However, the U.S. Bureau of Land Management, the U.S. Forest Service and other Federal and State agencies charged with managing the public lands, often restrict the term "culture resources" to artifactual evidence of the human past: structures, tools, and waste products; their distribution in space and time, and their relationship to the natural environment.

Documents are also cultural resources and constitute the historic record. Since most of these repose in libraries, county records and other archives, they will not be impacted by geothermal development and will not be further discussed here except to say that archives usually have to be consulted when other kinds of cultural resources are studied.

A third kind of cultural resource is altogether non-material and resides in lore, myth, and folk religion. These resources are outwardly expressed in stories, placenames, beliefs and attitudes which often have never been written down or formally studied by historians or anthropologists. For example, the large granite boulder on a slope above Washoe Lake is picturesque to most of us and an interesting geological phenomenon to a few others, but to the Washoe Indians, the rock is the Kingfisher, a mythical being who was turned to stone (d'Azevedo 1956). Geothermal development can have impacts on such resources and Federal law requires the mitigation of such impacts.

CASE STUDIES

Certain facts make it likely that development of geothermal resources will damage cultural resources: (1) cultural resources are widely distributed, and (2), they are fragile and subject to destruction by disturbance of the surface of the land. Moreover, human exploitation of geothermal resources began in prehistoric times and was important in the adaptation of prehistoric humans. The ethnographic literature contains numerous references to hot springs. The Washoe Indians who lived in the area centered on Lake Tahoe from Antelope Valley to Honey

Lake, preferred hot springs for the location of winter village sites (Downs 1966). Virtually every hot spring in Washoe territory has a large archeological site associated with it. Julian Steward (1938), who collected ethnographic information on the Numic-speaking peoples of the Great Basin and Columbia Plateau (Paiutes and Shoshone) lists scores of winter village sites associated with hot springs.

Some of the reasons that prehistoric people occupied sites adjacent to hot springs are obvious. Hot water is pleasant to bathe in and does not freeze solid in the winter. Thermal waters can also be used to process hides, pine nuts and other foods. Sometimes hot springs feed a marsh which may support ecologically valuable plants such as cattails and attracts birds and other game animals. In fact, the likelihood of an association between hot springs and archeological sites is directly related to the presence of other resources within the "catchment" (area within which people on foot could have traveled within a day) around the spring. The richer the catchment in food, water, fuel, and shelter, the larger and more complex the archeological sites within it are likely to be.

Valuable minerals are also often available within geothermal areas. The presence of heavy metal ores attractive to historic miners is well known, but hot spring minerals were also exploited by prehistoric peoples as well. At least one hot spring system (Steamboat, south of Reno) has created chalcedonic sinter deposits which, through tectonic activity, (White, Thompson and Sandberg 1964), were made available to prehistoric people to quarry as raw material for stone tools. The pink and red Steamboat sinter was highly valued by the Washoe Indians who thought it had magical qualities (Dangberg 1968).

Historic sites are also often associated with hot springs. Ranch headquarters with lambing pens built over warm ground were constructed at Walti Hot Springs in Grass Valley, Nevada, while resorts and spas, some dating back to a hundred years or more, have been constructed at Walley's Hot Spring, Carson Hot Springs, Boiling Springs at Gerlach, and Steamboat Hot Springs. Double Hot Springs near Black Rock Point was used by people on the Emigrant Trail to water stock and wash off the dust of the Black Rock Desert.

Thus, it is reasonable to hypothesize that cultural resources, both historic and prehistoric, are likely to be concentrated in geothermal resource areas, especially around hot springs. Furthermore, geothermal development will damage these cultural resources in much greater proportion to the land area affected than damage caused by other modern uses such as irrigation and recreation. In an attempt to test this hypothesis, or to provide an indication of its validity, the archeological records for several geothermal areas in northern Nevada were investigated.

The discussion which follows is intentionally vague when discussing the actual location of archeological sites. It is a matter of national policy that the location of archeological sites be regarded as privileged information, so that unauthorized collection of artifacts from the sites be discouraged. This discussion is also limited by the scope of this environmental overview to an archival exercise, and of course, the results are limited by the nature of the sample, which is further discussed below.

The geothermal areas discussed in this report were selected to represent a range of characteristics: urban and rural areas; areas with natural hot springs, and those without; areas with known archeological remains, and those which are little known. Eight geothermal areas were selected: Carson, Black Rock, Kyles Hot Springs, Dixie Valley, Humboldt House, Grass Valley, Beowawe, and Bradys Hot Springs. It is important to note that the amount of information available about each of these places varies considerably as the intensity of survey for archeological information has varied among the localities.

