YANKEE/CAITHNESS JOINT VENTURE, L.P.
STEAMBOAT HILLS GEOTHERMAL PROJECT

PLAN OF OPERATION/PLAN OF UTILIZATION AMENDMENT FOR GEOTHERMAL FLUID RATE INCREASE

ENVIRONMENTAL ASSESSMENT

NV920-9201

Lead Agency:
BUREAU OF LAND MANAGEMENT
Nevada State Office
123 Harvard Way
Reno, Nevada 89502

Cooperating Agency:
UNITED STATES FOREST SERVICE
Toiyabe National Forest
1200 Franklin Way
Sparks, Nevada 89431

September, 1993

Prepared by:

ENVIRONMENTAL MANAGEMENT ASSOCIATES
100 West Grove Street, Suite 100
Reno, Nevada 89509
(702) 828-3939

YANKEE/CAITHNESS JOINT VENTURE , L.P.
STEAMBOAT HILLS GEOTHERMAL PROJECT
PLAN OF OPERATION/PLAN OF UTILIZATION
AMENDMENT FOR
GEOTHERMAL FLUID RATE INCREASE
ENVIRONMENTAL ASSESSMENT

TABLE OF CONTENTS

Page

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

Page

TABLE OF CONTENTS
(continued)

LIST OF FIGURES

TABLE OF CONTENTS
(continued)

Page

LIST OF TABLES

APPENDICES

**YANKEE/CAITHNESS JOINT VENTURE, L.P.
STEAMBOAT HILLS GEOTHERMAL PROJECT
PLAN OF OPERATION/PLAN OF UTILIZATION
AMENDMENT FOR
GEOTHERMAL FLUID RATE INCREASE
ENVIRONMENTAL ASSESSMENT**

1. EXECUTIVE SUMMARY

This Environmental Assessment (EA) has been prepared for the proposed increase in geothermal fluid production and injection rates (Proposed Action) at the Yankee/Caithness Joint Venture, L.P. (Caithness) owned and Caithness Power, Inc. (CPI) operated Steamboat Hills Geothermal Project (Steamboat Hills Project) in compliance with the National Environmental Policy Act (NEPA), as well as Bureau of Land Management (BLM) guidelines and regulations for the implementation of NEPA.

1.1. Proposed Action and Alternatives

The Proposed Action is to increase the total geothermal fluid production and injection rates for the Steamboat Hills Project from the Unit participating area from 1.9×10^6 pounds per hour (lb/hr) up to a maximum of 3.8×10^6 lb/hr. Because the Proposed Action is limited to an increase in the production and injection rate of geothermal fluid from the existing Steamboat Hills Project, the only alternatives identified were: 1) a project which limited the geothermal fluid production and injection rates to less than the proposed rate of 3.8×10^6 lb/hr but greater than the existing approved rate of 1.9×10^6 lb/hr; 2) one or more project(s) which involved alternative locations for one or more of the geothermal fluid production and/or injection wells; and 3) the No Action alternative. Two (2) of these three (3) alternatives have been eliminated from further consideration, although elements of these alternatives are considered as potential mitigation measures in this EA. The only reasonable alternative to the Proposed Action is the No Action alternative, which would deny the increase in production and injection rates.

1.2. Environmental Resources

As a result of the analysis in this EA, it was determined that several environmental resources in the study area would not be impacted by the Proposed Action. Therefore, these resources, which include physiography, geology, wilderness, cultural and paleontological resources, visual resources, and noise, will not be further discussed in this section of the Executive Summary.

Mineral Resources: The geothermal activity in the study area has been ongoing since the Pliocene. Local faulting has channeled geothermal fluids from depths to the surface which has resulted in the deposition of siliceous sinter, forming the three (3) terraces (High, Main, and Low Terraces). Two (2) of the thermal areas are currently considered active. Geothermal resources are currently utilized for electrical power generation and residential heating. In addition to the ongoing use of the geothermal resource by CPI, other uses of the geothermal resource in the study area include the former Steamboat Spa Hot Springs and the SBG binary geothermal projects. The study area has historically produced numerous minerals.

Soils: There are numerous soil types within the study area due to the widely varied terrain and rock types in the area. Soils on slopes consist of residuum, mostly from altered andesite and volcanic rocks, and a small amount of colluvium, while soils in the valley areas consist mostly of alluvium from mixed rock types.

Unique soils have developed on the siliceous sinter terraces which occur over large areas associated with the fossil and historically active hot springs. These siliceous sinter deposits, ranging in age from 2.5 million years to the present, consist primarily of opaline sinter, which probably alters to chalcedonic sinter over time. Soils derived from parental material of siliceous sinter or alluvial material with siliceous sinter are characterized by extreme immaturity, and no diagnostic horizons. The last of the active Steamboat Hills hot springs and geysers ceased flowing in approximately 1989 and, as a result, deposition on the surface of new siliceous sinter is currently not occurring. It is likely that other periods of no sinter deposition occurred in the past, although this most recent occurrence may be unique because it appears to be largely caused by human activity.

If the springs and geysers continue to not flow, and sinter continues to not be deposited, eventually the development of these sinter soils will slow and, ultimately, stop as all available deposits of sinter are weathered to soil. However, because of the large areal extent and thickness of the existing sinter deposits, and the very slow rate at which the sinter is likely to weather to soil, a reduction in the sinter available for weathering to soil is not considered a realistic scenario for tens of thousands to hundreds of thousands of years to come. In the short term (hundreds of years to tens of thousands of years), if the sinter continues to not be deposited, the rate of development of sinter soil may actually increase, in that all deposited sinter would be available for weathering, and none would be covered by actively depositing sinter.

Surface Water: All drainages within the Steamboat Hills Project area are either intermittent or ephemeral. Surface flows in the Steamboat Hills Project area occur only during spring runoff and high-yield storm events. Immediately to the east of the Steamboat Hills Project area is Steamboat Creek, which is a perennial creek. Steamboat Ditch is located immediately north and east of the Steamboat Hills Project area.

The Steamboat Springs geothermal area includes numerous historically active hot springs and geysers. Although historically the third most active geyser area in the United States (behind Yellowstone Park and Beowawe, Nevada), the natural geysers were mostly most frequently reported as small and inconspicuous, typically erupting to heights of only 1 to 3 feet, and frequently no geysers were erupting within the complex. Because of this relatively unique occurrence of the thermal activity, the USGS conducted an extensive study of the Steamboat Springs area between 1945 and 1952. This study documented 74 springs in two (2) main areas of thermal activity (the Main and Low Terraces). Another area, known as the High Terrace, was identified as an area of previous hot springs activity. However, since the spring's discovery in 1863, no activity in this High Terrace area has been documented. Because of these unique thermal features in the Steamboat Hills, the BLM established the 40-acre Steamboat ACEC on a portion of the Main Terrace to protect the hot springs and geysers.

In 1986 it became evident that the springs on the Main Terrace were undergoing a systematic decline, although the decline may have begun earlier. By early 1986, only one (1) spring was discharging and water levels continued to decline through mid-1986. Discharge from the last flowing spring ceased in 1989. The decline in the spring discharge and the water levels in the thermal area is believed to have been caused by several factors.

Ground Water: Ground water in the Steamboat Hills area, and the Truckee Meadows in general, is abundant and highly utilized. The ground water is characterized by both geothermal aquifers and non-geothermal (fresh-water) aquifers. Fresh ground water is derived principally from the alluvial materials which overlie fractured igneous and metamorphosed volcanic rocks. The fresh waters in the alluvial material provide water supplies to South Truckee Meadows General Improvement District (STMGID) wells in the Whites Creek/Thomas Creek fan areas, to Westpac Utilities wells within the valley floor, and to numerous individual domestic wells.

Geothermal waters generally reside in, and are derived from, the fractured granitic and metamorphosed volcanic rocks underlying the alluvium, with some exceptions. Hot springs and geysers of the Steamboat Hills issue from alluvial deposits at the Main and Low Terraces. These alluvial deposits are also tapped by a number of shallow, lower temperature geothermal wells. In some instances, the chemical quality of these shallow wells suggests mixing of the fresh and geothermal waters; in others, the low temperature wells tap water of purely geothermal origin.

Although the hydrology of the Steamboat Hills geothermal system is complex, some general features of the system are known. Alternative models to explain the system have been suggested, though no single model clearly and unequivocally explains all of the observed phenomena all of the time. One model of the geothermal system postulates that there are at least three (3) geothermal systems operating beneath the Steamboat Hills. Each system is described as hydraulically isolated from the other by pressure boundaries or impermeable rocks. The three (3) systems are: a deep, high-temperature system tapped by the Steamboat Hills Project production and injection wells; a shallow, moderate-temperature system tapped by the SBG wells; and the low-temperature system(s) related to the hot springs at the Main and Low Terraces and thermal ground water found in the alluvial aquifer. Evidence cited as supporting this interpretation includes:

- Differences in elevation between the three (3) zones;
- Differences in temperature at each of the systems and the temperature gradient between the reservoirs;
- No convincing evidence of communication between the Steamboat Hills Project production/injection horizon and the hot springs; and
- Observed pressure support in the Steamboat Hills Project reservoir due to injection.

A second model suggests that only one (1) geothermal system operates at Steamboat. This model holds that regions of localized high permeability associated with faults and fractures exist within otherwise impermeable rocks and there is a degree of communication between some of these different systems. The model further suggests that upflow from the Steamboat Hills Project production horizons feeds the moderate temperature reservoir tapped by SBG and the Main Terrace. Evidence cited for this model includes:

- A perceived response at the hot springs to some Steamboat Hills Project production episodes; and
- General similarities in gross chemistry of the fluids from the different areas.

In reality, a conceptual model which depicts the Steamboat Hills geothermal system probably lies somewhere between the two (2) models discussed above.

Between 1985 and 1990, water level declines of 17 to 27 feet have been observed in fresh ground water wells completed in the alluvial aquifer in the southwest Truckee Meadows. Similar declines have been noted in available data for hot springs on the Main Terrace and wells completed both in the high-temperature reservoir and cold-water aquifers in the Steamboat Hills. The total decline in the head of the reservoir supplying thermal water to the hot springs and geysers system was probably close to 17 feet in 1989, and estimated to be as much as 20 feet in 1990. Significant reductions in the discharge of geothermal waters from the Steamboat Hills geothermal system have also been postulated, but this may simply reflect a diversion of geothermal waters into the shallow ground water system as ground water levels declined. The similarity in data trends for the different hydrostratigraphic units suggests that changes in water level in both the geothermal reservoir and alluvial aquifers may have a common cause or causes. The extended period of below-normal precipitation is also a factor. Based on comparisons of seasonal freshwater production rates and monitoring wellwater levels, and aquifer modelling, perhaps as much as 12 to 24 feet of the decline in water levels in the alluvial aquifer near the Steamboat Hills from 1986 through 1991 (2 to 4 feet per year) may be attributable to ground water withdrawals for domestic and quasi-municipal use.

