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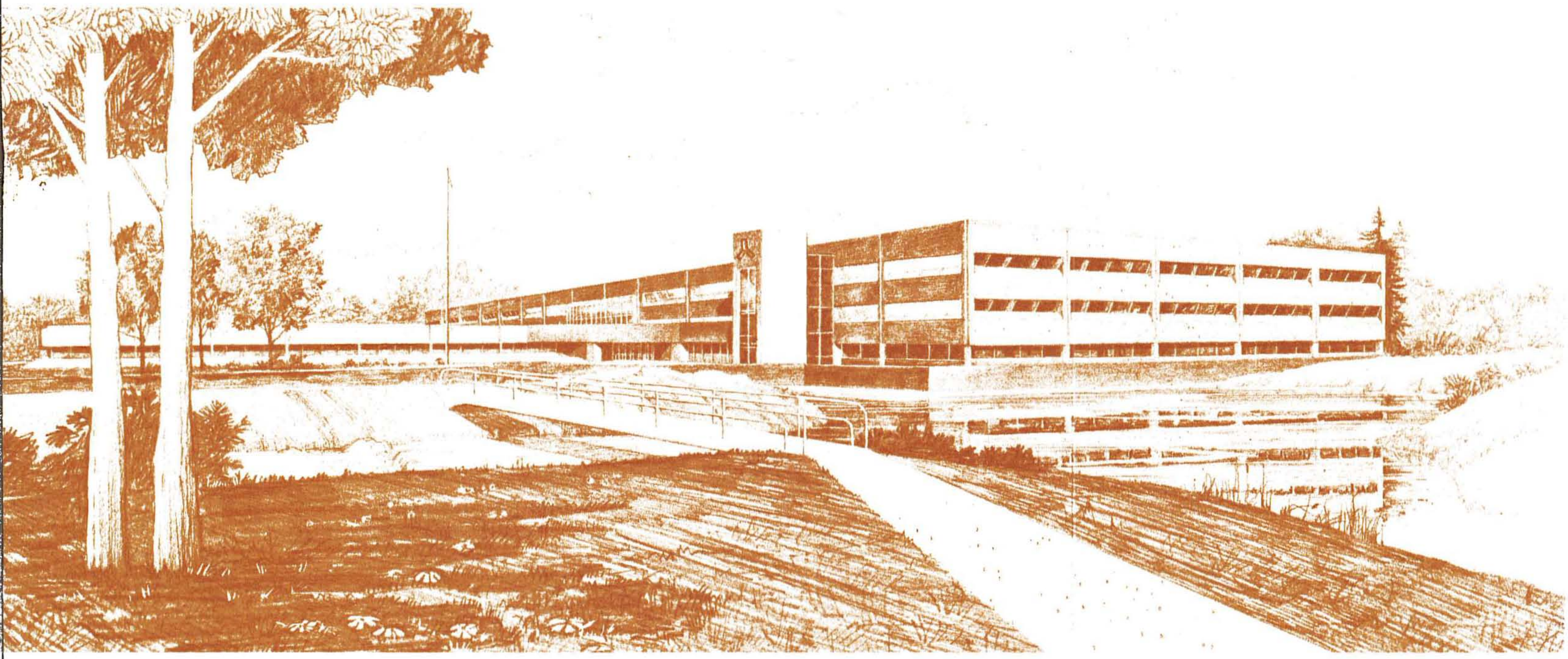

**Idaho National Engineering Laboratory**
Operated by the U.S. Department of Energy

# Final Environmental Report: INEL Geothermal Environmental Program

**Thomas L. Thurow**
**Lorie S. Cahn**

**September 1982**

Prepared for the
**U.S. Department of Energy**
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# FINAL ENVIRONMENTAL REPORT: INEL GEOTHERMAL ENVIRONMENTAL PROGRAM

Thomas L. Thurow
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EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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# ABSTRACT

The INEL Geothermal Environmental Program was designed to assess beneficial and detrimental impacts to the ecosystem resulting from the development of moderate temperature geothermal resources in Raft River Valley. The results of this research contribute to an understanding of the valley ecology and provides a basis for making management decisions to reduce potential long-term detrimental impacts on the environment. Also, the design of the program can serve as a guide to environmental issues associated with this type of development and the approaches that may be taken to address these concerns. This report summarizes the environmental monitoring and research efforts conducted throughout development of the Raft River Geothermal Research Facility.

# ACKNOWLEDGMENTS

Throughout the Raft River Geothermal Environmental Program, many individuals and agencies have provided technical advice and support. We would especially like to thank L. Wheeler and M. Dolenc for their time and effort spent reviewing this report. J. Sullivan and S. Spencer, formerly of EG&G, were involved in the Raft River environmental program since its early stages. We owe special thanks to E. G. Crosthwaite, formerly of the U.S. Geological Survey; R. Howard, U.S. Fish and Wildlife Service; J. Pribble, N. Cozakos, and K. Carter, Bureau of Land Management; the staff of the Idaho Department of Water Resources; R. Olsen, Idaho Department of Fish and Game; and J. Cate, National Oceanic and Atmospheric Administration. C. Lewis of Lewis and Associates performed the Raft River/Cassia County Socioeconomic Survey. J. Allan of the University of Utah Research Institute (UURI) performed the vegetation study. J. Barnes, and D. Shiozawa of Brigham Young University (BYU) conducted the aquatic survey of the Raft River. C. White, S. Clark, and D. Johnson of BYU participated in the raptor population research and assisted J. Gesseman of Utah State University on the raptor radiotelemetry study. A. Nelson, C. Tuckfield, W. Divine, and C. White of BYU performed the passerine bird survey. D. Crow, T. Rappolt, and K. Reheis of Erco, Inc., designed the air quality monitoring network and were responsible for the data analysis. The seismicity study was conducted by S. Schaff of UURI and E. Majors of Lawrence Berkeley Laboratory. C. Hurst, A. Olson, H. Peterson, and J. Shupe performed the fluorosis survey. The rodent study was conducted by C. Jorgensen, C. Pritchett, T. Johnson, and D. Landeen of BYU. We appreciate the efforts of all EG&G and DOE people who contributed to the program.

# SUMMARY

This report provides an overview of environmental monitoring programs and research during development of a moderate temperature geothermal resource in the Raft River Valley. One of the major objectives was to develop programs for environmental assessment and protection that could serve as an example for similar types of development. The monitoring studies were designed to establish baseline conditions (predevelopment) of the physical, biological, and human environment. Potential changes were assessed and adverse environmental impacts minimized. No major environmental impacts resulted from development of the Raft River Geothermal Research Facility. The results of the physical, biological, and human environment monitoring programs are summarized in Volume I.

The Physical Environmental Monitoring Program collected baseline data on geology, subsidence, seismicity, meteorology, and air quality. No increase in seismic activity was detected as a result of geothermal development, and it appears that the Research Facility is located in an area that is closely related to the inactive Snake River Plain. Although 0.9 m of subsidence was recorded in the northern Raft River Valley in the last 40 years because of excessive irrigation ground-water pumping, no changes in elevation were documented as a result of geothermal production or injection.

Air quality was identified as a major environmental concern. However, emissions generated from the Raft River geothermal development were measured as being well below National Ambient Air Quality Standards. Air quality in the area was found to be mainly affected by dust from agricultural and natural causes.

The Biological Environmental Monitoring Program collected baseline data on the flora and fauna of the fragile cold-desert ecosystem of the area, and surveyed the aquatic communities of the Raft River. Raptor disturbance research established a 0.6-km buffer zone that must be maintained around ferruginous hawk nest sites to protect this sensitive species. The nesting success of the ferruginous hawk in the Raft River Valley was not impaired by geothermal development and associated human activity as long as buffer zones were maintained. Declines in the nesting success of the ferruginous hawk population were associated with the natural cyclic trend in the black-tailed jackrabbit population. A survey of passerine birds suggested that sage thrashers and sage sparrows may be sensitive indicators of environmental change in sagebrush, greasewood, and shadscale communities because they are habitat specific. No spills of geothermal water into the Raft River occurred during the development and operation of the geothermal facility.

The Human Environment Monitoring Program surveyed historic and archaeological sites, the socioeconomic environment, and documented incidences of fluorosis in the Raft River Valley. The development of the Raft River Research Facility had no impact on known historic or archaeological sites, and no undiscovered sites were located during construction activities. The closest archaeological site discovered is 0.8 km from the development and the rest are at least 3 km away. Proper planning during all phases of the geothermal project ensured that adverse socioeconomic impacts were minimized and potential benefits to local residents realized. A survey of the dental health of Raft River Valley school children was conducted by a dentist in 1978. The dental health of these children was unusually poor, and 19% of the children displayed symptoms of fluorosis. Further studies failed to determine the source of fluoride.

In addition to the environmental monitoring programs, research on biological direct-applications was conducted at the Raft River Geothermal Facility. Survivability and productivity of various agricultural, aquacultural, rangeland, and silvicultural species were tested. Studies were also conducted to assess the potential of biological systems such as wetlands for water purification through bioaccumulation of elements from the water. Results of these efforts are presented at the end of Volume I.

The effects of geothermal development of the water quality and hydrology were a major environmental concern. Volume II discusses the Monitor Well Program. Changes in ground-water quality observed were negligible. Short transient pressure responses were noted as a result of geothermal production and injection. Potentiometric head values

returned to original levels when production/injection ceased. Thus, the effects of development at the Raft River Research Facility on groundwater were negligible. Because of the short duration of the hydrologic test, however, no long-term predictions can be made.

As of June 15, 1982, the engineering test phase of the 5-MW(e) facility was completed. The total accumulated amount of power generated by the facility since the plant was started was 2410.8 MWh. Engineering data gathered is presently being prepared in a final report.

On April 1, 1982, a Solicitation for Cooperative Agreement Proposals was issued by DOE to select a user for the facility. Since no proposals were received, the plant is currently in the process of being placed in cold standby prior to turnover to the General Services Administration for sale or disposition. All INEL project involvement in the power plant will be complete by October 1982.

# CONTENTS

## FIGURES

## TABLES

# FINAL ENVIRONMENTAL REPORT: INEL GEOTHERMAL ENVIRONMENTAL PROGRAM

## RAFT RIVER GEOTHERMAL DEVELOPMENT

The Raft River Geothermal Program at the Idaho National Engineering Laboratory (INEL) was initiated in 1973. The Raft River (previously Frazier) Known Geothermal Resource Area (KGRA) was chosen in 1971 based on two shallow boiling water wells. Preliminary geological, geophysical, and geothermometry work conducted by the U.S. Geological Survey (USGS)[1] predicted a geothermal resource at depth in the Raft River Valley with a temperature of 150°C. Therefore, in 1974, the U.S. Department of Energy (DOE) (then the Atomic Energy Commission—AEC), the Raft River Rural Electric Cooperative (RRREC), and the Idaho Department of Water Resources (IDWR) initiated a cooperative venture to investigate the potential of generating electricity using the moderate-temperature geothermal fluid. The program at Raft River was designed to demonstrate that moderate-temperature (150°C) geothermal fluids can be used to generate electricity and provide an alternate energy source for direct-use applications. The objectives of the Raft River program were to:

1. Determine the electrical power generation potential using moderate-temperature geothermal fluid
2. Demonstrate the economic feasibility of constructing large-scale plants using pilot facilities
3. Test the engineering design and component systems used in geothermal applications
4. Develop programs for environmental assessment and protection that could serve as an example for similar types of development
5. Test and develop beneficial direct uses of geothermal fluids.

Two experimental electrical generation plants have been operated at Raft River to demonstrate the feasibility of using moderate-temperature geothermal fluid for electrical power production and to develop Rankine Cycle conversion systems. Small-scale experiments have been performed on the 60-kW(e) prototype plant to develop methods for increasing the performance of the Rankine Cycle or reducing its cost. The basic system is a closed loop in which a heat exchanger heats a working fluid (e.g., isobutane). The working fluid then condenses and is pumped back to the heat exchanger, completing the cycle. The cooling water for the condenser circulates through a cooling tower. Other working fluids tested were an isobutane-propane mixture, isobutane-isopentane, and propane.

The 5-MW(e) pilot plant tested a dual-boiling binary cycle using isobutane as the working fluid. The quantity of geothermal water supplied to the facility was 2250 gpm. An additional 200 gpm bypass flow was used for plant regulation, and 400 gpm were used for advanced system experiments. Cooling tower makeup water came from the plant's cooled geothermal fluid at a rate of 450 gpm. The used geothermal fluid was then piped across the well field through transite (cement-asbestos) pipe. The water flowed into holding ponds for later injection.

In addition to the electricity generation tests, direct-application research was conducted. These studies included experiments on: heat exchangers, heat dissipation, space heating and cooling, high-temperature heat pumps (120 to 260°C), industrial and agricultural product drying, essential oil extraction, biological uses (see Biological Direct Applications Research section), and the use of geothermal heat for alcohol production.

An essential part of the geothermal development program was the Environmental Program. The environmental research and monitoring studies conducted at Raft River provide important insights on environmental aspects that must be understood before an assessment of impact can be made. Through understanding the environment's biotic and abiotic components, significant changes can be predicted and prevented, thus helping to ensure responsible development of the resource.

## Resource Agreements

The Raft River geothermal site has been operating under a cooperative research agreement between the former AEC and the Bureau of Land Management (BLM). This agreement was originally negotiated in 1973 to serve in the interim period while approval of an AEC land withdrawal application was pending. This application requested a withdrawal of 1960 ha of land from the public domain. The reason for this request was to restrain potential outside development that could possibly interfere with the geothermal resource being used for AEC/DOE research. The area within the proposed withdrawal consisted of 32 ha of reserved mineral rights and 1928 ha of national resource land (administered by the BLM). In 1981, the withdrawal application was dropped by DOE; thus, the land will remain available for DOE research on an annual basis under terms of the BLM cooperative agreement.

The Raft River KGRA is located in a region that has been designated as a Critical Ground Water Basin since 1963. This classification means that additional demands on the water resource will not be approved. If a new development is planned, the water rights must be purchased from an existing user. The Raft River geothermal development does not have a water-use permit from IDWR. IDWR's present position is that the Raft River project is a research facility for which no long-term water transfer is necessary. This position provides flexibility in pursuing a mutually acceptable policy for use of the geothermal aquifer for research purposes.

# PHYSICAL ENVIRONMENTAL MONITORING PROGRAMS

Physical aspects of the environment, such as air and water quality, meteorology, and subsidence, affect the entire ecosystem. Programs designed to monitor these aspects are essential to ensure effective management of the region's resources. The following monitoring programs were designed to detect changes in the physical environment and to indicate potentially adverse effects of the geothermal development on the environment. Due to the importance and the level of effort dedicated to the water quality monitoring program, this topic is discussed in a separate section of this report (see Volume II).

## Geology

The Raft River Valley trends north-south and is 60 km long and 20 to 24 km wide. The KGRA is located at the southern end of the valley very near the Idaho-Utah border. It is bounded by the Black Pine Mountains, the Jim Sage Mountains, the Raft River Range, and the Snake River Plain (Figure 1).

The Black Pine Mountains bound the east side of the Raft River basin. They are composed primarily of Late Paleozoic marine sediments, and minor Tertiary volcanic and Quaternary alluvial and colluvial sediments. The range exhibits high-angle Basin-and-Range normal faulting superimposed on older folds and low-angle thrust faults.

The Jim Sage Mountains form the western boundary of the basin. They are an anticlinal block tilted to the east.[2] The range consists of the Tertiary Salt Lake Formation capped by Tertiary rhyolite flows. Basin-and-Range forces created north-trending listric normal faults on the east flank of the Jim Sage Mountains. Movement along these faults has dropped the Raft River Valley with respect to the range.

The Raft River Range is one of the few east-west trending ranges in the Basin-and-Range province. The autochthonous core of the range, Precambrian adamellite, is mantled by two major allochthonous sheets of Precambrian, Paleozoic, and Triassic metasediments transported tens of kilometers over low-angle thrust faults. Strata from both the autochthon and part of the Precambrian allochthon form the basement complex in the Raft River Basin.[3] The present Raft River Range formed during the Pliocene as a broadly arched anticline oriented east-west.

Sheep Mountain to the north of the KGRA, and Round Mountain to the southeast are intruded rhyolite domes. They are approximately eight million years old (see Reference 1) and lie on a northwest-trending lineament that crosses the valley.

The basin stratigraphy consists of the Precambrian adamellite and metasediments mapped in the Raft River Range unconformably overlain by the Tertiary Salt Lake Formation, the Pleistocene Raft Formation, and Holocene alluvium and colluvium (Figure 2). The sediments overlying the Precambrian basement are approximately 1800 m thick.

The Precambrian adamellite basement rock is thought to be partially older than the overlying metasediments, and partially remobilized and intruded (see Reference 1). The Precambrian metamorphic sequence overlying the adamellite is approximately 150 m thick.[4] From oldest to youngest, the units are the Older Schist, the Elba Quartzite, the Upper Narrows, Schist, and the Yost Quartzite. Both the Older Schist and the Yost Quartzite are absent in exploratory wells RRGE-1 and -2. This absence may be a result of erosion or low-angle thrust faulting that characterizes the Raft River Range (see Reference 3).

The Tertiary Salt Lake Formation is a lacustrine, poorly consolidated deposit up to 1600 m thick. The formation consists primarily of tuffaceous siltstone and sandstone with minor conglomerate derived from the surrounding mountain ranges. Deformational structures in the Salt Lake Formation indicate rapid deposition and deformation of water-saturated sediments. Volcanic shocks may have produced sufficient force to cause rapid slumping and turbidity currents.[5]

No definitive stratigraphic break occurs between the Tertiary and Quaternary sediments. The division is based on the relative abundance of volcanic material, which is less in the alluvial and

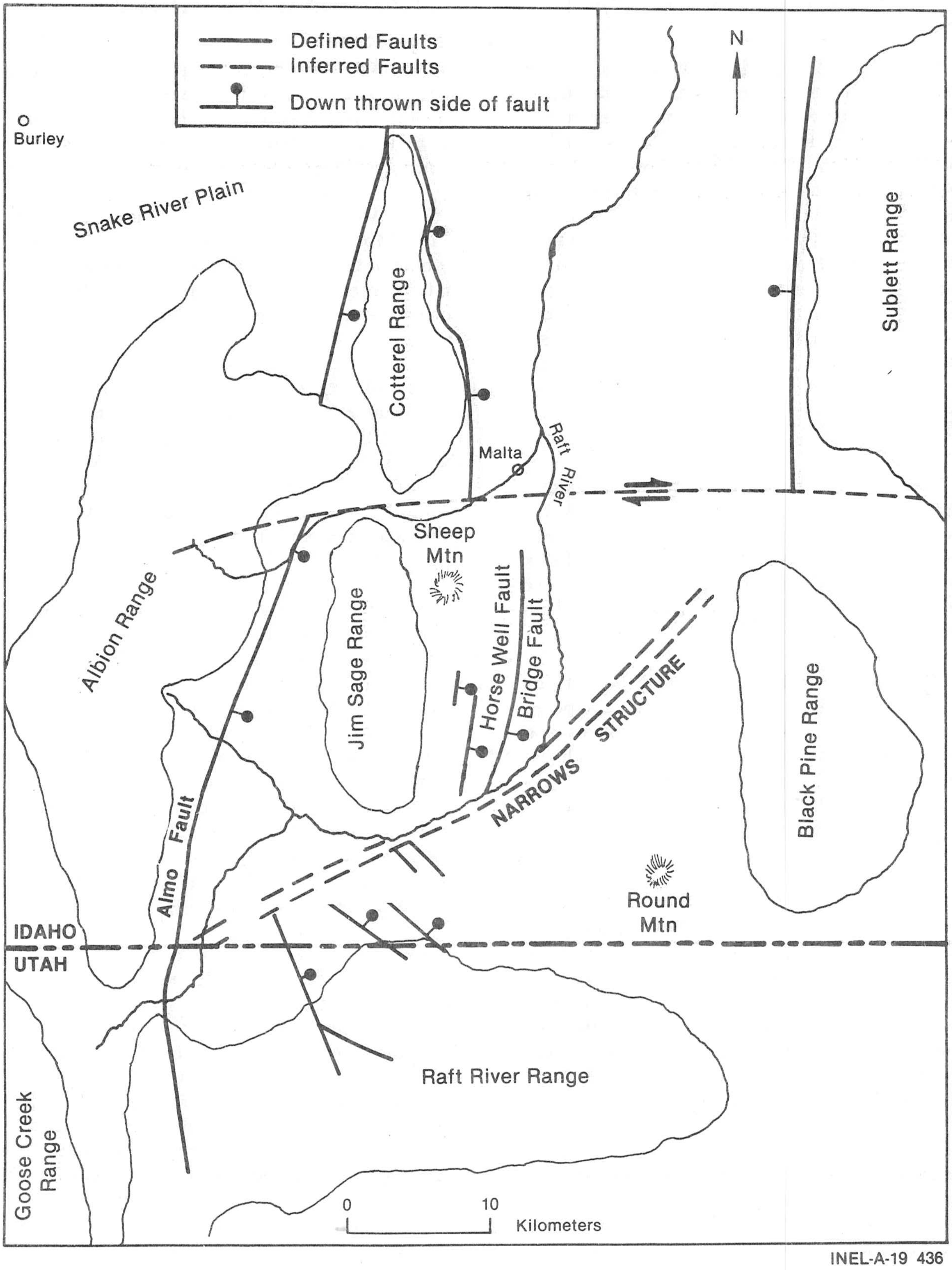
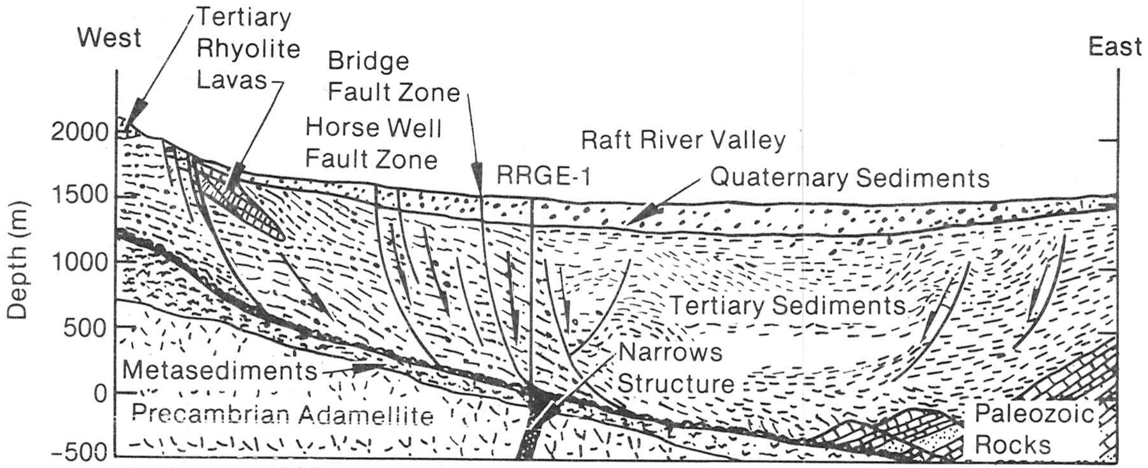


Figure 1. Major structural features of the southern Raft River Valley.



(Covington, 1980)

Figure 2. Geologic cross-section of the Raft River Valley.

fluvial deposits comprising the Pleistocene Raft Formation. This formation, up to 300 m thick, consists of unconsolidated quartz sand and silt, tuff, and minor rhyolite gravel originating from the surrounding mountain ranges. A correlation of the Raft Formation between wells is not possible because of the lenticular nature of deposition.[6]

Holocene alluvium and colluvium overlie the Raft Formation. The present topography near the KGRA is characterized by pediments and coalescing alluvial fans on the fringe of the Raft River floodplain. The Raft River meanders northward through the basin from the southern end of the Jim Sage Mountains.

The geologic structure of the Raft River basin near the KGRA has been studied extensively using geophysical methods, surface mapping, and aerial photography. The eastern side of the basin was formed by the downwarped flank of the Black Pine Mountains with secondary normal faulting. The western side of the valley is downdropped along listric faults in the Bridge and Horse Well Fault zones.[7] These north-trending listric faults dip 60 to 80 degrees to the east at the surface and flatten at depth to parallel the bottom of the Tertiary sediments (Figure 2). Covington[8] postulates that the Precambrian basement is not displaced and movement on the concave upward faults produced many near-vertical open fractures and cracks near the base of the Tertiary sediments. A structural lineament, the Narrows zone, is inferred by a compilation of anomalous data from geophysical surveys that suggest major changes occurring in a northeast trend. This zone extends across the valley from the southern end of the Jim Sage Mountains, and terminates the Bridge and Horse Well Fault zones. This poorly understood structure is possibly a basement shear related to the Humboldt zone of northern Nevada.[9]

The geothermal reservoir in the KGRA occurs near the Horse Well and the Bridge Fault[10] in fractures near the contact of the Salt Lake Formation and the metasediments. The metasediments and adamellite are also fractured and yield significant quantities of hot water. The recharge is assumed to be in the Jim Sage Mountains. A USGS tritium analysis of the thermal fluids in the geothermal reservoir suggests the fluid is at least 60 to 70 years old. Static water levels in the thermal reservoir are about 100 m above the land surface. Hydrothermal water may circulate to depth along basement fractures, then rise along faults that are permeable, and spread laterally into the Salt Lake Formation along anomalous permeable zones and soft-sediment fractures. This upward leakage (in the direction of the hydraulic gradient) is presumably the source of hot water to shallow- and intermediate-depth warm aquifers, and the shallow BLM and Crook wells. No evidence of a local heat source is apparent (see Reference 10 and Volume II).

## Seismicity

**Introduction.** Earthquakes can be triggered by some types of human activity. Induced seismicity may result from mining, underground nuclear testing, reservoir filling, fluid withdrawal, and fluid injection. These activities can alter the stress fields within the earth causing a release of energy in the form of an earthquake. Microseismic activity is common in many developed geothermal areas, implying that an active stress field exists at depth. The possibility of inducing earthquakes as a result of fluid withdrawal or injection is of concern during geothermal development. At Raft River, a seismic network was established to collect baseline data and monitor seismic activity during geothermal field testing, production, and injection.

**Background.** The Raft River Valley is bordered by the seismically active Basin-and-Range province to the south and west, the Intermountain Seismic belt to the east and the relatively aseismic Snake River Plain to the north. The valley is located in a seismic risk Zone 2, indicating a long-term hazard for seismic events of intensity 7 (modified Mercali).[11]

Historical data indicate no events greater than 3 $M_L$ (Richter magnitude) recorded within 30 km of the KGRA. Only three significant events occurred within 30 to 50 km of the site (5.1 $M_L$ in 1934, 5.4 $M_L$ in 1937, and 1.5 $M_L$ in 1973).[12] From these data, the Raft River Valley appears to be closely related to the Snake River Plain, which exhibits an extremely low level of both micro- and macroseismicity.[13] However, the absence of macroearthquakes in the Raft River Valley in historic times does not necessarily imply an absence of microseismic activity. A microseismic monitoring program was initiated in 1974 to gather background data on microseismic activity and to test whether production and injection of geothermal fluids at the Raft River facility induce microseismic activity.

**Methods.** The first seismograph array, established on July 26, 1974, consisted of a three-component (orthogonal) seismograph station at Pig House station and two single-component (vertical) seismometers located at the Narrows and on the eastern flank of Sheep Mountain (Figure 3). The two horizontal components of the orthogonal seismograph record shear waves (S) more precisely than the vertical component. Low frequency (1 hz) geophones were used, with telemetry equipment up to 16 hz. Although this 1- to 16-hz band pass is tailored for detecting regional events, it is capable of monitoring high frequency (microseismic) events; however, sensitivity decreases with increasing distance from the epicenter. After operating for two months, the Pig House seismometer was abandoned and moved to the HW station (Figure 3) because of noise generated by livestock and people near the site. This location change did not improve the high frequency noise problem and the two horizontal components were shut down. The remaining three-component vertical array, operated until October 29, 1974 (see Reference 12).

A three station seismic array operated from 1976 to 1978 until equipment problems forced its shutdown. The project was not summarized, and little is known about the instrumentation. This array provided a qualitative rather than quantitative evaluation of earthquake activity.

In April 1980, a new seismic array was established. This array consisted of three stations: one in the Jim Sage Mountains, one at Round Mountain, and one at the Narrows station (Figure 3). Each station housed a single vertical component seismometer with low frequency geophones. The band pass was 1 to 15 hz. Continuous monitoring began in June 1980. The signal from each seismometer was amplified, put into FM signal, and radio-transmitted to a relay in the Black Pine Mountains. The signals were then mixed and transmitted to a relay south of the Great Salt Lake. This relay transmitted them to a receiving center where they were recorded onto analog tapes for analysis.

The instrumentation of the seismograph array was changed in mid-March 1982. Although the locations of the stations did not change, each station was equipped with three-component seismometers. The band pass was 4.5 to 70 hz, tailored for monitoring microseismic events (which occur in the high frequency range—10 to 50 hz). The transmittal of data to the receiving center remained the same; however, the data were recorded onto digital cassette tapes. The recorders could record 200 samples per second and operated only when the seismometers were triggered by a seismic event.

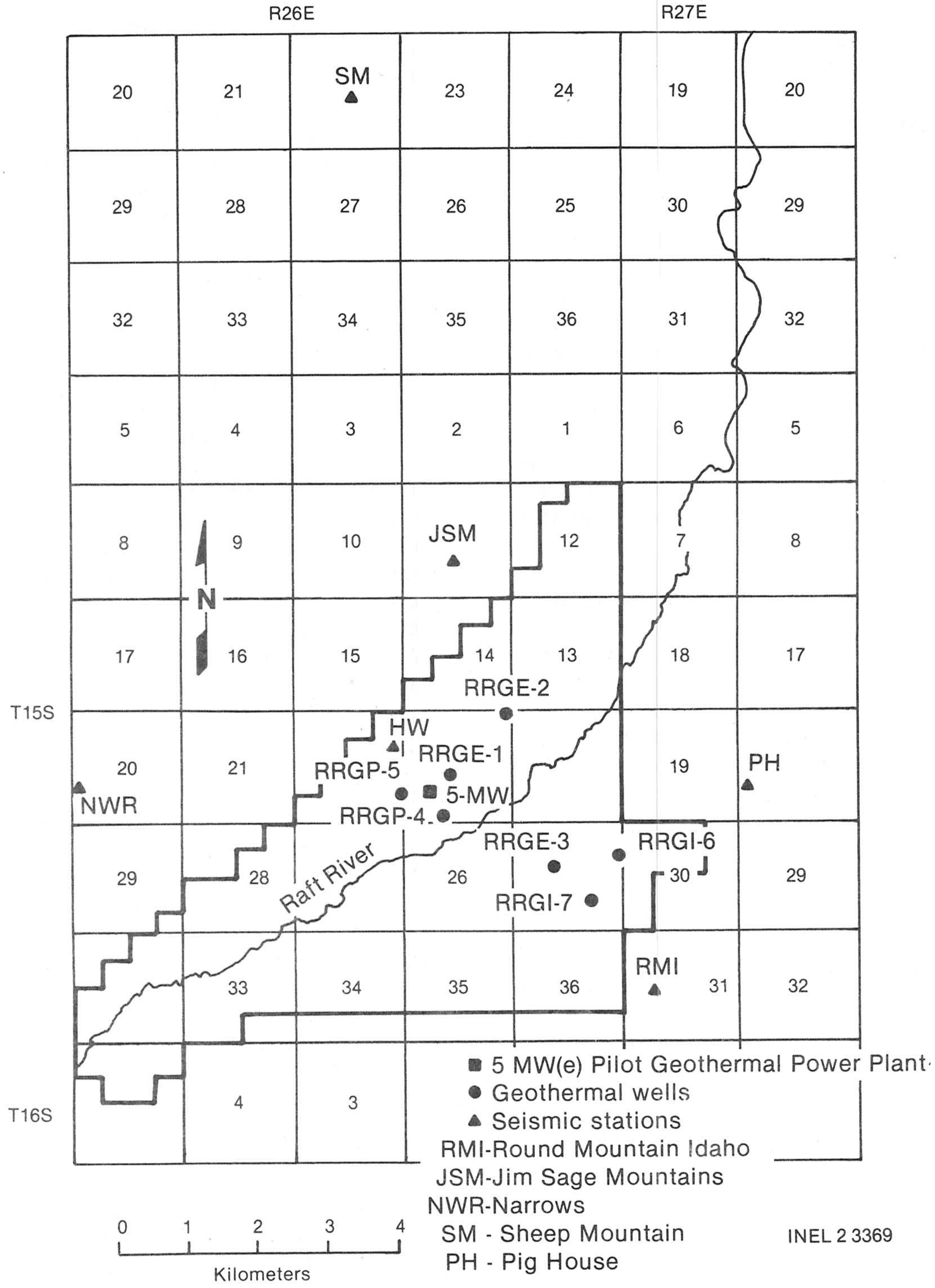


Figure 3. Location of the seismograph stations.

**Results and Discussion.** The 90-day microseismic survey in 1974 recorded seven events with epicenters within 17 km of the geothermal site [corresponding to S - P (shear waves minus compression waves) travel times less than 3.0 s]. These events were detected by one station only, either at Sheep Mountain or the Narrows. Unless three stations detect an event, the epicenter cannot be located. None of the events were greater than 0.2 M. Microseismic activity was estimated to be less than 0.2 events per day (see Reference 12). No earthquakes were recorded in the array between 1976 and 1978.[13] The. 1980 survey recorded several local events (within 65 km, S - P time less than 8 seconds). However, none of these local events can be related to the geothermal system because the epicenters were not within the Raft River array.[14] No seismic activity greater than 0.0 M with S - P time less than 2 seconds appears on the data collected from the three orthogonal-component seismometers installed in mid-March, 1982.

The Raft River seismic surveys provide data on background levels of seismicity and monitor seismic response to well testing, production, and injection. The absence of both macroseismic and microseismic activity indicate that the KGRA is more closely related to the inactive Snake River Plain than to the seismically active Basin-and-Range province and the Intermountain Seismic belt (see Reference 12). The low level of background seismicity in the vicinity of the KGRA indicates a low-stress environment. A greater increase in effective stress (created by withdrawal or injection of fluids) is required to induce an earthquake in a low-stress regime than in a high-stress regime. It is unlikely that earthquakes would be triggered by geothermal activities in the low-stress environment of the Raft River test facility and, to date, no increase in seismic activity has been detected.

## Subsidence

Excessive groundwater withdrawals from unconsolidated or poorly consolidated aquifers may cause land subsidence and fracturing. The declining water level lowers the hydraulic head, increasing the effective stress. This causes the aquifer to compact. If the compaction is propagated to the land surface, subsidence occurs.

Local areas in the northern Raft River Valley have subsided over 0.9 m in the last 40 years because of excessive groundwater pumping for irrigation (Figure 4).[15] A program to monitor potential subsidence caused by geothermal fluid withdrawal was initiated in 1975. A detailed surveying grid was established at the Raft River geothermal well field in 1975. The grid consisted of points spaced 1/4 mile apart in a 3- x 3-mile area with a total of 169 points. Using USGS bench marks as a reference, elevations in the geothermal development area could be checked and any significant changes measured. The grid, which encompasses the geothermal wells, was surveyed in 1978 and 1980. After completion of all wells in 1979, the monitoring program was expanded to periodically include elevation checks (second order, first class) at specific wells during production and injection tests. These portions of the well field were thought to be most susceptible to elevation changes from geothermal production and injection activities. The survey line began off the well field (about 1 km west of RRGE-2), and ran to RRGE-2; it then ran from RRGE-2 to RRGE-3, RRGE-3 to RRGI-6, and RRGE-3 to RRGI-7 (see Volume 2 for well locations and descriptions). In addition, the elevations of the monitor wells were surveyed during two injection tests.

Changes in elevation observed during the 1975 survey were within the expected error of the level runs with the exception of five points. These anomalous elevation changes were not related to geothermal activities; several of the points were located in cultivated fields where disturbance is likely. With the exception of these five points, all changes in elevation measured during the subsidence surveys were within the experimental error. No detectable changes in elevation occurred as a result of the geothermal development at Raft River.