The archeological records of the Nevada State Museum were consulted for each of the geothermal areas selected, and an area centered on the geothermal area and 10 miles in diameter was considered. Some of the following discussion is also based on the authors personal knowledge of the area.

Carson Geothermal Resource Area

The Carson Geothermal Resource Area extends from the south end of the Carson Valley to south Reno and includes several hot springs, such as Walley's or Genoa Hot Spring, Saratoga or Dangberg Hot Spring, Hobo Hot Spring, Carson Hot Spring and Steamboat Hot Spring. All of these hot springs have large archeological sites associated with them. In some cases, the sites are located adjacent to the hot spring and in other cases are further away, usually on a rise overlooking the spring area. These sites are typically deep (cultural deposits to over 2 meters) stratigraphically complex and artifact rich, and document continuous occupation for at least the last 5500 years (Elston 1970; Elston and Davis 1972; Davis and Elston 1972), while occupation of the region probably dates back to the end of the Pleistocene (10,000 years ago). This is particularly true of the area around Steamboat Hot Springs located between Reno and Carson City, Nevada.

Steamboat Hot Springs is well within the surburban "halo" of Reno. The area is occupied by housing developments, trailer courts, a spa, and some light industry and is transected by U.S. Highway 395. The area has been extensively surveyed for cultural resources (Elston and Turner 1968), and most of the geothermal area is known to have contained several important winter village sites of the Washoe (d'Azevedo 1956). Most of the archeological sites have been destroyed by urbanization, but some of them were excavated partially before they were destroyed so that the record of cultural resources at Steamboat is unusually complete considering the degree of urbanization in the area. Not only were the resources at and immediately adjacent to the hot springs exploited by prehistoric people, but the hard basalt from the Steamboat Hills was also quarried and used to manufacture stone tools.

Within the Carson Geothermal Area then, cultural resources are very strongly associated with hot springs, and since these sites are all winter villages and/or lithic manufacturing sites, they are large, complex, and rich in artifacts.

Black Rock Geothermal Resource Area

Cultural resources in the Black Rock Geothermal Resource Area have been most systematically studied in the area around Gerlach, located between the Black Rock Desert and the Smoke Creek Desert about 100 miles northeast of Reno. Gerlach is a small town of about 200 people. Other modern development in the area is limited to a railroad and highways which traverse the area. Great Boiling Hot Spring is a locally popular bathing spot. The Bureau of Land Management (BLM) has conducted archeological surveys of a substantial portion of the Gerlach area, in connection with proposed geothermal leasing. A great many prehistoric sites were found, and considerable portions of the area were withdrawn from leasing. However, the location of the archeological sites suggests that the sites may have been oriented to the shores of late Holocene lakes which existed in the playas (Davis and Elston 1972) as much as concentrated around the hot springs. The high site density in the geothermal area may be a coincidence rather than being due to the presence of the hot springs. Although the BLM did not conduct test excavations in the area, University of Nevada excavations at Trego Hot Springs, about 11 miles east of Gerlach, showed that human occupation in the area goes back 4000 years, and that deep stratified sites exist in the sand dunes in the area (Davis and Elston 1972; Seck 1980). Other work in the Black Rock Desert has revealed large archeological sites on the playa along the Quinn River (Clewlow 1968; Hester 1973) which may date to the end of the Pleistocene. Although these sites are not around hot springs they are within the Geothermal Resource Area and could be impacted by geothermal development.

Dixie Valley

Dixie Valley is located about 60 miles east of Fallon, Nevada, and is sparsely populated and little developed. Although hot springs occur in the valley, geothermal prospecting is concentrated in areas away from the hot springs. Parts of Dixie Valley have been intensively sampled along transects used for geophysical prospecting of the geothermal area. Archeological sites exist at the hot springs in the valley, on alluvial fans on the west side of the valley and among sand dunes, but they are very scarce on the valley floor. It is not known why this is so. Perhaps the valley floor offered few resources. Alternatively, sites may be there but may be buried by alluviation. In any case, it appears geothermal development in many parts of Dixie Valley will have few direct impacts on cultural resource.