Based on their analysis, Sorey and Colvard state that most (80 to 95 percent) of the long-term decline in the water table at the Main Terrace may be due to effects of declines in water levels in the shallow ground water system. Evidence also suggests that the specific impact of the Steamboat Hills Project's current operations on the thermal water levels under the Main Terrace (estimated to be 0.5 to 1.0 feet by Nork and 1.0 to 3.0 feet by Sorey and Colvard) has been small compared to the thermal water level declines created by other influences, such as the lowering of the nonthermal water table and the drought. Although the lowering of ground water tables is generally reversible (through increased recharge, decreased production, or manipulation of pressure gradients), based upon the observations to date, it is unlikely that discharge from the hot springs and/or geysers would resume even if production at the Steamboat Hills Project were to cease or be mitigated and recharge to the shallow ground water system from precipitation were to return to normal, because increased ground water withdrawals from the alluvial aquifer appear to be the major cause of thermal water level declines in the Main Terrace area.

Air Resources: The climate of the Steamboat Hills is characterized by warm, dry summers and cool, moist winters with local variations due to elevation and slope aspects. The mean annual precipitation at the Cannon International Airport monitoring station was 7.49 inches for the period from 1951 through 1980. Since the 1984-85 precipitation year, drought conditions have existing in the region for approximately eight (8) years. Between 1984 and 1989 average annual precipitation was 6.39 inches and in only one (1) year since 1984 was precipitation greater than the 7.49-inch historic average. Other periods of drought conditions in the region have also existed in recent history, particularly during the 1940's and again during the 1970's.

Air pollution in the Steamboat Hills Project area is generally of greater concern during the winter months, when temperature inversions trap pollutants near the surface. Most pollutants of concern in the Steamboat Hills Project area are combustion emissions resulting from motor vehicle traffic and wood burning. Air pollutant monitoring was conducted in the Steamboat Hills Project area from mid-January to mid-June, 1986 as part of the baseline environmental data gathering that was conducted for the Steamboat Hills Project. The Steamboat Hills Project emits essentially no pollutants, except for H_2S. The Steamboat Hills Project plant currently utilizes a chemical abatement system that scrubs the noncondensible gases exiting the power plant condenser in a packed tower to remove most of the H_2S entrained in the steam prior to release of the gases to the atmosphere. This chemical abatement tower system utilizes sodium hydroxide to scrub the noncondensible gases to remove approximately 95 to 97 percent of the H_2S prior to release to the atmosphere. The amount of H_2S actually released to the atmosphere during normal Steamboat Hills Project operations ranges from approximately 3.0 to 4.5 lb/hr. This amount is substantially less than the 5.5 lb/hr limit set by the Washoe County District Health Department. The previously approved modifications to the Steamboat Hills Project's H_2S abatement system would reduce current average emissions of H_2S by approximately 50 to 70 percent.

Since the H_2S abatement system was installed at the Steamboat Hills Project in 1987, there have been a few instances when local residents in Pleasant Valley observed detectable H_2S. These observations could not always be correlated with malfunctions in the Steamboat Hills Project H_2S abatement system. As a result of these observations, the Steamboat Hills Project agreed to undertake a 90-day H_2S monitoring program, initiated in June, 1992 at two (2) stations in Pleasant Valley. During operation of the monitoring program, several observations of H_2S were made by local residents that were coincident with monitoring analyses of greater than 5.0 part per billion (ppb) H_2S equivalent. One of these observations correlated with a malfunction in the Steamboat Hills Project H_2S abatement system.

Biological Resources: A mixed shrub/forb/grass community with two (2) variations is dominant in the Steamboat Hills Project area. One (1) of the variations is dominated by big sagebrush with lesser amounts of low sagebrush. The other variation is distinguished by desert needlegrass with lesser amounts of big sagebrush and Thurber needlegrass.

Altered andesite buckwheat, a.k.a. Lobb buckwheat is a Federal category 2 candidate species, which occurs within the study area in Section 32, Township 18 North, Range 20 East, and in Sections 26 and 35 in this same township, although outside of the study area. Additional individuals have also recently been identified in Sections 28 and 29 of Township 18 North, Range 20 East. This species is known to favor areas of acidic soil derived from historically hydrothermally altered andesite rock.

Steamboat buckwheat, Federally listed as an endangered species and state-listed as critically endangered, has been observed in Sections 28, 29, and 33, Township 18 North, Range 20 East. This species inhabits only those areas around the historically active and fossil hot springs on the Main, Low and High Terraces in the Steamboat Hills area. The species was proposed for Federal listing as endangered in 1985, and actually Federally listed as endangered in 1986, because of its limited range and plants were able to occupy the site, possibly out-competing the Steamboat buckwheat, which may cause it to decline or die out completely at a given site.

As part of the approval of the 1987 Steamboat Hills Geothermal Project POO/POU, formal consultation with the U.S. Fish and Wildlife Service (USFWS), under Section 7 of the Endangered Species Act, as amended, was conducted because the then-proposed activities were presumed to have the potential to directly or indirectly affect the Steamboat buckwheat. The analysis of potential impacts in the USFWS Biological Opinion concluded that no direct impacts would occur, but that indirect impacts from the Steamboat Hills Project could possibly develop if the Steamboat Hills Project altered the hydrologic regime of Steamboat Springs. However, the Biological Opinion concluded that the then proposed Steamboat Hills Project would not likely jeopardize the continued existence of the endangered Steamboat buckwheat as a result of alteration of the hydrologic regime. Monitoring of the hydrology of the surface water, ground water and hydrothermal features was to be conducted to determine if significant adverse impacts were occurring. If alteration of the hydrologic regime were to occur as a result of the proposed Steamboat Hills Project, then mitigation measures were to be implemented to minimize the impact.

Since the USFWS Biological Opinion was issued in 1987, a number of factors have interacted on the hydrology of the Steamboat Springs, causing the hot springs and geysers to cease flowing in 1989. These factors are, in order of believed importance: increased ground water withdrawals for domestic and municipal consumption; the extended regional drought; and the production and injection of geothermal fluids.

Because the hot springs and geysers are currently not flowing, siliceous sinter is currently not being deposited on the Main or Low Terraces. If the springs and geysers continued to not flow for a long period of time, and sinter continued to not be deposited, eventually the development of sinter soils would slow and, ultimately, stop as all available deposits of sinter were weathered to soil. The existing sinter soils would mature to the point that the Steamboat buckwheat would likely be pushed out by plants more competitive in the deeper, more mature soils. Because of the large areal extent and thickness of the existing sinter deposits, and the very slow rate at which the sinter weathers to soil, an appreciable reduction in the sinter available for weathering to soil is not considered likely for tens of thousands to hundreds of thousands of years. In the short term (hundreds of years to tens of thousands of years), if the springs do not flow and the sinter continues to not be deposited, the rate of development of sinter soil may actually increase, because all deposited sinter would be available for weathering, and none would be covered by actively depositing sinter. This would result in increased habitat for the Steamboat buckwheat over this time period, both because of the increase in immature sinter soils for the Steamboat buckwheat to colonize, and because no geothermal fluids, in which the Steamboat buckwheat apparently cannot grow, would be discharged to the surface to reduce the available sinter soils.

In 1991 a detailed, intensive survey of the Steamboat buckwheat on approximately 110 acres of private land in the southwestern portion of Section 28, Township 18 North, Range 20 East, MDB&M, was conducted as part of the SBG 2 and 3 expansion project for the Nevada Division of Forestry (NDF) Conditional Permit. This survey identified two (2) major populations, as well as several smaller, more fragmented populations, of Steamboat buckwheat in Section 28. The locations of these populations were generally consistent with those identified in the 1986 survey. In October of 1991, the Conditional Permit for Disturbance or Destruction of Critically Endangered Species for SBG 2 and 3 was issued and among other requirements, the permit required that a conservation agreement be "validated" prior to construction activities, and a management plan for the Steamboat buckwheat be developed and implemented within one (1) year from the date of permit issuance. SBG contracted with The Nature Conservancy to manage and implement the required mitigation measures, and as part of the construction approximately 17,000 individual Steamboat buckwheat plants were removed from the SBG 2 and 3 project area and either transplanted to other areas in Section 28 or to greenhouses for study.

A formal consultation with the USFWS concluded in 1993 with a USFWS Biological Opinion that the Proposed Action was not likely to jeopardize the continued existence of the Steamboat buckwheat in the foreseeable future.

A thirty-year Steamboat buckwheat management plan is currently being written by The Nature Conservancy for the 110-acre SBG 2 and 3 geothermal lease, which will include monitoring methods and techniques for the long-term protection of the existing Steamboat buckwheat populations, as well as the mitigated areas, inside the 110-acre SBG 2 and 3 geothermal lease area. This plan will be available for public review and implementation in the Spring of 1993.

Land Use: The Steamboat Hills Project area is located within the Steamboat Springs Unit Area in the Steamboat Springs KGRA on both public and private lands. Federal lands within the Steamboat Springs Unit Area are administered by the U.S. Forest Service. However, all geothermal-related development within the Steamboat Springs Unit Area requires the approval of the BLM, pursuant to the Geothermal Steam Act of 1970. The Steamboat Hills Project, a 12.5 MW electric geothermal power plant, has been in operation since early 1988. A 6.8 MW electric binary geothermal power plant which is owned by SBG is located approximately 1 mile north of the Steamboat Hills Project area.

Other land uses within and/or around the study area include residential uses, transportation, agriculture, livestock grazing, and vehicle-oriented recreation.

The BLM's Steamboat ACEC is located in the NE¼ of the NW¼ of Section 33, Township 18 North, Range 20 East, MDB&M, approximately 0.5 miles northeast of the Steamboat Hills Project area. The Steamboat ACEC was created by the BLM to preserve and protect the geothermal and geothermal related features found (including the Steamboat buckwheat) in the vicinity. Through an agreement between the BLM and Washoe County, Washoe County plans to develop a park with interpretive sites and recreation facilities within the Steamboat ACEC.

<u>Socioeconomics</u>: The Steamboat Hills Project area is located in Washoe County within northwestern Nevada. The nearest population center is the Reno/Sparks metropolitan area, which is located approximately five (5) miles north of the Steamboat Hills Project area.

1.3. Summary of Potential Impacts and Mitigation Measures

The proposed activities are to be conducted over several years and CPI plans to conduct these activities beginning as soon as conditions permit in 1993. Of the environmental resources present within the study area, a number are considered not to be potentially impacted by the Proposed Action and no mitigation measures are considered necessary. These include; physiography, geology, wildlife resources, cultural resources, paleontological resources, wilderness, visual resources, and noise, and are not further discussed in this section. For the environmental resources which may potentially be impacted by the Proposed Action, a summary of the potential impacts and identified mitigation measures are outlined in Table 1-1.

Implementation of the No Action Alternative would result in none of the environmental impacts of the Proposed Action and the positive indirect economic effects to Washoe County and its residents would also not occur.