## Meteorology

**Introduction.** Wind characteristics, precipitation, and temperature have a direct effect on most aspects of the environment. Meteorological data from the Raft River site provide important information needed to analyze the ecological research and the air quality program. For example, a cold, wet springtime affects the brood success of ferruginous hawks, and drought periods reduce the

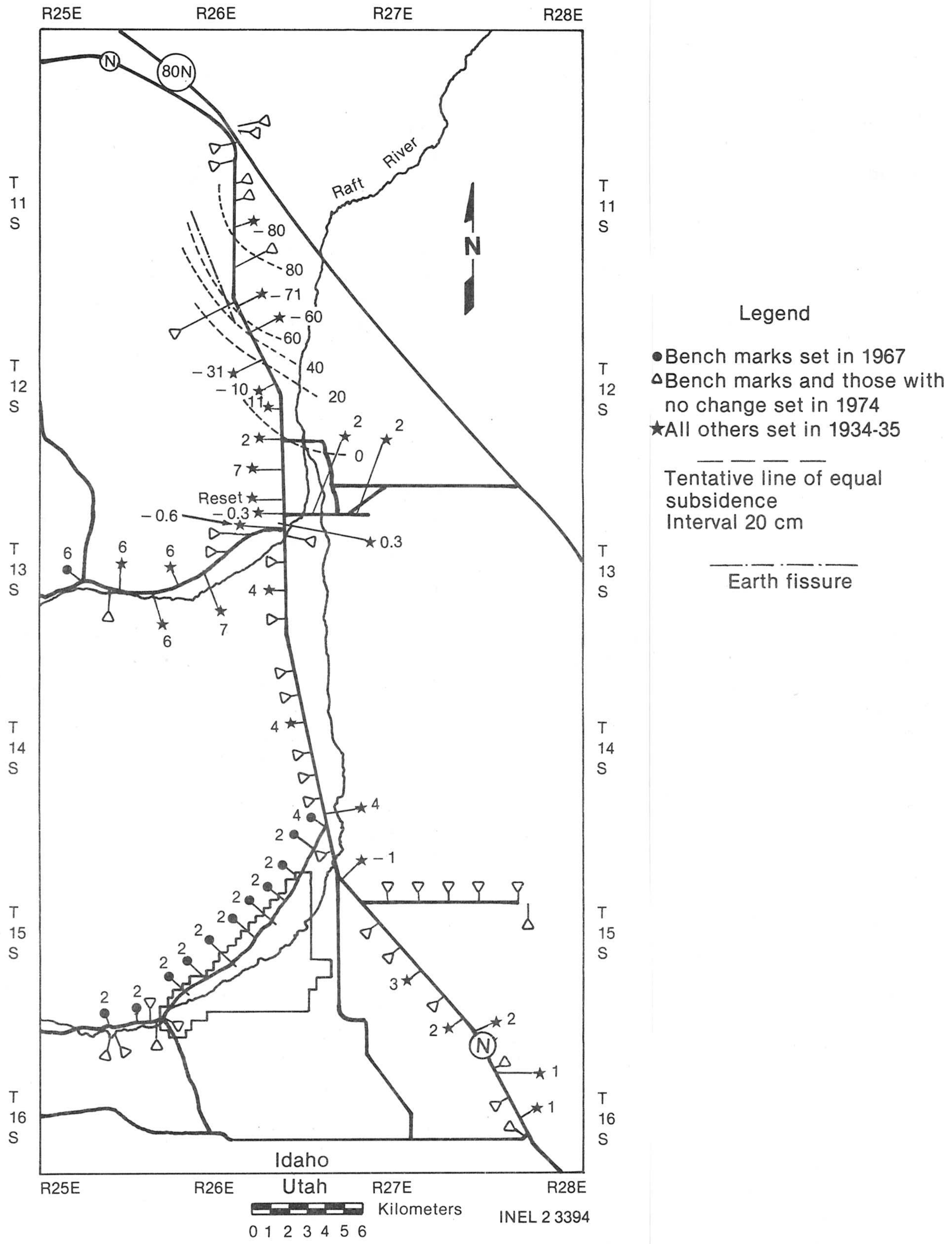


Figure 4. Measured subsidence in the Raft River Valley through 1974.

food supply for small mammals. Wind speed and direction affect the disperal of the plume from the cooling tower. The meteorological data are incorporated into the different environmental monitoring programs and may help explain some of the unusual phenomena observed.

**Methods.** A weather station was established in 1975 just east of RRGE-2 which monitors wind velocity and direction, precipitation, ambient air temperature, and dewpoint temperature. The station automatically samples once every 6 min and transmits the data to the National Oceanic and Atmospheric Administration (NOAA) computers at the INEL. In addition, total sky and normal incidence solar radiation instrumentation provide data for agricultural experiments and supplement solar data collected at the Energy Experiment Station at Idaho State University.

**Wind Rose.** The wind patterns in the Raft River Valley are strongly influenced by local and regional topographic features. This is evident in the wind roses for Strevell and the KGRA (Figure 5). Winds from the Wasatch Front flow into the valley at Strevell, which is located in a pass between two mountain ranges, the Raft River Range to the west and the lower Black Pine Mountains to the northeast. These southeasterly winds often carry smog into the valley. Hydrogen sulfide ($H_2S$) found in the valley does not appear to be related to the geothermal development, but rather to this northwesterly transport of pollution into the valley from the Wasatch Front.

The wind rose for the KGRA demonstrates the channeling effect of the Narrows on the wind. Winds are predominantly from the southwest (240 degrees). Less than 35% of all winds originate between 270 degrees (W) and 90 degrees (E). Wind roses for the site for 1978 and 1980 show the winds are calm only about 5% of the time. Because of the high frequency of windy days, dispersion characteristics of the site are good.

**Temperature.** The mean annual temperature in the Raft River Valley is 8°C. In the coldest months, December and January, the mean temperature is -3.1°C, and in the warmest months, July and August, the mean temperature is 20°C. The extremes on record are -30 and 40°C. As is typical of other western mountain states, inversions or isothermal conditions are common. In the region, they occur 40% of the time in the summer and 50% of the time in the winter. Rapid cooling during clear evenings creates night time inversions. Winds and morning heating of the ground usually clear the inversions before afternoon. Figure 6 presents a summary of average monthly temperatures at Strevell since 1974. These data show the low variability of average monthly temperatures from year to year in the area.

**Precipitation.** Precipitation results mainly from winter storms moving in from the west and summer thunderstorms moving in from Utah and Nevada. Local variations in precipitation patterns result from changes in topography. Although precipitation at the site would be expected to vary from precipitation at Strevell, precipitation data for Strevell are useful in showing general trends.

Comparisons of average monthly precipitation at Strevell during the 8 years of geothermal development (1974 through 1981) with the previous 9 years (1965 thorugh 1973) yield readily observable general trends (Figure 7). Precipitation during the latter period was markedly less than the earlier readings. During the earlier period, the average yearly precipitation was 314 mm; during the period of goethermal development, the average was 255 mm, a 59-mm (19%) average yearly difference. The largest monthly deviation occurred in June; from 1965 through 1973, average precipitation was 57.9 mm; from 1974 through 1981, the average was 21.2 mm. This is a 36.7-mm (63%) difference.

Some unusual seasonal trends in precipitation occurred during the 8-year period of geothermal development (Figure 8). October of 1976 marked the beginning of a severe drought, continuing through April of 1977. Precipitation for May 1977 was 89 mm. This was 30% of the total for that year. The period from May through September of 1977 accounted for 83% of the year's total precipitation. The summer of 1978 was exceptionally dry, accounting for only 4% of that year's precipitation. 1979 was generally a dry year; from February through July, precipitation was about half that of the same period in previous years. The spring of 1981 was extraordinarily wet; precipitation almost doubled the seasonal norm. March of 1982 was one of the snowiest months on record with over 50 mm of precipitation.

These data illustrate the degree of variability of precipitation in the vicinity of the KGRA from year to year and from month to month. The

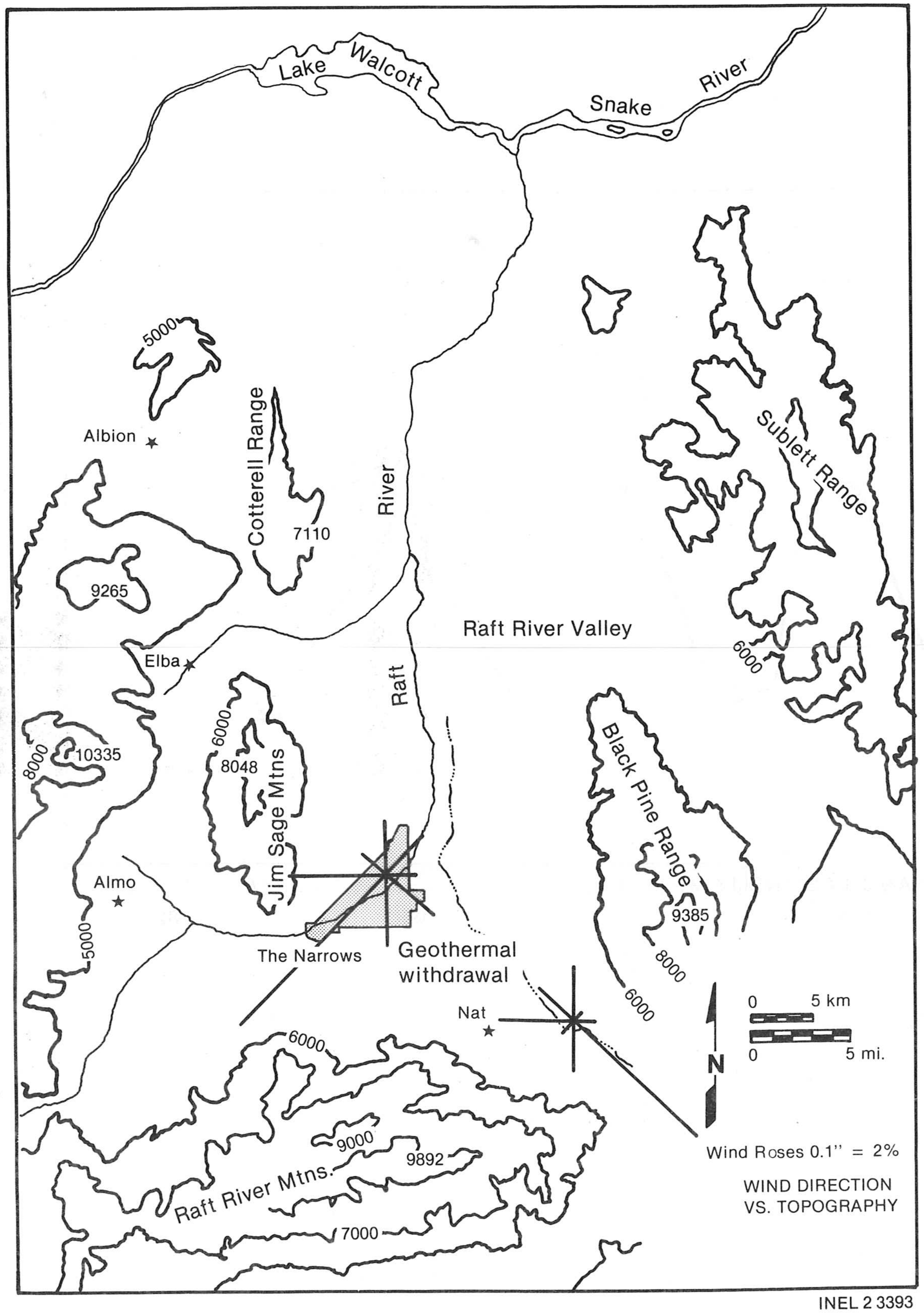


Figure 5. Wind roses for the southern Raft River Valley.

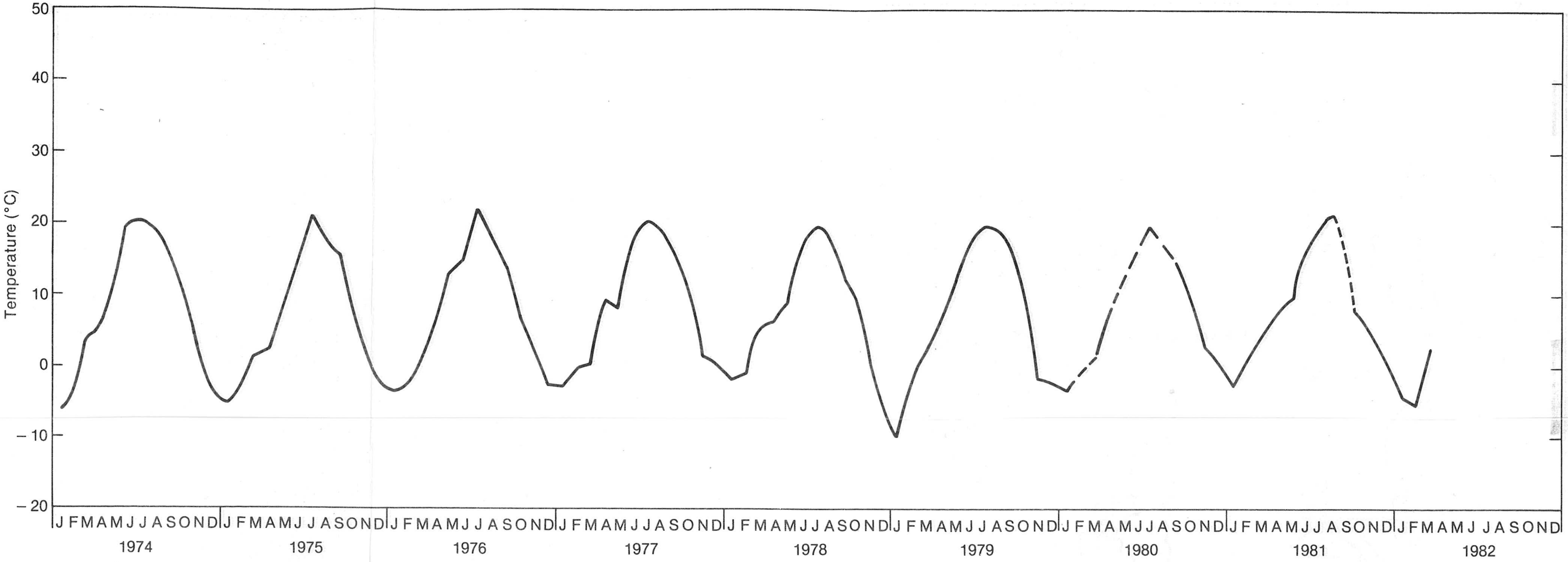


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Figure 6. Monthly average temperature from 1974 to 1982 at Strevell.

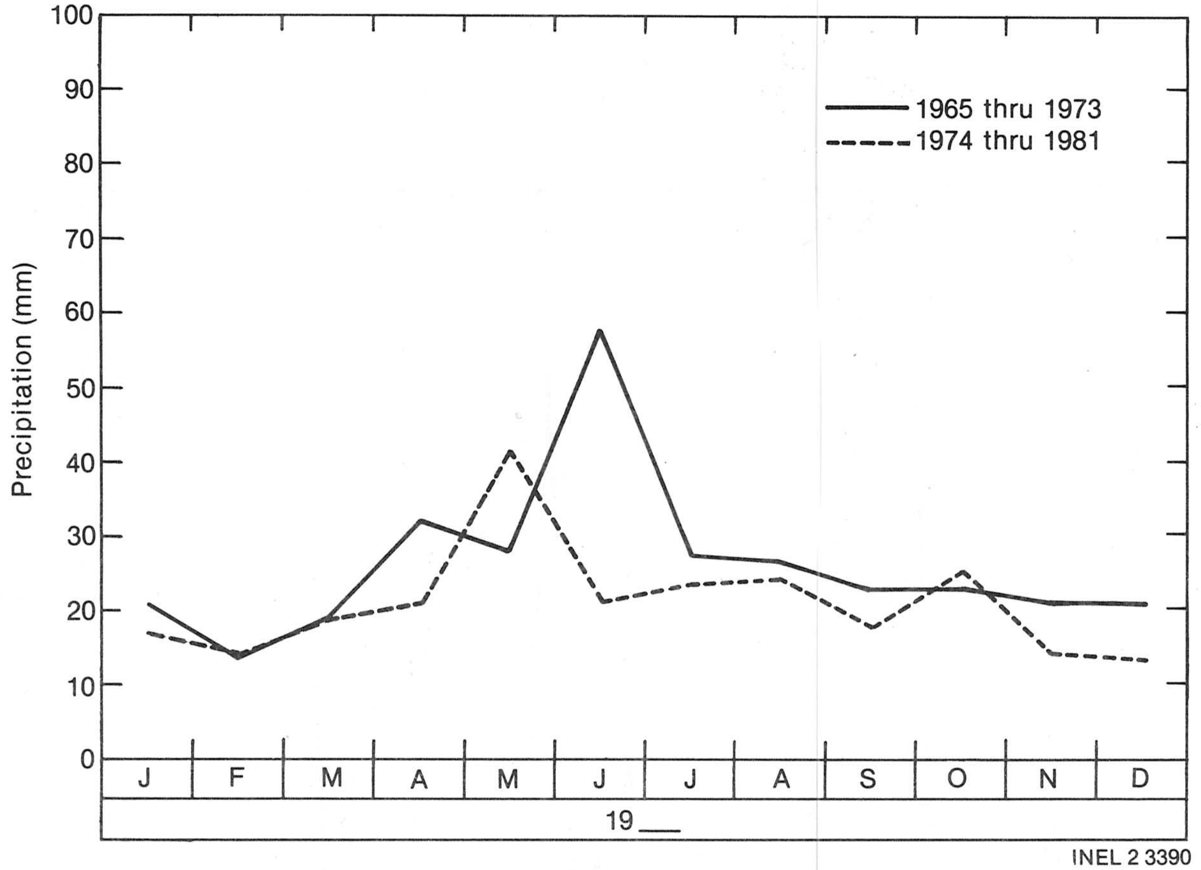

Figure 7. Comparison of monthly average precipitation at Strevell for the periods 1965 to 1973 and 1974 to 1981.

orological data were useful in explaining unusual occurrences observed during other monitoring activities of the Raft River Environmental Program.

## Air Quality Monitoring

**Introduction.** When geothermal development began in the Raft River Valley, the primary air quality concern was the emission of hydrogen sulfide, based upon experience at the Geysers in California. Particulate emissions were also of concern, because they result both from the drying of mists emitted from the cooling towers and from dust caused by construction and operation activities. Baseline air quality studies were initiated at Raft River in 1975. By measuring concentrations of various atmospheric pollutants, the existing background air quality was defined. Changes in air quality resulting from the geothermal development could then be assessed by comparing the baseline pollutant concentrations with the concentrations obtained after the major developments began in 1979.

Throughout the 7 years of monitoring, particulate measurements were collected by both high-volume and low-volume air samplers. The baseline air quality studies during the years 1975 through 1977 were directed toward the measurement and analysis of total suspended particulates size distribution and visibility. In March of 1976, the United States Environmental Protection Agency (EPA) collected measurements of radon gas emissions. In 1980 the air monitoring program was expanded in order to collect more statistically accurate data. Emissions from the cooling tower were measured in 1982.

Table 1 provides a complete summary of the air monitoring activities at Raft River between 1975 and 1982. By comparing the data obtained upwind of the plant to the downwind data, qualitative estimates of emissions and impacts from the power plant were made.

**Methods.** Total suspended particulate (TSP) concentrations were obtained with high-volume samplers by recording the flow rate of air through

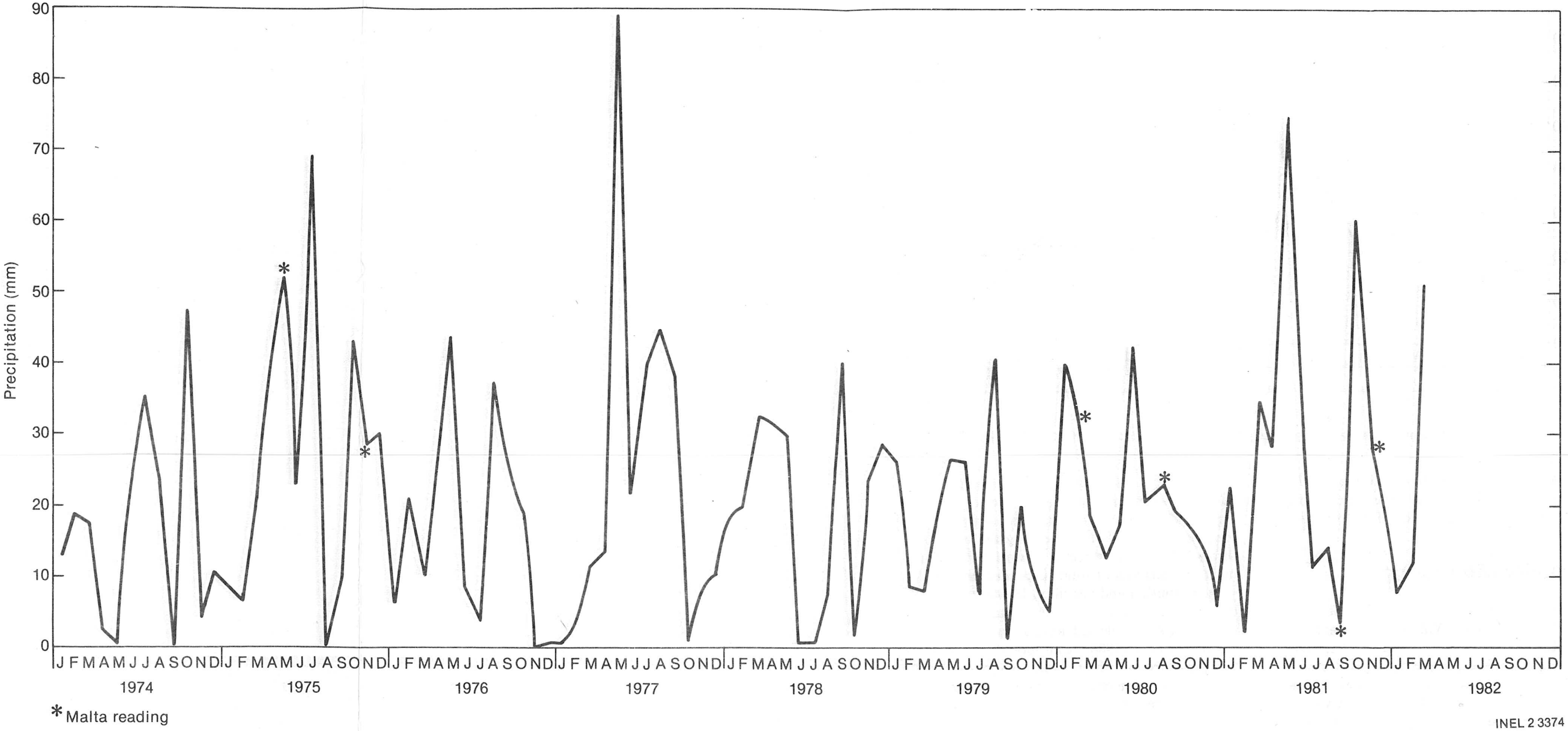

Figure 8. Monthly average precipitation at Strevell from 1974 to 1982.

## Table 1. Summary of air quality sampling conducted at the Raft River Geothermal Facility 1975 to 1982

| | | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Location | January | February | March | April | May | June | July | August | September | October | November | December |
| 1975 | Malta | — | — | — | — | — | — | HL | HL | HL | HL | — | — |
| | Crank | — | — | — | — | — | — | — | — | — | — | — | — |
| | Naf | — | — | — | — | — | — | — | — | — | — | — | — |
| | RRGE-2 | — | — | — | — | — | — | — | — | — | — | — | — |
| 1976 | Malta | — | — | — | — | HL | HL | HL | HL | — | — | — | — |
| | Crank | — | — | — | — | HL | HL | HL | HL | HL | L | L | L |
| | Naf | — | — | — | — | — | — | — | — | — | HL | HL | HL |
| | RRGE-2 | — | — | — | — | — | — | — | — | — | V | V | HLGV |
| | General | — | — | R | — | — | — | — | — | — | — | — | — |
| 1977 | Malta | — | — | — | — | — | — | — | — | — | — | — | — |
| | Crank | H | — | — | — | — | — | — | — | — | — | — | — |
| | Naf | — | — | — | — | — | — | — | — | — | — | — | — |
| | RRGE-2 | HLGV | V | — | — | — | — | — | — | — | — | — | — |
| 1978 | RRGE-2 | — | — | — | HL | HL | HL | HL | HL | HL | — | — | — |
| | Naf | — | — | — | HL | HL | HL | HL | HL | HL | — | — | — |
| 1979 | Limited sampling performed | | | | | | | | | | | | |
| 1980 | AQ A-D | — | — | — | — | — | — | — | — | — | HLS | HL | HL |
| 1981 | AQ A-D | HL | HL | HL | HL | HL | HL | HL | HL | — | HL | HL | HL |
| 1982 | AQ A-D | HL | HL | HL | HLC | — | — | — | — | — | — | — | — |

H = Hi-volume sampling.
L = Low-volume sampling.
G = Non-condensable gaseous pollutant monitoring.
V = Visibility monitoring.
R = Radon gas sampling.
S = SEM analysis.
C = Cooling tower test.

the filter, the duration of sampling, and the change in filter weight during sampling. TSP measurements were made throughout the study in accordance with the standard EPA reference methods (40 CFR 50, Appendix B). The flow rates of the high-volume samplers varied from 68 to 102 $m^3/h$ depending upon the pressure drop across the filter caused by dust loading. In order to accurately measure the volume of air sampled, each high-volume sampler was equipped with a flow recorder which recorded the volumetric flow rate and the sample duration.

In 1980, the four high-volume sampling stations were placed at the locations shown in Figure 9a and the results are shown in Figure 9b. Those locations conformed to the siting requirements specified in the Code of Federal Regulations (40 CFR 58, Appendix E). Because the prevailing winds are usually from the southwest, Stations AQ-B, -C, and -D were located downwind of the power plant and thus served as impact monitors. Station AQ-A was located upwind of the plant and thus served as the control, or background measurement. The monitoring stations were operated every 6th day for a 24-h period.[16]

Since 1980, low-volume air samplers were located at the same sites as the high-volume samplers. Nucleopore filters were used in the low-volume air samplers so that Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Analysis could be used to identify the chemical composition of the particles collected on the filter. Only one SEM analysis was performed; that analysis was done on the filter exposed at Site B on October 10, 1980. That filter was selected for analysis because of the direction of the wind, which blew toward the monitoring station from

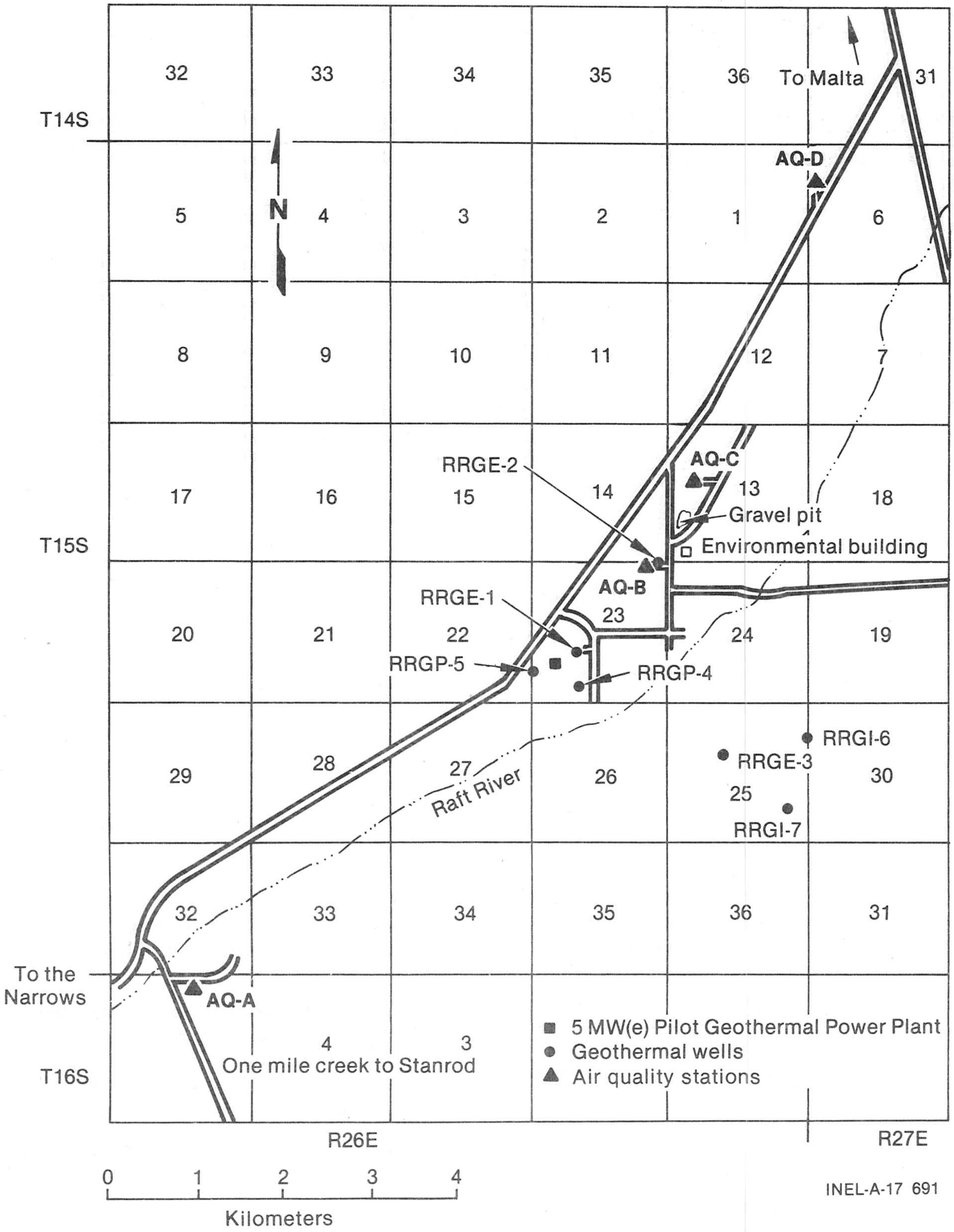

Figure 9a. Location of air monitoring stations.

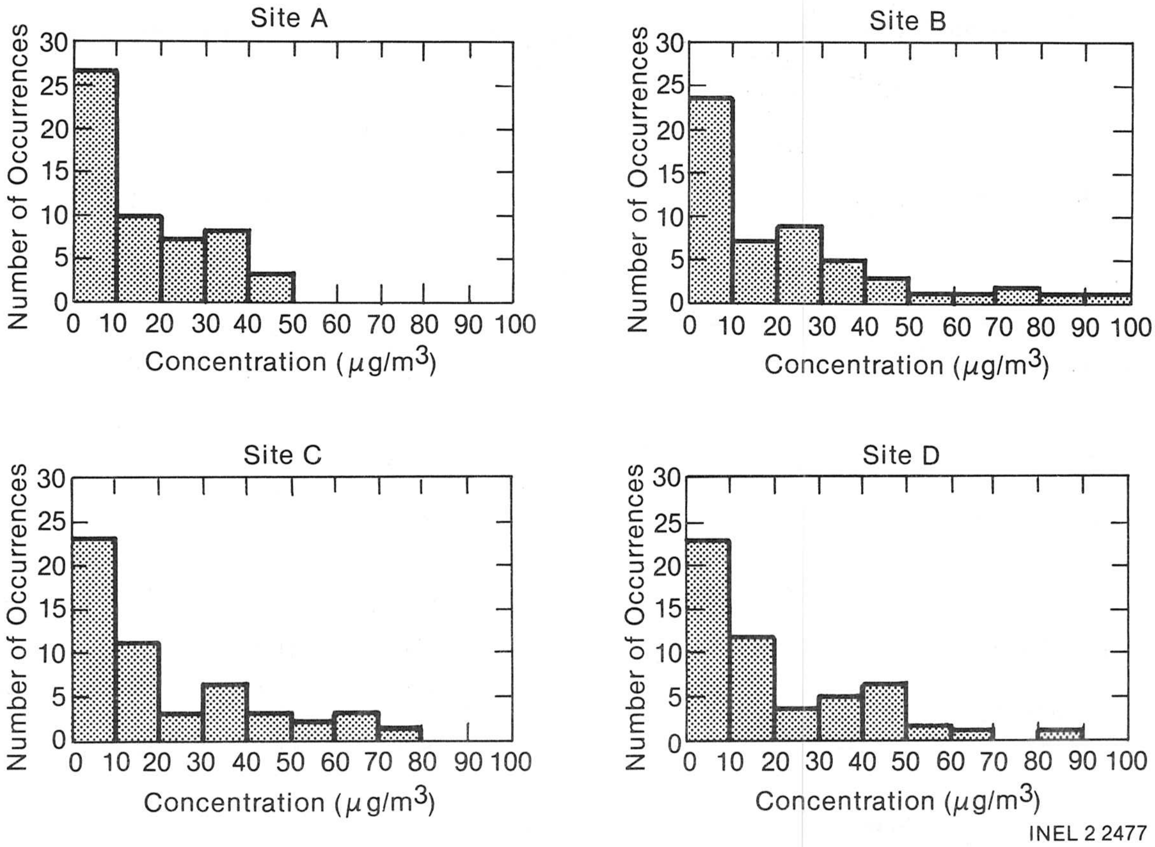

Figure 9b. 1981 annual average TSP frequency distributions, Sites A through D.

the geothermal power plant, across unpaved roads. During SEM analysis, care was taken to ensure that the composition of the filter media did not interfere with the determination of the particulate's chemical composition.

For October 1976 to February 1977, visibility studies were conducted using an integrating nephelometer and an automatic camera to measure the loca visual range. Color transparencies from the automatic camera were examined to determine the percent of time that selected landmarks were visible and their degree of clarity.

On April 28 and 29, 1982, the emissions from the cooling tower were sampled. The objective of the study was to determine the concentration of various trace compounds such as fluoride, sulfate, hydrogen sulfide, and zinc as well as total particulate loading suspended solids.

Four complete tests were performed. The first two tests were performed to determine sulfate concentrations along with total particulate, zinc, phosphate, and suspended solid concentrations. These tests were conducted in accordance with EPA Reference Method 8 entitled, "Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions From Stationary Sources."[17] The remaining two tests were performed to determine fluoride concentrations in accordance with EPA Reference Methods 13A and B entitled, "Determination of Fluoride Emissions from Stationary Source."[17] After each run, the filter assembly was transferred to the plant chemical laboratory for equipment cheanup and recovery of the contents of the sampling train. All sampling train recovery techniques were in accordance with EPA Reference Methods 5, 8, 13A, and 13B.[17] Individual samples were transferred into prepared sample containers until analzed.

**Results and Discussion.** The annual geometric mean concentration data obtained from the high-volume air samplers are shown in Table 2. The annual averaged concentrations are well below the permissible annual geometric mean concentration of 75 μg/m³ (Primary National Ambient Air

**Table 2. Annual geometric mean total suspended particulate (TSP) concentrations**

| | Sampling Station | | | | | | |
|---|---|---|---|---|---|---|---|
| Sampling Period | M | C | N | A | B | C | D |
| 07/75 to 10/75 | 40.7 | — | — | — | — | — | — |
| 05/76 to 08/76 | 55.9 | — | — | — | — | — | — |
| 06/76 to 01/77 | — | 27.5 | — | — | — | — | — |
| 10/76 to 12/76 | — | — | 20.1 | — | — | — | — |
| 12/76 to 01/77 | — | — | — | — | 36.3 | — | — |
| 04/78 to 06/78 | — | — | — | — | 42.6 | — | — |
| 07/78 to 09/78 | — | — | 25.0 | — | 47.7 | — | — |
| 10/80 to 12/80 | — | — | — | 10.7 | 14.5 | 12.7 | 16.4 |
| 01/81 to 03/81 | — | — | — | 4.7 | 6.7 | 6.7 | 7.6 |
| 04/81 to 06/81 | — | — | — | 11.3 | 19.5 | 17.2 | 16.1 |
| 07/81 to 08/81 | — | — | — | 34.6 | 41.1 | 45.7 | 45.1 |
| 10/81 to 12/81 | — | — | — | 6.4 | 7.9 | 6.2 | 6.7 |
| 01/82 to 03/82 | — | — | — | 5.5 | 6.0 | 5.5 | 5.2 |
| 04/82 | — | — | — | 9.5 | 13.5 | 12.0 | 12.2 |

M = Malta.

C = Co-op.

N = Naf.

A, B, C, D = 1980 to 1982.