Grass Valley

Grass Valley, Nevada, is located northeast of Austin, Nevada, and lies between the Toiyabe and Simpson Park Ranges. There are three hot springs in the valley, and all are associated with archeological sites (Wells 1980). The University of Nevada's (UNR) Gund Ranch headquarters is at Walti Hot Springs and contains prehistoric sites, a portion of the Austin-Cortez stage road and over a dozen buildings and structures, most of which date to the turn of the century or earlier (Elston 1980). It would be extremely difficult to further develop Walti Hot Spring, even for agricultural and domestic purposes without creating impacts on cultural resources there, as U.N.R. has discovered.

Beowawe

The Beowawe geysers lie in Whirlwind Valley, west of Crescent Valley and north of Grass Valley. The hot springs and geysers issue from the side and base of a ridge on the east side of the valley. Many prehistoric sites have been recorded on the ridge top above, and on the valley floor below the geysers. Several of these sites are already receiving adverse impacts connected with geophysical exploration of the area.

Kyles Hot Springs

Kyles Hot Springs is located in the north end of Buena Vista Valley about 30 miles south of Winnemucca, Nevada. No modern habitations exist within 5 miles of the hot spring, but an informal spa, with wood frame buildings, exists at the spring, and the spring is locally popular for bathing. Archeological records of Kyles are limited to a series of spot locations in the area which were examined prior to the drilling of geothermal test holes and installation of a powerline corridor which passed about 3 miles to the northwest. No cultural remains were found at the geothermal test holes, but 2 small prehistoric sites were noted in the powerline corridor. The spa at the hot spring is itself an historic site, but it is not recorded as such in the site records, and its significance has not been evaluated. The area immediately around the hot spring has not been archeologically surveyed. To date, the site records of Kyles Hot Springs do not support an association of cultural resources with geothermal resources but the amount of the area which has been surveyed is so slight that very little can be demonstrated about the area's cultural resources as a whole.

Humboldt House

The Humboldt House area is between Lovelock and Winnemucca, Nevada, along U.S. Interstate 80 adjacent to Rye Patch Reservoir. The area is traversed by the highway and a railroad. Rye Patch Reservoir, built in the 1930's, has flooded the lower portion of the terrain along the Humboldt River. Humboldt House itself is an historic siding on the original transcontinental railroad. Large areas have been surveyed archeologically here, both for geothermal prospecting, and in association with the impacts of the reservoir (Rusco, Davis, and Firby 1979; Rusco, Davis, Jensen and Seelinger 1977). No hot springs exist in the area today although certain geologic features suggest that hot springs existed in the area during the late Quaternary. Archeological site records show that cultural resources are very common and widespread near Humboldt House. One section, (i.e., one square mile), of the cadastral survey was surveyed for archeological sites and found to be a single continuous prehistoric site, extending off of the surveyed sections in all directions. The known sites seem to be related to the existence of the Humboldt River in the otherwise arid basin, rather than to the presence of a geothermal resource. Because only the public lands have been surveyed near Humboldt House, and the geothermal prospecting has been largely on unsurveyed private land, it is possible that geothermal prospecting has already led to unmitigated adverse impact to cultural resources at Humboldt House.

Bradys Hot Springs

Bradys Hot Springs is located on U.S. Interstate 80 between Fernley and Lovelock, Nevada. The hot springs were known historically by the users of the Emigrant Trail, and are the site of considerable mid-20th century industrial development. A geothermal food drying plant has recently been built here. The BLM has surveyed large areas nearby, and smaller plots have been surveyed by geothermal prospectors. The area of geothermal power generation potential, however, is removed from the hot springs. Archeological records show that prehistoric and historic archeological sites are plentiful in the area, including the Dansie Site, a late Pleistocene archeological site on a shore feature of Lake Lahontan (this site has already been destroyed by unauthorized collection) and the Eagle Salt Works. However, the sites show no pattern of association with the geothermal resource, and few sites are found in the area with power generation potential, except the historic Desert Queen Mine.

Conclusions Based on Case Studies

The hypothesis that cultural resources are commonly associated with hot springs is well demonstrated. Moreover, prehistoric sites at hot springs are likely to be large and complex. However, geothermal development and power plant siting may not be located at hot springs. In such cases, the probability that power plants and attendant facilities and structures such as roads, powerlines, pipelines, etc., will have impacts on cultural resources, falls to a "background" level (i.e., areas without hot springs).