Table 1-1: Summary of Potential Impacts and Mitigation Measures of the Yankee/Caithness Steamboat Hills Geothermal Project POO/POU Amendment for Geothermal Fluid Rate Increase

Resource	Potential Impacts	Mitigation Measures
Mineral Resources	Under the Proposed Action, the extraction of heat from the additional production and injection of geothermal fluids may increase the rate at which the reservoir is cooling. However, once project operations cease, which is anticipated to be in 30 years, the accelerated cooling will stop, and the reservoir is expected to return (over a few years to a few tens of years after cessation of operations) to essentially pre-production thermal conditions, resulting in no long-term impacts to the mineral (geothermal) resources of the area.	None considered necessary.
Soils	Because there would be no new surface disturbance associated with the Proposed Action, there would be no direct impacts to the soil resources in the study area from implementation of the Proposed Action. Implementation of the Proposed Action, if not correctly mitigated, may slightly increase the existing drawdown of the thermal water table below the Steamboat hot springs. However, because the Steamboat hot springs and geysers have already ceased flowing, and because other factors have been judged to be the primary reason for this cessation of flow of the springs, the Proposed Action, the Proposed Action will not have an effect on the now-ceased flow of the Steamboat hot springs and/or geysers, and thus on the deposition of silicious sinter and, ultimately, the formation of silicious sinter soil, until and unless the effects of the other factors are first reversed. Should the adverse effects of the other hydrologic factors be reversed, such that the springs would be able to flow again except for any effects of the Proposed Action, any effect the Proposed Action may have on the hot springs and geysers system, and ultimately the deposition of silicious sinter and the weathering of the sinter to soil, would only last for the duration of the Project and a short time (a few years to a few tens of years) after operations cease. As a result, implementation of the Proposed Action could, at worst, have a small, short-term, indirect impact on the silicious sinter soils, and would not have a long-term indirect impact to these sinter soils associated with the hot springs and geysers.	Because the only potential for impacts to soils from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Ground Water are considered necessary.
Surface Water	Implementation of the Proposed Action may as much as double the possible existing drawdown of the thermal water table from the Steamboat Hills Project, although the predicted drawdown from the other stresses on the hydrologic system, including the other geothermal projects and extensive ground water developments, are predicted to be substantially greater. However, because the hot springs and geysers have already ceased flowing, and other factors have and will contribute much more than the Proposed Action to this water table drawdown, the Proposed Action will not have an effect on the flow of the Steamboat hot springs and/or geysers until and unless the effects of the other factors are reversed. Should the adverse effects of the other hydrologic factors on the hot springs be first reversed, and should any residual, unmitigated adverse hydrologic effects of the Steamboat Hills Project (including the Proposed Action) still be great enough to prevent the springs from flowing again, there should be no long-term impacts (beyond a few years to a few tens of years after cessation of operations) to the geothermal reservoir, and thus the flow of the Steamboat hot springs and geysers, from implementation of the Proposed Action, because these residual effects of the Steamboat Hills Geothermal Project production and injection activities are reversible over this time period.	Because the only potential for impacts to surface water hydrology from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Ground Water are considered necessary.

Resource	Potential Impacts	Mitigation Measures
Ground Water	The results of the modelling suggest that doubling the production rate of geothermal fluid to 3.8 x 10^6 lb/hr, and the actual consumption of geothermal fluid to 0.38 x 10^6 lb/hr, could be expected to produce as much as a one (1) psi pressure decline in the geothermal reservoir under the Steamboat hot springs, which translates into a thermal water table decline of approximately 0.5 feet. This compares to the 20 psi pressure decline predicted to occur as a result of the operation of all of the current and proposed geothermal projects. An alternative, but more simplistic, method of estimating the possible impact of doubling the geothermal fluid production and consumption rate is to assume that the changes to the geothermal reservoir will be linear with the changes to the stresses to the system; that is, doubling the production/consumption rate would double the decline in the thermal water table. Given that the estimates for the decline in the thermal water table under the Steamboat Hills hot springs that has been produced by the existing Steamboat Hills Geothermal Project range from 0.5 to 3 feet, it would follow that a doubling of the production/consumption rate could double the declines in the thermal water table, adding an additional 0.5 to 3 feet to the current thermal water table decline. The projected life of the Proposed Action is anticipated to be 30 years. At the end of the project life, the operation of the power plant and the production and injection wells would cease, thus ending the Project's utilization of the geothermal resource. Because any effects that the production and injection activities were having on the thermal reservoir are judged to be reversible over time, these effects would begin to dissipate, first at the production and injection areas, then propagating to the other areas of the geothermal reservoir. As a result, there should be no long-term impacts (beyond a few years or a few tens of years after cessation of operations) to the geothermal reservoir and hydrology of the area from implementation of the Proposed Action, even if there are some short-term impacts.	The mitigation consists of two (2) parts. The first part is a monitoring program which can establish the nature and extent of the actual or impending hydrologic impacts, and can allow the definition, implementation and evaluation of suitable mitigation measures for the identified hydrologic impacts. It is recognized that implementation of a monitoring program is <u>not</u> actually mitigation *per se*, but a collection of data necessary to implement and evaluate mitigation measures. The second part of the mitigation program is the definition and implementation of the actual mitigation measures. A number of geothermal wellfield techniques are possible to accomplish the mitigation of potential impacts. The choice of which mitigation measures to implement must rely on the full range of hydrologic monitoring data available at the time, and upon its quality and consistency.
Air Resources	Aerial emissions of H_2S would change only slightly as a result of the increase in fluid flow through the power plant associated with the Proposed Action. However, the increased H_2S produced under the Proposed Action, when combined with the planned decrease in current H_2S emissions, would result in no H_2S emissions over the 5.5 lb/hr limit set by the Washoe County District Health Department. The potential for upset emissions from the increased use of geothermal fluid by the Project also exists, although any such emission would be very rare. No significant degradation of the existing ambient air quality should occur as a result of the Proposed Action, and project emissions should not exceed local, state and Federal standards. There would be no direct impacts to any Class I airsheds as a result of implementation of the Proposed Action.	None considered necessary.

Resource	Potential Impacts	Mitigation Measures
Vegetation Resources	Implementation of the Proposed Action will not directly impact any vegetation communities, including any direct impact to any altered andesite or Steamboat buckwheat populations or altered andesite or Steamboat buckwheat habitat, or any indirect impacts to any altered andesite populations or habitat. Implementation of the Proposed Action may slightly increase the existing drawdown of the thermal water table below the Steamboat hot springs if not properly mitigated. However, because the Steamboat hot springs and geysers have already ceased flowing, and because implementation of the Proposed Action may create only a relatively small additional decline in the thermal water table feeding the Steamboat hot springs reservoir compared to other factors, implementation of the Proposed Action will not have an effect on the flow of the Steamboat hot springs and/or geysers, the deposition of silicious sinter, the formation of silicious sinter soil, and thus the Steamboat buckwheat, until and unless the effects of the other hydrologic factors are first reversed. Should the adverse effects of the other hydrologic factors on the springs be reversed, and the adverse hydrologic effects of the Steamboat Hills Project (including the Proposed Action) still be great enough to prevent the springs from flowing again, the potential for any impact to the Steamboat buckwheat from the cessation of flow of the hot springs is extremely unlikely in the short term (hundreds to thousands of years), and low in the long term (hundreds to thousands of years and more). Any effect implementation of the Proposed Action may have on the hot springs and geysers system, and ultimately the deposition of silicious sinter and the weathering of the sinter to soil, would only last for the duration of the Steamboat Hills Project and a short time (a few years to a few tens of years) after operations cease. As a result, implementation of the Proposed Action could, at worst, have a small, short-term, indirect impact on the silicious sinter soils, and thus an even smaller potential indirect impact on the Steamboat buckwheat, and would not have any long-term impact to these sinter soils associated with the hot springs and geysers or the Steamboat buckwheat.	Because the only potential for impacts to vegetation communities, and specifically the Steamboat buckwheat, from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Ground Water are considered necessary.
Land Use and Status	Implementation of the Proposed Action, if not properly mitigated, is predicted to increase possible existing drawdown of the thermal water table from the Steamboat Hills Project. However, because the hot springs and geysers have already ceased flowing, and other factors have contributed much more than the existing Steamboat Hills Project or Proposed Action to this water table drawdown, the Proposed Action will not have an effect on the now-ceased flow of the Steamboat hot springs and/or geysers, and thus the Steamboat ACEC, until and unless the effects of the other factors are first reversed. If these effects of the other hydrologic factors are reversed, any unmitigated residual effects that the Steamboat Hills Project (including the Proposed Action) production and injection activities would have on the thermal reservoir are reversible over time, so there should be no long-term impacts (beyond a few years to a few tens of years after cessation of operations) to the geothermal reservoir, the flow of the Steamboat hot springs and geysers, and thus the Steamboat ACEC, from implementation of the Proposed Action.	Because the only potential for impacts to land use, and specifically the Steamboat ACEC, from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Ground Water are considered necessary.
Socioeconomics	Because the implementation of the Proposed Action would not result in any net increase or decrease in the number or type of employees at the Steamboat Hills Project, no appreciable direct impacts to the area's economy, housing or government services would be expected. However, because increased production of geothermal resources would result in increased royalties being paid to private lessors and the Federal government (which returns one-half of these royalties to the state), some indirect economic benefits would result.	None considered necessary.

utilization submitted under the BLM's geothermal regulations that are codified at 43 CFR 3200. This EA is intended to satisfy that requirement for the proposed increase in the production and injection of up to 3.8 x 10^6 lb/hr of geothermal fluid, as well as to satisfy the requirements of the National Environmental Policy Act (NEPA) and its implementing regulations to ensure that environmental information is available to public officials and citizens before decisions are made and actions are taken.

2.2. Steamboat Hills Project Environmental/Regulatory History

A POO/POU, the principal authorization granted by the BLM for geothermal resource operations on Federal geothermal leases, was first approved by the BLM on June 29, 1987 (1987 POO/POU) for construction and operation of the Steamboat Hills Project. The 1987 POO/POU approved the construction and operation of a single-flash condensing turbine, located on private lands, which would utilize approximately 1.9 x 10^6 lb/hr of geothermal fluid for the power plant to operate at its design capacity of approximately 12.5 MW (net). The geothermal fluid was to be obtained from four (4) or five (5) production wells, and the spent geothermal fluid was to be injected into one (1) or two (2) injection wells. Two (2) of the proposed production wellsites (wellsites 83-6 and 28-32) were to be located on public lands managed by the BLM; the remainder were to be located on private lands or their locations were not specified. All the geothermal production and injection wells, power plant facilities and other ancillary facilities were also approved by other responsible agencies, including issuance of a Washoe County Special Use Permit (SUP), a Nevada Department of Environmental Protection (NDEP) Authorization to Dispose (Injection Permit), and a Nevada Public Service Commission (NPSC) Utility and Environmental Protection Act (UEPA) Permit.

Prior to approval of the 1987 POO/POU, an EA (1987 EA) was prepared to analyze the possible impacts from implementing the 1987 POO/POU. Based upon the information contained in the 1987 EA, a Finding of No Significant Impact (FONSI) was issued and the Steamboat Hills Project was approved by a Decision Record, which concluded that no significant impacts would occur to the major resources or issues of concern (air quality, endangered species, hydrothermal features, cultural resources, and water quality). Central to this conclusion of no significant impacts was the BLM's decision to require implementation of a hydrologic monitoring and mitigation program, as specified in the 1987 EA, to ensure that potential impacts to the hydrologic reservoir under the Steamboat Hot Springs, and thus the Steamboat Geysers Basin Area of Environmental Concern (Steamboat ACEC), did not occur.

The hydrologic monitoring program required in 1987 included: continuous measurements of production and injection rates; pressure measurements from seven (7) stratigraphic test holes; water table elevations, temperature and water chemistry measurements from up to 13 wells; visually estimated discharge, depth to water, temperature, pH and electrical conductivity (EC) from six (6) springs; and flow rates and chloride levels from eight (8) creek, ditch and well locations. The BLM approval of the 1987 POO/POU also stipulated that should operation of the Steamboat Hills Project cause a significant adverse impact to the Steamboat ACEC, the BLM authorized officer retained the authority to amend, suspend or abandon well or power plant operations. Formal consultation with the U.S. Fish and Wildlife Service (USFWS) regarding potential impacts from implementation of the 1987 POO/POU to the Steamboat buckwheat, a Federally listed endangered species, which was associated with soils derived from sinter deposited by the Steamboat Hot Springs, resulted in the USFWS issuing a "no jeopardy" opinion. This opinion was based, in part, on the BLM requirements for the hydrologic monitoring program and retained authority to stop geothermal fluid production.