Quality Standard) as well as the secondary standard of 60 μg/m$^3$. All measured particulate concentrations, with only two exceptions, were well below both the maximum primary 24-h standard of 260 μg/m$^3$ and the secondary 24-h standard of 150 μg/m$^3$. The two exceptions occurred on June 30, 1976 and June 19, 1981. The cause for the 1976 violation was wind-raised dust from bare fields near the sample station. The 1981 violation was caused by the county road maintenance crews working on an unpaved area near Station B.

The TSP data obtained from 1980 to 1982 are more complete than the data obtained between 1975 and 1980. Therefore, better conclusions can be drawn from the later data. A summary of the seasonal averaged TSP concentrations for the fall 1980 through spring 1982 sampling period is presented in Table 3. Both arithmetic and geometric means are presented along with the annual average for the 1981 sample year. These data show that the TSP concentrations are higher during the dry summer months and lower during the wet seasons of fall and winter.

TSP concentrations vary considerably according to weather conditions resulting from wind, rain, snow, and humidity. The Raft River Valley experienced a wide array of weather conditions which affected the monitored particulate concentrations. The TSP levels from October 1980 through April 1982 were consistently reduced by ~80% at all TSP sampling locations when damp or wet weather conditions existed. As expected, particulate concentrations in the atmosphere are greatly reduced in these types of weather conditions due to the amount of moisture. This condition reduces the ability of particulates to be

## Table 3. Average total suspended particulates (TSP) concentrations for fall 1980 through spring 1982

| | Mean TSP Concentrations Arithmetic Mean/Geometric Mean ($\mu g/m^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Site | Fall $1980^a$ | Winter $1981^b$ | Spring $1981^c$ | Summer $1981^d$ | Fall $1981^e$ | Winter $1982^f$ | Spring $1982^g$ | Annual Average $1981^h$ |
| A | 13.71/10.74 | 7.55/4.74 | 15.46/11.34 | 35.55/34.56 | 9.35/6.46 | 8.35/5.55 | 32.20/20.34 | 15.66/9.58 |
| B | 19.91/14.55 | 10.37/6.72 | 47.65/19.55 | 49.90/41.07 | 12.35/7.95 | 9.47/6.01 | 35.62/25.60 | 28.95/13.48 |
| C | 16.76/12.73 | 11.96/6.69 | 23.26/17.23 | 48.23/45.70 | 9.29/6.20 | 8.91/5.55 | 38.30/28.48 | 20.78/12.00 |
| D | 22.19/16.43 | 11.37/7.59 | 23.41/16.16 | 46.46/45.14 | 10.20/6.68 | 8.11/5.24 | 30.58/21.42 | 20.24/12.16 |

a. October 1980 through December 1980.

b. January 1981 through March 1981.

c. April 1981 through June 1981.

d. July 1981 through August.1981.

e. October 1981 through December 1981.

f. January 1981 through December 1981.

g. January 1981 through March 1982.

h. April 1982 (partial listing).

emitted and suspended in the atmosphere from fugitive particulate sources such as roads, construction activities, and naturally occurring wind-blown dust.

Snow cover also affected the TSP concentrations measured in the Raft River Valley. During days where a snow ground cover existed, the TSP concentrations generally decreased by 80% as compared to clear, dry days with no existing snow cover. Table 4 tabulates the mean TSP concentrations for sampling days when wet weather conditions existed, (including snow cover) in conjunction with the mean TSP concentrations monitored on clear, dry sampling days.

Frequency distributions of suspended particulate concentration measurements for 1981 are shown in Figure 9b. The largest number of TSP occurrences falls within the range of TSP values between 0 to 10 $\mu g/m^3$. The particulate concentrations during the entire 1980-82 sampling period ranged from a low of 0.3 to 388.8 $\mu g/m^3$ with the average concentration being $\sim 19.3$ $\mu g/m^3$. However, the next highest value registered was only 92.8 $\mu g/m^3$ which accounts for a higher average value.

Monitoring activities provided quantitative information regarding background particulate levels and particulate emissions generated by various onsite activities such as construction, farming, and vehicular traffic. Generally, it was found that higher particulate levels were observed at Stations B, C, and D located near unpaved site access roads and major plant construction areas. Values at Station A, the upwind background sampler, were generally found to be 30 to 50% lower than the sites located around the plant facility. Lower concentrations are a result of the very limited vehicular traffic and construction activities which occur at Site A. Wind speed and wind direction can have a direct effect upon particulate concentrations. When wind speeds were higher and coming from the direction of an unpaved road, TSP values were generally observed to be of higher concentrations.[16]

Only one low-volume filter was analyzed and thus an accurate quanitative analysis could not be performed. On a qualitative basis, however, the SEM analysis indicated that soil dust was the principle particulate component by mass while the most predominant number of particles were the sulfate particles. The Energy Dispersive X-Ray

## Table 4. Summary of mean TSP concentrations as related to weather conditions

| | Wet Weather Conditions or Snow Cover | | | Clear, Dry Weather Conditions | | |
|---|---|---|---|---|---|---|
| Sampling Location | Arithmetic Mean ($\mu g/m^3$) | Geometric Mean ($\mu g/m^3$) | Standard Deviation ($\mu g/m$ ) | Arithmetic Mean ($\mu g/m^3$) | Geometric Mean ($\mu g/m^3$) | Standard Deviation ($\mu g/m^3$) |
| A | 6 | 5 | ±4 | 26 | 21 | ±16 |
| B | 8 | 6 | ±6 | 36 | 28 | ±24 |
| C | 7 | 6 | ±5 | 34 | 27 | ±20 |
| D | 8 | 6 | ±5 | 34 | 27 | ±20 |

Analysis showed that the collected particulates contained traces of aluminum, silica, sulfur, chloride, potassium, calcium, iron, and copper. No chromium was detected.

Visibility was measured near the environmental building with an integrating nephelometer. Those measurements suggested that the prevailing visibility was restricted to <20 miles due to some extremely localized steam and fog. Results from the automatic camera indicated that visibility was affected by particulates transported into the south end of the valley, presumably from the Wasatch Front. This suggests that the reduced visibility was not related to plant activities. Visibility data from 1976 and 1977 are included in Table 5. This table also includes background measurements of gaseous pollutants which were all below the applicable standards. Although gaseous pollutants were not monitored during operation of the power plant, these data are included for reference. Emissions from the cooling tower are generated from the evaporation of the cooling water within the cooling tower. The emission rate is dependent on the rate of evaporation of the cooling waters, while the type of pollutants that are emitted into the atmosphere are related to the compounds present in the cooling waters. The cooling tower emissions were expected to be very low due to the low concentrations of noncondensable gases in the geothermal makeup water and low evaporation rate of cooling water.

Table 6 presents the results of the cooling tower tests. Most of the measured parameters were below the lower detectable limits. The only measurements that were above the lower detectable limits were small concentrations of zinc and large concentrations of dissolved solids. The large concentrations of dissolved solids were expected since a considerable amount of foam from the cooling water was suspended inside the cooling tower.

In March 1976, the United States Environmental Protection Agency conducted measurements of radon gas emissions. Radon-222 concentrations in the geothermal fluids were 390 pCi/L; this is a low concentration which is not an environmental concern.

**Conclusions.** Listed below are the most significant results of the air monitoring program at the Raft River Geothermal Research Facility.

- Total suspended particulates were measured by high- and low-volume methods at several sites near the geothermal development. Concentrations of TSP were typical of rural agricultural areas of Idaho. The primary 24-h standard was exceeded only once with the probable cause being wind-raised dust.

- Particle types were identified by SEM on a selected sample. Submicron sulfate particles were more prevalent by number while most of the mass of total suspended particulates was composed of soil dust particles.

## Table 5. Twenty-four-hour average concentrations of various environmental pollutants near RRGE-2 and applicable air quality standards

| | Pollutants | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_2S$ | | $SO_2$ | | $NO_2$ | | NO | | $NO_x$ | | $O_3$ | | Visibility (nephelometer) |
| Dates | μg/m$^3$ | mg/L | μg/m$^3$ | mg/L | μg/m$^3$ | mg/L | μg/m$^3$ | mg/L | μg/m$^3$ | mg/L | μg/m$^3$ | mg/L | km |
| 12 (17-18) 76 | 19.3 | 0.0138 | 12.5 | 0.0048 | 3.2 | 0.0017 | 0.3 | 0.0002 | 3.5 | 0.0019 | 58.9 | 0.029 | 21.6 |
| 12 (22-23) 76 | 11.9 | 0.0085 | 13.5 | 0.0052 | 6.1 | 0.0032 | 0 | 0 | 6.1 | 0.0032 | 61.9 | 0.031 | 18.0 |
| 12 (29-30) 76 | 3.3 | 0.0024 | 7.8 | 0.0030 | 3.6 | 0.0019 | 0.8 | 0.0006 | 4.4 | 0.0025 | 37.9 | 0.019 | 21.3 |
| 01 (03-04) 77 | 7.8 | 0.0056 | 2.1 | 0.0008 | 3.0 | 0.0016 | 0.1 | 0.0001 | 3.1 | 0.0017 | 66.4 | 0.033 | 26.4 |
| Primary National Standard | $42^a$ | $0.03^b$ | $80^d$<br>$365^c$ | $0.03^d$<br>$0.14^c$ | $100^d$ | $0.05^d$ | NAS | NAS | NAS | NAS | $240^b$ | $0.12^b$ | NAS |
| Secondary National Standard | $42^a$ | $0.03^b$ | $1300^e$ | $0.5^e$ | $100^d$ | $0.05^d$ | NAS | NAS | NAS | NAS | $240^b$ | $0.12^b$ | NAS |

a. California standards for 1 h.

b. One hour standard.

c. Twenty-four hour standard.

d. Annual standard.

e. Three hour standard.

NAS—No applicable standard.

## Table 6. Results of cooling tower test

| Pollutant Concentrations (μg/m$^3$) | Test | |
|---|---|---|
| | Run 1 | Run 2 |
| Sulfate | <0.05 | <0.05 |
| Fluoride | <0.05 | <0.05 |
| Phosphate | <0.05 | <0.05 |
| Zinc | 14 | 8 |
| Dissolved solids | 26,000 | NA$^a$ |
| Suspended solids | <500 | <500 |
| Total particulates | <80 | <80 |
| $H_2S$ | <0.005 | <0.005 |

a. NA—Not available.

- Visibility as measured near RRGE-2 with an integrating nephelometer suggested the possibility of some localized effects from steam and fog. Visibility was affected by particulates transported into the south end of the valley. Particulates from the geothermal plant probably did not contribute to the reduced visibility.

- The measured concentrations of radon gas was only 390 pCi/L; a very low concentration.

- All TSP concentrations are well below the National Primary and Secondary Air Quality Standards. One registered violation was due to the close proximity of Site B to heavy construction activities occurring during 1 day. The other violation was due to wind-raised dust from barren fields nearby.

- The largest number of TSP concentrations fall within the range of 0 to 10 μg/m$^3$.

- TSP values at Station A were 30 to 50% lower than sites located near unpaved site access roads and plant construction activities.

- Higher TSP concentrations were measured during the dry summer months than during the wet winter period.

- TSP concentrations were reduced by 50% during days where precipitation occurred or a snow cover existed due to the reduced ability of particulates to be emitted and suspended in the atmosphere from fugitive particulate sources.

- For the cooling tower emissions, concentrations were below lower detectable limits with the exception of zinc and dissolved solids. Zinc concentrations were well below any applicable standards. The large concentrations of dissolved solids were a result of foam from the cooling water suspended inside the cooling tower.

- Impacts associated with the emissions from the cooling tower were minimal.

# BIOLOGICAL ENVIRONMENTAL MONITORING PROGRAMS

Effective environmental management requires an understanding of the diversity and population interactions of the biotic community. At the Raft River Valley, baseline data on flora and fauna have been collected. The valley habitat is classified as a cold-desert ecosystem. The vegetation communities are dominated by a mixture of sagebrush (*Artemisia*), greasewood (*Sarcobatus*), rabbitbrush (*Chrysothamnus*), bunch grass (*Agropyron*), and other low-growing shrubs and forbs. Wildlife of the region are adapted to and dependent upon this fragile desert ecosystem.

Ecological studies conducted at the geothermal site include a survey of the plant and aquatic communities as well as raptor, small mammal, and songbird studies. By understanding the ecosystem structure and function and by adjusting human activities to minimize ecological impacts, an equitable and intelligent use of the area resources has been achieved.

## Plant Ecology

**Introduction.** A four-year soil and vegetation study was initiated in 1976 as part of the Raft River environmental baseline research. The study objective was to quantitatively determine the response of vegetation to variations in meteorological, edaphic (soils), and other environmental factors. Plots were established to compare vegetation of similar and dissimilar community types and to statistically and graphically delineate yearly fluctuations in plant species cover. The results of the study are useful in monitoring possible impacts from development activities and geothermal effluents. Physical perturbations due to construction (e.g., pipeline installation, well pads, roads) are all disturbances which are permanent or semipermanent, at least for the life of the project. These, however, are expected and easily diagnosed. The effect of air and waterborne effluents on the vegetation and soils may be more subtle. The understanding gained of the basic requirements of the fragile Great Basin vegetation community can aid in detecting and mitigating potential detrimental impacts associated with geothermal development in the Raft River Valley. It will also serve as a basis for interpreting baseline conditions.

**Methods.** In 1976, 19 permanent circular plots, each with a radius of 8 m and an area of 0.02 ha, were established in a radiating pattern from RRGE-1 and -2. Four additional plots were established in 1977. Two of the 23 plots were destroyed by cattle grazing and construction activities; the remaining 21 plots were sampled yearly through 1979. Twenty-five 1-$m^2$ quadrats were sampled at each permanent plot. These quadrats were established by locating one quadrat every 3 m around the permanent plot boundary circle. All species occurring in each quadrat were recorded and cover class values were estimated for total living cover, litter, rock, and bare soil. Each life form class (shrubs, grasses, forbs, annuals, and cryptogams) was estimated for relative percent cover in the field. Notes on existing conditions were taken at each site. The plot locations were chosen to radiate in the four compass directions away from the first three geothermal production wells (RRGE-1, -2, and -3). The specific location for each site was determined by establishing plots in each major vegetation community and on each major soil type.

The relevance of this approach to monitoring studies, and more specifically to the collection of background data, is that it delineates the plant communities which are ecologically distinctive. This allows managers to decide which of the originally chosen plots or communities should be monitored periodically after the startup of the power plant. When plant communities do not differ distinctly, there is probably little justification to monitor all of them. Instead, areas in strategic sites near the development could be chosen and monitored.

The original design used in selecting observation plots was fourfold:

1. The plots were to be close enough to the development areas so that possible effluents could be monitored without the plots themselves being destroyed.

2. The plots were to radiate in all directions away from the development area.

3. Control plots were out of the area of influence of industrial activity.

4. At least one plot was to be established both upstream and downstream along the Raft River to measure the impact on the vegetation community in the event of a major spill. Much of the area is covered mainly with greasewood and sagebrush vegetation communities so the majority of the plots are located in these types of areas.

The upper 15 cm of soil were analyzed as a composite sample from 10 quadrats in each plot. The surface soil, and A and B horizon soils were sampled in selected plots. Precipitation, the maximum and minimum air temperatures, and the soil temperature at a 30-cm depth were also measured.

The vegetation data were analyzed using a cluster analysis developed from methods previously used.[18-21] Multiple linear correlation and multiple regression analyses were used to evaluate the various parameters measured in this study. These data were organized to provide correlation matrices for each year and to provide some multiple regression equations for some of the best subsets. These tests provide predictive capabilities based on the vegetation data and the regression of the physical factors of the environment.

Climatic data were gathered on a continuing basis from 12 stations since November 1979. Moisture stress was measured using a Cleary pressure chamber which measures plant response to moisture conditions of the soil. Moisture stress was measured in pounds per square inch of pressurized nitrogen gas needed to force xylem sap out of the cut end of a twig when placed with leaves downward in the chamber. The pressure was then converted to bars of pressure for use in correlation analyses.

**Results and Discussion.** The 23 vegetation plots were divided among nine vegetation types as follows:

- 6 greasewood
- 4 sagebrush-greasewood
- 4 sagebrush
- 2 river streamside
- 1 hot water streamside
- 2 saltbush
- 2 shadscale
- 1 grass
- 1 winterfat.

Figure 10 shows the location of the plots in relation to prominent features in the KGRA.

The field data were summarized for frequency and cover class composition in the laboratory (Table 7). The number of species per quadrat changed little over the four-year study. A total of 105 species were identified during the study, but all the same species were not found each year. The number of species identified on the plots was 75 in 1976, 73 in 1977, 74 in 1978, and 83 in 1979. Diversity shows a gradual decline over the first three years; it differed from an average of 10.8 species per plot in 1976 to 9.5 in 1977 to 9.3 in 1978. Species density per quadrat was much the same with a one-tenth of one percent increase in 1978 (4.0%/quad) over the 1976 value of 3.9%. In 1979 vascular species density increased, both per plot and per quadrat. Average diversity of species per plot increased to 10.5.

The relative frequency of shrubs remained stable throughout the study (20.8% in 1976; 20.6% in 1977; 20.4% in 1978; and 18.5% in 1979). Grass frequency was inversely related to the frequency of forbs and annuals. Thus, in wet springs and summers such as in 1976, grass frequency was relatively low (17.2%) compared to 23.4% in the dry year of 1977.

The similarity indices for each year of the study are generalized in Table 8. The closest year to the average was 1979. Most stands were quite similar to each other, varying only by basic community types. The four streamside locations are the most distinctive among the 23 sites.

Each of the four years of data were clustered and graphically illustrated with ordination diagrams called dendrograms.[18] The cluster dendrograms indicate variations in species composition and abundance from year to year (Figure 11). These responses are caused by yearly variations in precipitation, temperature (influencing germination in the spring), and desiccation (drying out) during the summer.

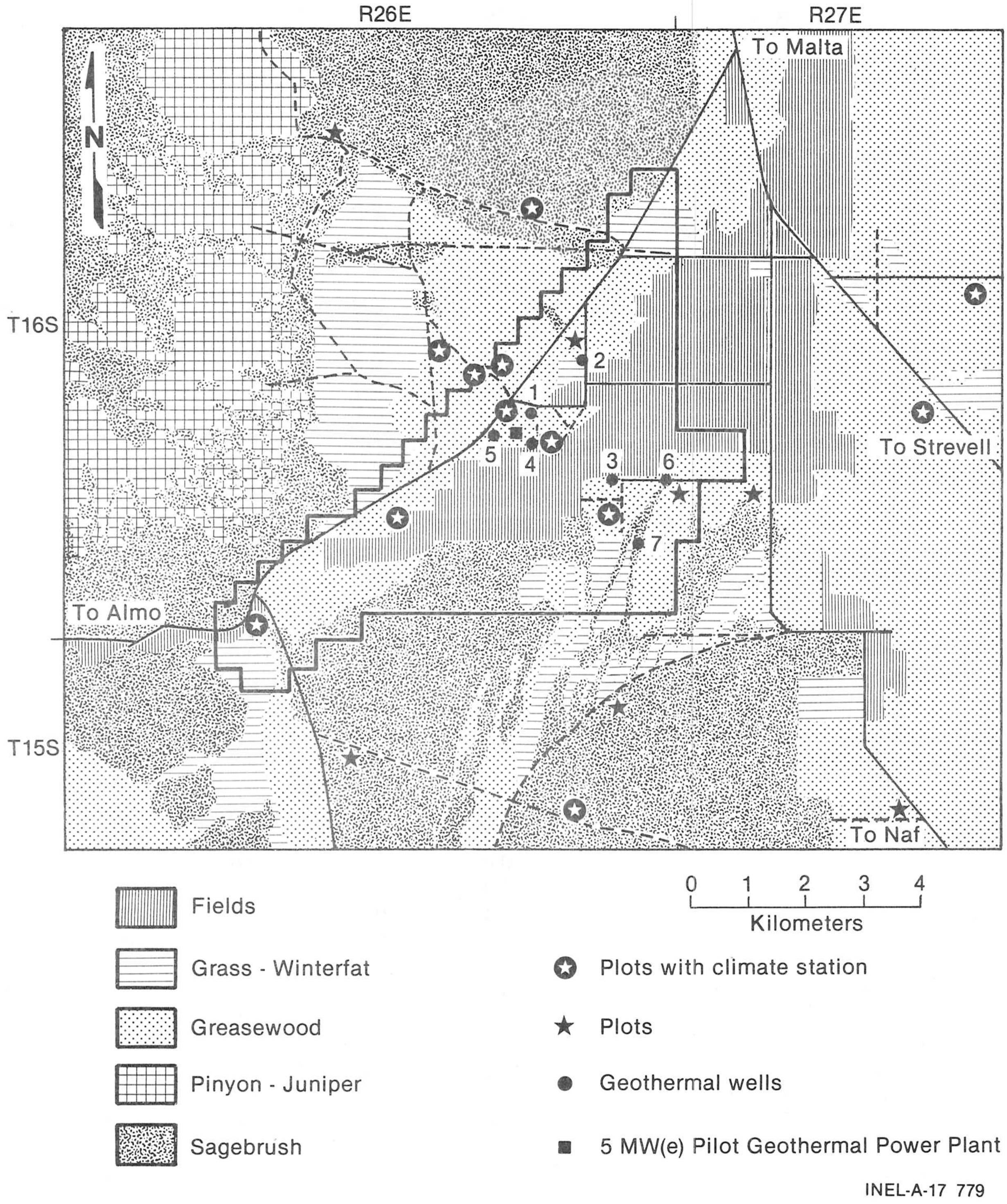

Figure 10. Location of permanent vegetation plots.

## Table 7. Summary of vegetation frequency on the permanent plots 1976 to 1979

| Species | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|
| Shrubs (13)[a] | | | | |
| *Artemisia nova* | 5.3 | 3.1 | 4.4 | 4.7 |
| *Artemisia tridentata* | 27.8 | 31.0 | 31.0 | 31.1 |
| *Atriplex confertifolia* | 6.1 | 9.0 | 8.5 | 8.5 |
| *Atriplex falcata* | 10.7 | 9.6 | 8.9 | 9.0 |
| *Chrysothamnus depressus* | 4.8 | 3.5 | 4.0 | 3.7 |
| *Chrysothamnus nauseosus* | 4.2 | 2.3 | 2.3 | 2.6 |
| *Chrysothamnus viscidiflorus* | 1.1 | 1.9 | 2.1 | 5.6 |
| *Eurotia lanata* | 10.5 | 10.2 | 8.0 | 10.6 |
| *Gutierrezia sarothrae* | 1.9 | 0.3 | 0.0 | 0.0 |
| *Rosa woodsii* | 0.2 | 0.0 | 0.2 | 0.4 |
| *Salix exigua* | 0.2 | 0.2 | 0.0 | 0.2 |
| *Sarcobatus vermiculatus* | 44.6 | 39.0 | 39.5 | 37.2 |
| *Tetradymia spinosa* | 0.2 | 0.0 | 0.2 | 0.0 |
| Total shrubs (%) | 117.6 | 110.1 | 109.1 | 113.6 |
| Perennial Forbs (54) | | | | |
| *Amsincka retrorsa* | 0.0 | 0.0 | 0.0 | 0.9 |
| *Antennaria rosea* | 0.0 | 0.3 | 0.0 | 0.4 |
| *Arabis holboellii* | 0.8 | 0.2 | 0.0 | 0.2 |
| *Asclepias speciosa* | 0.2 | 0.3 | 0.4 | 0.5 |
| *Aster chilensis* | 1.5 | 0.3 | 0.5 | 1.4 |
| *Aster hesperius* | 0.4 | 0.5 | 0.9 | 0.9 |
| *Astragalus lentiginosus* | 0.0 | 0.2 | 0.0 | 0.0 |
| *Astragalus utahensis* | 0.4 | 0.0 | 0.0 | 0.5 |
| *Brassica nigra* | 0.0 | 0.3 | 0.0 | 0.5 |
| *Castilleja applegatei* | 3.2 | 0.7 | 1.7 | 1.9 |
| *Caulanthus crassicaulis* | 0.4 | 0.2 | 0.2 | 0.2 |
| *Chaenactis douglassi* | 0.8 | 0.0 | 0.0 | 0.0 |
| *Cicuta douglasii* | 0.8 | 0.3 | 0.2 | 0.7 |
| *Cirsium utahense* | 2.1 | 0.5 | 1.9 | 1.0 |
| *Cirsium vulgare* | 2.1 | 2.8 | 0.2 | 1.0 |
| *Descurainia richardsonii* | 41.1 | 33.0 | 36.7 | 32.5 |
| *Epilobium adenocaulon* | 1.3 | 0.2 | 0.2 | 0.0 |
| *Epilobium paniculatum* | 0.6 | 0.0 | 0.0 | 0.0 |
| *Glaux maritima* | 2.1 | 2.4 | 2.6 | 3.8 |
| *Glycyrrhiza lepidota* | 0.2 | 0.9 | 0.7 | 0.7 |
| *Iva xanthifolia* | 0.2 | 2.8 | 0.2 | 3.3 |
| *Lactuca biennis* | 3.2 | 2.4 | 2.3 | 2.4 |
| *Lactuca scariola* | 2.1 | 2.4 | 0.7 | 2.1 |
| *Lemna minor* | 0.8 | 0.0 | 0.9 | 0.0 |

**Table 7. (continued)**

| Species | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|
| Perennial Forbs (continued) | | | | |
| *Lepidium virginicum* | 1.9 | 1.9 | 0.0 | 0.4 |
| *Leptodactylon pungens* | 0.0 | 0.7 | 0.7 | 0.5 |
| *Leucelene ericoides* | 2.5 | 0.9 | 1.9 | 2.3 |
| *Lomatium grayi* | 0.4 | 0.5 | 0.0 | 0.2 |
| *Melilotus alba* | 2.9 | 0.3 | 0.2 | 1.9 |
| *Mentha arvensis* | 0.0 | 0.2 | 0.0 | 0.0 |
| *Oenothera heteranthera* | 0.0 | 0.0 | 0.2 | 0.0 |
| *Opuntia fragilis* | 0.4 | 0.0 | 0.0 | 0.2 |
| *Opuntia polyacantha* | 10.1 | 15.0 | 14.3 | 14.1 |
| *Phlox longifolia* | 1.7 | 0.7 | 1.0 | 0.9 |
| *Physaria* sp. | 0.0 | 0.2 | 0.0 | 0.0 |
| *Plantago major* | 3.6 | 2.4 | 1.4 | 1.6 |
| *Potentilla* sp. | 0.0 | 0.3 | 0.0 | 0.0 |
| *Ranunculus* sp. | 0.0 | 0.2 | 0.0 | 0.4 |
| *Rorippa nasturtium-aquaticum* | 0.8 | 0.3 | 0.7 | 0.5 |
| *Rumex occidentalis* | 0.6 | 0.7 | 0.0 | 0.2 |
| *Sisymbrium altissimum* | 0.0 | 0.0 | 0.0 | 2.3 |
| *Sisymbrium linifolium* | 2.7 | 1.7 | 0.0 | 2.1 |
| *Solidago canadensis* | 0.2 | 0.0 | 0.0 | 0.0 |
| *Sphaeralcea munroana* | 4.0 | 5.2 | 4.2 | 3.5 |
| *Stachys palustris* | 0.0 | 0.0 | 0.2 | 0.0 |
| *Suaeda nigra* | 0.0 | 0.2 | 0.2 | 0.0 |
| *Taraxacum officinale* | 0.0 | 0.9 | 0.0 | 0.0 |
| *Townsendia florifera* | 0.6 | 0.0 | 0.0 | 0.0 |
| *Trifolium fragiferum* | 0.6 | 2.3 | 3.8 | 3.0 |
| Unknown Composite -1 | 0.0 | 0.0 | 0.5 | 0.0 |
| *Veronica anagallis-aquatica* | 0.2 | 0.5 | 0.5 | 0.5 |
| *Veronica scutellata* | 0.6 | 0.0 | 0.0 | 0.0 |
| *Xanthium strumarium* | 0.6 | 1.4 | 0.9 | 0.0 |
| Unknown *rosette* | 0.0 | 0.0 | 0.2 | 0.5 |
| Total perennial forbs (%) | 98.7 | 87.2 | 81.2 | 90.0 |
| Perennial Grasses (23) | | | | |
| *Agropyron cristatum* | 0.0 | 0.0 | 0.0 | 0.2 |
| *Agropyron spicatum* | 2.1 | 1.4 | 1.0 | 1.2 |
| *Agropyron trachycaulum* | 0.0 | 0.7 | 0.0 | 0.5 |
| *Agrostis alba* | 0.0 | 0.0 | 0.7 | 0.0 |
| *Agrostis stolonifera* | 0.0 | 0.5 | 0.3 | 0.0 |
| *Bromus inerme* | 0.0 | 0.0 | 0.4 | 0.0 |

**Table 7. (continued)**

| Species | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|
| PerenniaL Grasses (continued) | | | | |
| *Bromus* sp. | 0.0 | 0.2 | 0.0 | 0.0 |
| *Distichlis stricta* | 4.5 | 4.5 | 4.4 | 5.2 |
| *Elymus cinereus* | 0.0 | 3.0 | 3.1 | 3.3 |
| *Elymus glaucus* | 0.0 | 0.0 | 0.7 | 0.0 |
| *Festuca* sp. | 0.0 | 0.0 | 0.0 | 1.4 |
| *Hordeum brachyarantherum* | 0.0 | 0.0 | 0.5 | 0.5 |
| *Hordeum jubatum* | 3.2 | 3.4 | 3.0 | 1.7 |
| *Muhlenbergia asperifolia* | 2.3 | 3.3 | 1.7 | 0.2 |
| *Oryzopsis hymenoides* | 0.0 | 0.0 | 0.2 | 0.0 |
| *Phalaris arundinacea* | 0.0 | 0.7 | 0.0 | 0.5 |
| *Poa pratensis* | 1.5 | 1.6 | 2.0 | 1.9 |
| *Poa sandbergii* | 28.8 | 26.4 | 25.2 | 26.8 |
| *Poa* sp. | 0.0 | 0.0 | 0.0 | 0.2 |
| *Polygonum monospeliensis* | 7.4 | 5.9 | 6.8 | 6.1 |
| *Sitanion hystrix* | 47.6 | 73.6 | 72.4 | 78.6 |
| *Sporobolus airoides* | 0.0 | 0.0 | 0.2 | 0.0 |
| Unknown *aquatic* | 0.0 | 0.0 | 0.2 | 0.0 |
| Total perennial grasses (%) | 97.4 | 125.2 | 122.8 | 128.3 |
| Sedges, Rushes and Cattails (6) | | | | |
| *Eleocharis palustris* | 0.8 | 0.0 | 0.0 | 0.9 |
| *Equisetum arvense* | 0.6 | 0.0 | 0.0 | 0.4 |
| *Juncus balticus* | 3.2 | 2.3 | 3.5 | 4.4 |
| *Scirpus americanus* | 4.8 | 4.0 | 3.0 | 4.2 |
| *Typha latifolia* | 0.0 | 0.2 | 0.0 | 0.0 |
| Unknown *Juncus* | 0.0 | 0.0 | 1.0 | 0.0 |
| Total sedges, etc. (%) | 9.4 | 6.5 | 7.5 | 9.9 |
| Annuals (17) | | | | |
| *Bromus tectorum* | 29.7 | 9.0 | 17.4 | 16.5 |
| *Camissonia cf. minor* | 1.1 | 0.0 | 0.2 | 0.0 |
| *Camasonia scapoidea* | 0.0 | 0.0 | 0.0 | 0.4 |
| *Capsella burea-pastoris* | 0.0 | 0.0 | 0.0 | 0.5 |
| *Chenopodium glaucum* | 0.0 | 0.0 | 0.0 | 4.4 |
| *Chenopodium album* | 0.8 | 3.5 | 2.6 | 0.0 |
| *Chenopodium leptophyllum* | 0.2 | 0.2 | 0.0 | 3.0 |
| *Conyza canadensis* | 1.5 | 1.4 | 1.2 | 0.0 |
| *Chorispermum sp.* | 0.6 | 0.9 | 0.0 | 0.7 |
| *Cryptantha watsonii* | 2.3 | 0.0 | 0.0 | 0.4 |
| *Echinopsilon hyssopifolia* | 1.7 | 4.0 | 2.6 | 10.8 |
| *Halogeton glomeratus* | 5.1 | 8.9 | 1.0 | 6.8 |

### Table 7. (continued)

| Species | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|
| Annuals (continued) | | | | |
| *Helianthus annua* | 0.0 | 0.0 | 0.0 | 1.2 |
| *Kochia americana* | 0.0 | 1.2 | 0.0 | 0.0 |
| *Lappula redowskii* | 1.3 | 0.5 | 0.0 | 5.0 |
| *Lepidium perfoliatum* | 24.4 | 36.7 | 46.1 | 48.2 |
| *Salsola kali* | 16.2 | 0.7 | 0.0 | 0.4 |
| Unknown annual | 0.0 | 0.0 | 0.2 | 0.0 |
| Total annuals (%) | 84.9 | 67.0 | 71.3 | 98.3 |
| Cryptogams | | | | |
| Algae | 0.6 | 2.8 | 6.8 | 4.5 |
| Lichens | 83.6 | 76.5 | 75.5 | 87.3 |
| Moss | 73.5 | 59.7 | 60.5 | 80.7 |
| Mushrooms | 0.0 | 0.0 | 0.0 | 0.2 |
| Total cryptogams (%) | 157.7 | 139.0 | 142.8 | 172.7 |
| Grand total | 565.7 | 535.0 | 534.7 | 612.8 |
| Vegetational Characteristics | | | | |
| Number of vascular species/stand | 10.8 | 9.5 | 9.3 | 10.5 |
| Number of vascular species/quad | 3.9 | 3.7 | 4.0 | 4.4 |
| | 14.7 | 13.2 | 13.3 | 14.9 |
| | 75 | 73 | 74 | 83 |
| Cover Classes (%) | | | | |
| Living cover | 46.9 | 40.3 | 47.7 | 37.4 |
| Litter | 6.4 | 7.5 | 8.8 | 11.1 |
| Rock (>1 cm diameter) | 5.1 | 7.2 | 6.3 | 5.4 |
| Bare soil | 41.6 | 45.0 | 37.2 | 46.1 |
| Total | 100 | 100 | 100 | 100 |
| Composition of Living Cover (%) | | | | |
| Shrubs | 42.4 | 45.7 | 43.9 | 43.6 |
| Perennial grasses | 28.0 | 26.3 | 23.9 | 25.3 |
| Perennial forbs | 6.0 | 7.5 | 8.3 | 7.3 |
| Annuals | 9.8 | 7.3 | 8.9 | 9.4 |
| Cryptogams | 13.8 | 13.2 | 15.0 | 14.2 |
| Total | 100 | 100 | 100 | 99.8 |

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a. Total number of species sampled in each category.