Such probabilities have only been computed in a few areas subjected to systematic and intensive archeological reconnaissance such as the Reese River Valley (Thomas 1971), a part of Grass Valley (Elston 1980), and the Black Rock Range (Elston and Davis 1979). The probability of site presence varys from area to area depending on environmental factors, the presence of economically interesting mineral deposits which have been historically exploited, and so on. In most areas, the archeological data base is too poor to allow further generalizations to be made, except from personal experience which suggests archeological sites are most likely to be found in association with sand dunes, cold springs, permanent streams, and Pleistocene lake shore features.

The case studies at least serve to illustrate that cultural resources are widely distributed, and that any ground-disturbing activity (such as geothermal development) is likely to have an adverse impact on them. This supports the established national policy that an area to be affected by surface disturbance should be specifically examined for cultural resources before the disturbance occurs.

LAWS AND REGULATIONS REGARDING CULTURAL RESOURCES

The State of Nevada has little regulation concerning cultural resources. However, much of Nevada is public land and the Federal laws apply. If Federal funds are used in development, environmental assessments are required, but on private land in Nevada, there is no legal or regulatory requirement that cultural resources be considered in geothermal development.

There are numerous Federal laws and regulations regarding cultural resources; only the major ones are outlined below. Although none of these laws specifically mention geothermal development, they are all still in effect and their provisions govern all Federal actions, including the geothermal leasing of the public lands. Those interested in the details and historical background of these laws should consult McGinsey (1972), Lipe and Lindsay (1974), Schiffer and Gummerman (1977), and King, Hickman and Berg (1977).

The history of cultural resource management is nearly 75 years old in the United States, beginning with the passage of the Antiquities Act of 1906 which provided for the protection of all historic and prehistoric ruins or objects of antiquity on Federal lands (McGinsey 1972:235). This was followed by the passage of the Historic Sites Act in 1935, the Federal Aid Highway Act of 1956 and 1958, and the Reservoir Salvage Act of 1960, all of which protected cultural resources from the effects of particular kinds of Federal or federally sponsored actions.

In 1966, the Historic Sites Preservation Act was passed which established the President's Advisory Council of Historic Preservation along with an expanded National Register of Historic Places and required review of Federal actions affecting National Register sites. The Department of Transportation Act of 1966 also required prior consideration of cultural resources to minimize impacts of construction projects.

In 1969, the National Environmental Policy Act (NEPA) was passed, which requires that environmental, cultural, and historic values be weighed against the economic and technological benefits of proposed Federal actions.

In 1971, Executive Order 11593 was issued which calls for all Federal agencies to manage, preserve, and maintain cultural resources in their jurisdiction and to inventory those resources to determine which are eligible for the National Register.

In 1974, the Archeological and Historical Conservation Act was passed, which included the authorization for Federal agencies to fund the preservation and study of significant cultural resources threatened by Federal action.

In 1979, the American Indian Religious Freedom Act was passed which requires Federal agencies to manage the public lands so as to protect sites and places of religious significance to Indians.

Finally, the Archeological Resources Protection Act was passed in 1979, providing for fines of up to $100,000 and/or jail terms of up to 5 years for those convicted of disturbing cultural resources on public lands.

Each Federal agency has regulations implementing these laws, and both the Bureau of Land Management and the Forest Service have guidelines for the conduct of projects on the public land which could have negative impacts on cultural resources. In each case, the potential geothermal developer should contact the appropriate Federal land manager (BLM District Manager or Forest Service District Ranger) concerning the procedures to be followed.

REQUIRED PROCEDURES FOR MITIGATION OF IMPACTS TO CULTURAL RESOURCES

Exact procedures will vary from state to state and management district to management district, but generally, geothermal developers will be required to do the following:

Archive Search and On-the-Ground Reconnaissance

As early as possible in a planned project (as soon as a location or alternative locations have been chosen for the construction, drilling, or other activites) it is necessary to determine if any cultural resources exist there. The first step is to check the existing records of site location and of areas which have already been examined on the ground, or "surveyed"; this is an "archive search." Archive searches will also involve a review of the relevant ethnographic literature. In some areas, it may be required to interview local Indians to determine the existence of places of mythic or religious significance. In the event that the area in question has already been surveyed and found to be devoid of cultural resources, then no further cultural resource work is needed. Then, all that is required is a document verifying that the archive search was made, the area had been previously examined, and no sites exist there, along with a recommendation that a "clearance" be given. This document is submitted to the appropriate Federal agency, who will issue the actual clearance to proceed.