The Steamboat Hills Project was constructed in 1987 and commenced commercial operation in February 1988. It currently consists of the operation of the single-flash geothermal electrical generation facility; geothermal production and injection wells; and associated facilities such as pipelines, access roads, transmission line, etc. The required hydrologic monitoring program has also been implemented and is ongoing.

As of July 1, 1988, the Federal public lands located within the Steamboat Springs Unit, with the exception of the 40-acre Steamboat ACEC, were transferred to the Toiyabe National Forest, and have since been managed by the U.S. Forest Service (USFS). However, the Geothermal Steam Act of 1970, as amended, identifies the Secretary of the Department of the Interior, or his designee (in this case, the BLM), as the Federal agency responsible for regulating the development of geothermal resources located on any Federal lands which have been leased for geothermal resource development, with concurrence of the surface management agency (in this case, the USFS). The POO/POU is the principal authorization granted by the BLM for geothermal resource operations on Federal geothermal leases, whether located on lands managed by the BLM, USFS, or any other Federal agency. Under an approved POO/POU, the actual construction of production and injection wells on Federal lands requires the BLM approval of an Application for Permit to Drill (APD), and the approval of a Plan for Production is required to ensure proper royalty calculations and payments to the Federal government.

In January, 1990 CPI submitted applications to the appropriate Federal, state and local agencies, including an Amendment to the 1987 POO/POU (1990 POO/POU) to the BLM, to increase overall electrical generation at the Steamboat Hills Project by placing air- or water-cooled binary generation units into production on private lands in the immediate vicinity of the existing flash steam power plant, as well as to modify the existing hydrogen sulfide abatement system and modify other minor facility support systems, also constructed on private land. The binary generation units would utilize the existing produced geothermal fluids and condensed steam to power a working fluid prior to injection of the geothermal fluid. This working fluid would, in turn, power the binary turbines and generators to produce additional electricity.

In response to CPI's 1990 POO/POU, the BLM determined in February, 1990 that the construction and operation of the binary units and other proposed changes would not impact Federal lands, and utilization of the binary units would not require any increase in total well production from the then-approved rates. On this basis, the BLM determined that no Federal action was involved in the siting and construction of the binary units and other proposed changes in the 1990 POO/POU and, therefore, no Federal permits under the Geothermal Steam Act of 1970, as amended, or any analysis under NEPA, were required. However, the BLM concluded that if CPI desired to increase the geothermal fluid production rate above the previously approved 1.9×10^6 lb/hr, this would constitute a Federal action requiring an amendment to the 1987 POO/POU and an appropriate environmental analysis under NEPA.

The binary cycle electrical generation units and other ancillary facilities described in the 1990 POO/POU were subsequently approved by the other responsible state and local agencies and are currently in the process of being constructed. These approvals included amendments to the Washoe County Special Use Permit (SUP) and the Nevada Public Service Commission (NPSC) Utility and Environmental Protection Act (UEPA) Permit previously granted for the Steamboat Hills Project. The amendment to the County SUP included an environmental analysis of the potential impacts of the changes to the Steamboat Hills Project, including a detailed analysis of the potential visual impacts of the binary units and air impacts. The same information was utilized by the NPSC to grant their UEPA Permit amendment.

2.3. General Description of the Proposed Action

CPI's 1991 Amendment to the 1987 POO/POU (1991 POO/POU, or the Proposed Action) proposes to increase the approved maximum total geothermal fluid production and injection rates for the Steamboat Hills Project, from the public and private lands within the Steamboat Springs Unit Area, up to a maximum of 3.8×10^6 lb/hr. CPI states that the primary reason for the proposed increase is that lower-than-originally-expected temperatures have been encountered in the completed geothermal wells at the existing Steamboat Hills Project. As a result, the existing flash-steam power plant requires approximately 2.2×10^6 lb/hr of geothermal fluid, more than the previously approved 1.9×10^6 lb/hr, to operate at its design capacity of 12.5 MW. At this higher production rate, the approved binary units would generate approximately 8 MW. A secondary reason for increasing the production and injection rate from the previously approved 1.9×10^6 lb/hr of geothermal fluid, to approximately 2.9×10^6 lb/hr, is stated to be that this flow rate would allow the existing flash steam plant (together with the three (3) binary units) to operate at an increased, maximum capacity and generate up to a total annual average of approximately 25 MW of power. The final reason for the proposed increase is that more geothermal fluid (up to the requested 3.8×10^6 lb/hr) would be required in the future to operate all facilities at their maximum output if the temperature of the geothermal fluid produced from the reservoir declined over time. The Steamboat Hills Project proposed operating scenarios, fluid requirements, and power generation figures are summarized in Table 2-1.

Table 2-1: Summary of the Steamboat Hills Project Operating Scenarios, Fluid Requirements and Power Generation

Steamboat Hills Project Operating Scenarios	Geothermal Fluid Requirements	Power Production		
		Flash Plant	Binary System	Total
Design generating capacity with existing reservoir temperature	2.2×10^6 lb/hr	12.5 MW	8 MW	20.5 MW
Maximum generating capacity with existing reservoir temperature	2.9×10^6 lb/hr	13 MW	12 MW	25 MW
Maximum generating capacity with lower reservoir temperature	3.8×10^6 lb/hr	13 MW	12 MW	25 MW

In addition to the 1991 POO/POU filed with the BLM, the only other permit required for implementation of the Proposed Action to increase the geothermal fluid production and injection rates for the Steamboat Hills Project is an amendment to the Authorization to Dispose (Injection Permit) from the NDEP. The amendment to this permit, to increase the rate of injection up to a maximum of 3.6×10^6 lb/hr, was approved on July 9, 1991. In addition, an approved Application for Permit to Drill would be required prior to actual construction of any production or injection wells previously approved under the 1987 POO/POU, and approval of an amended Plan for Production, to ensure proper Federal royalty calculations and payments, would be required prior to actually increasing production.

2.4. Public Scoping and Environmental Review

This EA was prepared in accordance with BLM regulations for the management of geothermal resources (43 CFR 3200), the Council of Environmental Quality's regulations for implementing the National Environmental Policy Act of 1969 (NEPA) (40 CFR 1500-1508), and BLM guidelines for implementing NEPA (USDI, 1988). This EA was prepared by a third-party contractor, Environmental Management Associates (EMA), using information gathered from the files of, and discussions with: 1) BLM and USFS personnel; 2) other Federal, state and local agencies; 3) public literature; and 4) CPI.

An initial meeting was held between the BLM, CPI and EMA on July 24, 1991, to discuss the preparation of the necessary EA and outline the specific areas of environmental concern associated with the Proposed Action. An Interested Parties Letter (IP Letter) for preparation of the EA was distributed by the BLM on August 15, 1991 to 112 recipients. A copy of the IP letter is included in this EA as Appendix A. Comments regarding the IP Letter were received from four (4) individuals and organizations (Appendix B). Issues raised regarding implementation of the Proposed Action during this scoping process included the potential for the following:

1. Impacts to the flows and water quality (chemistry and temperature) of the hot springs and geysers on the Steamboat Hot Springs Main Terrace;

2. Impacts to the quality of ground water used for domestic consumption;

3. Impacts to air quality from additional emissions of noncondensible gases resulting from additional geothermal fluid being flashed;

4. Indirect impacts to Steamboat buckwheat and Steamboat buckwheat habitat resulting from potential changes in hot spring and geyser flows;

5. Indirect impacts to silicious soils on the Main Terrace resulting from potential changes in Main Terrace hot spring and geyser flows;

6. Indirect impacts to the Steamboat ACEC resulting from potential changes in Main Terrace hot spring and geyser flows;

7. Indirect impacts to terrestrial and aquatic wildlife resulting from potential changes in Main Terrace hot spring and geyser flows;

8. Impacts to surface water quality as a result of a possible well blowout;

9. Cumulative impacts from all projects in the Steamboat Hills area to issues 1, 2, and 4 though 7.

Issues 1 through 6 and 9 are addressed in this EA in Chapter 3, Description of the Proposed Action and Alternatives; Chapter 5, Environmental Consequences of the Proposed Action; and Chapter 9, Cumulative Impacts. As discussed above, the Proposed Action is limited to the increase in production and injection rates of geothermal fluid for the Project from 1.9×10^6 lb/hr to a maximum of 3.8×10^6 lb/hr. All other necessary facilities for the production, utilization and injection of the geothermal fluid (wells, power plants, buildings, etc.) have previously received their major approval and are not considered as part of the Proposed Action (see Section 2.3). Accordingly, issues 7 and 8 are not further addressed in this document because there is sufficient existing information and analysis that shows either the Proposed Action does not involve activities that could result in the potential impacts or the resources could not be affected.

Because of the limited nature of the Proposed Action and the nature of the issues developed during scoping, this EA is "focused" on the potential direct impacts of the Proposed Action to the hydrology (thermal and/or fresh water table decline, ground water mixing, and hot springs and geyser flow, etc.) and air quality of the study area; the potential indirect impacts to the Steamboat buckwheat, a Federally listed threatened species, silicious soils in the Steamboat Springs area and the Steamboat ACEC itself; and the cumulative effect from all activities that impact or potentially impact the hydrology and air quality of the study area and/or the Steamboat buckwheat. However, the EA also briefly summarizes the existing environment from the perspective of other environmental resources, and briefly analyzes the lack of potential for any impact to these resources from the Proposed Action.

2.5. Report Organization

This EA has been organized to incorporate the requirements for EA's as outlined in the CEQ regulations and BLM guidelines to implement NEPA. Chapter 3 describes the Proposed Action in detail, and discusses possible alternatives to the Proposed Action and the reason(s), if applicable, for the elimination of any alternatives from further consideration. Chapter 4 discusses the environmental resources of the Steamboat Hills Project area and surrounding lands. Chapter 5 discusses the potential environmental consequences of the Proposed Action on the environmental resources of the Steamboat Hills Project area and surrounding lands. Chapter 6 discusses the proposed mitigation measures for each of the environmental resources affected by the Proposed Action. Chapter 7 discusses the residual impacts that would result from implementation of the Proposed Action after mitigation. Chapter 8 describes the environmental consequences of the selected reasonable alternatives on the environmental resources of the Steamboat Hills Project area and surrounding lands. Chapter 9 discusses the cumulative impacts to the environmental resources in the surrounding lands and the incremental increase to those cumulative impacts that could potentially result from implementation of the Proposed Action. Chapter 10 provides information on the coordination and contacts made during the course of preparation of this EA. Chapter 11 lists those individuals who participated in the actual preparation of the document and their qualifications. Chapter 12 lists the references used in preparation of this EA.