**Table 8. Average similarity matrix from permanent plot vegetation frequency 1977 to 1979**

| Community Type | Permanent Plot Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | Average (%) | Relative (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Art-Gr | 1 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 46.6 | 5.76 |
| Art-Gr | 2 | 66 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 45.1 | 5.57 |
| Art | 3 | 59 | 63 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 38.5 | 4.75 |
| Gr | 4 | 62 | 53 | 42 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 45.8 | 5.65 |
| Gr | 5 | 50 | 57 | 41 | 57 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 40.4 | 4.99 |
| G | 6 | 41 | 41 | 39 | 38 | 24 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 32.1 | 3.96 |
| Gr-H-Str | 7 | 14 | 13 | 14 | 16 | 12 | 13 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 11.6 | 1.43 |
| Gr | 8 | 63 | 51 | 41 | 80 | 53 | 43 | 17 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 46.9 | 5.80 |
| Atr | 9 | 52 | 39 | 36 | 55 | 34 | 46 | 10 | 61 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 39.1 | 4.83 |
| Eur-G | 10 | 41 | 46 | 31 | 34 | 33 | 31 | 5 | 36 | 34 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | 31.9 | 3.94 |
| Gr | 11 | 45 | 53 | 41 | 65 | 67 | 29 | 12 | 65 | 40 | 33 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | 41.3 | 5.10 |
| SS-G | 12 | 49 | 44 | 38 | 48 | 31 | 51 | 9 | 50 | 49 | 49 | 36 | 100 | — | — | — | — | — | — | — | — | — | — | — | 39.1 | 4.83 |
| Art | 13 | 59 | 63 | 53 | 39 | 40 | 38 | 5 | 39 | 37 | 54 | 36 | 53 | 100 | — | — | — | — | — | — | — | — | — | — | 38.8 | 4.80 |
| Atr | 14 | 40 | 27 | 25 | 41 | 33 | 35 | 10 | 47 | 73 | 27 | 29 | 39 | 27 | 100 | — | — | — | — | — | — | — | — | — | 31.2 | 3.86 |
| Gr | 15 | 59 | 52 | 42 | 77 | 57 | 46 | 18 | 84 | 54 | 32 | 64 | 48 | 35 | 47 | 100 | — | — | — | — | — | — | — | — | 46.4 | 5.74 |
| Str | 16 | 0.3 | 0.2 | 1 | 0.4 | 0.2 | 0.4 | 9 | 1 | 0.1 | 0.0 | 1 | 0.2 | 0.1 | 0.1 | 0.2 | 100 | — | — | — | — | — | — | — | 1.1 | 0.14 |
| Art-Rb | 17 | 17 | 26 | 23 | 15 | 15 | 25 | 8 | 15 | 15 | 30 | 16 | 26 | 28 | 12 | 18 | 0.3 | 100 | — | — | — | — | — | — | 17.1 | 2.11 |
| Gr | 18 | 47 | 61 | 44 | 62 | 70 | 35 | 10 | 61 | 36 | 40 | 73 | 43 | 45 | 30 | 64 | 0.1 | 20 | 100 | — | — | — | — | — | 42.6 | 5.27 |
| Gr-Art | 19 | 65 | 47 | 38 | 61 | 55 | 34 | 17 | 68 | 45 | 36 | 47 | 40 | 39 | 43 | 64 | 0.6 | 14 | 44 | 100 | — | — | — | — | 41.0 | 5.06 |
| Art | 20 | 59 | 60 | 58 | 41 | 48 | 34 | 5 | 39 | 40 | 36 | 45 | 38 | 61 | 25 | 36 | 0.7 | 17 | 48 | 37 | 100 | — | — | — | 38.4 | 4.74 |
| Str | 21 | 13 | 10 | 15 | 11 | 7 | 14 | 15 | 14 | 11 | 2 | 6 | 10 | 3 | 11 | 16 | 8 | 5 | 6 | 14 | 7 | 100 | — | — | 9.8 | 1.21 |
| Gr-Art | 22 | 73 | 71 | 57 | 55 | 65 | 31 | 11 | 52 | 38 | 37 | 58 | 38 | 61 | 28 | 53 | 0.3 | 19 | 60 | 55 | 62 | 7 | 100 | — | 44.2 | 5.47 |
| SS-G | 23 | 51 | 48 | 45 | 54 | 41 | 47 | 12 | 52 | 54 | 34 | 47 | 70 | 39 | 38 | 55 | 0.2 | 19 | 44 | 39 | 47 | 11 | 43 | 100 | 40.5 | 5.00 |
| Grand totals | | | | | | | | | | | | | | | | | | | | | | | | | 809.2 | 100.00 |

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Legend to Community Types:

| | | |
|---|---|---|
| Gr | = | Greasewood. |
| Eur | = | Winterfat. |
| Art | = | Sagebrush. |
| Atr | = | Saltbush. |
| SS | = | Shadscale. |
| G | = | Grass. |
| H-Str | = | Hot streamside. |
| Str | = | Streamside. |
| Rb | = | Rabbitbrush. |

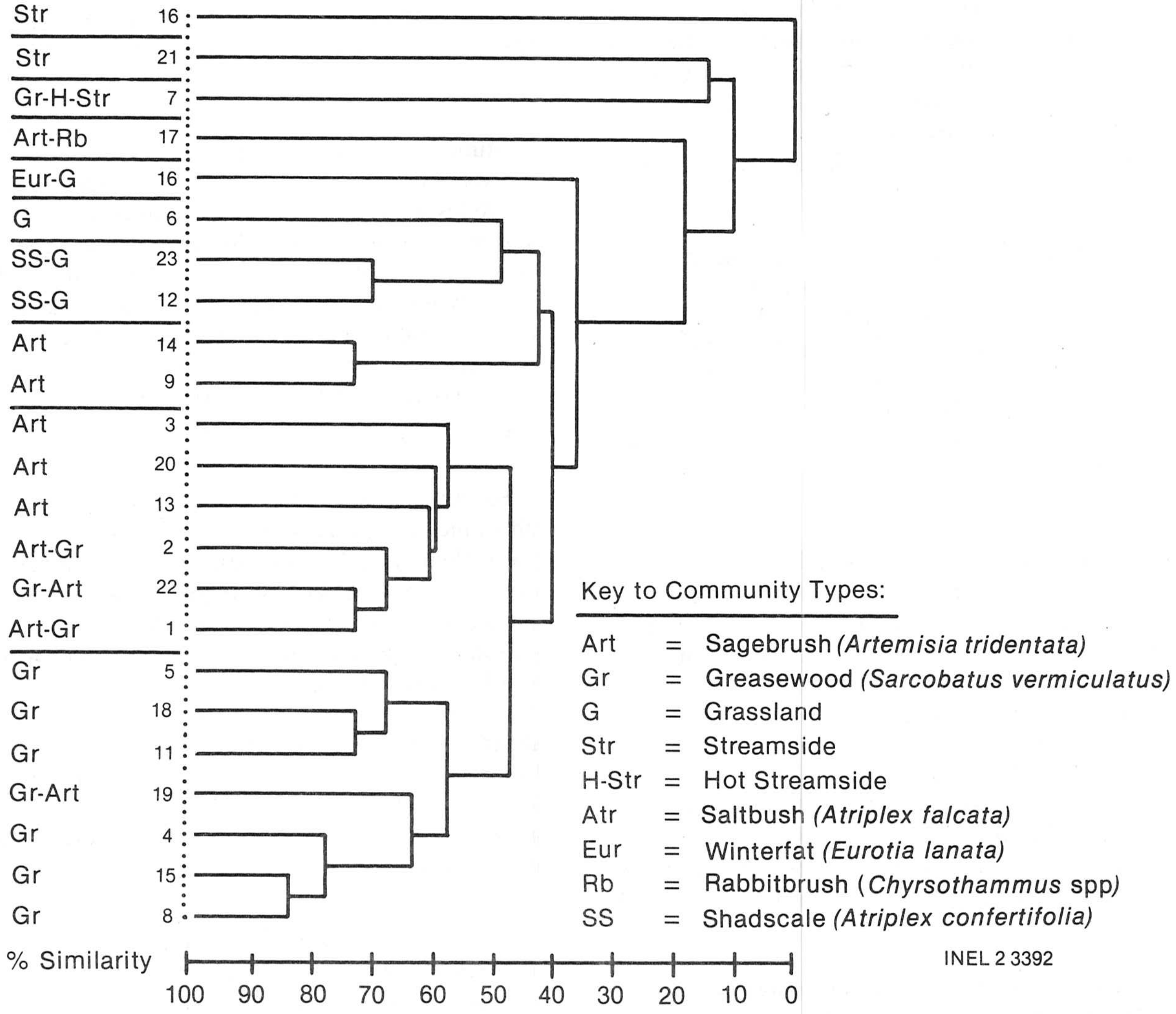

Figure 11. Cluster analysis dendogram of average frequency data collected from 1977 to 1979 on the 23 permanent plots.

The cluster of the average data is representative of the average responses which occurred over the study period. Data from any other time period would probably vary slightly from the data collected during the study, but would show an overall similar response. The cluster dendrograms do indicate dramatically that variation in plant response does occur from year to year. If additional future resource development occurs, there is a probability that a vegetation response may be much more dramatic in a given year than those observed during this study. Such a disturbance would be expected to cause the more sensitive species in the area to form a different clustering order than those observed so far.

Correlation analysis was used to define relationships between ecological factors and observed biotic responses. There were a number of negative correlations such as soil pH versus salinity (principally Na salts). This indicates that salinity increases as the pH goes down. Because of this, some of these soils fit the description of saline nonsodic soils, in which the pH is characteristically neutral to moderately basic. Moisture stress, which is really a dependent variable, showed negative correlations with salinity and calcium. This indicates that soils with high salt and calcium content had less moisture stress. The stands with less moisture stress were mainly streamside communities, but these also had higher salinity, which probably accounts for this unexpected correlation.

Significant positive correlations exist between plant diversity, and soil sand content and salinity. Diversity increases on sandier soils with higher salinity. Plants grow well on these sites because they are salt tolerant, and because the soil moisture is usually higher. Density increased with higher soil temperatures for winter, and higher air temperatures during spring and summer. As would be expected, the plant density is greatest where moisture stress is lowest.

A multiple correlation test using trivariate data was run for the density of vascular species per stand and for the independent soil variables of percent sand and electrical conductivity (EC). The multiple correlation coefficient (r) was 0.94 giving a multiple coefficient of determination ($r^2$) of 0.89. This indicates that about 89% of species density is accounted for by the variables percent sand and EC.

The density data were also differentiated into average species per quadrat, and numbers of shrubs, grasses, perennial forbs, and annual species per plot. Shrubs showed significant positive correlation to density with such parameters as organic carbon concentration, percent rock, percent clay, and percent nitrogen. It is, therefore, likely that these parameters are positively correlated with long-term vegetation species. The more ephemeral species, such as annuals and many perennial forbs, were strongly correlated with texture of soil, salinity, and pH factors.

Total living cover, which averaged 47.7% in 1978 (ranging from 31% to 83%), was best correlated with salinity and the sodium factors (Na, sodium adsorption ratio, and exchangeable sodium percentage). Soil saturation percentages also showed a positive correlation with total cover. This can be explained by the fact that high salinity is a result of high moisture, as water in this area has a high salinity.

Winter soil temperature, winter minimum temperature, and average yearly temperature were significantly correlated with grass and forb cover. Consequently, these temperature factors are also correlated with total percent cover. Litter cover was significantly correlated with soil, rock, percent clay, maximum winter temperature, and spring soil temperature. These litter correlations may be a result of winter kill, early senescence (old age) of annual grasses or forbs, or possibly dead flowering parts. The litter factor can also be used to indicate greater growth responses to the climatic and edaphic conditions when the moisture factor is favorable (as it was in the early part of 1978).

Multiple correlation tests were also run on various cover relationships as independent variables with such factors as salinity and winter soil temperatures. The multiple correlation coefficient (r) with total cover was r = 0.80 which indicates by the multiple coefficient of determination ($r^2$) that about 64% of the variation in total cover is accounted for by these two factors. Further work would need to be done to account for a higher percentage of the variability.

Sagebrush and other shrubs undergo pulse phenomena, especially in southern deserts.[22] The pulse phenomenon theory attempts to explain why increases in numbers of plants seem to occur periodically. It is hypothesized that after a dry period, there exist greater amounts of space due to shrub dieback; thus, seeds can germinate after the return of optimum moisture conditions. New shrub proliferation and growth takes on a pulse-like increase in density. The climatic factors in 1978 and 1979 were favorable to new shrub growth because a dieback probably occurred in the drought years of 1976 and 1977.

All forbs show a number of high correlation coefficients with salinity and sodium related variables, higher sand percent in soils (less silt), lower soil pH, winter and spring maximum temperatures, and winter soil temperature. The latter three factors may be associated with germination of annual and perennial forbs in the spring and subsequent growth under wetter soil moisture conditions.

Annual forb cover, like the perennial forbs, was positively correlated with salinity and sodium factors. Potassium (K) correlated positively at surprisingly high levels with the annual species percent of living cover. Rock percent cover and cation exchange capacity also correlated at significant levels with the relative cover of annuals.

Cryptogam cover showed high correlations with a number of factors. Soils with greater amounts of fines (especially silt), lots of bare surface, high pH, high calcium (Ca), and deeper soils seemed to be most favorable to mosses and lichens.

**Conclusions.** This research provides baseline data on the vegetation communities of the Raft River geothermal site and indicates that variations in plant community composition occur from year to year. If further development occurs, it is probable that a vegetation response much more dramatic than those fluctuations observed during this study may occur. If so, the sensitive perennial forbs and annuals would serve as good indicator organisms by clustering differently than previously observed. Thus, potential changes in the plant ecology of the region could be quickly identified.

## Small Mammals

**Introduction.** Small mammals are an important component of the Great Basin ecosystem. They are the principal granivores and herbivores of the area and potentially compete with commercial uses of range resources (i.e., livestock grazing and crop production). Small mammals also serve as the major prey source for most of the predators in the region. Thus, their populations are an essential factor in maintaining the ecological composition of the rangeland.

Two different studies of the small mammal communities were conducted at the Raft River site. One, conducted in 1977 and 1978, concentrated on establishing population densities and distributions of the Cricetinae (deer mice and harvest mice) and Heteromyidae (kangaroo rats and pocket mice). The population trends of selected species of these families are very sensitive to changes in the environment and can therefore be used as indicators to help identify and assess the impacts of changes that may result from development of the area.

A separate investigation was conducted on the lagomorph (rabbit) community. Rabbit censuses were begun in 1978 to provide prey data necessary for an analysis of the ferruginous hawk population. The black-tailed jackrabbit (*Lepus californicus*), pygmy rabbit (*Brachylagus idahoensis*), and Nuttall's cottontail (*Sylvilagus nuttalli*) inhabit the valley. Emphasis during the 1980 research was placed on the black-tailed jackrabbit and pygmy rabbit. The Nuttall's cottontail, a generally abundant species throughout North America, was the least common of the three species and was limited in distribution to riparian or moist habitat in the Raft River Valley. The black-tailed jackrabbit was studied because knowledge of the 8- to 11-year cyclic population makes it possible to accurately assess the prey-dependent predator populations. The pygmy rabbit population was studied to determine the distribution of this uncommon species in the valley. Also, the health of the pygmy rabbit population may be a good indicator of subtle changes in the specific habitat required by this species, and thus could be useful as an environmental monitoring tool for the area.

### Methods

***Rodent Census***—Rodent populations were censused in 1977 and 1978 using two techniques.[23] The first technique employed the use of a base grid throughout the duration of the study. The grid was established in the sagebrush-greasewood biotic community and included a 12 x 12 trapping pattern (2.72 ha). Trapping stations were set 15 m apart and were equipped with two live-traps per station. The traps were baited with rolled oats and were operated for 10-day periods during both May and August. All animals captured were marked with a toe-clip, weighed, and released. Data recorded for all recaptures included species, sex, trap location, weight, and age.

The capture-recapture data were analyzed using a variation of the marked to unmarked ratio that causes the population estimate ($\hat{N}_i$) to approach the population parameter ($N_i$) as the trapping days increase.[24] This method reduces the variance as $N_i$ is approached. $N_i$ is estimated with:

$$\hat{N}_i = \frac{\sum_{k=2}^{i} n_k M_k^2}{\sum_{k=2}^{i} m_k M_k}$$

where

$\hat{N}_i$ = population estimate of $N_i$

$M_k$ = accumulated number of animals marked and released before day i

$m_k$ = number of marked animals caught on day i

$n_k$ = number of marked and unmarked animals caught on day i.

When every animal in the population has been marked, $M_{k-1}$ will equal $M_k$, and $n_k$ will equal $m_k$; thus, $\hat{N}_i$ would equal $M_k$.

The second technique employed satellite mini-grids in 12 random locations among the principal biotic communities. A mini-grid was also established adjacent to the base grid. Each of the 13 mini-grids consisted of four trap stations 15 m apart, with two live-traps per station. The mini-grids were trapped for five consecutive days (one to three periods per month for May, June, July, and August), and all animals were released at the point of capture after weighing, sexing, and aging.

Population estimates for the mini-grids were obtained by establishing a ratio between the mini-grid adjacent to the base grid and the 12 satellite mini-grids. The ratio was adjusted on the basis of the estimated number of mammals on the base grid at the time the mini-grids are sampled. A more detailed description can be found in Jorgensen and Smith.[25] Populations on the mini-grids ($N_s$) were estimated with:

$$\hat{N}_s = (c_s/b_s)(\hat{N}_s')$$

where

$c_s$ = average captures for the 5-day trapping period on the particular mini-grid

$b_s$ = average captures for the 5-day trapping period on the base mini-grid

$\hat{N}_s'$ = estimate of population size on the base grid, adjusted for the time when mini-grids are trapped.

This procedure provides an estimate comparable to that derived from the base grid. Estimates of population changes on the base grid were assumed to be linear when adjusted for the mini-grid estimates.

This type of census yields accurate population densities and distributions for Cricetinae and Heteromyidae on the base grid. These trapping methods discriminated, however, against the other small mammals that inhabit the region and were not conducive to accurate sampling. This discrepancy is explained by the behavioral and physical differences between the small mammal groups. In addition, data collected from satellite mini-grids that differ from the base grid in vegetation or soil are not necessarily comparable.

### *Lagomorph Census*

***Black-tailed Jackrabbit Census***—Density estimates for the black-tailed jackrabbit population were determined by walking 1.6-km transects through habitat types representative of the vegetation in the valley. Ten transects were run in early July during both 1978 and 1979. These censuses coincided with the fledging period of ferruginous hawks. In 1980, the census frequency was increased to 15 transects and was run during March, July, and October. The census data were analyzed using the following flushing distance equation:[24]

$$N_T = \frac{1}{2L}\left(\frac{F_i}{d_i} \quad \frac{F_2}{d_2} + \dots + \frac{F_n}{d_n}\right)$$

where

$N_T$ = density estimate

L = transect length

$F_i$ = number of rabbits flushed at corresponding flushing distance

$d_i$ = flushing distance.

The correction factor[26] (multiplying $N_T$ by 1.14) was used to reduce the inherent underestimate of the Hayne method.[24] By applying the census criteria of Gross et al.,[26] the Raft River Valley data were consistent with the long-term population data they collected for an adjacent area in southern Idaho and northern Utah. The comparable census methods and survey areas provide an estimate of the jackrabbit population trends in the region back to 1963 with only several years of data missing in the early and mid-1970s.

***Pygmy Rabbit Census***—The pygmy rabbit, a species which appears to have an obligatory-like relationship with sagebrush,[27] is endemic to the Great Basin where it occurs in scattered colonies. Because of its restricted distribution and undetermined population status, this species receives special attention from state and federal land management agencies. In the course of the jackrabbit census, two pygmy rabbit colonies were found in the valley, one within the geothermal area. Aside from these two colonies, no pygmy rabbits were sighted. In 1980, research was initiated to determine the population density and to characterize the habitat parameters of the colonies. Because it is difficult to census this secretive small mammal, three different sampling methods were employed. To locate the transects within the colony, intensive sampling sites were chosen on the basis of previous observations (Figure 12).

Walk transects,[24] fecal pellet counts,[27] and capture/recapture[28] were the three census methods used. Population density estimates obtained by these methods were transformed[29] for parametric statistical analysis. Vegetation analysis of pygmy rabbit habitats was conducted using the point-quarter method[30] to quantify density, height, and cover of woody vegetation. Herbaceous cover, litter, bare soil, and rock cover were evaluated using the basic technique recommended by Daubenmire.[31] Importance indices for shrub species were calculated using the combined values for relative frequency, relative cover and relative density.[32]

**Results and Discussion.** Table 9 lists the mammal species sighted in the Raft River Valley. Many of these species are commonly found throughout the western states. The studies conducted at the Raft River KGRA concentrated on species that either inhabit very specific habitats or are a very dominant member of the mammal community. The in-depth studies are discussed in the following text.

***Rodents***—Population estimates from the base grid provide data from which subtle changes in populations can be detected. Also, population data collected on the base grid serve as the baseline for estimating populations on the mini-grids with comparable vegetation and soil. Table 10 gives an

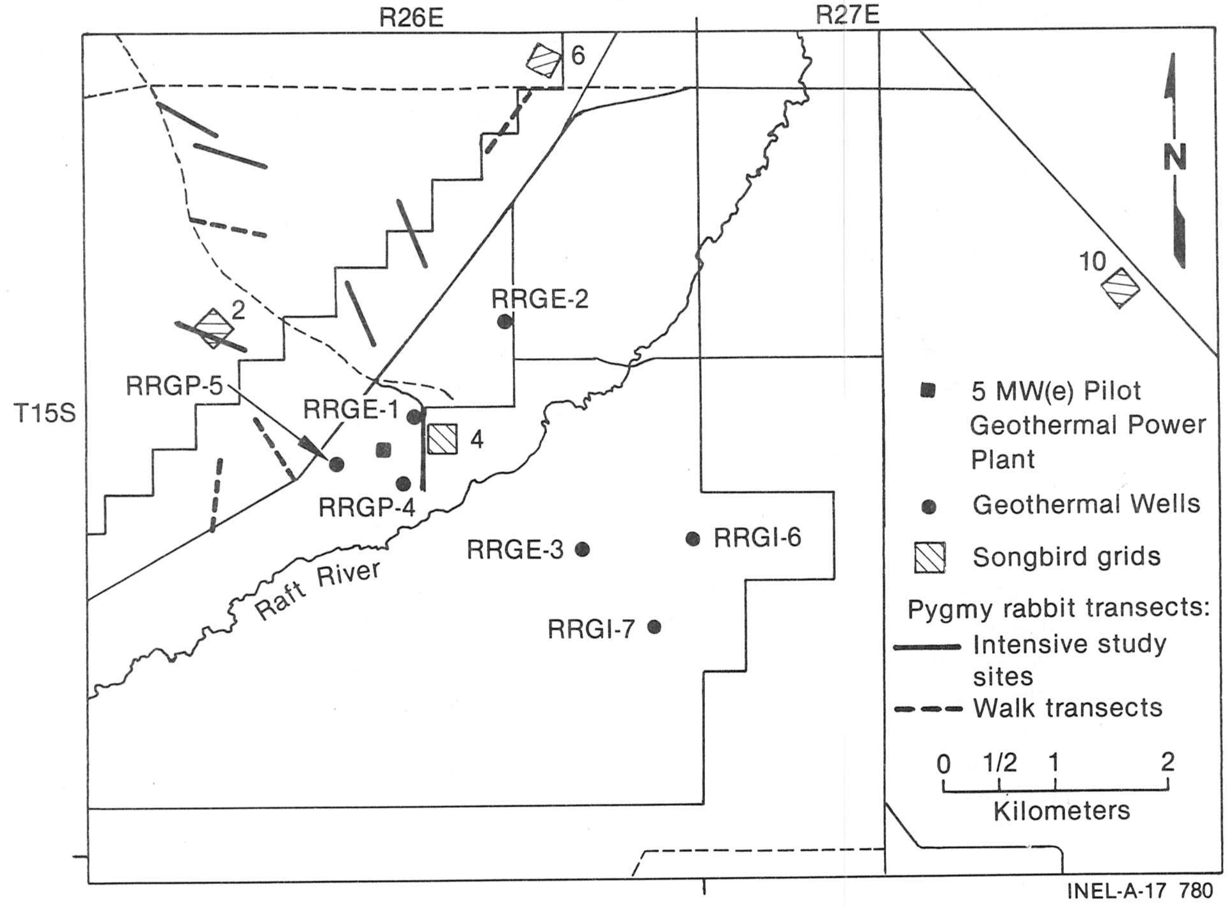

Figure 12. Location of pygmy rabbit transects and passerine bird grids.

### Table 9. Mammals observed in the Raft River Valley and the adjoining mountains

| | |
|---|---|
| Masked shrew | *Sorex cinereus* |
| Vagrant shrew | *Sorex vagrans* |
| Little brown bat | *Myotis lucifugus* |
| Raccoon | *Prycyon lotor* |
| Long-tailed weasel[a] | *Mustela frenata* |
| Badger[a] | *Taxidea taxus* |
| Spotted skunk | *Spilogale gracilis* |
| Striped skunk | *Mephitis mephitis* |
| Coyote[a] | *Canis latrans* |
| Red fox | *Vulpes vupes* |
| Black-tailed jackrabbit[a] | *Lepus californicus* |
| Pygmy rabbit[a] | *Brachylagus idahoensis* |
| Nuttall's cottontail[a] | *Sylvilagus nuttallii* |
| Townsend's ground squirrel[a] | *Spermophilus townsendii* |
| Richardon's ground squirrel | *Spermophilus richardsonii* |
| Golden-mantled ground squirrel | *Spermophilus lateralis* |
| Yellow pine chipmunk[a] | *Eutamias minimus* |
| Least chipmunk | *Eutamias amoenus* |
| Red squirrel | *Tamiasciurus hudsonicus* |
| Northern flying squirrel | *Glaucomys sabrinus* |
| Northern pocket gopher[a] | *Thomomys talpoides* |
| Ord's kangaroo rat[a] | *Dipodomys ordii* |
| Chisel-toothed kangaroo rat[a] | *Dipodomys microps* |
| Great basin pocket mouse[a] | *Perognathus parvus* |
| Western harvest mouse[a] | *Reithrodontomys megalotis* |
| Deer mouse[a] | *Peromyscus maniculatus* |
| Grasshopper mouse[a] | *Onychomys leucogaster* |
| Desert woodrat[a] | *Neotoma lepida* |
| Bushytailed woodrat[a] | *Neotoma cinerea* |
| Meadow vole | *Microtus pennsylvanicus* |
| Moutane vole | *Microtus montanus* |
| Sagebrush vole[a] | *Lagurus curtatus* |
| Muskrat[a] | *Ondatra zibethica* |
| Norway rat[a] | *Rattus norvegicus* |
| House mouse[a] | *Mus musculus* |
| Porcupine[a] | *Erthizon dorsatum* |
| Pronghorn | *Antilocapra americana* |
| Mule deer[a] | *Odocoileus hemionus* |

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a. Observed on or near the KGRA.

## Table 10. Population estimate of small mammal species censused during the 1977 to 1978 study

| | Total Population on 2.72 Ha Plot | | | |
|---|---|---|---|---|
| | 1977 | | 1978 | |
| | Spring | Summer | Spring | Summer |
| Great Basin pocket mouse (*Perognathus parvus*) | 10.5 | 27.0 | 5.1 | 11.0 |
| Ord's kangaroo rat (*Dipodomys ordii*) | 7.3 | 3.7 | 5.0 | 9.9 |
| Deer mouse (*Peromyscus maniculatus*) | 21.8 | 2.4 | 92.8 | 34.1 |
| Harvest mouse (*Reithrodontomys megalotis*) | 14.9 | 6.5 | 17.5 | 10.3 |
| Grasshopper mouse (*Onychomys leucogaster*) | 0.0 | 1.0 | 0.0 | 7.3 |
| Least chipmunk (*Eutamias minimus*) | 12.1 | 6.9 | 6.9 | 0.0 |

estimate of the small mammals during the spring (May) and summer (August) samples. These data could be used on a comparative basis to determine any changes (annual or seasonal) that may have been induced from geothermal development.

### *Lagomorphs*

***Jackrabbit Population***—The density of the black-tailed jackrabbit population[26,33] was estimated in the summer to be $309/\text{km}^2$ in 1978, $287/\text{km}^2$ in 1979, $188/\text{km}^2$ in 1980, $116/\text{km}^2$ in 1981, and $93/\text{km}^2$ in 1982. The black-tailed jackrabbit population densities for 1978 and 1979 were high when compared with population estimates in the literature,[26,34,35] indicating that the population was at or near peak-population density in 1978 (refer to Figure 14). A qualitative indication of the population was also obtained by counting jackrabbits killed on an 8-km stretch of the only paved road through the valley. In 1978, 85 dead jackrabbits were counted. In 1980, at the same time of year and over the same stretch of road, only 32 dead jackrabbits were counted. These observations support the walk transect data, indicating a substantial population decline since 1978.

The decline in the jackrabbit population from 1979 to 1980, despite a mild winter for that year, appears in part to be the result of an epizootic outbreak in the population in late 1979. In late summer of 1979, abnormal jackrabbit behavior was observed, evidenced by "dazed" individuals seemingly unaware of the surrounding environment. Jackrabbits were frequently found dead in the field from no apparent external cause. Autopsies revealed tularemia as the probable cause of death. Very few young jackrabbits were present in the 1980 summer population, composing only 19% of the total.

Similar transects were run in Curlew Valley (located about 35 km east of Raft River Valley) during 1978 and 1979, yielding population density estimates of $50/\text{km}^2$ and $66/\text{km}^2$, respectively. The much lower jackrabbit densities in Curlew Valley probably reflect the more intense agricultural and rangeland development in this area than in Raft River Valley. The altered environment appears to hold the jackrabbit population in check, so it does not fluctuate as much as populations in large native stands of vegetation. A cyclic pattern is evident in population data collected in Curlew Valley,[26] indicating that the last population peak occurred about 1970.

***Pygmy Rabbit Population***—The mortality factors contributing to the decline of the black-tailed jackrabbit population were diseases, external and internal parasites, predation, and poor nutrient intake resulting from intense grazing pressure exerted by the high population density. These factors may also affect other sympatric species of lagomorphs. In 1980 the pygmy rabbit population showed a noticeable decline from the spring through the summer. Overall, pygmy rabbits on the six study sites averaged 3.6 individuals/ha and ranged from 0.8 to 8.4 individuals/ha. The location of the colonies appeared to be related to very specific habitat conditions. Big sagebrush (*Artemisia tridentata*) was by far the most dominant woody vegetation observed in conjunction with pygmy rabbits. The average importance index of big sagebrush along the six 500-m walk transects located within the areas intensively used by pygmy rabbits was 59.5% (coefficient of variance cv = 39.2%). The same trend was evident for the average importance indices of grasses and grass-like species. Along the six 500-m walk transects, this vegetation had an average importance index of 12.8% (cv = 82.4%), and increased to 21.5% (cv = 53.3%) at trap sites within the five intensive use areas. Grasses have been identified as important components for pygmy rabbit diets in spring and summer.[27,36]

A multiple regression analysis of the average importance indices of big sagebrush and grasses and grass-like plants at the five trap sites accounted for 91.1% of the observed variability in population density of pygmy rabbits on the same sites. A similar test with importance indices of big sagebrush and grasses and grass-like plants along the six 500-m walk transects showed these measurements accounted for 68.9% of the variability observed in estimates of population density of pygmy rabbits. Height of woody vegetation was not taken into account in the importance indices for woody vegetation. Used alone, height of big sagebrush at trap sites and along walk transects accounted for 39.2 and 59.2%, respectively, of the observed variability in estimates of pygmy rabbit density.

The results of this research have more clearly delineated the close association between big sagebrush and pygmy rabbits. Pygmy rabbits select habitats where stands of big sagebrush fit within high and low limits of height, cover, density, and frequency.

**Conclusions.** The small mammal studies provide important insights for understanding ecological communities in Raft River Valley. These data can serve as an indicator of changing ecological conditions in the valley. The population status of sensitive, habitat-specific species such as the pygmy rabbit would quickly respond to any change that affects their environmental needs. Likewise, shifts in the composition of rodent species may also indicate changing habitat. Such changes in environmental parameters warrant further research to document the causes. Also, since rodents and rabbits are the major prey base of the larger predators of the region, the status of the small mammal population is an important factor when analyzing trends in the predator population.

## Raptor Ecology

**Introduction.** Raptors, often at the top of the food chain, are important biological indicators that reflect changes within the ecosystem. Land management policies that change patterns in land use, habitat, prey densities, or environmental pollution levels are all likely to strongly impact the raptor community. Data generated by this research provide baseline information for south-central Idaho which can be used as a reference for similar habitats typical of the Great Basin. These data are available for use in making wise management decisions. Should adverse changes in the environment begin to occur, they can be quickly assessed by comparison with historical conditions so that corrective measures can be implemented.

A community approach was attempted in conducting a study of the Raft River Valley raptor population.[37] Studies reported by Cody and Diamond[38] used this approach for studying passerine and nonraptorial bird populations; however, few studies have assessed entire raptor communities. Craighead and Craighead[39] studied complete raptor communities in Michigan and Wyoming. Smith and Murphy[40] studied a raptor community in the Great Basin, but were restricted by the numbers of nesting pairs found for each species.

**Methods.** The population status of the raptor species inhabiting the Raft River Valley was ascertained in conjunction with the ferruginous hawk (*Buteo regalis*) perturbation study.[37] Nests of raptors were censused to the degree that they could conveniently be studied while conducting the raptor disturbance research (see Raptor Disturbance Research section for a description of census methodology). In addition, an organized census of Swainson's hawk (*Buteo swainsoni*) nests was conducted by searching within a 0.8-km radius of 15 active and 15 inactive ferruginous hawk nests during both 1978 and 1979. An organized search for long-eared owl (*Asio otus*) nests was conducted by surveying 0.5-km sections (14 in 1978; 17 in 1979) along the juniper-sagebrush ecotone. Both Swainson's hawks and long-eared owls frequently used nest sites concealed within the tree canopy. Because it was essential that no nests be overlooked during these surveys, each tree was examined closely.

**Results and Discussion.** Twenty-one raptor species were present in the Raft River Valley, providing an excellent opportunity for an integrated study of the ecology of the raptor community. The raven (*Corvus corax*) is included as a functional raptor. The design and intensity of the raptor disturbance study limited in-depth research to the ferruginous hawk, nest placement of ferruginous and Swainson's hawks, and long-eared owl prey and nesting density. The additional observations included in this report serve as an overview of a diverse raptor community occurring in the shrub-grassland ecosystem that characterizes Raft River vegetation.

A total of 181 active raptor nests were found in the Raft River Valley during 1978 and 1979, with emphasis placed on the ferruginous hawk, Swainson's hawk, red-tailed hawk (*Buteo jamaicensis*), golden eagle (*Aquila chrysaetos*) and the long-eared owl. Species known to breed in the study area and the number of nests located in 1978 and 1979 are: Cooper's hawk (*Accipiter cooperii*) (4), harrier (*Circus cyaneus*) (1), ferruginous hawk (66), red-tailed hawk (3), Swainson's hawk (29), golden eagle (6), prairie falcon (*Falco mexicanus*) (4), American kestrel (*Falco sparverius*) (3), great horned owl (*Bubo virginianus*) (15), short-eared owl (*Asio flammeus*) (0), long-eared owl (24), barn owl (Tyto alba), burrowing owl (*Athene cunicularis*) (9), common raven (16—data collected in 1979 only). In addition, the turkey vulture (*Cathartes aura*), goshawk (*Accipter gentilis*), sharp-shinned hawk (*Accipiter striatus*), merlin (*Falco columbarius*), and the screech owl (*Otus asio*) have all been sighted and may possibly breed in the valley. The rough-legged hawk (*Buteo lagopus*) and the bald eagle (*Haliaeetus leucocephalus*) are present in the valley as migrants and winter residents.

At least two key factors affect the composition of the raptor community; these include juniper trees for nest sites and jackrabbits for food. The favorable combination of these two critical elements in 1978 and 1979 is responsible to a large degree for the high density and diversity of the raptors in the study area. The alteration of these factors yields different effects. Removal of suitable junipers would essentially eliminate the Swainson's hawk, reduce the ferruginous hawk population to a few ground nesting pairs, and restrict other raptors to the limited number of suitable cliff nest sites. Changes in the jackrabbit population reduce the golden eagle and ferruginous hawk breeding densities, but have little effect on the densities of generalist species such as the raven.

Within this community of raptors, some species will respond more quickly to changes than others, some will benefit by human alteration of the environment, and other species will be harmed. Moderate grazing practices may increase passerine bird populations.[41] Nonintensive agricultural crops such as alfalfa may increase the pocket gopher population, creating an additional prey source which would otherwise be unavailable in the undisturbed ecosystem. Grazing practices and rangeland alteration also help to create open spaces that may be colonized by ground squirrels. Both pocket gophers and ground squirrels stabilize the prey source. As a result, the raptor population has a more diverse prey base and is not dependent solely on the cyclic jackrabbit population. Therefore, moderate rangeland and agricultural development may actually help the raptor population over the short term. Jackrabbits, however, remain the prime food source for large raptors such as the golden eagle and ferruginous hawk. If the vegetation of the region is altered to such an extent that the jackrabbit population is seriously limited, the populations of these larger raptors will probably decline.