More typically, the records show no sites in the area, but will also show that no survey has been made. It is then necessary for archeologists to perform an on-the-ground examination of the area, to see if there are cultural resources there. This is the reconnaissance or "survey", and it involves walking methodically back and forth across the area looking for artifacts or other evidence of past human activities. If evidence of cultural resources is not found, then a document describing the survey, stating that no evidence was found, and stating that no sites are recorded in the archives, will be submitted to the appropriate agency along with a recommendation to issue a clearance.

However, since clearances are based on surface evidence, they will be qualified to the effect that if buried cultural remains are found during the course of construction, it is the responsibility of the constructor to notify the authorities, and stop work. A "clearance" is not a guarantee that no cultural resources exist in the project area, but is based on documentation that a reasonable search for them was made.

Assessment and Mitigation

If the records show that cultural resources exist in the project area, or if cultural resources are found during the reconnaissance, the simplest and cheapest thing to do is to relocate the project, and avoid any impact to the cultural resources, thus avoiding any requirement for mitigation. This is commonly done in drilling test holes and running seismic lines; the archeologist walks the lines, or drill pads, and helps the geotechincal crews adjust the location of the work to avoid any cultural resources. Sometimes, however, the nature of the project or of the cultural resources makes relocation impossible. It is then necessary to evaluate the resources to see how significant they are, and what mitigating measures will be appropriate. The nature of this assessment depends upon the nature of the evidence discovered.

On prehistoric sites, the evidence is usually a scatter of artifacts on the surface of the ground. In assessment, these are usually picked up in a controlled fashion, on a grid, and test pits are dug to determine if cultural information is preserved beneath the surface. If the artifacts are on the surface only, mitigation is necessary to describe and report on the artifacts, but the site can usually be "cleared" without further field work. If buried artifacts are discovered, further work is required.

On historic sites, the evidence may be a scatter of artifacts, which may be dealt with as described above for prehistoric artifacts, although post-World War I sites are usually not regarded as significant and are ignored. There may be buildings or other structures at an historic site, and these may require that an historical architect examine them for evidences of integrity of style. Assessment of buildings also calls for examination of the historical records of the area, including historical archives, to determine age, function and specific history of the structures.

Once the asssment is complete, a plan for the mitigation of subsurface or structural cultural resources must be devised and submitted for review and approval by the appropriate Federal agencies. The requirements of proper mitigation may make the relocation of the project a viable economic alternative.

Proper mitigation of impacts to subsurface or structural cultural resources varies according to the nature of the resources. Historical structures may be moved, reinforced, or in some cases, carefully recorded by large-format photography, and measured drawings, and then torn down. Excavation should be undertaken around and beneath historic structures. Prehistoric sites with buried artifacts require extensive excavation to recover artifacts, features, stratigraphic information and environmental information. Once the records and specimens are removed from the field, the site may be "cleared" and the project can proceed; the analysis and reporting of the results typically will cost as much or more as the field work, and typically requires about a year of time.

Reconnaissance and Mitigation Costs and Required Personnel

The costs of reconnaissance vary widely depending on the location of the project, the nature of the terrain to be covered, the size of the study area, and other factors. It costs between $200.00 and $250.00 per day, including travel time, to put a trained technician in the field on a short-term project (one to several days). Thus, the examination of a single well pad and access road could cost several hundred dollars per acre. Costs can be reduced when projects are longer term and/or cover larger areas. The average cost of large surveys is about $5.00 an acre.

It is not possible to give average costs for assessment and mitigation. The surface collection, analysis, description and report on a small surface site could run from $1000.00 to $10,000 depending on how large it is, how many artifacts it contains, and where it is located. Subsurface testing and excavation is very expensive as it takes about 1 person day to move, screen, record, and sort artifacts from 1 cubic meter of soil. Projects involving extensive excavation start at $25,000 to $50,000 and run into the millions. Expenses of all mitigation work must include the cost of curating, in perpetuity, the specimens collected during the project.

Much of this work is done by trained technicians and must be directed and signed off by a qualified person holding a valid Federal antiquities permit. Lists of firms and institutions who are qualified for this work can be obtained from the appropriate Federal agency.

SUMMARY

This overview of cultural resources and their relation to geothermal resources in northern Nevada has emphasized several points:

(1) There seems to be a positive correlation between large, complex cultural sites, and hot springs. However, the data base concerning the general distribution of cultural resources in

northern Nevada is poor, so no formal predictions concerning site location away from hot springs can be made. On the other hand, experience suggests that most archeological sites are in the vicinity of permanent surface water (cold springs and streams), sand dunes, and ancient lake shores.