3. DESCRIPTION OF THE STEAMBOAT HILLS PROJECT, THE PROPOSED ACTION AND ALTERNATIVES

3.1. Existing Steamboat Hills Project Operations

Figure 3-1 shows the location of the current Steamboat Hills Project, as well as the Steamboat Springs (Federal geothermal) Unit and the Unit participating area boundaries. The Steamboat Springs Unit boundary includes both private and public land covering all of Sections 5 and 6 and the N½ of Section 7, Township 17 North, Range 20 East, MDB&M; and all of Sections 31 and 32, the SW¼ of Section 28, the S½ of Section 29, and the W½ of Section 33, Township 18 North, Range 20 East, MDB&M. For the purposes of this EA, the Steamboat Hills Project area is defined to be the same as the Unit participating area within the Steamboat Springs Unit. In addition, for the purposes of this EA, the EA study area is generally defined as all those lands shown on Figure 3-1.

Access to the Steamboat Hills Project is via an existing paved secondary road from the Mt. Rose Highway (State Route 431). The total permitted surface disturbance for the Steamboat Hills Project, both existing and not yet constructed, is 10 acres. The Steamboat Hills Project has an anticipated life of approximately 30 years.

3.1.1. Current Operations

The Steamboat Hills Project flash-steam power plant currently utilizes steam from three (3) geothermal production wells: No. 83A-6, No. 21-5 and No. 23-5 (see Figure 3-2). These three (3) existing geothermal production wells currently produce a combined total flow rate of approximately 1.6×10^6 lb/hr of geothermal fluid at reservoir temperatures of approximately 410°F, which is below the original

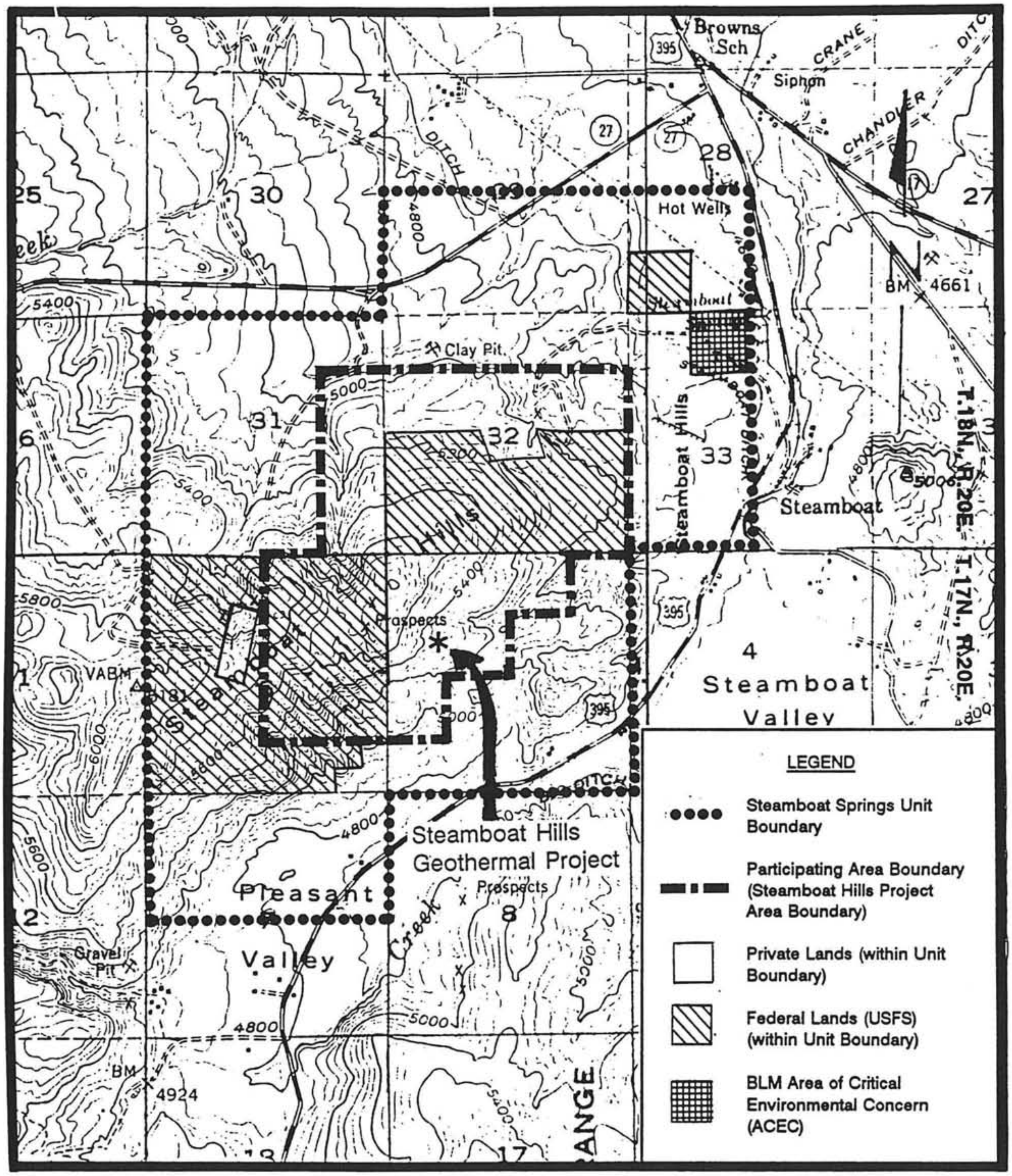


Figure 3-1: Study Area for the Steamboat Hills Geothermal Project EA, Showing the Study Area, Unit Boundary, and the Steamboat Hills Project Area Boundary

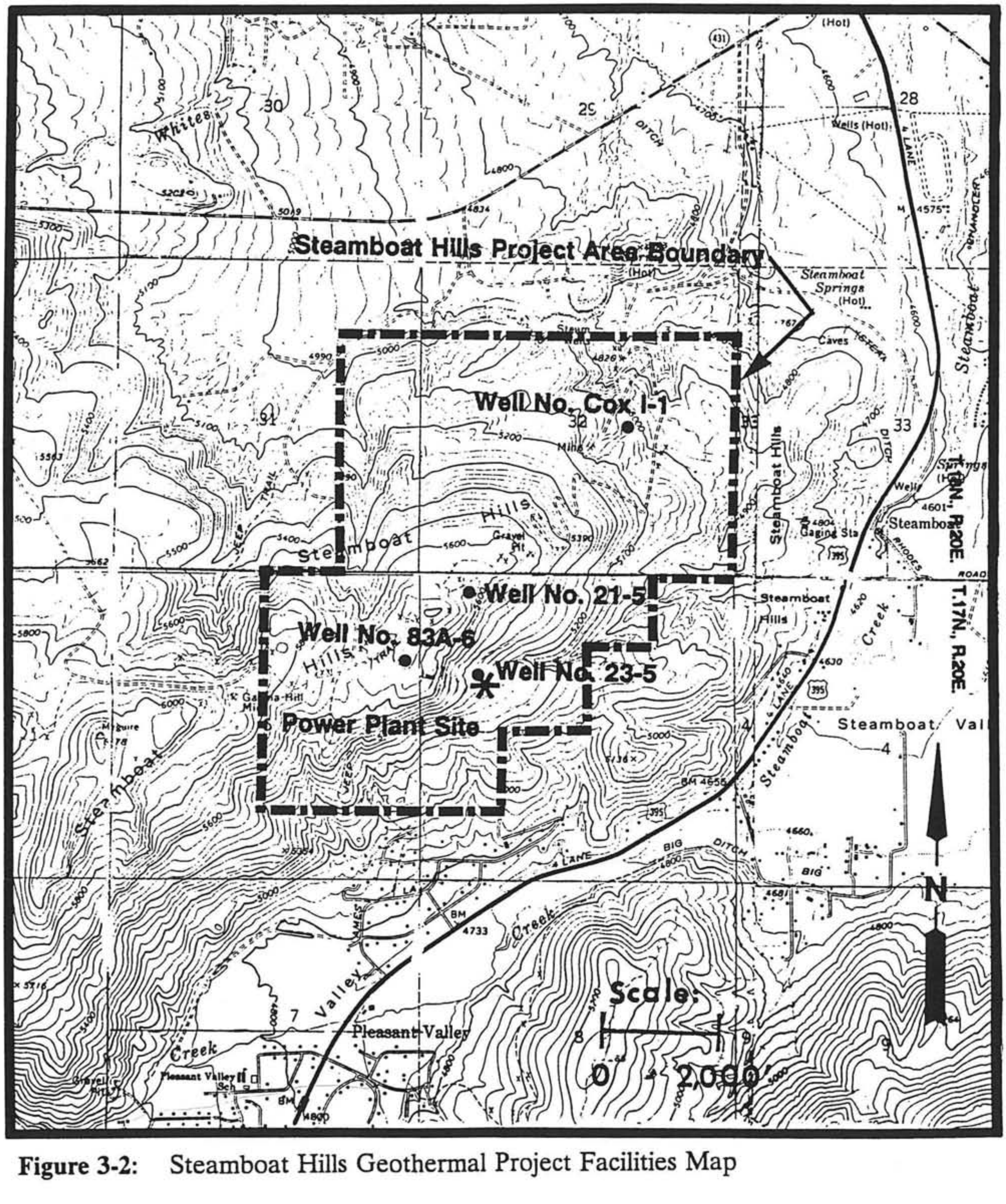


Figure 3-2: Steamboat Hills Geothermal Project Facilities Map

design conditions of 1.9×10^6 lb/hr of geothermal fluid at approximately 460°F. This produced fluid is directed via surface pipelines to, and utilized by, the single-flash geothermal electrical generation facility located on private land in the NW¼ of Section 5, Township 17 North, Range 20 East, MDB&M to produce approximately 10 MW at the plant (which is below the design plant capacity of 12.5 MW). At the power plant site, the geothermal fluid produced by the production wells is directed into a cyclone separator. The geothermal liquids are separated from the geothermal steam and exit the separator at approximately 300°F and are injected into well No. Cox I-1 along with the cooling tower blowdown water.

Approximately 15 percent of the total produced geothermal flow is flashed to steam in the separator and directed through the steam turbine, after which it is condensed to water in a direct contact condenser by the circulating cooling water. The condensed steam becomes the source of the water required to makeup for that portion of the cooling water evaporated, or lost through water droplet drift, from the cooling tower. Under existing operating conditions, the cooling water/condensed steam not lost to the atmosphere during the cooling process is injected as cooling tower blowdown with the separated geothermal liquid into the injection well No. Cox I-1. Due to the dependence of cooling tower atmospheric water loss on the atmospheric temperature and relative humidity, the estimated average water loss (consumption of condensed geothermal steam) is approximately 10 percent of the total quantity of geothermal fluid produced.

Therefore, on a yearly average basis, currently approximately 1.6×10^6 lb/hr of geothermal fluid is produced, 0.16×10^6 lb/hr (about 10 percent of the produced fluid) is consumed, and 1.44×10^6 lb/hr is injected back into the geothermal reservoir system. The minimum injection temperature has been approximately 280°F.

3.1.2. Approved Steamboat Hills Project Facilities Not Yet Constructed

Because the three (3) existing production wells are insufficient to produce the quantity of geothermal fluid authorized by the approval of the 1987 POO/POU (1.9×10^6 lb/hr), CPI is currently developing additional production and injection well(s) to allow the production and injection of the permitted quantity of geothermal fluid in an optimum manner. The additional wells necessary to produce and inject this additional geothermal fluid were previously discussed and approved in the 1987 POO/POU, subject to the approval of an Application for Permit to Drill (APD) for those wells located on Federal lands. An updated Plan for Production must also be approved by the BLM under the existing POO/POU to assure proper calculation and payment of royalties.