The ferruginous hawk popluation in the Black Pine and Curlew Valleys adjacent to the Raft

River Valley has already shown a response to the changing nature of the vegetation.[42] For example, in Curlew Valley the jackrabbit population is five to six times less dense than in the Raft River Valley, probably due to extensive rangeland development and agricultural activity. Jackrabbits use very little of the large crested wheatgrass seedings that are more than 300 m away from the sagebrush borders.[43]

Changes in the raptor community of the Raft River Valley should be carefully documented as the character of the valley continues to change in the face of agricultural, rangeland, and potential geothermal development. To provide some background information, the reproductive data for the major raptor species are presented (see Tables 11 and 12). The limited land disturbance and increase in human activity associated with the current Raft River geothermal development did not have an observable effect on the raptor populations in the valley. Rather, declines in the large raptor nesting success (i.e., golden eagle and ferruginous hawk) are associated with the natural cyclic trend in the

## Table 11. Reproductive data of raptorial species in Raft River Valley from 1978 through 1980

| | 1978 | | | 1979 | | | 1979 | | |
|---|---|---|---|---|---|---|---|---|---|
| Species[a] | Number of Nests | Mean Clutch Size | Mean Number Fledged | Number of Nests | Mean Clutch Size | Mean Number Fledged | Number of Nests | Mean Clutch Size | Mean Number Fledged |
| Swainson's hawk | 16 | 2.56 | 2.13 | 13 | 2.38 | 2.15 | 4 | 2.50 | 2.25 |
| Raven | — | — | — | 16 | — | 4.37 | — | — | — |
| Long-eared owl | 10 | 3.90 | 3.40 | 14 | 4.28 | 4.00 | — | — | — |
| Golden eagle | 3 | — | 1.67 | 3 | — | 2.00 | 2 | — | 2.00 |
| Prairie falcon | 1 | 4.00 | 3.00 | 3 | 4.33 | 3.00 | 2 | 5.00 | 4.50 |
| Cooper's hawk | 1 | 4.00 | 4.00 | 3 | 4.00 | 4.00 | 1 | 4.00 | 4.00 |
| Great horned owl | 7 | — | 2.16 | 8 | — | 1.57 | 4 | — | 2.25 |
| Red-tailed hawk | 2 | — | 2.50 | 1 | 3.00 | 0.00 | 1 | — | 3.00 |

a. Exclusive of the ferruginous hawk (see Table 12) and burrowing owl.

## Table 12. Ferruginous hawk fledging rate in Raft River Valley

| | Total Nests that Fledged Young (% of yearly total) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Young Fledged per Nest | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 |
| 5 | 1 (6) | 0 (0) | 0 (0) | 0 (0) | 1 (9) | 0 (0) | 2 (12) | 5 (24) | 0 (0) | 0 (0) | 0 (0) |
| 4 | 5 (29) | 9 (0) | 3 (23) | 2 (15) | 1 (9) | 1 (13) | 8 (47) | 10 (48) | 5 (21) | 6 (23) | 2 (9) |
| 3 | 6 (35) | 19 (67) | 3 (23) | 3 (27) | 3 (27) | 5 (62) | 4 (23) | 2 (9) | 10 (42) | 11 (42) | 10 (43) |
| 2 | 4 (24) | 3 (20) | 6 (47) | 6 (47) | 3 (27) | 2 (25) | 3 (18) | 2 (9) | 5 (21) | 6 (23) | 6 (26) |
| 1 | 0 (0) | 2 (13) | 2 (15) | 2 (15) | 3 (27) | 0 (0) | 0 (0) | 1 (5) | 2 (8) | 1 (4) | 2 (9) |
| 0 | 1 (6) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (5) | 2 (8) | 2 (8) | 3 (13) |
| Average number of young fledged per nest | 3.0 | 2.53 | 2.46 | 2.38 | 2.45 | 2.87 | 3.53 | 3.62 | 2.58 | 2.69 | 2.26 |

jackrabbit population (see sections on Small Mammals and Raptor Disturbance Research).

## Raptor Disturbance Research

**Introduction**. The ferruginous hawk (*Buteo regalis*) is the largest hawk in North America. It is prone to nest desertion, especially during the incubation period.[44-46] Because of its sensitivity and apparent declining nationwide population, it has been placed on the "Blue List." This classification indicates cause for special concern.[47]

The Raft River Valley contains one of the most prolific ferruginous hawk populations remaining in the country (Figure 13). This abundance strongly contrasts with other regions of the Great Basin[48] and the Snake River Plains where similar habitats support a much lower population density. The hawks were studied here and in adjacent valleys from 1972 through 1977. Consequently, their population densities and dynamics are known.[49,50] Such baseline data are essential for establishing population trends and separating the effects of human factors from natural environmental fluctuations.

The ferruginous hawk disturbance research was conducted from 1978 through 1980. The objectives of the study were to (a) assess the potential impact of geothermal development activities on the nesting success of the species, (b) approximate a buffer zone around nest locations beyond which geothermal development would presumably not impair nesting success, and (c) accumulate information and baseline data that will be useful to other studies aimed at determining similar parameters.

**Methods**. Between April and July of 1978 and 1979, the ferruginous hawk territories were censused by traveling 13,000 km of road. New nest sites were located by traveling along the sagebrush-juniper ecotone and looking for characteristic flat-topped juniper trees preferred by the birds. Ground nests were found by observing the behavior of pairs sighted in areas which did not have suitable tree nest sites; these nests were typically located near utility poles which provided a perch for the hawks. In addition to the ground census, an aerial survey was conducted in late May of 1979 when the young were large, downy, white chicks and thus, easily visible from the air.

Nests were visited at least twice during the year. On the first visit in late April, nests were observed using a 15-60X telescope to determine whether the nest was active. The latter visit occurred during the first or second week of June when the chicks were three to four weeks old. All nestlings were banded with U.S. Fish and Wildlife Service bands. Data were collected on clutch size, brood size, fledging success, behavior of the adults, and prey items in the nest.

In 1978, 1979, and 1980, nests were randomly designated as either control or treatment nests. During 1978, four treatments were applied: (a) three nests were disturbed by investigators approaching on foot, (b) two were disturbed by placing continuously operating 3-1/2 hp gasoline engines near them, (c) three were disturbed by an approaching vehicle, and (d) three were disturbed by discharging firearms in the vicinity. The 1979 treatments were applied as follows: (a) five nests were approached on foot, (b) five nests were approached by vehicle, and (c) four nests were treated with wind- or battery-powered noisemaker devices placed 30 to 50 m from the nests. Noise at the nest sites (80 ± 5 db) was designed to simulate noises common to a geothermal site. The 1980 treatments are discussed in the following paragraphs.

During the treatments, nests were approached until the attending adult flushed (left the nest). When this occurred, the investigator approached no further and immediately left the area. The distance between the investigator and the nest was estimated and recorded as the level of stress or anxiety beyond which the hawks could no longer tolerate the presence of the disturbing factor. All nests contained eggs at the initiation of the various treatments and were disturbed once daily until the young fledged from the nest. Data collected at each visit included presence or absence of adults, flushing distance, general behavior of adults, and unusual climatic conditions. To more accurately determine the distance at which these birds actually become stressed, a radiotelemetry study, initiated in 1980, monitored increased heart rates as the nests were approached. A transmitter sensitive enough to detect the heart rate of a nesting adult (incubating) bird was encased in an addled (unhatched) ferruginous hawk egg and placed in the nest along with the other eggs. This was only partially successful because nests treated thusly were often abandoned.

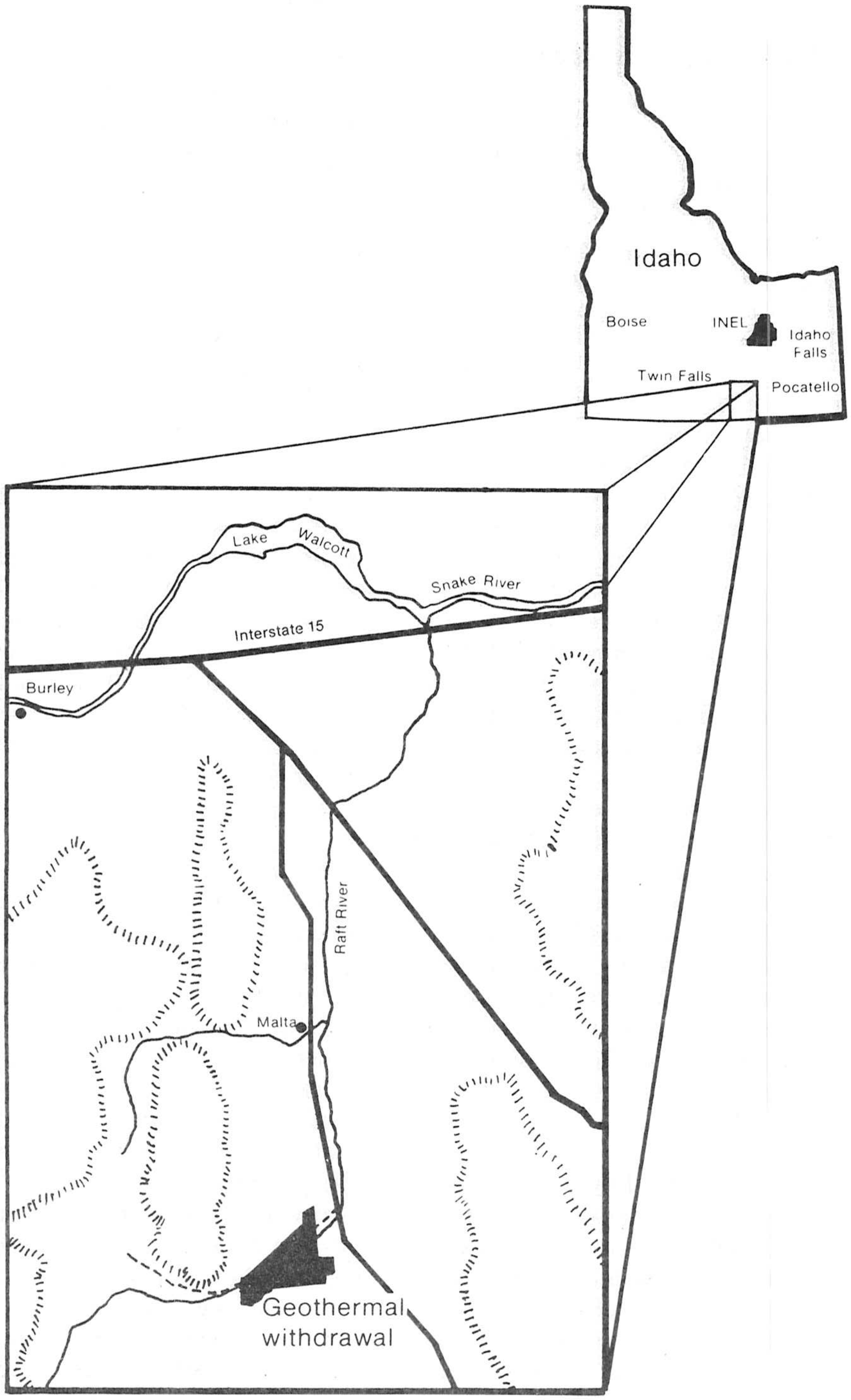

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Figure 13. Location of ferruginous hawk nesting habitat.

**Results and Discussion.** The ferruginous hawk still remains the most common buteo in the Raft River Valley, probably owing to moderate land use history and a large prey base. Table 12 shows the distribution and average number of young fledged per nest for 1972 through 1982.

Because of the ferruginous hawk's ability to utilize both tree and ground nesting sites, a uniform distribution occurs allowing the birds to more fully exploit available prey. Nest spacing was fairly regular and historical nesting territories were almost all occupied, suggesting maximum nesting density and reflecting high prey densities.

Unlike previously reported findings of nest desertion resulting from human interference, few nest failures resulted from our treatments. During 1978, three pairs (out of 10 treatment nests) abandoned their nesting attempt and four out of 13 treatment pairs deserted during the 1979 season (Table 13). During these years of the study, however, the black-tailed jackrabbit (*Lepus californicus*) population was at a near peak density. This abundant food supply may have increased the tolerance of nesting pairs. As the jackrabbit cycle began to decline, the physiological state of the hawks probably also declined, as well as their tolerance to human activity. This seemed to be the case in 1980 when the telemetry studies were conducted, as the first two attempts to place transmitters in ferruginous hawk nests resulted in desertion. Although a third attempt to place a transmitter in an active nest was temporarily successful, that pair also deserted.

Each pair of birds showed varying responses to the different treatments; however, none seemed to develop a tolerance to the presence of investigators. Flushing response data during the incubation period indicate that most pairs were more sensitive to disturbance during this time. Once the chicks hatched, a zone of security (approximately 100 m radius from the nest) seemed to be established where the adults appeared to feel relatively safe. Providing that zone was not entered, adults did not flush 60% of the time. Throughout 1979, the average flushing distance was 120 m. When direct human activity was restricted to greater than 200 m from the nest, flushing was avoided by 84%; when activity was restricted to greater than 250 m, 90% of the flushing was avoided.

The difference in fledging rate between the control and successful treatment nests in 1978 was statistically significant ($P = 0.10$) as evaluated by the independent t-test.[51] In 1979, the difference was again significant ($P = 0.01$). Of particular interest is the trend that appears in the data (Table 14); 14 of the 21 control nests in 1979 (or 71%) fledged either four or five young per nest while the maximum number of young fledged by any treatment nest was three.

Behavioral data collected during each visit to the nests suggest that adults became sensitized to the presence of investigators and were not as attentive to their young which may have contributed to the lower fledging success of treatment nests. Although flushing distance was used as an indication of critical stress threshold and consequent nest desertions, the hawks might well have reached a critical stress level long before they flushed. Busch, deGraw, and Clampitt[52] recorded a threefold increase in heart rate, an indication of stress, of a caged ferruginous hawk viewing an approaching human. We postulated that under field conditions, stress and, consequently, the

**Table 13. Ferruginous hawk fledging rates for 1978 and 1979 nesting seasons**

| | Number of Nests | | Fledging Rate | |
|---|---|---|---|---|
| | 1978 | 1979 | 1978 | 1979 |
| All treatment nests | 10 | 13 | 1.70 | 1.85 |
| Successful treatment nests | 7 | 9 | 2.43 | 2.67 |
| Control nests | 15 | 21 | 3.53 | 3.81 |

## Table 14. Distribution of the number of ferruginous hawk chicks fledged per nest

| Number of Young Fledged | Number of Nests (1978) | | Number of Nests (1979) | |
|---|---|---|---|---|
| | Control | Treatment | Control | Treatment |
| 5 | 2 (13)[a] | 0 (0) | 5 (24) | 0 (0) |
| 4 | 7 (47) | 3 (30) | 10 (48) | 0 (0) |
| 3 | 3 (20) | 9 (0) | 4 (19) | 6 (46) |
| 2 | 3 (20) | 2 (20) | 1 (5) | 3 (23) |
| 1 | 0 (0) | 1 (10) | 1 (5) | 0 (0) |
| 0 | 0 (0) | 4 (40) | 0 (0) | 4 (31) |

a. (Percentage of nests in each category).

heart rate might increase long before hawks flushed. Upon successful planting of a transmitter in a ferruginous hawk nest, a basal heart rate of approximately 130 beats per minute and an increased heart rate as researchers approached the nest were noted. After this nesting pair deserted, the transmitter was placed in a Swainson's hawk (*Buteo swainsoni*) nest, a species with similar sensitivity levels to those of the ferruginous hawk. Swainson's hawk heart rates typically increased by 50% when a human or vehicle within 300 m was first sighted by the incubating bird. The heart rate continued to increase until it had doubled the basal rate.

These data confirm the results obtained from a captive ferruginous hawk.[52] Stress, as measured by a rise in heart rate, begins to occur at a distance of up to nine times that at which the bird actually flushes. This information was used in determining a "buffer zone" that should be maintained around active nest sites during the breeding season. Such a zone defines a minimum critical area that must be maintained to prevent harmful effects associated with disturbance. This maintenance is particularly crucial during the breeding season, from early March through early July.

Fledging success varied over the 11-year study period (Figure 14). The pattern clearly illustrates that the number of young successfully fledged per nest is closely tied to the prey base density. In 1978, the jackrabbit population was at its peak density; in 1975, the population was near its low. Prey data collected at ferruginous hawk nests show to what extent lagomorphs constitute total prey biomass (Table 15). For predators that eat prey which leave no remains, quantification of relative prey importance based on biomass remains may be misleading. However, in the case of the ferruginous hawk, biomass provides a realistic estimate of the importance of prey in the diet as long as consideration is given to wastage, thus not overemphasising the importance of large prey items that cannot be swallowed whole. Figure 15 illustrates that most nests produce four and five young in an abundant prey year; however, in a year when the jackrabbit cycle is low, two young were most commonly fledged and no nests produced as many as five young. In fact, both the number of nesting attempts and the clutch size appear to be adjusted downward during the low years of the jackrabbit cycle (Figure 16).

**Conclusions.** Nesting success of the ferruginous hawk in Raft River Valley was not impaired by geothermal development and associated human activity as long as buffer zones were not violated. Our data were obtained, however, in an area

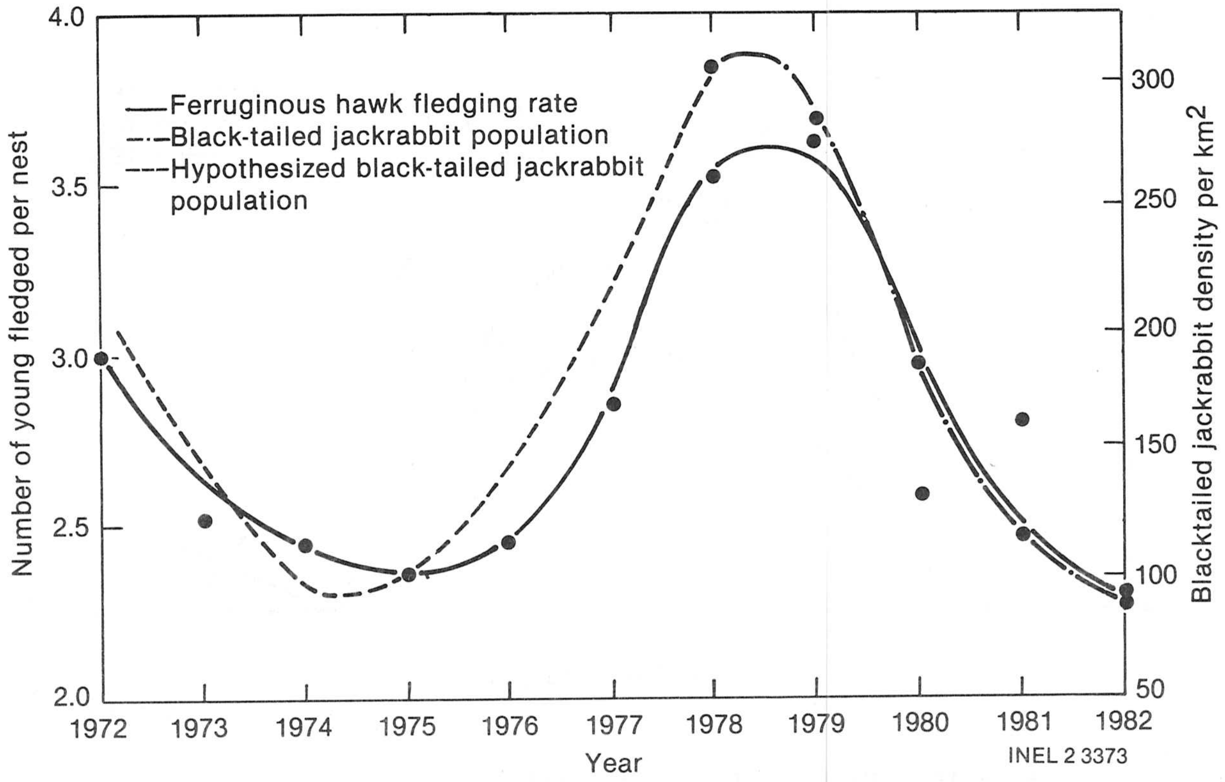

Figure 14. Comparison of ferruginous hawk fledging rate with the black-tailed jackrabbit cycle over an 11-year period.

## Table 15. Prey remains found in ferruginous hawk nests from 1978 to 1980

| Species | Approximate Weight (g) | Number of Individuals | Individuals (%) | Biomass (%) |
|---|---|---|---|---|
| Black-tailed jackrabbit (*Lepus californicus*) | 2300 | 41 | 36.6 | 83.5 |
| Nuttal's cottontail (*Syvilagus nuttallii*) | 1000 | 8 | 7.1 | 7.1 |
| Pygmy rabbit (*Brachylagus idahoensis*) | 750 | 1 | 0.9 | 0.7 |
| Northern pocket gopher (*Thomomys talpoides*) | 170 | 21 | 18.7 | 3.3 |
| Townsend ground squirrel (*Spermophilus townsendii*) | 190 | 8 | 7.1 | 1.3 |
| Richardson ground squirrel (*Spermophilus richardsonii*) | 280 | 1 | 0.9 | 0.2 |
| Least chipmunk (*Eutamias minimus*) | 80 | 2 | 1.8 | 0.1 |
| Ord kangaroo rat (*Dipodomys ordii*) | 65 | 6 | 5.4 | 0.4 |
| Great Basin pocket mouse (*Perognathus parvus*) | 15 | 1 | 0.9 | Tr[a] |
| Deer mouse (*Peromyscus maniculatus*) | 30 | 1 | 0.9 | Tr |
| Mountain vole (*Microtus montanus*) | 35 | 2 | 1.8 | 0.1 |
| Long-tailed weasel (*Mustela frenata*) | 180 | 2 | 1.8 | 0.3 |
| Mammal total |  | 94 | 83.9 | 97.1 |
| Pintail duck (*Anas acuta*) | 900 | 1 | 0.9 | 0.8 |
| Gray partridge (*Perdix perdix*) | 480 | 1 | 0.9 | 0.5 |
| Mourning dove (*Zenaidura macroura*) | 155 | 1 | 0.9 | 0.2 |
| Pinyon jay (*Gymnorhinus cyanocephalus*) | 180 | 1 | 0.9 | 0.2 |
| Black-billed magpie (*Pica pica*) | 175 | 2 | 1.8 | 0.3 |
| Horned lark (*Eremophila alpestris*) | 30 | 5 | 4.4 | Tr |
| Mountain bluebird (*Sialia currucoides*) | 45 | 1 | 0.9 | Tr |
| Western meadowlark (*Sturnella neglecta*) | 145 | 6 | 5.4 | 0.8 |
| Avian total |  | 18 | 16.1 | 2.8 |
| Overall total |  | 112 | 100.0 | 99.9 |

---

a. Tr = trace amount.

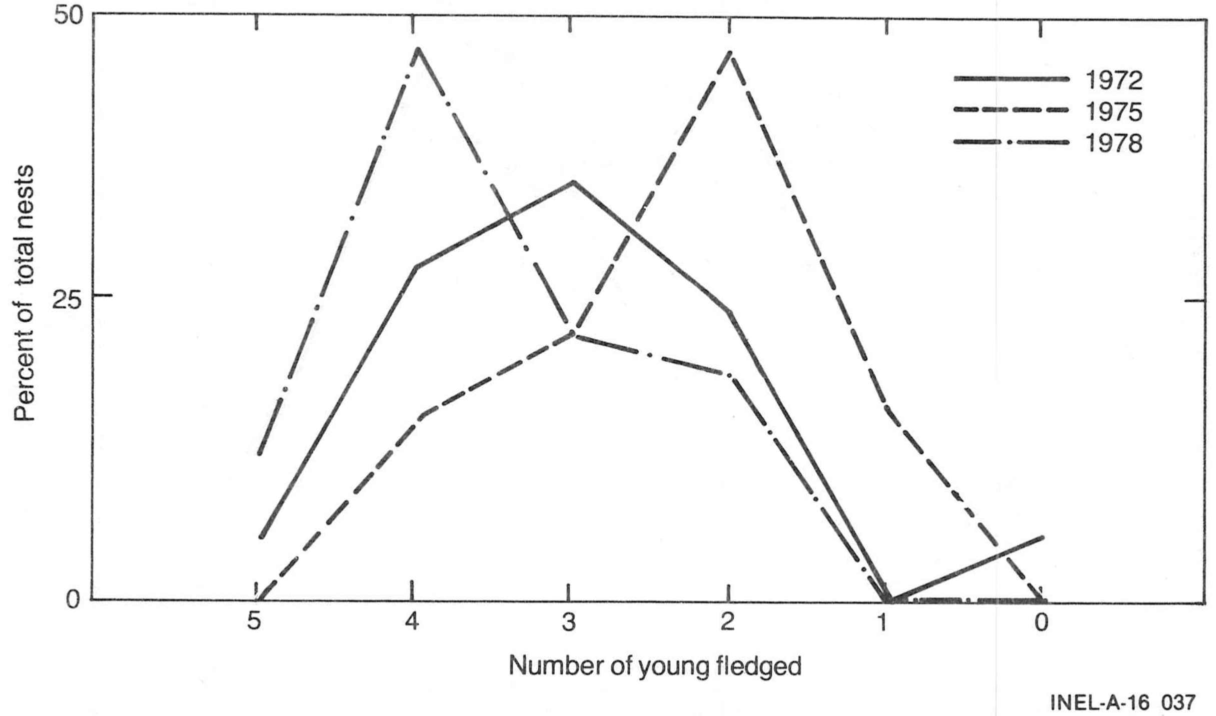

Figure 15. Ferruginous hawk fledging rate per nest as a percent of total nests throughout the black-tailed jackrabbit cycle.

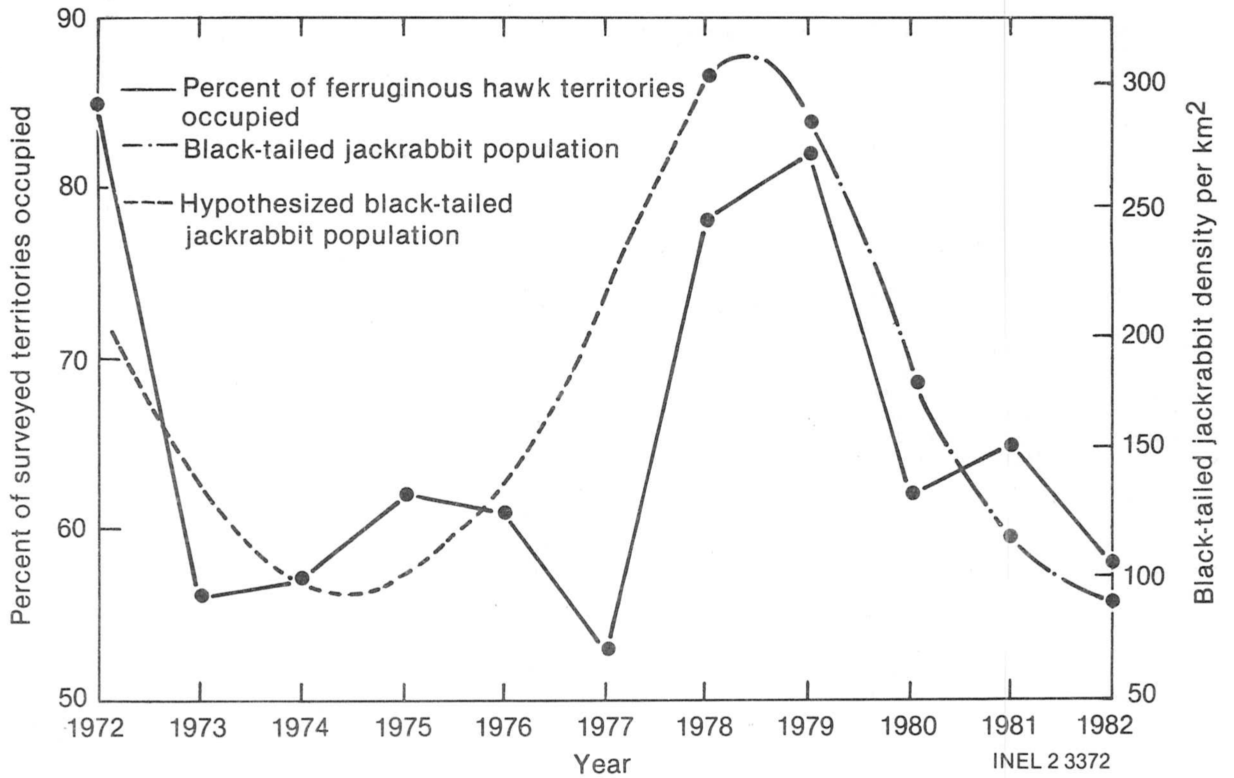

Figure 16. Percent of ferruginous hawk territories occupied compared with the jackrabbit population cycle over an 11-year period.

where the hawk population has not been exposed to long-duration human contact near the nesting areas (hence, no opportunity to become accustomed to disturbance over time). Also, the data were collected during years with an abundant prey base. Consequently, the hawks were in prime physiological condition and better able to cope with the induced stress. In years of low prey availability, nesting birds may require buffer distances of up to 1-1/2 times our estimation. With this and certain site-specific factors in mind, we interpret the flushing, heart rate, and behavioral data to suggest disturbances greater than 0.6 km away from the nest will be tolerated, providing they are not excessively prolonged or environmentally disruptive.

## Passerine Birds

**Introduction.** Passerine birds are an integral component of the Great Basin ecosystem and, as primary and secondary consumers, constitute a significant portion of the energy flow through the biotic community. This study collected baseline data on passerine birds in the Raft River Valley and predicted the possible impact of geothermal development on the songbird populations. The study was conducted in 1977, 1978, and 1980. The research emphasized potential impacts on entire avian communities, rather than on specific species. Selected species were identified as "indicator organisms" because of their restricted habitat requirements. These species are particularly sensitive to changes in that habitat. A quantitative change in density or structure of those selected breeding populations could thus be used to monitor environmental perturbations as they affect bird communities.

**Methods.** Four 16-ha plots were established in 1977, one in each of four compass directions from the geothermal site. The specific sites represent the major habitat types found in the immediate area. A fifth 16-ha study site was established in 1978. All sites were regularly surveyed to determine the nest densities and success of the major bird species. Each site, with the exception of the study site established in 1978, was censused once every 12 days from early May through June using the census techniques of Williamson et al.,[53] and White et al.[54] The data recorded included the total number of birds and species observed. In addition, some territories were mapped. Censusing was not extended beyond June because the majority of breeding activity for the species found on the study plots occurred prior to July. A list of all bird species sighted in the Raft River Valley and surrounding mountains was compiled.

**Results and Discussion.** Table 16 lists all the bird species sighted in the Raft River Valley from 1977 through 1982. Of these species, most are found in the riparian or wooded areas of the valley. These vegetation types are typical of the majority of the valley and the KGRA, which are dominated by big sagebrush and greasewood (see Plant Ecology section). Of the bird species which use this habitat type, four species are common. These are the horned lark (*Eremophila alpestris*), sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Amphispiza belli*), and Brewer's sparrow (*Spizella breweri*). The emphasis of this study was primarily on these species. Other relatively common species such as the mourning dove (*Zenaida macroura*), black-billed magpie (*Pica pica*), loggerhead shrike (*Lanius ludovicianus*), and vesper sparrow (*Pooecetes gramineus*) are generalists and were also regularly observed on the plots.

The nesting success and distribution of breeding birds on the four study plots (Table 17) was primarily affected by changes in vegetation (Table 18) resulting from year to year variations in spring precipitation. Total precipitation for May and June was 121 mm in 1977, 55 mm in 1978, and 158 mm in 1980. Thus, precipitation in 1980 during this crucial time when plants germinate was 31% greater than in 1977 and 185% greater than in 1978. This increase in precipitation caused a marked difference in cover on many of the plots. Shrub density remained relatively constant over the years; however, grass cover varied substantially from year to year. The greatest variation in vegetation occurred on Plot 2 which is located on a disturbed area near RRGE-1. In 1978, grasses accounted for only 2.8% of the ground cover. In 1980, in response to abundant moisture during the spring, grass cover increased to 21.1%.

The effect of the increase in vegetation ground cover is apparent in the Brewer's sparrow data from Plot 2. These birds prefer only a minimum of cover. In 1977, when total living cover was the lowest of the three-year sample period, an average of 34 Brewer's sparrows inhabited the plot compared to 5.6 in 1978 when total living cover was greater. In 1980, no Brewer's sparrows were observed in Plot 2 during the extremely wet period from May to mid-June when grass cover was

## Table 16. Birds observed in the Raft River Valley and the adjoining mountains

| | |
|---|---|
| Eared grebe | *Podiceps auritus* |
| White pelican | *Pelecanus erythrorhynchos* |
| Canada goose | *Branta canadensis* |
| Mallard[a] | *Anas platyrhynchos* |
| Pintail | *Anas acuta* |
| Green-winged teal[a] | *Anas carolinensis* |
| Blue-winged teal | *Anas discors* |
| Cinnamon teal[a] | *Anas cyanoptera* |
| Bufflehead | *Bucephala albeola* |
| Ruddy duck | *Oxyura jamaicensis* |
| Turkey vulture[a] | *Cathartes aura* |
| Sharp-shinned hawk[a] | *Accipiter striatus* |
| Cooper's hawk[a] | *Accipiter cooperii* |
| Red-tailed hawk[a] | *Buteo jamaicensis* |
| Swainson's hawk[a] | *Buteo swainsonsi* |
| Rough-legged hawk | *Buteo lagopus* |
| Ferruginous hawk[a,b] | *Buteo regalis* |
| Golden eagle[a] | *Aquila chrysaetos* |
| Bald eagle[b] | *Haliaeetus leucocephalus* |
| Marsh hawk[a] | *Circus cyaneus* |
| Prairie falcon[a] | *Falco mexicanus* |
| Merlin[a] | *Falco columbarius* |
| Kestrel[a] | *Falco sparverius* |
| Blue grouse[a] | *Dendragapus obscurus* |
| Ruffed grouse | *Bonasa umbellus* |
| Sage grouse[a] | *Centrocercus urophasianus* |
| Ring-necked pheasant | *Phasianus colchicus* |
| Chukar | *Alectoris graeca* |
| Gray partridge[a] | *Perdix perdix* |
| Great blue heron | *Ardea herodias* |
| Killdeer[a] | *Charadrius vociferus* |
| Common snipe | *Capella gallinago* |
| Long-billed curlew[a,b] | *Numenius americanus* |
| Spotted sandpiper[a] | *Actitis macularia* |
| Greater yellowlegs | *Totanus melanoleucus* |
| American avocet | *Recurvirostra americana* |
| Wilson's phalarope | *Steganopus tricolor* |
| California gull | *Larus californicus* |
| Ring-billed gull | *Larus delawarensis* |
| Rock dove[a] | *Columba livia* |
| Mourning dove[a] | *Zenaidura macroura* |
| Screech owl | *Otus asio* |
| Great horned owl[a] | *Bubo virginianus* |
| Long-eared owl[a] | *Asio otus* |
| Short-eared owl[a] | *Asio flammeus* |

### Table 16. (continued)

| | |
|---|---|
| Barn owl[a] | *Tyto alba* |
| Burrowing owl[a,b] | *Speotyto cunicularia* |
| Poor-will[a] | *Phalaenoptilus nuttallii* |
| Common nighthawk[a] | *Chordeiles minor* |
| Broad-tailed hummingbird | *Selasphorus platycercus* |
| Calliope hummingbird[a] | *Stellula calliope* |
| Belted kingfisher | *Megaceryle alcyon* |
| Common flicker[a] | *Colaptes auratus* |
| Lewis' woodpecker | *Asyndesmus lewis* |
| Yellow-bellied sapsucker[a] | *Sphyrapicus varius* |
| Hairy woodpecker[a] | *Dendrocopos villosus* |
| Downy woodpecker[a] | *Dendrocopos pubescens* |
| Eastern kingbird[a] | *Tyrannus tyrannus* |
| Western kingbird[a] | *Tyrannus verticalis* |
| Ash-throated flycatcher[a] | *Myiarchus cinerascens* |
| Say's phoebe[a] | *Sayornis saya* |
| Willow flycatcher[a] | *Empidonax traillii* |
| Hammond's flycatcher[a] | *Empidonax hammondii* |
| Dusky flycatcher[a] | *Empidonax oberholseri* |
| Gray flycatcher[a] | *Empidonax wrightii* |
| Western flycatcher[a] | *Empidonax difficilis* |
| Western wood pewee[a] | *Contopus sordidulus* |
| Olive-sided flycatcher | *Nuttallornis borealis* |
| Horned lark[a] | *Eremophila alpestris* |
| Bank swallow[a] | *Hirundo rustica* |
| Tree swallow | *Iridoprocne bicolor* |
| Rough-winged swallow | *Stelgidopteryx ruficollis* |
| Violet-green swallow[a] | *Tachycineta thalassina* |
| Bark swallow[a] | *Riparia riparia* |
| Steller's jay | *Cyanocitta stelleri* |
| Scrub jay[a] | *Aphelocoma coerulescens* |
| Pinyon jay[a] | *Gymnorhinus cyanocephalus* |
| Gray jay[a] | *Perisoreus canadensis* |
| Black-billed magpie[a] | *Pica pica* |
| Clark's nutcracker[a] | *Nucifraga columbiana* |
| Common raven[a] | *Corvus corax* |
| Common crow[a] | *Corvus brachyrhynchos* |
| Black-capped chickadee[a] | *Parus atricapillus* |
| Mountain chickadee[a] | *Parus gambeli* |
| Plain titmouse[a] | *Parus inornatus* |
| Common bushtit | *Psaltriparus minimus* |
| Dipper | *Cinclus mexicanus* |
| White-breasted nuthatch | *Sitta carolinensis* |
| Red-breasted nuthatch | *Sitta canadensis* |
| Brown creeper | *Certhia familiaris* |

## Table 16. (continued)

| | |
|---|---|
| House wren[a] | *Troglodytes aedon* |
| Rock wren[a] | *Salpinctes obsoletus* |
| Sage thrasher[a] | *Oreoscoptes montanus* |
| Robin[a] | *Turdus migratorius* |
| Townsend's solitaire | *Myadestes townsendi* |
| Hermit thrush[a] | *Hylocichla guttata* |
| Swainson's thrush | *Hylocichla ustulata* |
| Veery | *Hylocichla fuscescens* |
| Western bluebird | *Sialia mexicana* |
| Mountain bluebird[a] | *Sialia currucoides* |
| Golden-crowned kinglet | *Regulus satrapa* |
| Ruby-crowned kinglet[a] | *Regulus calendula* |
| Water pipit | *Anthus spinoletta* |
| Cedar waxwing | *Bombycilla cedrorum* |
| Northern shrike | *Lanius excubitor* |
| Loggerhead shrike[a] | *Lanius ludovicianus* |
| Starling[a] | *Sturnus vulgaris* |
| Solitary vireo[a] | *Vireo solitarius* |
| Warbling vireo[a] | *Vireo gilvus* |
| Orange-crowned warbler | *Vermivora celata* |
| Yellow warbler[a] | *Dendroica petechia* |
| Yellow-rumped warbler[a] | *Dendroica auduboni* |
| Yellowthroat[a] | *Geothlypis trichas* |
| Yellow-breasted chat[a] | *Icteria virens* |
| MacGillivray's warbler[a] | *Oporornis tolmiei* |
| Wilson's warbler | *Wilsonia pusilla* |
| House sparrow[a] | *Passer domesticus* |
| Western meadowlark[a] | *Sturnella neglecta* |
| Red-winged blackbird[a] | *Agelaius phoeniceus* |
| Brewer's blackbird[a] | *Euphagus cyanocephalus* |
| Brown-headed cowbird[a] | *Tangavius aeneus* |
| Northern oriole[a] | *Icterus bullockii* |
| Western tanager[a] | *Piranga ludoviciana* |
| Northern Grosbeak[a] | *Pheucticus melanocephalus* |
| Lazuli bunting[a] | *Passerina amoena* |
| Indigo bunting | *Passerina cyanea* |
| Purple finch | *Carpodacus purpureus* |
| Cassin's finch[a] | *Carpodacus cassinii* |
| House finch[a] | *Carpodacus mexicanus* |
| Gray-crowned rosy finch | *Leucosticte tephrocotis* |
| Pine siskin | *Spinus pinus* |
| American goldfinch[a] | *Spinus tristis* |
| Red crossbill | *Loxia curvirostra* |
| Green-tailed towhee[a] | *Chlorura chlorura* |
| Rufous-sided towhee[a] | *Pipilo erthrophthalmus* |

## Table 16. (continued)

| | |
|---|---|
| Savannah sparrow | *Passerculus sandwichensis* |
| Lark bunting[a] | *Calamospiza melanocorys* |
| Vesper sparrow[a] | *Pooecetes gramineus* |
| Lark sparrow[a] | *Chondestes grammacus* |
| Sage sparrow[a] | *Amphispiza belli* |
| Dark-eyed junco[a] | *Junco oreganus* |
| Tree sparrow | *Spizella arborea* |
| Chipping sparrow[a] | *Spizella passerina* |
| Brewer's sparrow[a] | *Spizella breweri* |
| White-crowned sparrow | *Zonotrichia leucophrys* |
| Fox sparrow | *Passerella iliaca* |
| Lincoln's sparrow | *Melospiza lincolnii* |
| Song sparrow[a] | *Melospiza melodia* |
| Lapland longspur | *Calcarius lapponicus* |
| Snow bunting | *Plectrophenax nivalis* |

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a. Known to breed in Raft River Valley.

b. Species which merit special consideration due to their threatened or unknown status.