(2) Geothermal development, as a ground disturbing activity, is likely to have adverse impacts on cultural resources.

(3) Cultural resources are well protected by Federal law and regulation.

(4) Mitigation of impacts to cultural resources can be extremely expensive. Possibly the most cost effective mitigation is complete avoidance.

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AGENDA

NORTHERN NEVADA GEOTHERMAL-ENVIRONMENTAL OVERVIEW MEETING AND WORKSHOP

October 11 & 12, 1979

AGENDA
NORTHERN NEVADA GEOTHERMAL-ENVIRONMENTAL OVERVIEW MEETING AND WORKSHOP

October 11, 1979

0745 - 0900 a.m.	Registration
0845 - 0855	Welcome (Burt Slemmons, University of Nevada-Reno)
0855 - 0920	State of Nevada Geothermal Energy Perspective (Noel Clark, Nevada State Department of Energy)
0920 - 0925	Discussion
0925 - 0945	Geothermal-Environmental Project: A preliminary Assessment (Paul Phelps, Lawrence Livermore Laboratories)
0945 - 0950	Discussion
0950 - 1020	Environmental Perspectives (Rose Strickland, Sierra Club and Timothy Grinsell, National Wildlife Federation)
1020 -1025	Discussion
1025 - 1045	Break
1045 - 1110	Industry's Views: Geothermal Resources and Potential (Dick Benoit, Phillips Petroleum)
1110 - 1115	Discussion
1115 - 1140	Generic View of Health and Environmental Issues Related to Geothermal Development (Lawrence Livermore Laboratories)
1140 - 1145	Discussion
1145 - 0115 p.m.	Lunch Break
0115 - 0145	Ecosystems Overview (Thomas Lugaski, Patricia and Hamilton Vreeland, University of Nevada-Reno)
0145 - 0155	Discussion
0155 - 0210	Air Quality Overview (Richard Egami, Desert Research Institute)
0210 - 0220	Geothermal Noise (Phil Leitner, St. Mary's College)
0220 - 0225	Discussion
0225 - 0255	Water Quality Overview; Water Resources (Michael Campana, Desert Research Institute)
0255 - 0300	Discussion
0300 - 0320	Break
0320 - 0340	Geology Overview (Burt Slemmons, University of Nevada-Reno)
0340 - 0350	Discussion
0350 -0410	Socioeconomics Overview (William Eadington, University of Nevada-Reno)
0410 - 0420	Discussion
0420 - 0440	Archeology-Human Settlement Overview (Jonathan Davis, Nevada State Archeological Survey)
0440 - 0450	Discussion Adjourn

AGENDA

NORTHERN NEVADA GEOTHERMAL-ENVIRONMENTAL OVERVIEW MEETING AND WORKSHOP

October 12, 1979

0830 - 0900 a.m.	Description of workshop process, purpose and objectives. Introduction of workshop leaders. Questions taken. (Phil Leitner, St. Mary's College).
0900 - 1200	Workshops (in all eight study areas).
1200 - 0115	Lunch Break
0115 - 0245	Additonal work as necessary.
0245 - 0300	Break
0300 - 0500	Report of workshop findings (issues, priorities, etc.) Order of priorities for all study areas.

End.

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APPENDIX E

GEOTHERMAL OVERVIEW: REPORT OF THE GREAT BASIN GROUP

BY

Rose Strickland, Chair
Reno, Nevada

October 11, 1979

ENVIRONMENTAL PERSPECTIVES ON GEOTHERMAL-RESOURCE DEVELOPMENT

The Sierra Club welcomes this opportunity to express its concerns and recommendations regarding geothermal resource development in northern Nevada. Hamilton Hess, the geothermal coordinator for the Sierra Club's National Energy Policy Committee regrets that time conflicts prevented him from making this presentation. From materials supplied by him and in coordination with Majorie Sill, a long-time Nevada conservationist and Margaret Williams of the Northern Nevada Native Plant Society, I will present some of our environmental concerns in the development of geothermal resources in northern Nevada.