Up to two (2) additional geothermal production wells may need to be drilled and completed to produce the authorized 1.9×10^6 lb/hr and have sufficient back-up well capacity. These two (2) additional geothermal production wells would be drilled (or redrilled) from one (1) or more of seven (7) alternative wellsites, all of which are located within the currently defined Steamboat Hills Project area, and include: existing wellsites 83-6 or 28-32 (located on Federal lands); existing wellsites 21-5, 23-5 or 32-5 (located on private lands), or new or expanded wellsites 13-5 or 22-5 (located also on private lands). Wells drilled from the wellsites located on Federal lands (83-6 and 28-32) were previously approved by the BLM in the 1987 POO/POU, subject to the approval of APDs by the BLM for the actual drilling of these wells on Federal lands. The APDs will specify specific well drilling and completion procedures. Any proposed amendment to those procedures will be reviewed by the authorized officer and are subject to sundry notices submitted to and approved by the BLM on Federal lands, and/or the Nevada Department of Minerals (NDOM) on all lands. All other necessary permits and approvals for the drilling of the wells have been obtained.

In addition to those wells necessary to initially produce 1.9×10^6 lb/hr of geothermal fluid, it is expected that each production well will lose some productivity, and possibly temperature, over the life of the well, such that additional production wells may need to be drilled and produced from one (1) or more of these seven (7) wellpads or other wellpads within the Steamboat Hills Project area over the life of the Steamboat Hills Project. As necessary, all production wells may be periodically cleaned out, reworked and/or redrilled over the life of the Steamboat Hills Project. Reworking or redrilling of those wells located on Federal lands has been previously approved under the 1987 POO/POU, subject to BLM-approved sundry notices or Applications for Permit to Drill, respectively.

One (1) or more additional injection wells may also be drilled, completed and utilized in parallel with, or as backup to, existing well No. Cox I-1. These additional geothermal injection wells would be drilled (or recompleted) from one (1) or more of three (3) alternative wellsites, all of which are located within the currently defined Steamboat Hills Project area, and include: existing wellsites 32-5 or Cox I-1 (also known as wellsite 55-32) (both located on private lands); or proposed wellsite 62-32 (also located on private lands). All necessary permits and approvals for the drilling of these wells have been obtained.

As previously stated, CPI plans to increase overall electrical generation by placing air-cooled binary generation units into production on private lands in the immediate vicinity of the existing flash steam power plant (see Section 2.2) and modify the existing hydrogen sulfide abatement system (see below) and modify other minor facility support systems. CPI has already commenced construction of some of these facilities, with commercial operation of the binary units anticipated to commence in 1993. In addition, CPI is in the process of modifying and expanding the existing hydrologic monitoring program, which has been required by the BLM as part of the approval of the 1987 POO/POU (see Section 3.1.3).

Currently, the amount of H_2S actually released to the atmosphere from the cooling tower and chemical abatement tower during normal Steamboat Hills Project operations ranges from approximately 3.0 to 4.5 lb/hr. This is substantially less than 5.5 lb/hr limit set by the Washoe County District Health Department. The planned modifications to the H_2S abatement system include the installation of a new noncondensible gas control system at the existing power plant site to further control the noncondensible gas emissions from operation of the direct contact condenser system for the Steamboat Hills Project. With the new system, the noncondensible gases ejected from the single-flash power plant condenser (which includes nearly all of the H_2S in the geothermal fluid) will first enter a gas compression system. Once compressed, the noncondensible gases will be directed, via a welded steel pipeline to be located immediately adjacent to the existing pipeline to injection well No. Cox I-1, to injection well No. Cox I-1, where the gas will be added to the combined cooling tower blowdown and geothermal brine, and then injected into the geothermal reservoir through the injection well. When in use, the noncondensible gas compression system will eliminate the current emissions of H_2S from the chemical abatement tower, which should result in a substantial reduction (by more than 50 percent) of the H_2S currently emitted to the atmosphere by the Steamboat Hills Project. Estimated emissions of H_2S with the compression system in use are less than 2.0 lb/hr. The existing H_2S chemical treatment system will continue to be maintained as a back-up facility to the new noncondensible gas compression system.

3.1.3. Expanded Hydrologic Monitoring Program

Based upon the data collected under the existing required hydrologic monitoring program, and upon recommendations of the U.S. Geological Survey (see Section 4.4), the BLM, in 1992, directed CPI to modify and expand the hydrologic monitoring program approved under the 1987 POO/POU. The specifics of the program (Caithness, 1993; Petty and Adair, 1993) were approved by the BLM in 1993. The objectives of this expanded monitoring program are to: 1) monitor geothermal reservoir performance in order to better predict future behavior and best manage the resource under use; 2) better understand ground water responses to changes in recharge, precipitation, withdrawal, and production and injection operations at the Steamboat Hills Project geothermal field; and 3) obtain the necessary data on the hydrology of the Steamboat Springs area to better understand the potential for impacts, and the mitigation of impacts, to the Steamboat ACEC from the operation of the Steamboat Hills Project.

Under the expanded monitoring program, the production wells in the CPI field will be monitored for pressure, temperature, total fluid produced, and brine chemistry. Effects, if any, from changes in plant operations such as shut-downs will be detected in these wells first. Wells adjacent to the production zone will be monitored for water level and pressure. If responses to wellfield operation changes are noticed in the production zone, these adjacent wells should be the next to respond. Wells positioned near and at the boundaries of the Steamboat Hills Project geothermal field will be monitored for water level and pressure, as well. Hot springs activity, if any, will be visually monitored at the Main Terrace, along with water level and chloride concentration from one (1) or more well(s) previously completed within the Steamboat ACEC (Byers Well and GS-4 and/or GS-5). Monitoring of this area should detect any effects of regional ground water levels and operations of the nearby S.B. Geo., Inc. (SBG) geothermal power plant, as well as any effects of the Steamboat Hills Project operation, on the geothermal reservoir which feeds the hot springs located on the Main and Low Terraces. Water levels and chemistry will also be monitored in several domestic and geothermal wells and surface water points in the region surrounding the Steamboat Hills.

The expanded monitoring program specifies the monitoring frequency and monitoring locations to monitor the geothermal hydrologic system of the Steamboat Hills. Highly sensitive pressure transducers, electronic water level indicators, Kuster pressure and temperature tools, and float level recorders will be utilized in monitoring water levels and pressures within the geothermal system. Water samples will be collected from fresh water and geothermal sites throughout the Steamboat Hills area. These samples will be analyzed for constituents that serve to distinguish between the distinctly different geothermal water and the regional ground and surface waters.

Monitoring under this program of the three (3) Steamboat Hills Project production wells and the one (1) Steamboat Hills Project injection well, and any new wells completed within the deep geothermal zone, should provide data to quantify the level of reservoir drawdown from production, the degree of pressure support from injection, and trends in the reservoir behavior. Monitoring of the six (6) stratigraphic wells completed to an intermediate depth between the deep geothermal zones and the shallow geothermal zones and regional ground water aquifers is intended to quantify the amount of reservoir drawdown from production and the degree of pressure support from injection in the intermediate depth geothermal zone. Monitoring of 10 domestic surface water sites and ground water and geothermal wells that have been completed to shallow depths (above the deep and intermediate geothermal zones) should provide data to quantify any effects geothermal production and injection may have on the regional ground water aquifers surrounding the geothermal field. The hot springs and wells located on the Main Terrace (Byers Well and GS-4 and/or GS-5) will be monitored to aid in defining the interaction between the hydrothermal reservoir under the Main Terrace (which includes the Steamboat ACEC), operations in the Steamboat Hills Project geothermal field and other geothermal areas (see Section 9.2), shallow ground water withdrawals, and other regional hydrologic effects. Chloride levels and total fluid conductivity of waters from these wells should help determine if the hot springs and geysers have been directly affected by the regional ground water decline, by withdrawal of hot water as part of geothermal production, or are the result of changes in the load on the geothermal aquifer at intermediate depths as the shallow fresh ground water aquifer level changes.

In the approval of the expanded hydrological monitoring program, the BLM authorized officer has specified that he may require CPI to amend the approved hydrologic monitoring program to alter the monitoring locations, data collected, monitoring frequency or reporting requirements if such an amendment is necessary to ensure the collection of data of acceptable quality which meets the objectives of the program. The authorized officer also specifically reserved the right to require that CPI establish an effective point to monitor the level of the thermal ground water table under the Main Terrace hot springs if the authorized officer determines that the Beyers well and GS-4 and/or GS-5 do not provide sufficiently effective monitoring points for this purpose.

Quarterly and annual monitoring reports will be prepared by CPI. The quarterly reports will discuss significant geothermal wellfield operational changes such as well shut-ins, start-ups, or production/injection rate changes, and will record data both graphically on the data plots and in tables. Plant operational changes affecting the field will also be tabulated. Production and injection wellhead pressures and temperatures will be collected and plotted for each month of the quarter. Total production and injection rates and steam fraction will be reported as daily averages for each month of the quarter. The report will discuss the results of monitoring, including interpretation of any significant data. The BLM has required that this would include the magnitude of responses of any wells to operational changes at the Steamboat Hills Project field, or any other known operational changes, such as other geothermal fields (see Section 9.2), ground water withdrawal wells, or natural changes such as precipitation, stream flow, or other significant events; and a value for any reservoir properties which can be calculated from these responses. The quarterly reports will also contain the following data: 1) the results of the chemical analyses performed in the quarter; 2) for each month, total volume of fluid produced and injected; 3) for each month, daily injection temperature and pressure; 4) plots of injection pressure and temperature over time; and 5) tabular and graphic presentation of monitored well pressures and levels.

The annual report will include reinterpretation of the reservoir conceptual model based on the year's collected and analyzed data. The monitoring plan will also be reevaluated on an annual basis to determine its effectiveness in providing useful information for both reinterpretation of the reservoir conceptual model and the connection between the Steamboat Hills Project field and the hot springs system. As data is accumulated and the model refined, the monitoring program can be restructured to provide the best information from the best monitoring sites for future monitoring. Sites which appear to be contributing little new data to the understanding of the resource may be recommended for reduced frequency of monitoring, changes in chemical monitoring, or other monitoring changes. All recommended changes will be thoroughly documented in the annual report for the review of the BLM authorized officer.

3.2. Proposed Action

Because several of the Steamboat Hills Project's completed wells have encountered, and produce, geothermal fluid at lower-than-originally-expected temperatures, the existing flash-steam power plant requires more than the previously approved 1.9×10^6 lb/hr of geothermal fluid (approximately 2.2×10^6 lb/hr) to operate at its design capacity of 12.5 MW (see Table 2-1). With approximately 2.9×10^6 lb/hr of geothermal fluid of the temperature currently available from the Steamboat Hills Project geothermal reservoir, the flash-steam plant is capable of producing as much as an average of 13 MW. Finally, if in the future the temperature of the produced geothermal fluid declines, additional geothermal fluid would be required to maintain the maximum level of power production. Therefore, the Proposed Action consists of CPI's request to increase the approved maximum total geothermal fluid production and injection rates from the Steamboat Springs Unit area for the Steamboat Hills Project up to a maximum of 3.8×10^6 lb/hr.