## Table 17. Density of major breeding songbirds on 16-ha plots

| | Study Site[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | | 4 | | |
| Parameters | 1977 | 1978 | 1980 | 1977 | 1978 | 1980 | 1977 | 1978 | 1980 | 1977 | 1978 | 1980 |
| Total number of bird-days of observation/plot | 195 | 91 | 680 | 338 | 41 | 320 | 327 | 168 | 654 | 322 | 189 | 693 |
| Average number of breeding pairs[a] | | | | | | | | | | | | |
| per plot | 27 | 6.4 | 15.3 | 39 | 3.0 | 9.9 | 52 | 12.2 | 11.2 | 41 | 12.6 | 13.6 |
| per ha | 1.7 | 0.4 | 1.0 | 2.4 | 0.2 | 0.6 | 3.3 | 0.8 | 0.7 | 2.6 | 0.8 | 0.9 |
| Average density of Brewer's sparrows/plot | 10 | 3 | 10 | 34 | 5.6 | 8 | 14 | 13 | 18 | 15 | 12 | 14 |
| Average density of sage thrashers/plot | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 2 | 2 | 7 | 5.4 | 10 |
| Average density of sage sparrows/plot | 9 | 12.6 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 1.4 | 2 |
| Average density of horned larks/plot | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 13.6 | 19 | 13 | 14.6 | 10 |
| Average density of vesper sparrows/plot | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 |

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a. 1977 data include Brewer's sparrows, sage thrashers, and sage sparrows.
1978 data include only sage sparrows and Brewer's sparrows.
1980 data include all of the above and also western meadowlarks, mourning doves, loggerhead shrikes, and Vesper sparrows.

## Table 18. Percent relative frequencies of plant overstory and percent cover of understory at the songbird sites

| | 1 | | | 2 | | | 3 | | | 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1977 | 1978 | 1980 | 1977 | 1978 | 1980 | 1977 | 1978 | 1980 | 1977 | 1978 | 1980 |
| Overstory | | | | | | | | | | | | |
| Sagebrush | 60 | 65 | 71 | 14 | 21 | 11 | 100 | 100 | 100 | 1 | 3 | 0 |
| Greasewood | 40 | 35 | 22 | 82 | 79 | 89 | 0 | 0 | 0 | 95 | 91 | 97 |
| Rabbit brush | 0 | 0 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| Shadscale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 5 | 3 |
| Understory | | | | | | | | | | | | |
| Grasses | 7.7 | 5.2 | 19.5 | 3.0 | 2.8 | 18.5 | 24.7 | 24.5 | 16.0 | 19.6 | 17.4 | 7.4 |
| Forbs | 1.2 | 0.7 | 2.9 | 4.5 | 6.7 | 7.4 | 28.5 | 15.6 | 21.5 | 17.2 | 11.6 | 14.1 |
| Cactus | 0.3 | 0.5 | 0.4 | 4.9 | 5.4 | 5.7 | 1.8 | 0.8 | 0.4 | 0.2 | 0 | 2.7 |
| Bareground | 64 | 51 | 65 | 78 | 70 | 55 | 42 | 57 | 48 | 36 | 38 | 63 |
| Total living cover | 36 | 49 | 35 | 20 | 30 | 45 | 60 | 43 | 52 | 67 | 62 | 37 |

dense. In late June, it was considerably drier and six Brewer's sparrows established nests in Plot 2. In July, 16 Brewer's sparrows were observed in this plot. The average population of Brewer's sparrows over the three month period was eight.

The increase in grass cover in 1980 attracted vesper sparrows to breed at Plot 2. These birds nest in grass cups and are typically found in open fields and meadows. They were observed in Plot 2 only in 1980.

The density of shrubs such as big sagebrush and greasewood did not change appreciably over the years of the study. Consequently, the population density of species that rely on these shrubs for nest sites and foraging areas (e.g., sage thrashers and sage sparrows) was not noticeably affected by the increase in precipitation. If, however, factors began to affect the health of the shrub community, these species would probably respond dramatically.

Greater precipitation and the resulting changes in vegetation composition and possibly prey abundance may have affected the territory size of breeding birds.[a] For example, in 1977 the average territory size of Brewer's sparrows was 0.34 ha compared to 0.65 ha in 1978. In 1980, the territory size dropped to 0.22 ha, perhaps reflecting the increase in insects resulting from the denser ground cover.

In 1980, data on the territory size and distribution of species not recorded in previous years were collected. Territory size estimates were established for sage thrashers (1.23 ha), vesper sparrows (1.59 ha), loggerhead shrikes (2.10 ha), and meadowlarks (2.56 ha).

**Conclusions.** Results of the songbird study indicate a low diversity of species composition on the geothermal site; only a few species are relatively abundant. This research shows that songbirds are influenced by changes in climatic conditions, habitat type, and food base. Passerine species that are habitat-specific are extremely sensitive to slight changes in that habitat, and serve as good indicators of environmental change. Species that are more adaptable to changing environmental conditions are not good indicator organisms. For sagebrush, greasewood, or shadscale communities, sage sparrows and sage thrashers may be sensitive indicators while the ubiquitous Brewer's sparrows would not be, due to their general use of habitat and adaptability. Likewise, horned larks are too restricted to grasslands and disturbed areas to be a sensitive indicator of environmental

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a. An increase in territory size does not necessarily mean an increase in density or population.

change on the KGRA which is dominated in its undisturbed state by big sagebrush and greasewood.

## Aquatic Ecology

The Raft River is the only perennial stream in the southern half of the valley and is an important component of the region's ecosystem. The river is also used as a source of water for livestock and crop irrigation. This element of the ecosystem was studied because the transite pipe used for the geothermal supply and injection system carries water from the production wells to the binary plant and from the binary plant to the injection wells crosses the river twice. A spill of geothermal fluid into the Raft River drainage could potentially have occurred, particularly because of the proximity of the river to the geothermal facility. Prediction and assessment of the impact of a geothermal fluid spill would have been difficult without first establishing the structure of the aquatic communities and then evaluating their functional components. Early inventories of the Raft River surveyed algae,[55,56] and macroinvertebrates,[57] but these studies provided little insight into the community structure of various sections of the river. Therefore, in 1978 and 1979 a complete evaluation of Raft River community components was conducted.[58] The objectives of the study were to: (a) characterize the faunal and floral communities of the river, (b) assess the physical conditions of various habitat types near the geothermal site, and (c) establish baseline information concerning community stucture and population dynamics. The results of the study were analyzed in terms of potential recovery of downstream communities from the impact of geothermal water-induced disturbances. These data are also useful for assessing the potential of surface disposal of the geothermal water.

**Description of the Study Area.** The Raft River is, in general, a meandering stream whose banks are highly eroded; these banks often rise six or more vertical feet from the water surface. Sagebrush and rabbitbrush are the dominant riparian species when woody vegetation occurs along the stream. In some locations sandbar willows (*Salix exigua*) grow on the bank. Sedges and cattails are found in several of the moist oxbows and serve as good habitat for still-water organisms.

Three stations were established on the Raft River near the geothermal facility (Figure 17). Station A was located 1.2 km downstream from the main geothermal facility (at RRGE-1). Station B was directly south of RRGP-4, and Station C was 6.5 km upstream of the geothermal facility. Because Station C is upstream from the geothermal site, it would not be affected by geothermal fluid spills and could be compared with downstream stations to assess impacts.

Aquatic community structure is strongly influenced by physical factors. Stations A and C had the most similar substrate types, being composed of 56 and 51% rubble (particle size >64 mm), respectively; while Station B was only 29% rubble. Stations A and B had much greater fluctuations in water depth (shallower in the summers and deeper in the winters) than Station C. During sampling in November through December 1979, both Stations A and B were completely ice covered with at least 30 cm of ice and a 2 to 5 cm water space. This freezing phenomena creates a refuge for benthic invertebrates, but is selectively detrimental to large fish. Thus, the importance of large pools for wintering fish is increased at Stations A and B.

Total dissolved solids (TDS) content increased downstream, with Station A having 2.3 times the TDS (1105 mg/L) and Station B having 1.8 times the TDS (856 mg/L) of Station C. The overall TDS decreased from April to September. The higher TDS of Stations A and B are related to the presence of carbonates which cement the rubble and sediment matrix together, forming a hardpan in the riffle areas. Much of this precipitant is associated with the photosynthetic activities of epilithic crustose algae. The net result is that a more permanent stream bed is formed over the riffle areas. This hardpan protected Stations A and B, leaving them unchanged during the spring flood in 1980, while Station C was completely restructured.

### Methods

***Physical Environment***—Existing data collected by personnel from the USGS, the Idaho Department of Fish and Game, and the geothermal site were used for characterizing the physical aspects of the stream. Water chemistry was analysed using EPA

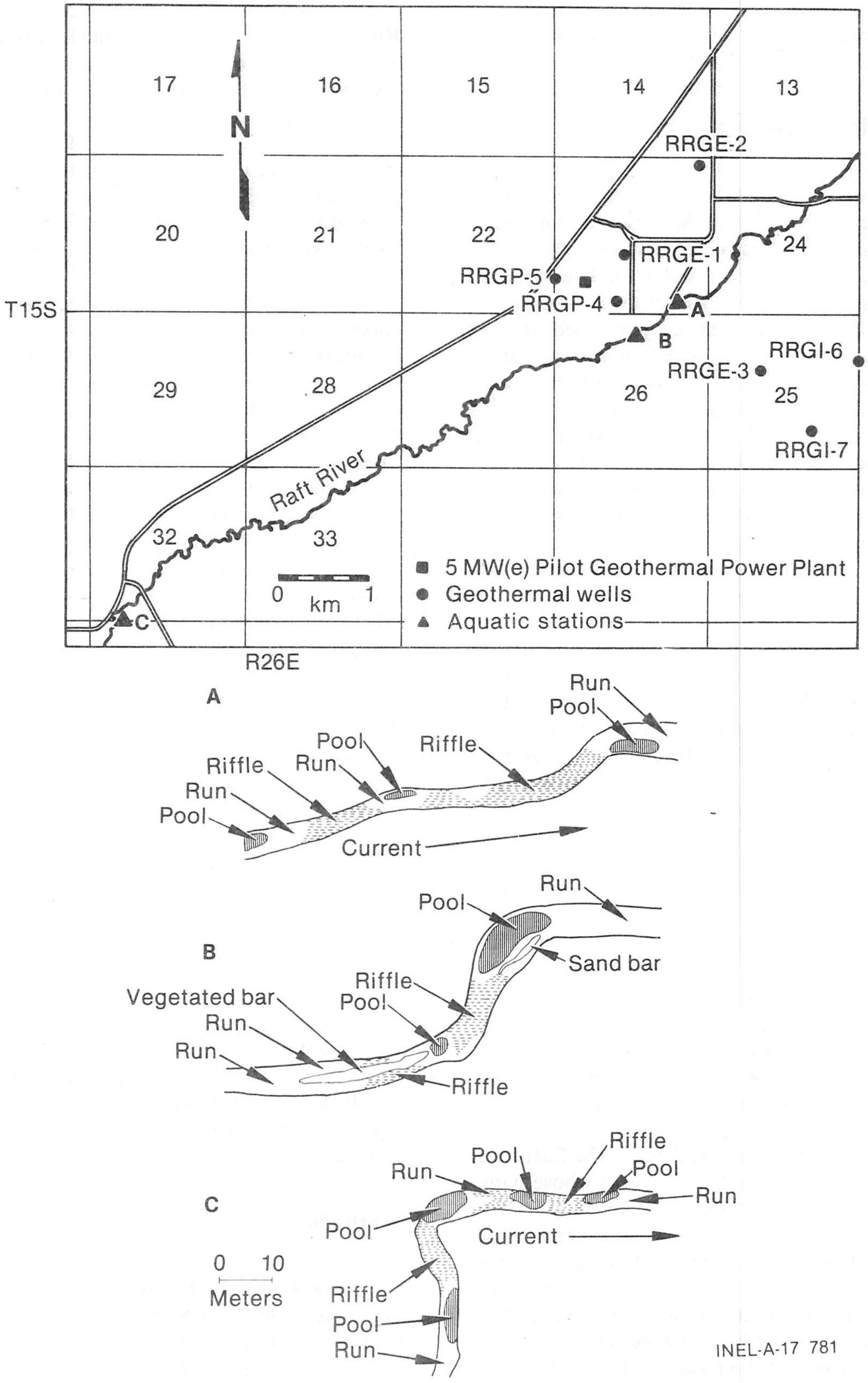

Figure 17. Map of the aquatic sampling stations located on the Raft River.

standard methods. A Nypric velocity meter measured discharge rate, and Ryan underwater thermographs measured water temperature for 30-day periods.

***Benthos***—Benthic samples were collected in March, April, June, July, September, and December of 1979. Ten benthic samples were collected at each station during each sample period. These sample sites were located along five transects separated by 10-m intervals. At each transect, two randomly located samples were taken. The macroinvertebrate community was censused using a standard Surber sampler. Ten samples were collected at each station during each sample period, resulting in a total of 180 benthic samples. Organisms were identified to genus with the exception of the Chironomidae and Oligochaeta which were subsampled prior to counting. Their sample density and diversity was then determined. Benthic numbers were clustered using Ruzicka's[59] index of similarity.

Sediment size was analyzed using the methods of Cummins.[60] The sediments were separated into size fractions. These were weighed and were converted to percents for between-sample comparison. The data were arranged and clustered. Initially, silts were examined. However, the silt categories were never found to consist of more than 2% of the total sediment weight. Silts were therefore eliminated from the analysis.

Algal cover was categorized into one of five percentage classes for each benthos sample collected. Cover class was estimated from visual inspection.

***Fish***—Fish populations were sampled during November 1978 and July, September, and December 1979. Two methods were used for collecting fish. Initially, electroshocking was used. This method was satisfactory for dace and sculpins, but it was selectively lethal to large Utah and mountain suckers. Also, electroshocking was ineffective for collecting redside shiners and was hampered by the high turbidity levels of the Raft River. Because of these problems, the mode of sampling was changed to seining in July 1979.

When seining, the upstream and downstream boundaries of a 75-m length of stream were blocked by positioning stationary seines. This prevented the movement of fish into or out of the section during the census. This section was then seined; all captured fish were identified to species, measured, weighed, marked with a caudal fin clip, and then released in the stream. After several hours, a recapture run was conducted. The data yielded a species list, the abundance of each species at each station, and the size class distribution and age structure of each fish species.

## Results and Discussion

***Physical Environment***—The U.S. Geological Survey has a permanent gauging station approximately 6 km upstream from the main geothermal facilities. The station records the mean monthly discharge (Table 19) for the Raft River in the study area. Peak discharge occurs with snow melt, usually during April and May. The lowest discharge occurs from July to September. This depression is related to both low summer rainfall and diversion of water for irrigation. However, summer storms can raise the water level rapidly because the xeric surroundings have a low water retention capacity. Conductivity (Table 19) follows a trend inversely proportional to the discharge. This is expected because an increased volume of water flowing through the system, especially from surface runoff, would dilute the dissolved solids in transport, thus reducing the

**Table 19. Raft River discharge and conductivity (based on USGS Water Data Reports 1976, 1977, 1978)**

| Date (month) | Discharge (L/s) | Conductivity ($\mu$mohs) |
|---|---|---|
| October | 334 | — |
| November | 436 | 1255 |
| December | 535 | 1060 |
| January | 512 | 1091 |
| February | 643 | — |
| March | 824 | 965 |
| April | 1143 | 1005 |
| May | 1193 | 1018 |
| June | 610 | 1145 |
| July | 285 | 1260 |
| August | 246 | 1300 |
| September | 246 | 1200 |

concentration of charged ions. The discharge rate of the Raft River accounts for 60% of the observed seasonal variation in conductivity. The lack of a higher correlation is probably related to factors such as the rate of inflow from subterranean sources and irrigation return flow.

## Benthic Communities

***Sediment***—A total of 210 benthic samples were taken during the study. Cluster analysis of the sediment frequency composition from each station showed that seasonality was not apparent. Station C showed the most heterogeneity over time. The cause of these differences is related to the presence of the previously described hardpan at Stations A and B. The riffle areas, with stable stream beds resulting from the hardpan, do not facilitate siltation. Therefore, only Station C would be expected to undergo seasonal changes in sorting (with spring runoff) and siltation (with decreasing water flow), while Stations A and B would be permanent in their size composition because of the encrusted surface.

***Algae***—Algal cover was categorized into five percentage classes for each sample. Algal cover depended upon the amount of rubble for attachment, and the time of year. A seasonal trend occurred with low algal cover in the spring and increasing cover throughout the summer into September, with filamentous green algae becoming more dominant. The increase in algal cover was most rapid on the more stable rubble material collected in the box samplers. An algal colonization lag is apparent in the finer substrates collected in the core samples because these substrates are more susceptible to erosion. The hardpan at Stations A and B not only increases the resistance of the riffles and runs to erosion, but it also increases the area available for the growth of epilithic filamentous algae. Station B had fewer samples with high algae densities than Station A because of an extensive sand run not conducive to effective algae colonization.

***Invertebrates***—Forty-eight invertebrate genera were collected and identified at the three stations. The invertebrates were separated into ecological functional groups (Table 20) as designated by Merritt and Cummins.[61] This system divides aquatic insects into six categories based on trophic mechanisms. Shredders are herbivores and detritivores that consume food with a particle size greater than 1000 μm. Collectors are herbivores and detritivores that generally consume food with a particle size less than 1000 μm. Grazers and filterers are algae consuming herbivores while predators are divided into piercers and engulfers. Collectors dominated the systems throughout the year at all stations. All functional groups increased throughout the year reaching peak densities in the autumn. These peak densities indicate that autumn is the critical time in this stream system for many functions of energy processing.

**Fish Communities.** Seven species of fish, representing four families, were collected at the sampling stations during this study. Two cyprinids, longnose dace (*Rhinichthys cataractae*) and redside shiner (*Richardsonius balteatus*), and one catostomid, mountain sucker (*Pantosteus platyrrhynchus*), were abundant. The Utah sucker (*Catostomus ardens*) and Piute sculpin (*Cottus beldingi*) were common. The speckled dace (*Rhinichthys osculus*) and cutthrout trout (*Salmo clarki*) were rare; only one of each species was caught.

Fish diversity was lowest in the riffles and highest in the large pools. This is opposite to the relationship found for the benthic organisms but can be explained by diurnal (24-h) movements. The fish may move out of the large pools at night to forage in the more productive shallow parts of the stream, especially the riffles. Since sampling was conducted during the day, the stream data reflect only the preferred refuge areas rather than a full diel habitat preference.

An examination of fish density over time reflects trends in the fish population (Table 21). Redside shiners, mountain suckers, and Utah suckers show a progressive shift in density distribution between the three stations. There was a definite decrease in the shallow downstream Station A in September. These fish migrate upstream, perhaps as a response to water temperature or seasonal changes such as decreasing flow rates or increasing fish size. Migrating upstream in the fall may increase the chance of surviving the winter, particularly if the downstream stations freeze as observed in December 1979.

Another trend observed from the density data is a general population increase from July to September. Much of this increase is a result of greater catchability of the young-of-the-year longnose dace, because by midsummer they have grown large enough to be regularly captured in the seines.

## Table 20. Density of Raft River invertebrates by functional group (individuals/100 cm²)

| Station | Functional Group | Total | 1979<br>March | April | June | July | September | December |
|---|---|---|---|---|---|---|---|---|
| A | Shredder | 0.18 | 0.12 | 0.00 | 0.00 | 0.03 | 0.00 | 0.03 |
|  | Collector | 6183.35 | 47.73 | 21.23 | 768.21 | 522.70 | 4356.88 | 466.60 |
|  | Grazer | 157.24 | 4.61 | 0.15 | 17.27 | 23.76 | 103.62 | 7.83 |
|  | Filterer | 314.02 | 2.26 | 0.91 | 0.77 | 16.50 | 269.69 | 23.89 |
|  | Piercer | 0.55 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.55 |
|  | Engulfer | 15.62 | 0.06 | 0.00 | 0.03 | 0.09 | 14.56 | 0.88 |
| B | Shredder | 0.79 | 0.09 | 0.12 | 0.00 | 0.00 | 0.59 | 0.00 |
|  | Collector | 3810.94 | 107.39 | 136.35 | 798.16 | 854.26 | 1372.22 | 542.56 |
|  | Grazer | 82.61 | 2.47 | 1.22 | 3.40 | 6.07 | 61.74 | 7.71 |
|  | Filterer | 87.55 | 4.18 | 7.35 | 0.63 | 2.57 | 64.44 | 8.38 |
|  | Piercer | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|  | Engulfer | 9.686 | 1.06 | 0.00 | 0.00 | 4.53 | 2.156 | 1.94 |
| C | Shredder | 0.37 | 0.61 | 0.61 | 0.00 | 0.00 | 1.15 | 0.00 |
|  | Collector | 5323.87 | 73.56 | 48.46 | 1187.65 | 435.71 | 2907.72 | 673.77 |
|  | Grazer | 137.74 | 3.42 | 5.89 | 18.44 | 6.59 | 66.01 | 34.39 |
|  | Filterer | 924.83 | 10.62 | 2.85 | 7.40 | 2.42 | 886.69 | 16.93 |
|  | Piercer | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|  | Engulfer | 2.25 | 0.95 | 0.12 | 0.28 | 0.15 | 0.12 | 0.63 |

## Table 21. Estimated densities of the fish population for a 250-m length of stream

|  | Density of Fish (% of population) |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | Station A |  | Station B |  | Station C |  |  |
| Species | July | September | July | September | July | September | December[a] |
| Longnose dace | 301 (59) | 466 (95) | 299 (56) | 418 (62) | 261 (33) | 385 (36) | 192 (48) |
| Speckled dace | 0 | 0 | 0 | 0 | 0 | 2 (T) | 0 |
| Redside shiner | 163 (32) | 15 (3) | 162 (30) | 113 (17) | 266 (33) | 264 (24) | 12 (3) |
| Mountain sucker | 25 (5) | 5 (1) | 24 (4) | 94 (14) | 227 (28) | 367 (34) | 217 (53) |
| Utah sucker | 21 (4) | 0 | 44 (8) | 30 (4) | 28 (4) | 35 (3) | 9 (3) |
| Piute sculpin | 2 (T) | 6 (1) | 8 (2) | 19 (3) | 14 (2) | 29 (3) | 11 (3) |
| Cutthroat trout | 1 (T) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 512 | 492 | 537 | 674 | 796 | 1082 | 411 |

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a. Stations A and B were frozen in December 1979.

The hypothesis that some species of fish migrate upstream in late summer or early fall is further supported by a cluster analysis. Samples from Stations A and B always cluster together at the 80% similarity level while samples from the C stations are not similar to each other. This indicates a temporal change in the fish community structure at Station C, while Stations A and B do not have the same trend. As the Utah and mountain suckers and the redside shiners migrate upstream, the age and species structure of the population remains the same at the downstream stations, thus maintaining a high correlation over time. However, Station C with its pools and relatively deep water is dominated by larger fish (averaging 50% larger) than those at Stations A and B. With the upstream movement of small fish, the average length of fish at Station C decreases. Thus, the size of fish inhabiting Station C changes over time and becomes slightly more similar to Stations A and B in the late summer. The disparity in fish size and population composition in November 1978 is due to the bias induced by electroshocking.

**Conclusions.** Raft River ecology downstream of the geothermal site differs from the upstream portion and appears to be related to physical factors. Carbonate precipitation stabilizes the downstream riffles but does not occur at the upstream station. The more shallow gradient of the lower stations results in higher susceptibility to freezing and creates a much harsher winter environment. The fish population appears to adjust by migrating out of the downstream sections in the late summer and fall. For several species, the downstream areas act as a nursery ground for the young where competiton is minimized. Whether these fish actively move downstream to spawn or if the young simply drift downstream is not known; but, young-of-the-year fish were also collected at Station C. The invertebrate community is not as location-sensitive but is influenced by seasonal factors. The invertebrates most likely respond to the pulsed nature of detritus which is the predominant source of energy in stream systems regardless of its origin. All levels of detrivitores would be similarly influenced. Grazers rely upon the growth of algae, which is also seasonal and is influenced by physical conditions such as the amount of rubble and cementation.

No spills of geothermal water into the Raft River occurred during the development and operation of the geothermal facility. The impact of a geothermal spill, assuming the spill would be a single, short-lived perturbation, would be minimal. The invertebrate community would recover through colonization by drifting organisms. While some immature fish would be lost, the entire juvenile class would not be eliminated since the young are also found in the upstream stations. The fish use the downstream areas as habitat for the offspring, but not as the sole refuge for the population's survival.

# HUMAN AND CULTURAL MONITORING PROGRAMS

Developing the geothermal resources of the Raft River Valley may affect the human environment of the nearby communities. This development offers local residents many benefits and opportunities; however, some undesirable alterations may result. The high fluoride levels sometimes associated with geothermal developments have been of concern in the Raft River Valley. Consequently, a program was established to monitor and document any changes in the domestic or irrigation water supply. The human environment monitoring program was designed to identify the tradeoffs and potential socioeconomic changes that could arise from geothermal resource development. The program was used to minimize short- and long-term adverse changes and maximize beneficial changes.

## Historic and Archaeological Sites

During any major development, such as the geothermal project in the Raft River Valley, it is important to document the existence of area historic and archaeological sites. By becoming aware of these site locations, their protection can be ensured. A survey for such a purpose was conducted in the Raft River Valley. The development of the Raft River resource had no impact on known sites and no undiscovered sites were located during construction activities.

**Historic Sites.** Two historic sites listed on the National Register of Historic Places are in southern Cassia County. These sites, the City of Rocks and Granite Pass, are connected with migration routes used during westward expansion when the Raft River Valley was an emigrant crossroads. The Oregon Trail crossed the Raft River and split, one fork leading northwest to the Oregon territory and the other to California via Salt Lake City. The City of Rocks, currently under consideration as a state park, is located about 30 km from the withdrawal area. This area was one of the popular landmarks along the route to California from the Oregon Trail. The well-protected valley, with its great variety of granite formations, was a camp site for thousands of emigrants, many of whom carved their names on the rock formations. Granite Pass, the other historic site, approximately 55 km from the withdrawal area, was an important pass along the California fork from the Oregon Trail. This historic site consists of an unimproved road and a section of the original California Trail.

In addition to these historic sites associated with the California Trail, there are other historic sites in the area. There are traces of two other emigrant trails through the Raft River Valley: the Kelton-Wood River Stage Line and the Kelton-Boise Road. Neither trail passes through the withdrawal area. The BLM recognizes two other sites of historic significance in the Raft River Valley: Reed Spring, a campground at a large spring along the California Trail, and the Earncliff Post Office, a stagecoach station on the Kelton-Boise Road. Both sites are located just west of the withdrawal area. Neither site is currently listed on or proposed for the National Register of Historic Places. None of these sites were disturbed by the development of the Raft River Geothermal site.

**Archaeological Sites.** A survey to determine the existence of archaeological resources in the Raft River Valley was conducted. Since the Raft River would have been attractive to early aboriginal inhabitants of the region, survey efforts were concentrated along the river and its adjacent floodplain. The study consisted of a surface examination of an 11-km stretch along the river from The Narrows to Route 81. Seven sites with good archaeological potential were found within the withdrawal area. None of the seven sites are within the area of the thermal loop facility; the closest site is 0.8 km away, and the rest are at least 3 km away. None of these potential archaeologic sites were disturbed during development of the Raft River Geothermal Research Facility.

## Socioeconomics

**Introduction.** Construction of a power plant in a rural, sparsely populated region can have significant social and economic effects on small communities near the development site. Although these effects are often beneficial, communities can suffer if the infrastructure is not prepared to cope with a population influx. Insufficient housing, police protection, fire fighting equipment, sewer capacity, school facilities, and a change in the general lifestyle are potential socioeconomic problems associated with a sudden influx of people. By characterizing the existing socioeconomic environment of a community and projecting the requirements of the proposed development, direct and indirect socioeconomic impacts can be predicted. Proper planning early in the development stages can help to identify and minimize potential adverse impacts and maximize benefits.

A socioeconomic evaluation of Cassia County and potential impacts that could be associated with development at the Raft River site was conducted from 1976 through 1980. A prediction of socioeconomic impacts on the community was made in 1976. Data were collected between 1977 and 1979 and summarized prior to construction of the 5-MW(e) power plant. This study described the existing socioeconomic environment, investigated historic changes, projected the future socioeconomic environment in the absence of any significant geothermal resource development, assessed the attitudes of area residents, and provided a preliminary scenario of direct and indirect socioeconomic impacts that could be associated with geothermal resource development. In 1980, the socioeconomic survey was completed and a comprehensive prediction of impacts was provided. Employment options, population increases, and socioeconomic impacts associated with three potential levels of resource development were predicted. The scenarios included predictions of the effect each may have on employment, population, land use, and the public sector.

**Methods.** Socioeconomic data were collected from the federal and state governments and from universities in the region. Projections of the region's socioeconomy in the absence of geothermal development and for three different development scenarios were compared to existing conditions. Socioeconomic parameters that were expected to significantly change were identified. Surveys of area residents were used to assess public opinion and identify acceptable lifestyle tradeoffs. Employment, population, and income multipliers were developed and used to provide economic and demographic projections during both construction and operation for three alternative levels of geothermal development.

### Existing Socioeconomic Environment

***Population***—A 1980 census estimated the population of Cassia County to be 19,427 or 4.75 people per $km^2$. This is a 14% increase from the 1970 census. The population is predominately Caucasian with 9% being Hispanic and 1% Black, Native American, or Asian. Of the population, 8% do not fall into any of these categories.[62] In 1980, 44% (8525 people) of the Cassia County residents lived in Burley. Of the other towns in the county, 663 people lived in Oakley, 286 in Albion, 276 in Declo, and 196 in Malta. The rest of the county population (49%) lived in rural areas or small towns such as Naf, Almo, Elba, or Strevell.[62]

***Labor Force***—The number of people employed in Cassia County in 1981 averaged 7800. Employment ranged from a low of 7100 in December to a high of 8735 in June. These figures exclude self-employed people which, if included, raise the number of people employed to about 11,000. Unemployment in the County from 1977 to 1981 averaged 5.3%. In 1981, unemployment was highest during August (8.3%) and lowest in October (3.4%), averaging 5.3%. Therefore, Cassia County unemployment in 1981 was less than the Idaho unemployment average (6.3%) and the national unemployment average (7.6%).[63] Estimates of the total labor force (unemployed and employed) in Cassia County varied from 7488 to 9144 (excluding self-employed people). This variability results from difficulty in obtaining accurate numbers as many workers have two or more jobs.

Average per capita income for Cassia County was $7881 for 1979. This is 10% below the national average but higher than the average per capita income for the State of Idaho ($7632).[64] In 1977, the per capita income for Cassia County was $4982 and was lower than the average per capita income of $5350 for Idaho.[65] Cassia County accounts for 2% of the total income for Idaho and 2% of the population. Median family income was $7852 in 1981.[62]

Agricultural production is the primary source of employment in the county. Farm workers and farm proprietors account for approximately 23 to 25% of total county employment. The food processing industry employs about 18% of the county workers. Twenty-one percent of the jobs are in the retail and wholesale industry, 15% in service industries, and 13% in federal and local government. The manufacturing industry accounts for 4% of total employment and the construction trade employs 3%. The rest of the work force is employed in transportation, communications, and utilities (3%); finance, insurance, and real estate (3.4%); and mining (0.4%).[62]

Each wage earner in Cassia County supports an average of 1.25 additional people. Currently (1982), the average hourly wage for a hired farm worker in southeastern Idaho is $4.00 per hour and is likely to be similar for Cassia County.[63] Although no statistics are available for average wages for selected trades in the county at the end of 1981, data for nearby Magic Valley show that trade union wages are approximately 1.5 times larger than nonunion wages. Most trade workers in southeastern Idaho do not belong to a union.[66]

***Economy***—The Cassia County economy is based primarily on production and processing of agricultural products. Among counties in Idaho, Cassia County ranks second in the production of wheat and barley, third in sugar beets, and fourth in potatoes. The agricultural base in the southern part of the county near the Raft River geothermal site is livestock, alfalfa and feed grain production.