The Sierra Club is not opposed to geothermal resource development. We regard it as an alternate energy source which holds at least moderate promise for the future. It is well known that the Sierra Club is urgently concerned for the development of alternative energy sources to replace nuclear fission and the fast depleting fossil fuels. Earth heat energy is an attractive concept, and we hope that it may be developed as an environmentally benign source which will contribute significantly to the energy needs of mankind. Its more important contribution, we believe, is likely to come from its advanced concepts, such as the utilization of dry hot or the Earth's normal heat gradient than from the use of reservoirs of naturally occurring hot water or steam. Hot water and steam reservoirs, as exploitable under known technologies, are distinctly limited in quantity over time, and their development and production involve a number of objectionable impacts on the natural and social environments.

Under present methods of development and production the impact of geothermal operations on the local environment is heavy. Geothermal production facilities require large areas of land (in excess of one square mile for every 100 MW), and geothermal resources frequently occur in regions which are prized for inherent natural values, for recreation, for residence or for scenic quality. We need energy but our society has other equally important priorities as well.

In Nevada, known geothermal resources exist within inventoried Bureau of Land Management (BLM) wilderness areas. Three areas are: the Black Rock Desert, the Jackson Range, and the Stillwaters. There may be others as well. Conflicts over land use will not be resolved until April, 1980, by BLM in its official recommendations to the President for additions to the wilderness system.

Our endorsement of geothermal is further qualified by the fact that there are several unanswered questions regarding the long-term cumulative effect of large scale production under present technology. Perhaps the most important among these is the matter of atmospheric emissions from geothermal steam plants and their ultimate effects on biological organisms through the build-up of toxic substances in the environment and through micro-climatic changes. In our opinion, questions of this nature are of sufficiently serious import to demand answers and to require the elimination of adverse effects before commercial production takes place, especially near residential areas.

For these reasons, we have serious reservations about geothermal production under present technology. Our intention is to be constructively critical in bringing our concerns before this assembly.

A geothermal field is an industrialized area during both its development and production phases. Operational noise from drilling rigs and other heavy equipment, the noise of steam escaping at high pressure, service roads for wells, and generating units, networks of steam or hot water gathering lines, power plants and cooling towers, plumes and columns of steam from a variety of sources: all of these effectively combine to make a geothermal-development area heavily industrial. Locating a geothermal development next to a small rural community or ranching complex might result in industrial type impacts which of course are less serious in Nevada than in more heavily populated California.

Of more direct and vital concern to Nevadans is water ! Geothermal development requires or is typically associated with millions of gallons of water a day. Is this quantity available in this Great Basin State? Will geothermal fluids be taken from acquifers with existing water rights? If the development adversely affects existing water users, who will be responsible for compensation? What possible compensation could be made for drying up sources of water for wildlife and other biological organisms dependent on already infrequent watering holes, springs, etc.?

The most serious adverse environmental effects resulting from geothermal operations have been erosion and siltation, air and water pollution, and noise. The major cause of air pollution is the emission of noncondensible gases contained in geothermal brines or steams. At The Geysers in California, twenty-four tons of hydrogen sulfide are emitted to the atmosphere daily. Hydrogen sulfide is a toxic gas characterized by a rotten egg odor and capable of damaging vegetation and causing physical and psychological symptoms in humans at low concentrations.

The pollution of surface water resulting from spillage of drilling muds, geothermal brines and steam condensate has been a recurrent problem at The Geysers and is a constant hazard in a geothermal field. In an operating field, geothermal fluids are produced by the millions of gallons daily, and they normally contain toxic substances such as ammonia, arsenic, boron, and mercury. How will these wastes be disposed?

Other possible environmental hazards include groundwater contamination; land subsidence following fluid withdrawal: seismic activity induced by the reinjection of geothermal fluids; uncontrollable blowout; pollution of surrounding lands by chemical depositions from materials in cooling-tower steam emissions; detrimental effects upon plant and animal life through land and water pollution, and climatic modification in enclosed air basins caused by vapor emissions and ejected heat.

In Nevada, three proposed endangered plant species are hot springs habitat dependent:

1. Castilleja salsuginosa or paintbrush grows at Monte Neva Hot Springs in White Pine County.

2. Eriogonum argophyllum , a buckwheat, is found at Sulfur Hot Springs in the Ruby Valley in Elko County.

3. Astragalus lentiginosus sesquimetralis a milkvetch, is found at Sodaville in Mineral County. It is also found in one other location, Big Sand Spring in Inyo County in California, north of Death Valley.

These three known plants are in direct danger of extermination by being trampled in the process of geothermal development, or having their unique ecosystems disturbed or destroyed by toxins, water depletion, etc.