Under current geothermal fluid temperature conditions, approximately 2.2×10^6 lb/hr of geothermal fluid would need to be produced and delivered to allow the flash-steam power plant to operate at its design capacity of 12.5 MW. As is currently the case, approximately 15 percent of the total produced geothermal flow would be flashed to steam in the separator. This steam would still be directed through the turbine generator, after which it would be condensed to water in the direct contact condenser by the circulating cooling water. The geothermal fluid separated from the steam would exit the separator(s) at a temperature of about 300°F and be used as input to the binary power plant system. This amount of geothermal fluid will allow the three (3) binary geothermal units to produce an average of approximately six (6) to eight (8) MW of electrical power. The outlet temperature of the geothermal fluid from the binary plant is estimated to be approximately 160°F.

The condensed steam produced from the geothermal fluid would become the source of the cooling tower makeup water for the flash-steam power plant. Under the design operating conditions, the steam condensate would be able to supply sufficient makeup water for that lost from the flash plant cooling towers (the binary power plants utilize a dry (air-cooled) cooling system).

Therefore, for the combined flash steam plant and binary plants to operate at design capacity, approximately 2.2×10^6 lb/hr of geothermal fluid at current geothermal fluid temperature conditions would be produced; no more than an annual average of approximately 0.22×10^6 lb/hr of the produced geothermal fluid would be consumed; and an annual average of approximately 1.98×10^6 lb/hr of spent geothermal fluid/cooling tower blowdown, at a temperature of approximately 160°F, would be injected back into the geothermal reservoir. Although additional injection well capacity is being installed (see Section 3.1.2), based on the well pressure data that has been obtained to date, the existing injection well No. Cox I-1 could easily accept all of this fluid at a wellhead pressure below 250 pounds per square-inch (psi).

Approximately 2.9×10^6 lb/hr of geothermal fluid at current geothermal fluid temperature conditions would need to be produced and delivered to allow the flash-steam power plant to operate at its maximum capacity of approximately 13 MW. Under these conditions, the associated binary units would be capable of producing an annual average of approximately 12 MW, which would mean that the combined output would be an annual average of approximately 25 MW. The geothermal fluid, and separated steam and brine, would be handled in exactly the same manner as described above. A maximum of approximately 0.29 x 10^6 lb/hr of the produced geothermal fluid (as condensed geothermal steam) would be consumed as cooling tower makeup water; and an annual average of at least 2.61 x 10^6 lb/hr of spent geothermal fluid/cooling tower blowdown, at a temperature of approximately 160°F, would be injected back into the geothermal reservoir. As above, the existing injection well No. Cox I-1 could easily accept all of this fluid at a wellhead pressure below 250 psi, although additional injection well capacity is being installed.

CPI's current plan is to operate the Project with the production of 2.9 x 10^6 lb/hr of geothermal fluid. However, if in the future the temperature of the produced geothermal fluid decreases, total demand for geothermal fluid could rise to a maximum of 3.8 x 10^6 lb/hr in order to maintain the maximum annual average production of electrical energy at approximately 25 MW. At the maximum geothermal fluid production rate of 3.8 x 10^6 lb/hr, a maximum of approximately 10 percent (0.38 x 10^6 lb/hr) of the produced geothermal fluid could be consumed and a minimum of approximately 3.42 x 10^6 lb/hr of spent geothermal fluid/cooling tower blowdown, at a temperature of approximately 160°F, would be injected back into the geothermal reservoir.

3.3. Alternatives Eliminated from Further Consideration

Because the Proposed Action is limited to an increase in the production and injection rate of geothermal fluid from an existing project, the only alternatives to the Proposed Action identified were: 1) a project which limited the geothermal fluid production and injection rates to less than the proposed rate of 3.8 x 10^6 lb/hr but greater than the existing approved rate of 1.9×10^6 lb/hr; 2) one (1) or more project(s) which involved alternative locations for one (1) or more of the geothermal fluid production and/or injection wells; and 3) the No Action alternative. Two (2) of these three (3) alternatives have been eliminated from further consideration, for the reasons presented below, although elements of these alternatives are considered as potential mitigation measures in Chapter 6 of this EA.

3.3.1. Production and Injection Rates Less Than the Proposed Action

Under this alternative, a geothermal fluid flow rate less than that proposed under the Proposed Action would be considered. This alternative, developed during the scoping process, is based on the assumption that if there is hydrologic or pressure communication between the Steamboat Hills Project geothermal production and injection zones and the hydrothermal reservoir feeding the Main and Low Terrace hot springs which has resulted in some adverse consequences to the hot springs hydrothermal reservoir, then the increase in the geothermal fluid production or injection rate under the Proposed Action could have a greater adverse effect on the hot springs and geysers system on the Main and Low Terraces and the Steamboat ACEC. Therefore, a smaller increase in the production and injection rate could potentially lessen or eliminate the impact to the hot springs and geysers.

However, based upon the hydrologic evaluation developed for the BLM by the USGS and the hydrologic analysis conducted for this EA (see Section 4.4 and Section 5.4), at present it appears that there is insufficient data available to distinguish the environmental effects of the current operation of the Steamboat Hills Project on the Steamboat hot springs and geysers hydrologic system from the potential environmental effects of the Proposed Action on the Steamboat hot springs and geysers hydrologic system. Accordingly, an alternative project which limited the geothermal fluid production and injection rates to less than the proposed rate of 3.8 x 10^6 lb/hr but greater than the existing approved rate of 1.9 x 10^6 lb/hr would not, at present, have any definable environmental advantage over the Proposed Action, and therefore was eliminated from further consideration as an alternative. However, as stated in Section 3.3, the actions under this alternative (limiting the rates of geothermal fluid production and injection) are reasonable elements for potential mitigation measures to the Proposed Action, and are further discussed in Chapter 6 of this EA.

3.3.2. Relocation of Production and Injection Wells

This alternative would relocate existing or approved but unconstructed production and/or injection wells as necessary to alter the hydrologic and/or pressure regime between the Steamboat Hills Project geothermal production and injection zones and the hot springs area to reduce the adverse consequences to the hot springs and geysers of the increased geothermal fluid production or injection rates under the Proposed Action. However, as was the case for the reduced flow rate alternative described in Section 3.3.1, insufficient data is presently available to define an alternative consisting of relocated production and/or injection wells which would produce environmental effects on the Steamboat hot springs and geysers system which could be distinguished from the potential environmental effects that the Proposed Action would have on the Steamboat hot springs and geysers system. Accordingly, an alternative project which relocated one (1) or more of the geothermal fluid production and/or injection wells similarly does not have any currently discernible environmental advantage over the Proposed Action and, therefore, was eliminated from further consideration as an alternative. However, as was also the case in Section 3.3.2, the proposed actions under this alternative are reasonable elements for potential mitigation measures and are further discussed in Chapter 6 of this EA.

3.4. No Action Alternative

The No Action Alternative would occur if the BLM rejected the Proposed Action and did not approve the 1991 POO/POU. As a result of implementing the No Action Alternative, CPI would be unable to operate the Steamboat Hills Project at either design or maximum electrical generation capacity with increased geothermal fluid production and injection rates, as outlined in the Proposed Action. However, implementation of the No Action Alternative through denial of the 1991 POO/POU would not affect the current operation of the existing Steamboat Hills Project facilities, nor affect CPI's ability to complete construction and operate the binary power plants and produce and inject up to 1.9×10^6 lb/hr of geothermal fluid.

4. AFFECTED ENVIRONMENT

The affected environment that is discussed in this EA has been previously documented in the EA completed for the original approval of the Steamboat Hills Project (1987 EA) (USDI, 1987). In addition, an Environmental Impact Statement (EIS) was prepared for the U.S. Highway 395 realignment which cuts across the Steamboat Springs Unit Area (USDOT, 1983). This EA incorporates by reference the affected environment portion of the 1987 EA and the EIS, and discusses information contained in the EIS and the 1987 EA in the appropriate environmental resource sections of this chapter.

4.1. Physiography

The Steamboat Hills study area (see Figure 3-1) is located in the Steamboat Hills, which is an outlying portion of the Carson Range. The Carson Range is a classical expression of the Basin and Range Province (Fenneman, 1938). The north-south trending ranges of the study area were created by faulting and subsequent erosion. The Carson Range is relatively steep with perennial, intermittent and ephemeral drainages. The Steamboat Hills portion of the range contains intermittent and ephemeral drainages. Elevations in the study area range from approximately 4,500 feet above mean sea level (AMSL) to 6,200 feet AMSL.

4.2. Geology and Mineral Resources

4.2.1. Geology

The oldest rock units within the Steamboat Hills consist of Triassic and Jurassic Age sedimentary and volcanic rocks. These units were metamorphosed during the Cretaceous Period, which is coincident with the emplacement of the granitic Sierra Nevada Batholith, which also crops out in the Steamboat Hills Project area. These units were uplifted, faulted and eroded during the early Tertiary and subsequently intruded and overlain by Pliocene to Pleistocene basaltic and rhyolitic flows and domes. Faulting and erosion have continued, which has resulted in the present-day topography.

The geothermal activity in the study area has been ongoing since the Pliocene (White, 1968). Local faulting has channeled geothermal fluids from depths to the surface, which has resulted in the deposition of siliceous sinter, forming the three (3) terraces (High, Main, and Low Terraces). The Main and Low Terrace thermal areas are currently considered active. A more detailed description of the geothermal system is included in Section 4.4.

Seismicity in the study area is moderately high. During the period from 1968 to 1972, 25 earthquakes were detected within the state of Nevada within a 30-mile radius of the study area. Of these, 17 earthquakes had a magnitude between 4.0 and 4.9, five (5) earthquakes had a magnitude between 5.0 and 5.8, and three (3) earthquakes had a magnitude between 6.0 and 6.9 on the open-ended Richter scale (Husband, 1975).

4.2.2. Mineral Resources

The study area and surrounding vicinity have historically produced numerous minerals. The Steamboat Springs mining district, which is located within the study area, produced mercury and sulfur during the late 1800's. Gold, silver and stibnite are also present in the study area (Bonham, 1969). The Galena Mining District, which is located directly southwest of the Steamboat Hills Project area, produced gold, silver, copper, lead and zinc during the early 1900's, mostly from the Union, or Commonwealth, Mine (Lincoln, 1982). Cinder, clay and aggregate have also been produced in the study area vicinity (Bonham, 1969). The Steamboat Hills are an area of active geothermal features, which are discussed in Section 4.4.2.2. In addition to the ongoing use of the geothermal resource by CPI, other users of the geothermal resource in the study area include the former Steamboat Spa Hot Springs and the SBG Geothermal Project (see Section 9.2).

4.3. Soils

There are numerous soil types within the study area due to the widely varied terrain and rock types. Soils on slopes consist of residuum, mostly from altered andesite and volcanic rocks, and a small amount of colluvium. Soils in the hot spring terrace area are sometimes very thin, little more than rock outcrops, while soils in the valley areas consist mostly of alluvium from mixed rock. While depths to bedrock are generally shallow on slopes, they are much deeper in areas of alluvial soils (CH_2M Hill, 1986a).