Most business activity is concentrated in the Burley area. Eighty-six percent of all establishments representing 90% of all receipts are accounted for by Burley area establishments. For the rest of the county, retail and service establishments are quite limited. Except for service stations, restaurants and small grocery stores, travel to the larger population centers (i.e., Burley, Twin Falls, etc.) is required.

***Public Attitude***—Batelle Northwest Laboratories and a private consultant issued questionnaires to Raft River Valley residents in 1977 and 1979, respectively.[64,67] The purpose was to survey the opinions of residents about their communities and potential changes. In general, area residents stated they were relatively satisfied with the quality of life in their community. They also stated, however, that they would like to see an increase in employment opportunities and in the range and quality of public and private services. Area residents generally favored development of the region's geothermal resources and the accompanying industrialization. Although most had some reservations about the development, they were generally in favor of it. Relatively few, if any, residents opposed the industrialization providing that consideration be given to the people of the area and the environment.

In 1977, 75% of the 115 respondents indicated that either they or a member of their family would like to work at the geothermal site. Over 40% of the 115 respondents in 1979 indicated that they would be available for full time year round work. Residents indicated that they were willing to commute across the county for employment.

**Socioeconomic Impact Predictions.** The Idaho National Engineering Laboratory sponsored studies in 1977, 1979, and 1980 to predict the socioeconomic impact of both electric and nonelectric geothermal development in the Raft River Valley.[64,67,68] Three scenarios were considered because of the uncertainty concerning the extent of the resource and the amount of development that would occur. These scenarios are outlined below.

1. Minimum—5-MW(e) power plant, 4-ha greenhouse by 1982, and 37.3 metric tons aquaculture production per year by 1981
2. Intermediate—Two 5-MW(e) plants and an 8-ha greenhouse by 1983, and 74.6 metric tons aquaculture production per year by 1981
3. Maximum—30 to 50-MW(e) plant by 1985, 12-ha greenhouse by 1983, and 186.6 metric tons aquaculture production by 1982.

The socioeconomic studies predicted that radical changes typically associated with large-scale development in rural areas, such as boom towns, would not occur from any of these alternatives. These studies provided detailed projections of the effects development might have on employment, income, population, land use, and public sector. Table 22 summarizes the number of new jobs, the number of nonlocals moving into the area, and the number of family members accompanying the immigrants predicted for the minimum development scenario.[68] The increase in revenue from property tax, sales tax, personal income tax, and corporate net income tax are projected to the year 1986 (Table 23).[68]

### Actual Socioeconomic Impacts

***Labor***—Employment trends at the Raft River geothermal test facility were estimated based on EG&G payroll records and conversations with Raft River personnel and EG&G managers (Table 24). Over the 8 years of facility development, an average of 43 people worked at the site for at least one month. Of this work force, 40% were local (Cassia County). Forty percent of all

## Table 22. Summary of employment, labor source, and population impact projections for the minimum development scenario[8]

| Year | 1980 | | 1981 | | | | 1982 | | | | 1983 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quarter | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Total new jobs | 27 | 37 | 52 | 84 | 84 | 90 | 85 | 115 | 129 | 130 | 142 | 149 | 149 | 149 |
| Direct (construction and operations) | 24 | 35 | 35 | 56 | 56 | 58 | 53 | 78 | 93 | 83 | 83 | 83 | 83 | 83 |
| Indirect | 3 | 2 | 17 | 28 | 28 | 32 | 37 | 36 | 47 | 59 | 66 | 66 | 66 | 66 |
| Source of labor | | | | | | | | | | | | | | |
| Local residents | 13 | 13 | 26 | 53 | 53 | 55 | 51 | 74 | 82 | 77 | 86 | 91 | 91 | 91 |
| Outside region | 14 | 22 | 26 | 31 | 31 | 35 | 34 | 41 | 47 | 53 | 56 | 58 | 58 | 58 |
| Total population impact[a] | 35 | 55 | 65 | 78 | 78 | 88 | 85 | 103 | 118 | 133 | 141 | 146 | 146 | 146 |
| Household units—single workers | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 9 | 9 |
| Household units—married workers | 9 | 14 | 17 | 20 | 20 | 22 | 22 | 26 | 30 | 34 | 36 | 37 | 37 | 37 |
| Total—household units | 11 | 17 | 21 | 25 | 25 | 27 | 27 | 32 | 37 | 42 | 44 | 46 | 46 | 46 |
| School-age children | 11 | 18 | 21 | 25 | 25 | 28 | 27 | 33 | 37 | 42 | 45 | 46 | 48 | 48 |

a. Assumptions: 1. Average family size for married workers is 3.7 people.
2. In one third of families moving into the region, both husband and wife will be employed.
3. 15% of new workers will be single.
4. 74% of children will be of school age.

## Table 23. Summary of projected property, sales, and income tax impacts associated with geothermal resource development for the minimum development scenario[8]

| | 1980 ($K) | 1981 ($K) | 1982 ($K) | 1983 ($K) | 1984 ($K) | 1985 ($K) | 1986 ($K) |
|---|---|---|---|---|---|---|---|
| Property Taxes | | | | | | | |
| Assessed value | | | | | | | |
| Industrial | — | 132.0 | 353.0 | 353.0 | 353.0 | 353.0 | 353.0 |
| Residential | 87.6 | 137.7 | 209.7 | 220.5 | 220.5 | 220.5 | 220.5 |
| Total | 87.6 | 269.7 | 562.7 | 573.5 | 573.5 | 573.5 | 573.5 |
| Revenue per 1 mill levy | 0.88 | 2.70 | 5.63 | 5.74 | 5.74 | 5.74 | 5.74 |
| Revenue at 70 mill levy | 6.1 | 18.9 | 39.4 | 40.2 | 40.2 | 40.2 | 40.2 |
| Sales Taxes | | | | | | | |
| Total spending on taxable sales[a] | 144.2 | 609.5 | 808.5 | 913.6 | 934.1 | 949.5 | 964.2 |
| State revenue (3%) | 4.3 | 18.3 | 24.3 | 27.4 | 28.0 | 28.5 | 28.9 |
| State Personal Income Taxes | | | | | | | |
| Total income impact | 360.5 | 1,523.8 | 2,021.2 | 2,284.0 | 2,335.2 | 2,373.8 | 2,410.6 |
| Tax revenue[b] | 10.8 | 45.7 | 60.6 | 68.5 | 70.1 | 71.2 | 72.3 |
| Corporate net income tax[c] | — | 1.2 | 6.7 | 12.9 | 12.9 | 12.9 | 12.9 |

a. 40% of gross income impact.

b. Estimated at 3% of gross income impact.

c. 6.5% of taxable income which is estimated at 12% of gross investment in plant and equipment.

## Table 24. Actual total direct employment summarized for half-year intervals

| | 1974 | 1975 | | 1976 | | 1977 | | 1978 | | 1979 | | 1980 | | 1981 | | 1982 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | II[b] | I[a] | II | I | II | I | II | I | II | I | II | I | II | I | II | I | Average |
| Contract | 4 | 23 | 2 | 12 | 0 | 2 | 12 | 24 | 42 | 37 | 32 | 28 | 28 | 15 | 4 | 0 | 17 |
| Local (Cassia County) | 1 | 4 | 0 | 2 | 0 | 0 | 1 | 3 | 4 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| Nonlocal (Idaho) | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 6 | 18 | 21 | 23 | 19 | 19 | 8 | 2 | 0 | 8 |
| Nonlocal (non-Idaho) | 3 | 19 | 2 | 10 | 0 | 1 | 5 | 15 | 20 | 14 | 8 | 8 | 8 | 6 | 2 | 0 | 8 |
| Site Employees | 1 | 6 | 7 | 7 | 7 | 11 | 15 | 19 | 25 | 31 | 44 | 42 | 50 | 54 | 51 | 49 | 26 |
| Local (Cassia County) | 1 | 6 | 6 | 6 | 6 | 7 | 11 | 13 | 18 | 18 | 25 | 23 | 27 | 31 | 29 | 28 | 16 |
| Nonlocal (Idaho)[c] | 0 | 0 | 1 | 1 | 1 | 4 | 4 | 6 | 7 | 13 | 19 | 19 | 23 | 23 | 22 | 21 | 10 |
| Totals | | | | | | | | | | | | | | | | | |
| Local (Cassis County) | 2 | 10 | 6 | 8 | 6 | 7 | 12 | 16 | 22 | 20 | 26 | 24 | 28 | 32 | 29 | 28 | 17 |
| Nonlocal | 3 | 19 | 3 | 11 | 1 | 6 | 15 | 27 | 45 | 48 | 50 | 46 | 50 | 37 | 26 | 21 | 26 |
| Total Work Force | 5 | 29 | 9 | 19 | 7 | 13 | 27 | 43 | 67 | 68 | 76 | 70 | 78 | 69 | 55 | 49 | 43 |

a. I-first 6 months of calendar year.

b. II-last 6 months of calendar year.

c. Only includes INEL employees who were at the site almost every day for at least a month.

employees associated with the Raft River project were on contract with drilling or construction companies operating at the site. Local contractors were used when available. Six percent of the subcontracts were let to Cassia County enterprises, and 47% were let to other Idaho contractors. The rest of the contractors were from outside of Idaho, usually because no local skilled labor supply was available. Drilling, for example, was primarily performed by non-Idaho contractors, because local contractors had little or no experience in drilling deep geothermal wells. EG&G used local labor when available, but the local labor supply was insufficient to fill all of the technical positions. Of the EG&G employees, 62% were locals and 38% were from the Idaho Falls office.

The above figures show that local interest in employment at the site was very high. A comparison of typical Cassia County salaries with the average site salary for 1978 through 1980 show that site salaries were much higher than typical county salaries (Table 25). The average site salary continued to increase and was $11.62 per hour or $2014 per month in April 1982. Total EG&G expenditures as of April 1982 for site employee salaries amounted to 3.34 million dollars[69] (not escalated).

There were several peaks in total employment at the site. These corresponded to periods when wells were being drilled concurrently with construction on the 5-MW(e) plants. One peak occurred in October of 1978 with an average of 82 people working onsite during the drilling of RRGI-6, -7, and RRGP-4. Another peak occurred during May of 1979, with average monthly employment of 93.

It is difficult to assess indirect employment that resulted from the employment of an average of 18 nonlocals over the past 8 years at the Raft River Geothermal Facility. Lewis[68] used employment multipliers of 0.2 for construction workers and 0.8 for operations employees. Using these figures, approximately 10 indirect support jobs would have been created. These figures may be high, however, as many nonlocals commuted home for the weekends. Many of the indirect jobs would have been in Burley in support roles such as in restaurants and motels. It is impossible to document this type of impact. In Malta, however, a few changes occurred that were attributed to geothermal development. Schorzman's Mercantile expanded, the Malta cafe remodeled, and a second gas station reopened.

In assessing the increase in population (family members) from nonlocals moving into the Raft

## Table 25. Typical monthly wage rates in Cassia County and at Raft River geothermal site

| | Cassia County (estimated) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1978 | | 1979 | | 1980 | | 1981 | |
| | Entry Level ($) | Experienced ($) | Entry Level ($) | Experienced ($) | Entry Level ($) | Experienced ($) | Entry Level ($) | Experienced ($) |
| White collar[a] | 635 | 765 | 685 | 830 | 745 | 900 | 815 | 940 |
| Blue collar[b] | 630 | 915 | 680 | 995 | 735 | 1075 | 750 | 1025 |
| | Geothermal Site | | | | | | | |
| | Average 1978 ($) | | Average 1979 ($) | | Average 1980 ($) | | Average 1981 ($) | |
| Site employee wage | $1497 | | $1480 | | $1605 | | $1795 | |
| Number of employees | 18 | | 40 | | 41 | | 45 | |

Source: EG&G payroll records, J. Yockey and K. Argast.

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a. White collar includes clerical, professional, managerial, and technical.

b. Blue collar includes skilled labor and general labor.

River area, Lewis[68] used 2.51 as the population employment multiplier. This resulted in a gross overestimate since few nonlocals actually moved permanently into the area or brought family members with them. Of the site employees, only four moved permanently to the area, not 17.5 as predicted. Two families moved to Elba, one to Bridge and the other to Rupert; the average family size was 5.25. Although one site employee was accompanied temporarily by his wife, most nonlocal site employees commuted home on weekends. At least one contractor employee moved permanently to Twin Falls; it is difficult to assess how many others did. In general, nonlocals moved only temporarily to the area for the duration of their jobs. An average of 20% of nonlocal employees stayed in trailers on the site, with a maximum of five employees for any half-year period (second half of 1979). An average of 40% of EG&G nonlocal employees rented or bought trailers or homes in Burley, Malta, Bridge, Declo, Rupert, Almo, Albion, or Naf. The number of nonlocal site employees that rented or bought an accommodation reached a peak of 13 during the first half of 1981. On the average, two nonlocal site employees stayed in motels in Burley or Malta. It is likely most nonlocal contractors temporarily stayed in area motels, as many of them would have received per diem.

Although Lewis[68] predicted that locals would be hired for 50% of all power plant jobs, actual employment of Cassia County residents was lower (40%). Only 6% of contractors were local as opposed to 62% of all site employees. It is difficult to assess the impact that the geothermal test facility had on reducing unemployment in the county. For any given half-year period, a maximum of 32 Cassia County residents worked at the site, or 0.4% of the county work force. During the 8 years of geothermal development, an average of 0.2% of the county work force was employed at the Raft River Facility. If only south Cassia County is considered, the percentage of this smaller work force employed at the site would be much higher.

**Land Use.** No significant impacts on land use occurred. There are two reasons for this:

1. The amount of land required for the development was small relative to the total available land in the county. More specifically, a maximum of 100 acres of the 5000 acres of the withdrawal area were developed for the geothermal test facility and related direct-use experiments.

2. The number of people that moved into the area (four workers) was small relative to the existing population base.

**Public Sector.** The impact of the geothermal development on the public sector created no significant problems. The influx in population was small enough that the infrastructure of the local communities readily absorbed the new population.

Impacts from nonlocal site employees renting or buying homes in the area were negligible as there appeared to be sufficient housing. Seven of these people resided in Burley, seven in Malta, four in Rupert, three in Bridge, two in Albion, and one each in Declo, Almo, Naf, and Elba.

The only problem predicted by the socioeconomic surveys was that the increase in public school enrollment in Burley and at the Malta elementary school would be larger than the schools could handle. These schools would have exceeded their nominal capacity even without geothermal development due to a normal increase in population. A small increase in enrollment at the Malta elementary school would not significantly impact an existing problem. The Malta secondary school could have easily absorbed many more students and the impact from geothermal development was negligible.

The local motel industry benefited from the geothermal development. Assuming an average of eight contractor and two site employees stayed in motels over the past 8 years at an average cost of $25 per night, the local motel industry received $700,000.

Increases in income, total assessed valuation of residential property, and retail sales add to government revenue. Therefore, the revenues of the local and state government increased as a result of development in the Raft River Valley; however, the actual amount of increase is unknown.

The increase in Idaho sales and income tax revenue over the last 8 years as a result of the geothermal project is estimated (nonescalated) at $273,800 (Table 26). Several assumptions were used in deriving this value.

1. Fifty percent of construction dollars were for labor. This is an average based on discussions with EG&G budget personnel. EG&G contracts are usually 40% labor, but these are for high technology projects.[70] Sixty percent labor may be a more realistic estimate for this project.[71]

**Table 26. Estimated Idaho sales and income tax associated with geothermal resource development revenues**

| | Revenues ($K) | Associated Taxes ($K) |
|---|---|---|
| Idaho personal income taxes | | |
| Total construction contracts (12000K) | | |
| Total contractor's income (assuming 50% labor) (6000K) | | |
| Idaho contractor's income (assuming 53% Idaho contractors) | 3180 | |
| Income impact (EG&G) | 3340 | |
| Total income impact | 6520 | |
| Tax revenue (3% of gross income impact) | | 195.6 |
| Sales taxes | | |
| Total spending on taxable sales (40% of gross income impact) | 2608 | |
| State revenue (3%) | | 78.2 |
| Total revenue | | 273.8 |

NOTE: Values are not escalated over the 8 years of the project.

2. Fifty-three percent of contractors were from Idaho.

3. State tax revenue is 3% of gross income.

4. Total spending on taxable sales is 40% of gross income, based on IRS data for 1977.

Although this increase in revenue is not large it is not insignificant to the local government.

**Conclusions.** Many beneficial socioeconomic impacts resulted from the development of the Raft River Geothermal Test Facility, particularly for the people in the surrounding area. Residents generally favored the development and a portion of the local population was recruited to work at the site. By hiring local labor whenever possible, the influx of a new population and the associated impacts were minimized. Geothermal wages were much higher than average wages in the county and the work was fairly regular, despite several large-scale layoffs. As a result of this local labor recruitment, population multipliers were much lower than predicted in the 1980 study. Only 10 nonlocal operations employees were actually recruited, although the projected number was 17.5. Four employees moved permanently to the area and relocated their families. Geothermal development increased tax revenues and reduced unemployment, particularly in the south Cassia County area. There were no significant impacts on land use. Proper planning during all phases of the project ensured that adverse socioeconomic impacts were minimized and potential benefits to the local residents realized.

## Fluorosis

**Introduction.** Water with a high fluoride concentration has been known to cause chronic fluoride poisoning (fluorosis) in humans and animals. The town of Oakley, about 30 km west of the KGRA, was one of the first two towns in the United States where dental fluorosis in humans was linked to high fluoride levels in the water supply.[72] Although optimal amounts of fluoride are required for maximal dental health and proper bone development, insufficient or excessive amounts of fluoride pose potential health hazards. Fluoride deficiency can cause osteoporosis (demineralization), calcified abdominal nodes and ligaments, bone spurs, and an increase in tooth decay.[73] Excessively high levels of fluoride may lead to harmful accumulations of fluorides in the skeleton and teeth. Up to 99% of the body burden of fluoride is found in the skeleton. Symptoms of dental fluorosis include mottled or discolored teeth, rapid wear, and erosion of enamel from dentine. Although humans are most susceptible to fluorosis until age 16, the most critical years are from age 2 to 10 when teeth are forming and calcifying.

The average daily intake of fluoride in the United States from food is 0.2 to 0.3 mg and an additional 1.0 mg is obtained from drinking water.[73] The American Dental Association (ADA) and the American Medical Association (AMA) recommend from 0.7 to 1.2 mg/L fluoride in drinking water, depending upon average ambient air temperatures.[72] The maximum level of fluoride in drinking water recommended by the federal government depends upon the annual average of maximum daily air temperature. For the Burley area, (17.2°C), the maximum recommended level is 2.0 mg/L.[74] With daily intake levels of 3 or 4 mg of fluoride, the body should excrete the same amount in urine, sweat, tears, milk, or feces. Higher intake levels result in fluoride deposits in bone. The incidence of dental fluorosis in children whose drinking water contains 4 mg/L fluoride is very high.[73]

High fluoride concentrations are common in geothermal fluids. Concentrations found in Idaho are as high as 30 mg/L. In Raft River, the geothermal fluids contain between 5 and 10 mg/L fluoride, and high concentrations (6 mg/L) are found in some irrigation and domestic wells. An anomalously high concentration of fluoride (14 mg/L) was found in a spring but the water is not consumed by either livestock or humans.

**Background.** Incidences of fluorosis in cattle and horses in the Raft River Valley have been noted in the past by ranchers. They observed that the teeth of cattle with access to warm waters at an early age, wore down quickly to the gum lines. The teeth of cattle that were kept from these waters until they were 3 years old did not show excessive wear. Other symptoms of fluorosis observed were lameness in cattle, and excessive tooth wear in horses raised near certain warm water sources. The horses were unable to work because they could not eat properly.

In 1976, two veterinarians, Shupe and Olson, conducted a survey of domestic animals in the KGRA to gather background data.[72] Borderline damaging levels of fluoride were found in some of the animals. Because human tolerance to excessive fluoride intake is much lower than that of other animals,[75] a fluorosis study of Raft River Valley residents was initiated in 1978 by the Utah State University Research Foundation.

The purpose of the Raft River fluorosis study was to:

1. Document the dental health of valley residents, including the incidence of fluorosis

2. Determine the relationship between fluoride content of culinary water and dental fluorosis in humans

3. Determine other source(s) of fluoride in the valley

4. Notify residents of potentially harmful fluoride sources.

**Preliminary Research.** The public school system provided the best and easiest access to the portion of the population most susceptible to fluorosis. Children attending the Malta and Almo schools were examined by Dr. Clyde F. Hurst,[76] a practicing dentist with a long-time professional interest in water fluoridation. Out of 270 children examined, 132 (49%) had some type of dental anomaly. Of these, 52 had lesions that are typical of fluorosis. These figures represent a level of dental health which is unusually poor.

If incidences of fluorosis in the Raft River Valley were induced by the water supply, a direct relationship between fluorosis and fluoride content of water would be expected. Samples of the culinary water used at home by 48 children exhibiting symptoms of fluorosis were analyzed for fluoride concentration in 1978. Statistical analysis of the data indicates that at the 99.5% confidence interval, the fluoride content of the domestic water is not related to the incidences of fluorosis in children. Several possibilities exist to account for the unexplained dental fluorosis.

1. Raft River Valley residents may be obtaining fluoride from eating home-grown vegetables. Although plant roots generally discriminate against fluoride uptake, the plant leaves may accumulate fluoride from the air or from sprinkler irrigation water.

2. Fluoride may be obtained from milk. Cows can ingest fluoride by grazing on plants irrigated with high fluoride water or by drinking from wells with a high fluoride concentration.

3. Children may be obtaining fluoride during the summer while moving irrigation pipes. Although fluoride is poorly absorbed through skin, it is readily absorbed through inhalation of moist air.[73] Water used for irrigation may have much higher fluoride levels than the acceptable federal drinking water standard for the Raft River region of 2 mg/L, since these wells are typically deeper and tap water of poorer quality than those typically used for culinary use.

4. There may be a correlation between incidence of fluorosis and the number of years of residence in the Raft River Valley.

5. Symptoms of fluorosis may be typical of other dental diseases. Poor dental health care may result in higher incidences of dental anomalies. The age when a child first began dental visits may also be significant.

6. Children may be obtaining high levels of fluoride from food sources. Almost all food contains fluoride. Some suspect sources would be vitamins, fluoride tablets, and fluoride toothpastes.[72]

**Methods.** A questionnaire designed to address these possibilities was distributed in the Almo and Raft River elementary schools and Raft River High School. These questionnaires were compared to the dental classification from the 1978 study and analyzed statistically to determine if any correlations existed. The dental classification used in 1978 by the examining dentist is outlined below:

0 Normal

1 Questionable effect

2 Slight fluoride effect (Figure 18)

3 Moderate fluoride effect

4 Marked fluoride effect (Figure 19)

5 Severe fluoride effect.

Duplicate water samples were collected in May and again in August 1980 from the 46 domestic wells previously sampled in 1978; the results were compared with those from the previous tests. Samples were also taken from the Malta high school and some irrigation and cattle wells.

**Results and Discussion.** The fluoride content of the domestic water samples was low and would

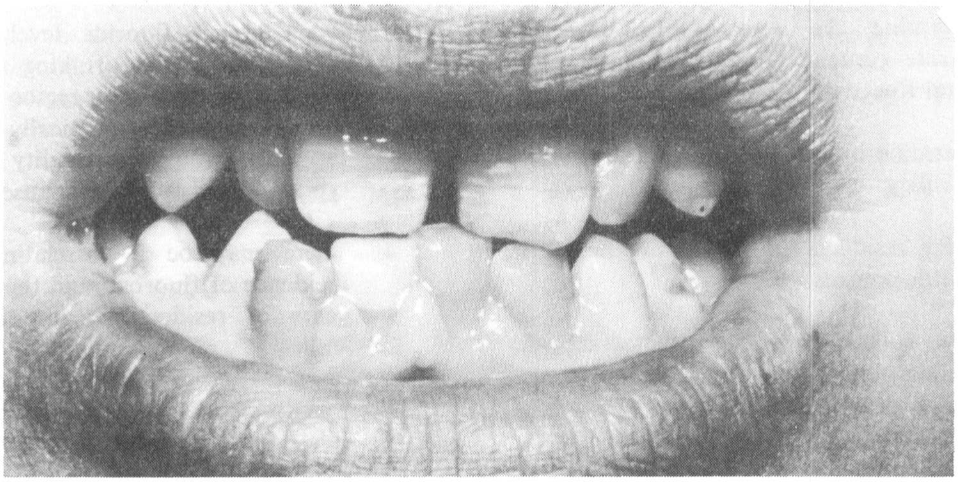

Figure 18. Teeth showing slight fluoride effect.

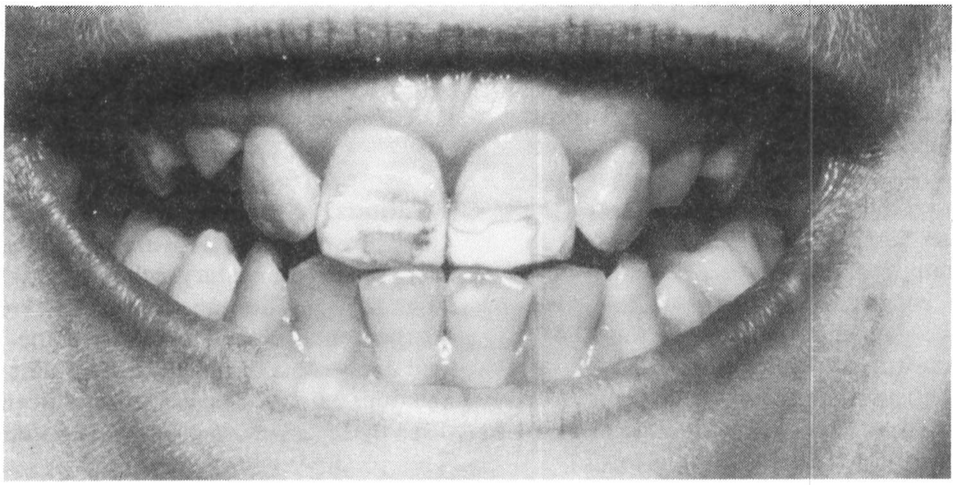

Figure 19. Teeth showing marked fluoride effect.

not be expected to cause fluorosis. Forty-four out of 46 domestic wells in the Raft River Valley sampled in 1978 had less than the recommended federal drinking water standard of 2 mg/L fluoride. The average fluoride concentration in these 44 wells was 0.5 mg/L (standard deviation = 0.3 mg/L) in 1978. This is less than the 1 mg/L recommended by the ADA and the AMA. Only two wells had high fluoride concentrations (>6 mg/L), but one family had no children and the other family did not drink this water. The fluoride concentrations in domestic water samples collected in 1980 were comparable to the 1978 levels. The average concentration was 0.68 mg/L in May (standard deviation = 0.37 mg/L). However, the 1980 estimated averages appear higher than actual because 63% of the wells had less than the 0.5 mg/L detection limit, but 0.5 was used in computing the averages. Water from the Raft River High School contained less than the 0.5 mg/L fluoride. These results do not indicate that there is enough fluoride in the drinking water to induce the high incidence of dental anomalies.

Nine irrigation wells throughout the valley were also sampled, and they averaged 1.22 mg/L fluoride. Two of these wells were higher (4.32 and 2.10 mg/L) than the federal drinking water standard, and three were lower than the lower detection limit of 0.5 mg/L. Although some of the irrigation water used in the valley may be high enough to induce dental fluorosis, there does not appear to be any direct relationship between dental classification and either existence of home vegetable gardens or summertime occupations of students. Eighty-five percent of the students have a garden at home, and 68% move irrigation pipes in the summer. Based on statistical analysis both of these hypotheses can be rejected at the 90% confidence interval.

Studies conducted on animals with high fluoride intakes show that very little fluoride is excreted through the mammary glands.[72] This would lead to the conclusion that the children are not receiving fluoride from the milk they drink, even if the water supplies used by the cattle are high in fluoride. Only seven children lived on dairy farms; six of those had dental classifications of 0 or 1, and only one child had a classification of 2. The milk produced in Raft River Valley that is processed does not return to the valley but is distributed to other areas.

Incidences of dental fluorosis did not appear to correlate with the number of years a child had lived in the Raft River Valley, or the percentage of time spent in the valley during the critical years from 2 to 10. However, 71% of the children with dental classifications of 3 or 4 and 25% of those with classifications of 2 had lived somewhere besides the Raft River Valley. One family had recently moved from Nevada; two children had Class 3 teeth and the other had Class 4. It is possible that the children who had lived elsewhere may have been exposed to high levels of fluoride in those other places. However, this does not explain the exposure of the children that have always lived in the Raft River Valley and also exhibit symptoms of fluorosis (up to Classification 3).

No relationship was found between the age when dental visits were initiated and dental classification, or between present age and dental classification. The only statistically significant correlation found is between dental classification and frequency of visits to the dentist. Since a dental classification of 1 is a questionable fluoride effect, this was not used in the correlation. Frequency of dental exams of the students with fluorosis symptoms (Classes 2, 3, and 4) averaged once every 1.42 years compared with 1.19 years for those showing no fluoride effect (Classification 0). This is statistically significant using the t-test at the 95% confidence interval. Students that had dental exams every 6 months had an average dental classification of 0.64. These scores increased with decreasing frequency of dental visits, with those students visiting the dentist once every 2 years having the highest average dental classification ($\bar{X} = 1.33$). However, many of the children with slight dental fluorosis had, on the average, less tooth decay than the children with "normal" teeth.[72]

If the dental anomalies exhibited by the Raft River Valley children are truly symptoms of fluorosis, then the direct correlation observed between dental class and infrequency of dental visits is puzzling. One would not expect incidences of fluorosis to be correlated with poor dental care. These results possibly indicate that the symptoms were improperly diagnosed and are not related to fluorosis, at least not in all cases. However, Dr. Hurst, the examining dentist, felt confident that symptoms of fluorosis are unique and not easily mistaken.[76] Those students with questionable fluorosis symptoms were given a dental classification of 1.

**Conclusions.** If one assumes that the symptoms observed were properly diagnosed, then the incidence of dental fluorosis in the Raft River Valley is abnormally high. The cause remains a paradox due to the low fluoride levels in the domestic water. The children are not receiving detrimental amounts of fluoride from the drinking water supplies, home-grown vegetables, home-produced milk, or irrigation water. Incidence of fluorosis is also not correlated with residence time in the valley. Fluoride could be obtained from several different sources not associated with the Raft River Valley. Many of the children displaying moderate to marked fluoride effects have lived elsewhere and may have been exposed to high fluoride levels at their previous residences. The source of fluoride for those children with fluorosis who have always lived in the Raft River Valley remains unknown. Because of the cumulative nature of fluorides, the children may be receiving fluorides from many different sources, not any of which are abnormally high. Possible sources are vitamins or fluoride toothpastes. Symptoms diagnosed as fluorosis during the 1978 examination may have been symptoms created by trauma, prolonged use of antibiotics, high fevers, poor nutrition, or other diseases during the formative years.

# BIOLOGICAL DIRECT APPLICATION RESEARCH

Research designed to test the feasibility of using energy expended geothermal fluid for beneficial biological uses was conducted at the Raft River site. The impetus for such research is several fold. The warm, constant temperature of the water may be used to stimulate biotic growth. The water itself is a resource in limited supply throughout much of the arid west and is in demand whenever it can be used for agriculture or rangeland irrigation.

Survivability and productivity of various agricultural, aquacultural, rangeland, and tree species were tested at the Raft River facility. Studies were also conducted to assess the potential of biological systems such as wetlands for water purification through bioaccumulation of elements from the water. Such surface disposal methods offer an alternative to an expensive geothermal fluid injection system. The following experiments, which tested uses for low-temperature geothermal fluid, are particularly useful for development of small-scale direct applications that could not economically inject the geothermal fluid.

## Aquaculture

Use of thermal effluents for enhancing aquaculture production has received increasing interest from fish culturists. Geothermal discharges are attractive aquaculture resources because they continuously maintain the temperature of culture medium and provide a constant source of water for culturing warm-water fish species.

Benefits of geothermal aquaculture include: (a) enhanced growth rates as a function of controlling water temperatures within a narrow range; (b) improved food conversion efficiency in response to consistent temperature control; and (c) the introduction of a warm-water fishery industry into the geothermally-rich west, currently limited to the culture of cold-water species. By directly using low-temperature resources or spent fluids from other processes, geothermal aquaculture can conserve energy, reduce the amount of waste heat released into the environment, and produce a valuable high-quality product.

The use of thermal effluents in aquaculture is a recent development. The concept of intensive thermal aquaculture offers great potential for fish culture, allowing the maintenance of water at an optimum growing temperature for the desired species, thus completely eliminating the seasonality of growing warm-water fish in temperate climates. However, virtually no work had been done on intensive culture of fish directly in geothermal water. Additionally, no work had been done on evaluating the reproductive parameters of fish reared directly in geothermal water.[77]

In 1976, research was initiated at Raft River to investigate the commercial potential of geothermal aquaculture. Species studied included channel catfish (*Ictalurus punctatus*), tilapia (*Tilapia zillii*), Malaysian prawns (*Macrobrachium rosenbergii*), and common carp (*Cyprinus carpio*). The overall objective of the study was to evaluate the commercial feasibility of culturing aquatic animals directly in geothermal water. Specific objectives included the assessment of growth rate to determine if cultured organisms could be raised to a marketable size at a commercially acceptable rate, assessment of disease susceptability, determination of the bioaccumulation of heavy metals in the edible portion of the fish, and evaluation of the physiological (hematological, serological, histological, and oxygen uptake) and reproductive effects on common carp reared directly in geothermal water.

No adverse impacts where detected that were associated with rearing fish in geothermal water. In fact, it appears that growth was slightly enhanced by culture in geothermal water. Reasons that may cause this are speculative, but the higher growth rate may be related to the salinity and/or hardness of the water and its affect on osmoregulation.[78] There were no clinical signs whatsoever of any infectious or noninfectious diseases present during the year-long culture period. The physiological tests performed showed no measurable differences between test fish in geothermal water and control fish in nongeothermal water. Bioaccumulation of some heavy metals (Pb, Hg, Zn) in the edible portion of the fish flesh occurred during the culture period, but did not reach levels of concern for human consumption.[79]

Overall, this study encountered no problems with geothermal aquaculture in water of Raft

River quality. The fish remained healthy and demonstrated high growth rates, indicating a vast potential for commercial geothermal aquaculture.

## Agricultural Irrigation

Suitability of geothermal water for irrigation of agricultural crops and rangeland is determined by the amount and types of constituents present in the water and the characteristics of the receiving crops and soil. The objectives of this study were to determine the survivability, growth rate, yield, and bioaccumulation potential of agricultural crops irrigated with geothermal fluid. Also, changes were assessed in root zone soils following sustained irrigation with geothermal water. The 16 plant species tested (Table 27) represented a broad range of adaptive characteristics compatible with local soils, climate, water quality, and farming practices.

The three types of irrigation used were flood, furrow, and sprinkler. The flood and furrow methods offer an advantage over sprinkler systems when irrigating salt-sensitive crops. Sprinkling may cause salt to crystallize on the leaves, resulting in severe foliar damage. Also, since soils receiving geothermal water may experience increasing salinity and decreasing permeability, flushing with excess water to leach the salts may be required to maintain a favorable soil-salt balance. General flood irrigation practices uniformly apply excess water over the surface, satisfying the crop consumption and soil-leaching requirements. Furrow irrigation is less desirable than flooding for non-row crops because salts tend to accumulate in the ridges between furrows.

The results of the study indicated essentially no difference in yields between salt tolerant crops (barley, sugar beets, alfalfa, forage grasses) receiving geothermal water and crops irrigated with water from the wells used to irrigate farms. Yields from the geothermally irrigated test plots also compared favorably with average yields in the surrounding farm area. This compares with preliminary irrigation studies conducted at East Mesa, California.[80] Crops watered via flood and furrow irrigation at the Raft River site did not demonstrate a significant increase in fluoride concentration of the foliage. However, forage crops watered with sprinkler irrigation absorbed fluoride through the leaves in concentrations ranging from 100 to 300 ppm. There is no indication that the seeds of cereal crops accumulate fluoride when sprinkled with geothermal water.