Another associated environmental impact is the use made of the developed geothermal resource. Direct uses, such as hot water heating systems, greenhouses, dehydration facilities, or even refining alcohol from potatoes for conversion to gasohol appear to have less adverse environmental impacts than indirect uses, at least in the short run. Conversion of geothermal steam to electricity necessitates its transfer to areas of high energy needs. In this case, the Reno or Carson City areas would be closest, but California has greater energy needs. The politics of power line siting have been debated and fought before in this State as the most direct route favored by power companies usually crosses de facto wilderness areas, hitherto untrampled by man. Energy losses and staggering costs of transmission lines are well known.

The geothermal-energy policy statement revised and adopted by the Board of Directors of the Sierra Club on May 2, 1976, recognizes both the benefits and the problems of geothermal energy, and urges a carefully controlled national program for development that considers the needs for environmental protection and balanced land-use values, as well as the need for alternative energy sources.

In considering geothermal energy as an alternative, it is necessary to recognize that its probable rate of depletion makes it a short-term resource and that its proportionate contribution to the energy supply will be in any case, relatively small, or "a blip on the energy chart" as described by Mr. Hess. A slower rate of withdrawal, for example, would extend the longevity of the resource, but would also reduce its output. The utilization of natural deposits of hot water and steam will likely be of only moderate significance as an interim measure. Some of the more advanced concepts of earth-heat extraction, however, may prove to be of great importance in the distant future.

Sierra Club National Geothermal Energy Policy

(Board of Directors - May 2, 1976)

MSC (Smith-Fontaine) The Sierra Club recognizes geothermal energy as a potentially favorable energy source. Geothermal is presently characterized both by quantitative uncertainties and by a number of adverse environmental effects associated with resource production and utilization. In view of the urgent need to discover and develop alternatives to current environmentally destrictive energy sources, the Sierra Club favors public as well as private funding for research and development which is directed toward the solution of these problems. Regulatory agencies and the geothermal industry should give urgent attention to the mitigation or elimination of the adverse effects of current and future exploration and resource production, and to the resolution of land use conflicts arising from project siting proposals. Research and development projects should also be carried out under conditions of appropriate environmental protection and in areas of minimal environmental and land use sensitivity.

Specifically, the Sierra Club proposes that research and development be initiated or expanded in relation to the following:

1. The gathering of base-line data, monitoring environmental impacts, and effecting appropriate environmental and social safeguards in relation to existing and proposed geothermal development projects in the United States;

2. The possible utilization of heat and other forms of energy contained at depth in dry, hot rock, in sedimentary basins and in geo-pressured systems;

3. The development of directional drilling technology for minimizing surface disturbance in resource production areas;

4. The containment of geothermal steam or brines and accompanying gases and chemical components within enclosed production systems;

5. Geothermal reservoir management procedures which will allow a balance to be maintained, where possible, between field recharge and heat and fluid withdrawal;

6. The use of Earth's heat and geothermal fluids for space and agricultural heating, water desalination, mineral by-products and

other non-electrical applications.

The Sierra Club opposes geothermal operations in the following areas:

1. Lands included in or adjacent to Federal, State, or local park systems or in wildlife refuges and management areas.

2. Areas known to provide habitat, feeding or mating grounds for rare or endangered species.

3. Areas designated as valuable for archaeological remains.

4. Units of the National Wilderness Preservation System.

5. Units of the Wild and Scenic Rivers System.

6. Units of the National Trails System.

7. Areas reserved by the Secretary of the Interior or the Secretary of Agriculture for ecological, scenic, natural, wildlife, geological, educational, historical, or scientific value, including Primitive Areas, Roadless Areas, Natural Areas, and Pioneer Areas.

8. Areas of _de facto_ wilderness under study by the Secretary of the Interior or the Secretary of Agriculture for reservation as part of one of the preservation systems listed above.

9. Areas of _de facto_ wilderness under jurisdiction of the Forest Service or the Bureau of Land Management not presently under study by the Secretary of the Interior or the Secretary of Agriculture, but which are the subject of intensive study by recognized citizen groups or coalitions, resulting in formal proposals to the agencies and/or Congress for reservation as a part of one of the preservation systems listed above.

In addition, the siting of these facilities should be consistent with protection of the ecological, educational, aesthetic and recreational values of thermal pools, hot springs, geysers, mud pots and fumeroles.