## Wetlands

Research to evaluate the potential of using geothermal fluid to create wetlands was initiated in 1979. The purpose of the initial study was to evaluate the survivability and productivity of aquatic plants and to determine their ability to bioaccumulate chemicals inherent in the geothermal fluid (see Volume 2 of this report, Water Quality section). A review of the pertinent literature provided information on plant species

**Table 27. Crops cultured in the Raft River irrigation experiment plots**

| Field Crops | | Vegetables | |
|---|---|---|---|
| Barley | *Hordeum vulgare* | Beet | *Beta vulgaris* |
| Sugar beets | *Beta vulgaris* | Potato | *Solanum tuberosum* |
| Wheat | *Tritum vulgare* | | |
| Alfalfa | *Medicago sativa* | Lettuce | *Lactuca sativa* |
| Oats | *Avena sativa* | Radish | *Raphanus sativas* |
| Forage Grass | | Carrot | Datucus carota |
| | | Squash | *Cucurbita maxima* |
| Brome | *Bromus inermis* | | |
| Fescue | *Festuca arundinacea* | Turnip | *Brassica rapa* |
| Orchard | *Dactylis glomerata* | Swiss chard | *Beta vulgaris* |

that were known to be efficient bioaccumulators.[81] A small test pond was constructed, and 20 aquatic plant species native to the Great Basin were screened for their ability to survive in the Raft River geothermal water. The wetland research was expanded in 1980 to include non-native plants that were adapted to warm water and/or saline conditions. Twenty-five species were planted in late March. Samples were collected every 2 weeks throughout the growing season and analyzed to assess the extent of accumulation of several elements. Several species accumulated geothermal water constituents but were unable to survive for the duration of the growing season (Table 28). Some of the species which survived and showed substantial bioaccumulation during this screening study were selected for further research in 1981 and 1982.

The objective of research during 1981 and 1982 was to determine the extent to which wetlands can reduce the concentrations of elements found in the geothermal water. Based upon the promising data of the previous 2 years of research, a 1/4-ha wetland consisting of two ponds was constructed in the spring of 1981 for continuing research. Geothermal fluid flows through the ponds at a rate of approximately 2 L/s. The upper pond is planted with submergent aquatic plants, primarily *Egeria densa*, and three species of pondweeds (*Potamogeton* spp.). The lower pond contains emergent plants, principally common cattail (*Typha latifolia*), hardstem bulrush (*Scirpus acutus*), and common reed (*Phragmites communis*). After the initial transplanting shock, the plants exhibited good growth and reproduction. Water, plant, and soil samples were collected throughout the summer. These data are currently being analyzed.

In addition to the wetland, an indoor laboratory was established. The ability of individual species to purify geothermal water is being determined in a controlled environment. Duckweed (*Lemna minor*), coontail (*Ceratophyllum demersum*), and the plants mentioned above are grown in 114-L aquaria. Research at both the aquatic laboratory and artifical wetland is continuing in 1982 and will provide data from an established system, with plant densities more closely approaching those found in natural systems.

Other benefits of the wetland system may also be important. For example, valuable habitat can be created for waterfowl and furbearers. Several

## Table 28. Peak concentrations (mg/L) in aquatic plants during the 1980 growing season (concentrations on a dry weight basis)

| Plant[a] | F | B | Cl | Na | Comments |
|---|---|---|---|---|---|
| *Ceratophyllum demersum* var. *echinatum* | 273.5 | 19.6 | 17500 | 7895 | — |
| *Chara* sp. | 260.0 | 983.0 | 7500 | — | Planted 07/17[b] |
| *Distichlis stricta* | 174.0 | 25.0 | 12600 | 6370 | — |
| *Egeria densa* | 178.0 | 58.4 | 13800 | 15692 | — |
| *Juncus balticus* | 210.0 | 19.4 | 2600 | 3828 | Dead by 06/26, only 3 samples[c] |
| *Lemna minor* | 374.0 | 1034 | 23000 | 18709 | — |
| *Myriophyllum heterophyllum* | 103.0 | 13.0 | 43400 | 21620 | Dead by 05/15, only 2 samples |
| *Nymphaea odorata* | 303.0 | 30.5 | 52200 | 35024 | Dead by 09/04, only 7 samples |
| *Phragmites communis* | 150.0 | 3.0 | 12000 | 4400 | — |
| *Pistia stratoides* | 171.0 | 57.0 | 26400 | 14100 | — |
| *Potamogeton americanus* | 331.0 | 25.1 | 27000 | 14100 | — |
| *Potamogeton foliosus* | 128.0 | 162.1 | 12700 | 14332 | — |
| *Sagittaria lancifolia* | 213.0 | 23.5 | 50500 | 31526 | — |
| *Scirpus acutus* | 165.0 | 17.3 | 24000 | 10630 | — |
| *Scirpus americanus* | 162.0 | 15.8 | 18300 | 5883 | Grew poorly, only 4 samples |
| *Typha latifolia* | 171.0 | 21.2 | 42700 | 15697 | — |
| *Zizania aquatica* | 107.0 | 13.0 | 7200 | 4732 | Dead by 06/26, only 4 samples |

a. *Typha angustiofolia, Sagittaria latifolia, Tamarix parviflora, Elaeagnus angustifolia, Salix exigua, Scirpus olneyi, Salicornia rubra*, were also present in the wetland, but were not sampled on a regular basis.

b. All species were planted in late March 1980 unless otherwise noted.

c. For plants which did not survive the growing season, a limited number of samples were collected.

species of commercial fish grow very well in geothermal water[82-84] and could be stocked in a wetland. Table 29 presents data from selected literature[85] that indicate the production potential of aquatic macrophytes. Although these data are not for plants grown in geothermal water, preliminary data from the Raft River research indicate that geothermal wetlands could produce comparable or greater quantities of biomass that could be used as a feedstock for energy conversion. Previous research at Raft River demonstrated the technical feasibility of using cattail shoots and tubers to produce ethanol.[86]

## Silviculture

Silviculture plantations stocked with species tolerant to geothermal water may be a viable source for producing woody biomass. This biomass could represent a renewable, reliable, and economical energy feedstock. With sheer biomass production as the objective, optimum rotations of 3 to 15 years are possible with yields of 10 to 40 dry tons/ha/year.[85]

Essentially all past biomass production research on trees in the U.S. has been conducted in the East and Midwest.[87] The sites are usually on arable land; therefore, the tree production results are obtained under conditions that would also be favorable for agricultural crop production. Even when competing with agricultural crops for the most economical use of the land, tree biomass plantations can be marginally profitable.[88,89] In the arid west, however, economically competitive land uses are not a major factor. The soil is usually of good quality and the large number of sunny days provides abundant solar radiation needed for growth. Water availability is often the limiting factor to crop growth in the west. By using waste-water (geothermal, municipal, or secondary coolant) to irrigate a tree plantation, a beneficial use would be obtained, as well as the potential of being an acceptable method for waste-water disposal. Also, soils or water not conducive to domestic crop production could be used to produce trees. Many tree species are more salt tolerant than agricultural crops. Salt tolerant tree species that have high biomass production rates could, therefore, represent a successful crop on an area otherwise unsuited for agricultural crops.

The current silviculture research project was initiated in 1981. The water that is used for irrigation in this study is heat-expended geothermal

**Table 29. Productivity of aquatic macrophytes**

| Type of Plant (Genus) | Location | Productivity ($gm^{-2}$ $day^{-1}$) | Standing Crop ($gm^{-2}$) |
|---|---|---|---|
| Submerged plants | | | |
| Milfoil (*Myriophyllum*) | Wisconsin | 4.3 | |
| Hydrilla (*Hydrilla*) | Florida | 4.2 | |
| Small floating | | | |
| Duckweed (*Lemna*) | Florida | 3.3 | |
| Emergent | | | |
| Cattail (*Typha*) | Minnesota | | 4720 |
| Bulrush (*Scirpus*) | Iowa | | 1833 |
| Reed (*Phragmites*) | Minnesota | | 1118 |
| Reed canary grass (*Phalaris*) | New York | | 1370 |

fluid produced at the Raft River facility. This study objective is to determine whether the use of geothermal effluent for silviculture plantations is a practical alternative to injection. Another benefit is that the water being used has a salinity similar to many cold-water aquifers of the world. The salinity of the Raft River water is about 1500 mg/L. Worldwide, there are 600 million ha of desert that overlie saline aquifers containing 1000 to 3000 mg/L. This represents a land area 15 times the size of California. Four hundred thousand km$^2$ of the United States (one-twelfth of the continental land area) overlie aquifers with a salinity near 3000 mg/L that could be economically developed. Two-thirds of the U.S. has what is considered slightly saline water, containing from 1000 to 3000 mg/L of salt. Every year, another two hundred thousand ha become too salty for conventional agriculture because of saline accretions resulting from irrigation with saline water. Since the earliest farmers learned to irrigate, about 25% of the earth's irrigated cropland has become too salty to farm. In the past, land has been abandoned as desert if agricultural crops could not be grown. With the evolving incentive for producing biomass for energy conversion, much of this water resource could be used to grow hardy, salt tolerant tree and shrub species. In many cases, tree and/or shrub production would rehabilitate, or at least stabilize, abandoned land that has been devastated as a result of past land use practices.

In 1981, ten tree species were planted to determine survivability and production potential. The criteria used to select the trees were high production potential, known tolerance to the climate of the region, and the ability to coppice (regenerate from cut stumps), an important attribute for obtaining multiple harvests.

Based on the qualitative success of the 1981 research, the study was expanded in 1982 to test additional tree species and obtain a quantitative estimate of production potential. Twenty-four species are currently being tested (Table 30). Preliminary results of this research will not be available until the autumn of 1982.

**Table 30. Tree species tested in the current silviculture research**

| | |
|---|---|
| Honey locust | (*Gledetsia tricanthos*) |
| Black locust | (*Robinia pseudoacacia*) |
| Hybrid locust | (*Robinia hybrid*) |
| Tamarisk | (*Tamarix gallica*) |
| Green ash | (*Traxinus pennsylvanica*) |
| Boxelder | (*Acer negumdo*) |
| Silver maple | (*Acer saccharinum*) |
| Russian olive | (*Eleagnus angustifolia*) |
| Siberian elm | (*Ulmus pumila*) |
| Chinese elm hybrid | (*Ulmus hybrid*) |
| European sycamore | (*Platimus occidentalis*) |
| Globe willow | (*Salix hybrid*) |
| Laurel-leaf willow | (*Salix pentrandra*) |
| Golden willow | (*Salix babylonica*) |
| Common cottonwood | (*Populus deltoides*) |
| Narrowleaf cottonwood | (*Populus angustifolia*) |
| Freemont cottonwood | (*Populus fremontii*) |
| Lombardy poplar | (*Populus nigra*) |
| Poplar hybrids (2 varieties) | (*Populus hybrids*) |
| Russian mulberry | (*Morus rubra*) |
| Smooth sumac | (*Rhus glabra*) |
| Rubber rabbitbush | (*Chrysothemnus nauseosis*) |
| Four-wing saltbush | (*Atriplex canescens*) |
| Milkweed | (*Asclepias speciosa*) |

# REFERENCES

1. P. L. Williams et al., "Geology and Geophysics of the Southern Raft River Valley Geothermal Area, Idaho, U.S.A.," *Proceedings of the Second U.N. Symposium on the Development and Use of Geothermal Resources, San Francisco, California, 2, May 20-29, 1975*, 1976, pp. 1273-1282.

2. A. L. Anderson, "Geology and Mineral Resources of Eastern Cassia County, Idaho," Idaho Bureau of Mines and Geology Bulletin 14, 1931.

3. T. L. Thurow et al., *1981 Annual Report—An Analysis of the Response of the Raft River Geothermal Site Monitor Wells, Earth and Life Sciences Office in Conjunction With Energy Programs Division*, EG&G Informal Report, April 1982.

4. S. G. Spencer and D. M. Callan, *An Analysis of the Response of the Raft River Monitor Wells to the 1979 Injection Tests*, EGG-2027, 1980.

5. S. C. Devine and B. Bonnichsen, *Petrography of Drill Cores from the Raft River Geothermal Area, Southern Idaho*, Unpublished Report to the Department of Energy, December 1979.

6. K. S. Kennedy, *Environment of Deposition of the Upper 300 Meters of Sediments of the Raft River KGRA*, EG&G Idaho, Inc., PG-G-80-026, 1980, p. 39.

7. J. A. Tullis and M. R. Dolenc, "Geoscience Interpretations of the Raft River Resource," *Geothermal Resources Council Bulletin, 2*, February 1982, pp. 6-9.

8. H. R. Covington, "Subsurface Geology of the Raft River Geothermal Area, Idaho," *Geothermal Resources Council Transactions, 4*, September 1980.

9. D. R. Mabey et al., "Reconnaissance Geophysical Studies of the Geothermal System in Southern Raft River Valley, Idaho," *Geophysics 43*, 7, 1978, pp. 1470-1484.

10. M. R. Dolenc et al., *Raft River Geoscience Case Study, Volume 1*, EGG-2125, November 1981, pp. 4-9.

11. International Conference of Building Officials, *Uniform Building Code*, Whittier, California: 1982.

12. L. H. Kumamoto, *Microseismicity Investigation of the Raft River Valley, Idaho*, Letter Report to DOE on Contract AT (11-1)-2476, March 1, 1976.

13. W. D. Pennington, R. B. Smith, and A. B. Trimble, "A Microearthquake Survey of Parts of the Snake River Plain and Central Idaho," *Bulletin of Seismic Society of America, 64*, 2, 1974, pp. 307-312.

14. G. Zandt et al., *Seismic Baseline and Induction Studies, Roosevelt Hot Springs, Utah and Raft River, Idaho*, UNRI-ESL, DOE/IDO/1821-1, May 1982, p. 58.

15. B. E. Lofgren, *Land Subsidence and Tectonism, Raft River Valley, Idaho*, USGS Open-file Report 75-585, 1975.

16. Energy Resources Company, Inc., *Draft Summary of Raft River Geothermal Air Quality Monitoring Program September 1980—April 1982*, unpublished report submitted to EG&G Idaho, Inc., from ERCO, LaJolla, CA, June 18, 1982.

17. U.S. Environmental Protection Agency, Office of Research and Development, *Quality Assurance Handbook for Air Pollution Measurement Systems*, EPA-600/9-76-005, Volume I, February 1980; Volumes 2, 3, and 4, 1976, 1977, and 1978.

18. R. R. Sokal and P. H. A. Sneath, *Principles of Numerical Taxonomy*, San Francisco: W. H. Freeman and Company, 1963.

19. N. E. West, "Matrix Cluster Analysis of Montane Forest Vegetation of the Oregon Cascades," *Ecology, 47*, 1966, pp. 975-980.

20. E. F. Kleiner and K. T. Harper, "Environment and Community Organization in Grasslands of Canyonlands National Park," *Ecology, 53*, 1972, pp. 299-309.

21. K. T. Harper, J. R. Murdock, and S. L. Welsh, *Vegetation of the Salt Wash Area, Wayne County, Utah*, Report submitted to the Environmental Systems Department of Westinghouse Corporation, 1975.

22. N. E. West, K. H. Rea, and R. O. Harniss, "Plant Demography Studies in Sagebrush-grass Communities of Southeastern Idaho," *Ecology, 60*, 1979, pp. 376-388.

23. C. D. Jorgensen, C. M. White, and C. L. Pritchett, *Raft River Environmental Studies, Annual Report*, Department of Zoology, Brigham Young University, January 1978.

24. D. W. Hayne, "An Examination of the Strip Census Method for Estimating Animal Populations," *Journal of Wildlife Management, 13*, 1949, pp. 145-157.

25. C. D. Jorgensen and H. D. Smith, "Mini-grids and Small Mammal Estimates," *Proceedings of Utah Acadamy of Science and Arts and Letters, 51*, 1974, pp. 12-18.

26. J. E. Gross, L. C. Stoddart, and F. H. Wagner, "Demographic Analysis of a Northern Utah Jackrabbit Population," *Wildlife Monograph, 40*, 1974.

27. J. S. Green and J. T. Flinders, "Habitat and Dietary Relationships of the Pygmy Rabbits," *Journal of Range Management, 33*, 1980, pp. 136-142.

28. L. Eberhart, "A Preliminary Appraisal of Line Transects," *Journal of Wildlife Management, 32*, 1968, pp. 82-88.

29. C. M. Woolf, *Principles of Biometry*, New York: D. Van Nostrand Co., Inc., 1968.

30. D. Muller-Dombois and H. Ellenberg, *Aims and Methods of Vegetation Ecology*, New York: John Wiley and Sons.

31. R. Daubenmire, "A Canopy Coverate Method of Vegetational Analysis," *Northwest Science, 33*, 1959, pp. 43-64.

32. J. T. Curtis and R. P. McIntosh, "The Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin," *Ecology, 32*, 1952, pp. 476-496.

33. F. H. Wagner and L. C. Stoddart, "Influence of Coyote Predation of Black-tailed Jackrabbit Populations in Utah," *Journal of Wildlife Management, 36*, 1972, pp. 329-342.

34. R. R. Lechleitner, "Movement, Density and Mortality in a Black-tailed Jackrabbit Population," *Journal of Wildlife Management, 22*, 1958, pp. 371-384.

35. O. W. Tiemeier, "The Black-tailed Jackrabbit in Kansas," *Kansas Agricultural Experiment Station, Technical Bulletin 140*, 1965, pp. 5-37.

36. D. B. Wilde, *A Population Analysis of the Pygmy Rabbit (Sylvilagus idahoenis)*, PhD Thesis, Idaho State University, Pocatello, 1978.

37. T. L. Thurow, C. M. White, R. P. Howard, and J. F. Sullivan, *Raptor Ecology of Raft River Valley, Idaho*, EGG-2054, 1980.

38. M. L. Cody and J. M. Diamond, *Ecology and Evaluation of Communities*, Cambridge: Belknap Press, 1975, p. 545.

39. J. Craighead and F. Craighead, *Hawks, Owls and Wildlife*, Harrisburg, Pennsylvania: Stackpole Company, 1969, p. 443.

40. D. G. Smith and J. Murphy, "Breeding Ecology of Raptors in the Eastern Great Basin of Utah," *Brigham Young University Science Bulletin Biological Series*, 1973.

41. R. M. Skinner, "Grassland Use Patterns and Prairie Bird Population in Missouri," *Prairie: A Multiple View*, Grand Forks: University of North Dakota Press, 1975, p. 433.

42. R. P. Howard and M. L. Wolfe, "Range Improvement Practices and Ferruginous Hawks," *Journal of Range Management, 29*, 1976, pp. 33-37.

43. M. Westoby and F. H. Wagner, "Use of a Crested Wheatgrass Seeding by Black-tailed Jackrabbits," *Journal of Range Management, 26*, 1973, pp. 349-352.

44. R. R. Olendorff and J. R. Stoddard, Jr., *The Potential for Management of Grassland Raptors*, pp. 47-99, cited in: F. N. Hamerstorm Jr., B. E. Harrell, and R. R. Olendorff (eds.), *Management of Raptors, Raptor Research Report Number 2*, Vermillion, South Dakota: 1974, p. 146.

45. R. W. Fyfe and R. R. Olendorff, "Minimizing the Danger of Nesting Studies to Raptors and Other Sensitive Species," *Canadian Wildlife Service, 23*, 1976, p. 17.

46. N. D. Woffinden and J. R. Murphy, "Population Dynamics of the Ferruginous Hawk During a Prey Decline," *Great Basin Naturalist, 37*, 1977, pp. 411-425.

47. American Birds, "The Blue List for 1974," *American Birds, 27*, 1974, pp. 943-945.

48. J. R. Murphy et al., "Nesting Ecology of Raptorial Birds in Central Utah," *Brigham Young University Science Bulletin, Biological Series, 10*, 1969, pp. 1-36.

49. L. R. Powers, R. P. Howard, and C. Trost, *Population Status of the Ferruginous Hawk in Southeastern Idaho and Northern Utah*, pp. 153-157, cited in: J. R. Murphy, C. M. White, B. E. Harrell, and R. R. Olendorff (eds.), *Status of Raptors, Raptor Research Report Number 3*, Vermillion, South Dakota: 1973.

50. R. P. Howard, *Breeding Ecology of the Ferruginous Hawk in Northern Utah and Southern Idaho*, M.S. Thesis, Utah State University, Logan, Utah, 1975.

51. F. E. Croxton, D. J. Cowden, and S. Klein, *Applied General Statistics*, Englewood: Prentice-Hall, Inc., 1967.

52. D. E. Busch, W. A. deGraw, and N. C. Clampitt, "Effects of Handling Disturbance Stress on Heart Rate in the Ferruginous Hawk (*Buteo regalis*)," *Raptor Research, 12*, 1979, pp. 122-125.

53. F. S. L. Williamson, M. C. Thompson, and J. Q. Hines, *Avifaunal Investigations*, cited in: N. J. Willimousky and J. N. Wolfe (eds.), *Environments of the Cape Thompson Region, Alaska*, USAEC PNE-481, 1966, pp. 437-488.

54. C. M. White, F. S. L. Williamson, and W. B. Emison, *Avifaunal Investigations*, (in press), cited in: M. L. Merrit and R. G. Fuller (eds.), *The Environments of Amchitka Island, Alaska*, USAEC/TID 26712, 1977.

55. R. Clark, *Aquatic Flora of the Raft River*, Unpublished Report to EG&G Idaho, Inc., from Ricks College, 1976.

56. Watson et al., private communication, Ricks College, 1977.

57. R. L. Speth, *A Density and Neutron Activation Analysis Study of the Aquatic Invertebrates in the Raft River Near the Geothermal Site*, Unpublished Report to EG&G Idaho, Inc., from Ricks College, 1976.

58. J. R. Barnes and D. K. Shiozawa, *A Description and Assessment of the Raft River Toxic System in the Vicinity of the Raft River Geothermal Area*, Unpublished Report submitted to DOE-ID, Brighman Young University, 1980, p. 21.

59. M. Ruzicka, "Anwendung Mathematischstatisticher Methoden in der Geobotanik (Synthetische Bearbeitung Von Anfuaken)," *Biologia, Batisl, 1*, 1958, pp. 647-661.

60. K. W. Cummins, 1962, "An Evaluation of Some Techniques for the Collection and Analysis of Benthic Samples with a Special Emphasis on Lotic Waters," *Amer. Midl. Natur., 67*:477-504.

61. R. W. Merrit and K. W. Cummins (ed.), *An Introduction to the Aquatic Insects of North America*, Dubuque, Iowa: Kendall Hunt Publishing Co., 1978, p. 441.

62. W. Morlang, Private Communication, Chamber of Commerce, U.S. Department of Commerce, Bureau of Census, Burley, Idaho, April 1982.

63. J. Hyer, Private Communication, Department of Employment, Burley, Idaho, April 1982.

64. W. C. Lewis, *The Socioeconomic Environment of Cassia County, Idaho and Preliminary Impact Projections of Geothermal Resource Development at Raft River*, Logan, Utah: Lewis and Associates, Inc., 1979.

65. T. C. Thurow, letter to J. F. Sullivan, Interoffice Memo, "Raft River Socioeconomic Survey," TLT-2-79, EG&G Idaho, Inc., December 6, 1979.

66. L. MacDonald, Private Communication, Based on 1981 Employer Unemployment Insurance Payments, Department of Employment, Twin Falls, Idaho, April 1982.

67. J. A. Goodnight, *Community Impact Assessment of a Diversified Geothermal Energy Project Proposed for the Raft River Valley, Idaho*, Unpublished Report to DOE-Idaho Operations Office from Battelle Human Affairs Research Center, 1977.

68. W. C. Lewis, *Detailed Socioeconomic Impact Projections of Geothermal Resource Development in South Cassia County, Idaho, 1980-1986*, Logan, Utah: Lewis and Associates, Inc., Unpublished Report Submitted to EG&G Idaho, Inc., 1980.

69. EG&G Payroll Records, Private Communication with J. Yockey and K. Argast, April 1982.

70. G. Longhurst, Private Communication, EG&G Idaho, Inc., April 1982.

71. F. Warren, Private Communication, EG&G Idaho, Inc., April 1982.

72. J. L. Shupe, A. E. Olson, and H. B. Peterson, *Incidence of Human Dental Fluorosis in the Raft River Geothermal Area in Southern Idaho*, Utah State Research Foundation, 1978, Unpublished Report Submitted to EG&G Idaho, Inc.

73. A. L. Knight, "Fluorides" in *Occupational Medicine-Principles and Practical Applications*, Carl Zenz, (ed.), 1975, pp. 649-659.

74. Federal Register, December 24, 1975.

75. Utah State University Research Foundation, *Material for Environmental Statement-Raft River Geothermal Program Project 85*, Logan, Utah: Unpublished Report, December 15, 1976, p. 41.

76. C. F. Hurst, Private Communications, Examining Dentist, 1981.

77. Sea Grant, *Geothermal Resources for Aquaculture*, Oregon State University, Sea Grant College Program Publications, ORESU-W-78-001, 1978.

78. J. R. Brett and T. D. Groves, "Physiological Energetics," *Fish Physiology, 8*, 1979, pp. 279-344.

79. M. H. Beleau, J. G. Woiwode, and G. W. Klontz, *Raft River Aquaculture Project: Annual Report*, EG&G Geothermal Direct Applications Program, INEL, Idaho Falls, Idaho, 1979.

80. F. E. Robinson, T. R. Thomas, and K. Singh, "Geothermal Fluids to Irrigate Energy Crops on Imperial East Mesa Desert, California," *Geothermal Resources Council Transactions, 5*, pp. 561-562, 1981.

81. N. E. Stanley et al., *Geothermal Wetlands: An Annotated Bibliography of Pertinent Literature*, EGG-2029, May 1980, p. 58.

82. D. K. Campbell et al., *Raft River Geothermal Aquaculture Experiment—Phase II*, EGG-TREE-1370, August 1979, p. 24.

83. H. B. Marshall and J. G. Woiwode, *Raft River Aquaculture Project Final Report*, DOE/ID/01757-3, July 1980, p. 44.

84. J. F. Sullivan and M. H. Beleau, "Potential for Utilizing Geothermal Resources for the Culture of Freshwater Fish," *Geothermal Resources Council Transactions, 3*, September 1979, pp. 689-692.

85. R. E. Chaney et al., *Assessment of Biomass as an Alternative Energy Source, Volume 1*, EGG-PGA-81-049, September 1981, p. 197.

86. J. G. Keller, Private Communication, EG&G Idaho, Inc., December 29, 1981.

87. K. Howlett and A. Gamache, *Silviculture Biomass Farms, Volume 2, The Biomass Potential of Short-Rotation Farms*, ERDA MTR-7347, 1977a, p. 136.

88. R. S. Evans, *Energy Plantations: Should We Grow Trees for Power Plant Fuel?* Canadian Forest Service Information Report VP-X-129, 1974, p. 15.

89. D. W. Rose and R. D. Wallstrom, "Economic Feasibility of Intensive Cultures," *USFS Minnesota Miscellaneous Journal Series*, 1615, 1976.

# APPENDIX A

## RAFT RIVER ENVIRONMENTAL INFORMATION REPORTS

# APPENDIX A

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Allan, *Vegetation Terrestrial Ecology Studies at the Raft River KGRA 1978-1979*, Unpublished report submitted to EG&G Idaho, Inc., Environmental Studies Laboratory, University of Utah Research Institute, 1980, p. 116.

Allman, Nelson, and Neimi, *Results at RRGI-6 During January 1979 Injection from RRGE-2*, GP-AP-004, February 1979.

Allman, *Lysimeter Soil Emplacement and Instrumentation Procedures*, GP-AP-007, May 1979.

Bishop and Peterson, *Fluoride and Soils in the Raft River Geothermal Area*, unpublished report to DOE-Idaho Operations Office from Utah State University, 1976.

Brown, Shaber, Homer, and Spencer, *Safety Analysis Report—5-MW(e) Raft River Pilot Plant*, PG-G-80-031, May 1980.

Brown, Homer, Shaber, and Thurow, *Safety Analysis Report—5-MW(e) Raft River Research and Development Plant—Energy Programs*, PG-G-81-52, November 1981.

Cahn, Thurow, and Martinez, *1980 Annual Report, INEL Geothermal Environmental Program*, EGG-2113, April 1981.

Callan, *Results of RRGE-2 to RRGI-6 Pump/Injection Test March 1979*, PG-G-80-035, September 1980.

Campbell, Kent, Rose, Watson, and Sullivan, *Raft River Geothermal Aquaculture Experiment—Phase II*, TREE-1370, August 1979.

Chaney, Jacoby, and LaRue, *Program Plan for Conversion of Biomass to Liquid Fuel Using Geothermal Energy*, GP-AP-008, September 1979.

Clark, *Aquatic Flora of the Raft River*, unpublished report to EG&G Idaho, Inc., from Ricks College, 1976.

Cole and Schmitt, *Fluidized-Bed Potato Waste Drying Experiments at the Raft River Geothermal Test Site*, EGG-2036, June 1980.

Dolenc, *The Integrated Well Field Test Report*, PG-G-79-012, September 1979.

Dolenc, Hull, Mizell, Russell, Skiba, and Strawn, *Raft River Geoscience Case Study—Volumes I and II*, EGG-2125, November 1981.

Energy Resources Company, Inc., *Draft Summary of Raft River Geothermal Air Quality Monitoring Program September 1980—April 1982*, unpublished draft submitted to EG&G Idaho, Inc. June 18, 1982, p. 38.

Findholt, *Baseline Ecological Data for Geothermal Development in the Raft River Valley, Idaho*, unpublished report to DOE-Idaho Operations Office from Idaho State University, 1977.

Goodnight, *Community Impact Assessment of a Diversified Geothermal Energy Project Proposed for the Raft River Valley, Idaho*, unpublished report to DOE-Idaho Operations Office from Battelle Human Affairs Research Center, 1977.

Hull and Fitch, *A User's Guide for Geothermal Chemical Data Base*, EGG-ELS-5510, September 1981.

Jorgensen and Knowlton, *Arthropods of the Raft River Geothermal Study Site Area*, unpublished report to DOE-Idaho Operations Office from Brigham Young University, 1976.

Jorgensen, White, and Pritchett, *Raft River Environmental Studies*, unpublished report to DOE-Idaho Operations Office from Brigham Young University, 1977.

Kennedy, *Environment of Deposition of the Upper 300 Meters of Sediments of the Raft River KGRA*, PG-G-80-026, January 1980.

Kumamoto, *Microseismicity Investigation of the Raft River Valley, Idaho*, unpublished report to DOE-Idaho Operations Office from Colorado School of Mines, 1976.

Lewis, *The Socioeconomic Environment of Cassia County, Idaho and Preliminary Impact Projections of Geothermal Resource Development at Raft River*, EG&G Idaho, Inc., 1979.

McAtee, Allen, and Lewis, *Chemical Logging of Geothermal Wells*, GP-AP-005, April 1979.

McCarthy and Spencer, *Environmental Assessment Raft River Heat Flow Holes*, GP-AP-003, September 1978.

McCarthy, *Monitor Well Data Summary Third Quarter 1979, June 30 to September 30*, PG-G-79-016, November 1979.

Michels, *Preliminary Considerations of Scaling Due to Thermal Waters in the Raft River Geothermal Experiment*, TR-695, September 1975.

Morilla and Ralston, *Preliminary Assessment of the Feasibility of Using a Shallow Ground-Water System for the Cooling Cycle of a Geothermal Power Plant*, unpublished report to DOE-Idaho Operations Office from University of Idaho, 1975.

Neudorfer, *Archaeological Resources of the Southern Raft River Valley*, unpublished report to DOE-Idaho Operations Office from Idaho State University, 1975.

Overton, Chaney, McAtee, and Graham, *Geochemical Modeling of the Raft River Geothermal Field*, EGG-2004, November 1979.

Roberts, *Fish Culture Utilization of Geothermal Energy*, ANCR-1220, June 1975.

Schmitt and Spencer, *Beneficial Uses of Geothermal Energy Description and Preliminary Results for Phase 1 of the Raft River Irrigation Experiment*, TREE-1048, January 1977.

Shupe, Olson, and Peterson, *Incidence of Human Dental Fluorosis in the Raft River Area in Southern Idaho*, unpublished report to DOE-Idaho Operations Office from Utah State University, 1978.

Skiba, Goldman, Spencer, and Hull, *The Raft River Geothermal Project, Groundwater Monitoring Program Progress Report*, EGG-2119, July 1981.

Spencer, *Environmental Report Deep Geothermal Test Wells in the Raft River Valley*, ANCR-1204, January 1975.

Spencer, *Environmental Assessment—Raft River Geothermal Production Well (RRGP-5) and Associated Development*, GP-128, September 1977.

Spencer, *Environmental Assessment, Raft River Geothermal Injection Well (RRGI-6) and Transfer Pipeline*, GP-125, December 1977.

Spencer, Stanley, and Hickman, *Environmental Report, Raft River Thermal Loop Facility*, unpublished report by EG&G Idaho, Inc., 1977.

Spencer, *Environmental Assessment, Raft River Geothermal Injection Well #7* (RRGI-7) and Transfer Pipeline, GP-126, January 1978.

Spencer and Russell, *Geothermal Development in Southwest Idaho: The Socioeconomic Data Base*, EGG-GTH-5008, September 1978.

Spencer, Sullivan, and Stanley, *1978 Annual Report, INEL Geothermal Environmental Program*, TREE-1340, April 1979.

Spencer and Russell, *Geothermal Development in Southwest Idaho; The Socioeconomic Data Base*, EGG-GTH-5007, September 1979.

Spencer, Russell, and Sullivan, *Potential Use of Geothermal Resources in the Snake River Basin: An Environmental Overview Volume I and Volume II*, EGG-2001, September 1979.

Spencer and Dolenc, *Raft River Injection Systems Evaluation Study*, PG-G-79-015, October 1979.

Spencer and Callan, *An Analysis of the Response of the Raft River Monitor Wells to the 1979 Injection Tests*, EGG-2057, September 1980.

Speth, *A Density and Neutron Activation Analysis Study of the Aquatic Invertebrates in the Raft River Near the Geothermal Site*, unpublished report to EG&G Idaho, Inc., from Ricks College, 1976.

Speth, Weber, and Simpson, "Trace Element Deposition in Samples Collected from the Raft River Geothermal Site Using Neutron Activation Analysis," *Journal of the Idaho Academy of Science*, 12, 1976, pp. 33-45.

Stanley, *Raft River Irrigation Experiment—Phase 2 Report*, GP-03-79, February 1979.

Stanley and Schmitt, *Effects of Irrigation on Crops and Soils with Raft River Geothermal Water*, EGG-2005, January 1980.

Stanley, Thurow, Russell, and Sullivan, *Geothermal Wetlands: An Annotated Bibliography of Pertinent Literature*, EGG-2029, May 1980.

Stanley, Engen, and Yrene, *An Overview of Engineering and Agricultural Design Considerations of the Raft River Soil-Warming and Heat-Dissipation Experiment*, EGG-GTH-5804, April 1982.

Suciu and Miller, *Short-Term Pilot Cooling Tower Tests*, EGG-FM-5087, January 1980.

Suciu and Miller, *Removal of Silica from Raft River Geothermal Water*, EGG-FM-5170, June 1980.

Suciu and Wikoff, *Corrosion Testing of Carbon Steel in Aerated Geothermal Brine*, EGG-GTH-5474, February 1981.

Sullivan and Spencer, *Raft River Injection Testing Monitor Well Plan*, GP-133, March 1978.

Thurow, *Raft River Geothermal Site Revegetation Plan*, PG-G-80-024, January 1980.

Thurow and Sullivan, *1979 Annual Report—INEL Geothermal Environmental Program*, EGG-2028, April 1980.

Thurow, White, Howard, and Sullivan, *Raptor Ecology of Raft River Valley, Idaho*, EGG-2054, September 1980.

Ursenbach, Edwards, and Allan, *Baseline Air Quality and Vegetation Studies in the Raft River Valley, 1975-1977*, unpublished report to DOE-Idaho Operations Office from University of Utah Research Institute, 1978.

Walker, *The Raft River Basin, Idaho-Utah as of 1966: A Reappraisal of the Water Resources and Effects of Ground-Water Development*, Idaho Department of Water Resources, Bulletin 19, 1970.

White, Thurow, and Sullivan, "Siting Criteria as a Function of Sensitivity of Nesting Ferruginous Hawks to Geothermal Development," *Proceedings, DOE Control Technology Symposium, Washington, D.C., November 27 to 30, 1978.*

*Environmental Report—Raft River Geothermal Pilot Plant (Supplement* #1 to TREE-1144), GP-120, November 1977.

*Environmental Report, Raft River Injection Monitor Well System*, GP-121, November 1977.

*A Project Plan to Evaluate Geothermal Water Disposal by Irrigation*, PG-G-79-022, December 1979.

*The Withdrawal of Lands for Federal Geothermal Development in the Raft River Valley, Idaho*, GP-103, August 1977.

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