Unique soils have developed on the siliceous sinter terraces which occur over large areas associated with the fossil and historically active hot springs. These siliceous sinter deposits, ranging in age from 2.5 million years to the present, consist primarily of opaline sinter, which probably alters to chalcedonic sinter over time (Silberman, et al., 1979). The sinter characteristically contains detectable quantities of gold, silver, antimony, arsenic and mercury. It is also typically highly porous, unless cemented by recirculating geothermal fluids, and breaks down into coarse fragments upon desiccation (CH_2M Hill, 1986d). Soils derived from parental material of siliceous sinter or alluvial material with siliceous sinter are characterized by extreme immaturity, and no diagnostic horizons (CH_2M Hill, 1986d).

As discussed in Section 4.4.1.2, the last of the active Steamboat Hills hot springs and geysers ceased flowing in approximately 1989 and, as a result, deposition on the surface of new siliceous sinter is currently not occurring. As also discussed in Section 4.4.1.2, it is likely that other periods of no sinter deposition occurred in the past, although this most recent occurrence may be unique because it appears to be largely caused by human activity (see Section 4.4.2.3).

If the springs and geysers continue to not flow, and sinter continues to not be deposited, eventually the development of these sinter soils will slow and, ultimately, stop as all available deposits of sinter are weathered to soil. However, because of the large areal extent and thickness of the existing sinter deposits, and the very slow rate at which the sinter is likely to weather to soil, a reduction in the sinter available for weathering to soil is not considered a realistic scenario for tens of thousands to hundreds of thousands of years to come. In the short term (hundreds of years to tens of thousands of years), if the sinter continues to not be deposited, the rate of development of sinter soil may actually increase, in that all deposited sinter would be available for weathering, and none would be covered by actively depositing sinter.

4.4. Hydrology

Information presented below on the hydrology of the study area is summarized from a report prepared for this EA which addresses the hydrogeology of the Steamboat Hills area through 1991 (Nork Report) (Nork, 1992). Text in this section of this EA directly incorporates portions of the text of the Nork Report and, except as noted, all information in this section of the EA is attributed to the Nork Report. The Nork Report has been attached to this EA as Appendix C. In addition, the U.S. Geological Survey (USGS) has recently completed a report which studies the hydrology of the Steamboat Hills area through 1989 (Sorey and Colvard, 1992).

Portions of the USGS report are also expressly cited in this section of the EA. The USGS report is also attached to this EA as Appendix D. A number of reports on the geothermal system, which have been prepared for CPI by independent consultants, are also cited in this EA. The portions of those reports which pertain to the information being cited in this EA are available for review at the BLM's Nevada State Office.

4.4.1. Surface Water

4.4.1.1. Streams

The principal streams in the vicinity of the Steamboat Hills are Thomas and Whites Creeks to the north, Galena Creek to the west and south, and Steamboat Creek (Figure 4-1). Whites, Thomas, and Galena Creeks all drain the Carson Range to the west. Infiltration of surface water from these influent streams is a major source of ground water recharge to the alluvial aquifers within the Truckee Meadows. The creeks are all tributary to Steamboat Creek which, in turn, is tributary to the Truckee River. The principal surface-water sources and average annual flow are provided in Table 4-1.

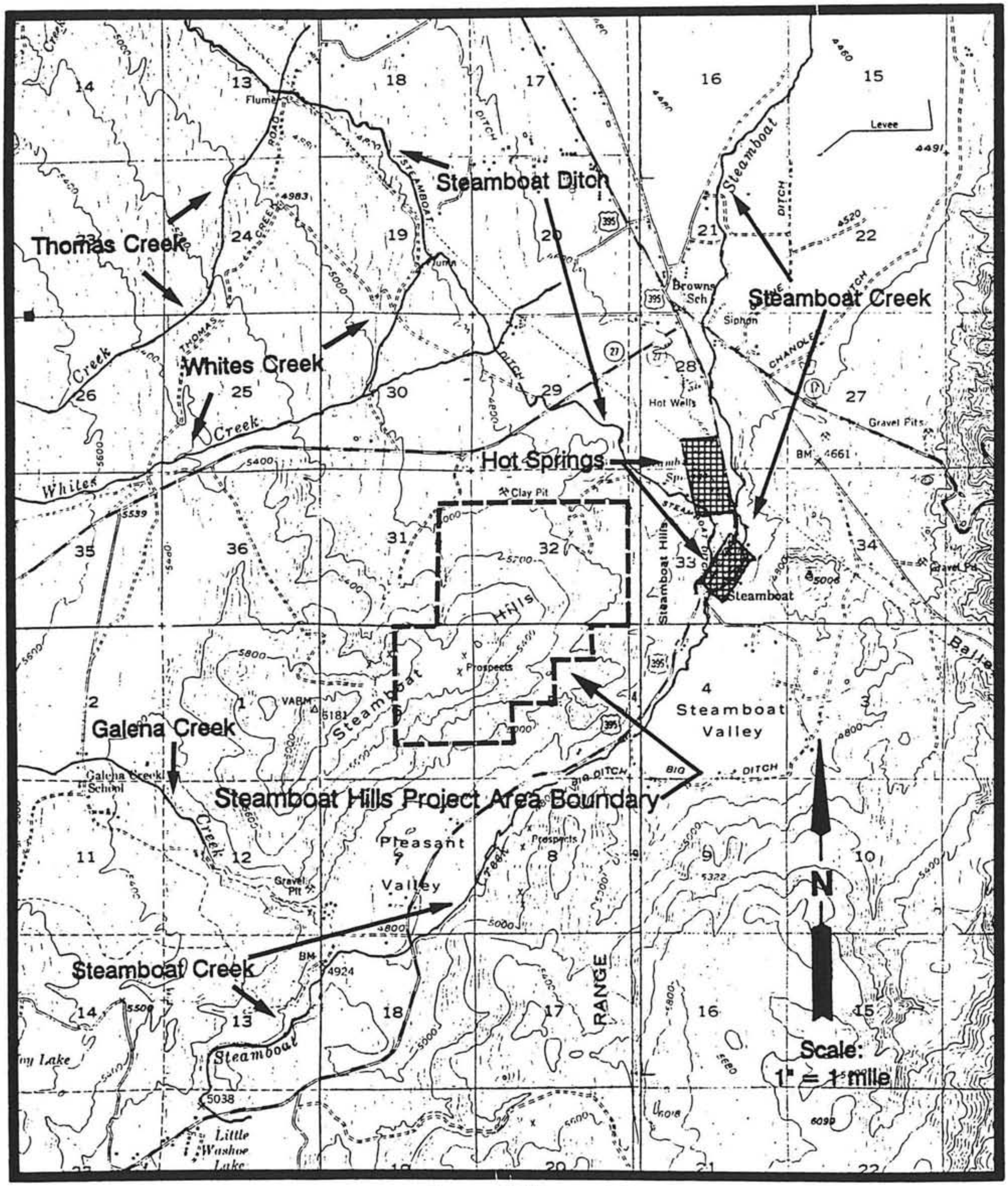


Figure 4-1: Surface Waters and Ground Waters Map

Table 4-1: Principal Surface Water Sources and Average Annual Flow

CREEK/CANAL	FLOWS (AFA[1])
Steamboat Creek (including 7,800 AFA from Galena Creek)	10,900
Steamboat Ditch	6,500
Whites Creek	4,700
Thomas Creek	4,300

[1] AFA = Acre-Feet Per Annum

Steamboat Creek is an effluent stream in the South Truckee Meadows. As such, it receives inflow from the ground water system via upward seepage through the stream bottom along its length. There are also a number of irrigation ditches and canals within the study area which derive water from either the Truckee River or one or more of the aforementioned creeks. These mostly unlined ditches and canals behave as local influent streams and contribute to ground water recharge, especially when running full. A portion of the ground water discharged to the creek originates as outflow from the geothermal system. During the period from 1945 to 1952, White (1968) estimated the natural discharge from the Steamboat geothermal system to be approximately 1,800 AFA, of which most was via subsurface discharge to Steamboat Creek.

4.4.1.2. Thermal Springs and Geysers

The Steamboat Springs geothermal area includes numerous historically active hot springs and geysers located at the northeastern end of the

Steamboat Hills. Surface flows from the springs, including geysering, have been noted since the springs were discovered in 1863 (Koenig, 1989). Although historically the third most active geyser area in the United States (behind Yellowstone Park and Beowawe, Nevada), the natural geysers were most frequently reported as mostly small and inconspicuous, typically erupting to heights of only 1 to 3 feet, and frequently no geysers were erupting within the complex (White, 1967). Because of this relatively unique occurrence of the thermal activity, the USGS conducted an extensive study of the Steamboat Springs area between 1945 and 1952 (White, 1968). This study documented 74 springs in two (2) main areas of thermal activity (the Main Terrace and the Low Terrace) (Sorey and Colvard, 1992). Another area, known as the High Terrace, was identified as an area of previous hot springs activity (White, 1968). However, since the spring's discovery in 1863, no activity in this High Terrace area has been documented.

On the Main Terrace were 46 springs, of which 13 erupted as geysers and six (6) were pulsating springs. Three (3) springs on the Main Terrace discharged continuously during the study, from June 1945 through August, 1952. On the Lower Terrace were 20 springs, of which nine (9) erupted as geysers and two (2) were pulsating springs. Six (6) springs on the Low Terrace discharged continuously during the study, from June 1945 through August, 1952. Of the 1,800 AFA of Steamboat geothermal fluid estimated to be discharged to Steamboat Creek (White, 1968), hot springs along the Main Terrace have historically only discharged 48 to 96 AFA; most of the rest is subsurface discharge to Steamboat Creek.

Age-dating studies indicated that hydrothermal activity has occurred at Steamboat Springs for more than 2.5 million years (Silberman, et al., 1979).

Although insufficient data was available to determine if this activity had been continuous or intermittent over this time period, it is likely that periods of surface discharge and sinter deposition alternated with periods of no activity and erosion (Silberman, et al., 1979).

Geysers are hydrothermal features which occur at a limited number of sites around the world. Geysers characterize a hot-springs system that is inherently unstable near the surface. The eruption of a geyser is a chain reaction which can be triggered by any one of many natural or human events (White, 1967). It is likely that no two (2) geysers are identical, and individual geysers can change greatly in their behavior over time (White, 1967). Geysers in general, and at the Steamboat Springs area in particular, are hot springs characterized by intermittent discharges of water which are ejected turbulently and accompanied by a vapor phase. The temperatures of the waters at the ground surface are generally near the boiling point of pure water; however, the gas content of the system is generally high enough for a vapor phase to form at temperatures below the boiling point (White, 1967). There are a number of factors involved in a hot springs system that create the mechanism for geyser eruptions, and there is probably no single theory to explain the mechanism (Iwasaki, 1962; White 1967). The triggering of the eruption can be caused by a build up of gas in the hot springs pumping system, either as individual bubbles increasing in size or as a single gas pocket, that at a certain point becomes large enough to impede the downward flow of the cooler waters above the gas, then overcoming the hydraulic pressure of the overlying column of water, forcing the water and gas up the pumping system and erupting at the surface as a geyser (White, 1967). Some of the factors that are essential to establishing the mechanism of geysers are: the development of fissures and voids in the pumping system; an adequate vapor phase in the water column; an adequate amount of dissolved SiO_2; and a water table sufficiently close to the surface for the eruption to occur. These systems are inherently unstable, and what could be interpreted as a minor deviation in the hot springs system could have a large effect on the chain of events necessary for the eruption of geysers. Such changes in the geysering of springs may also not be reversible upon recovery of the hot springs system; that is, geysering may not be reestablished in the old vents even though altered hot spring conditions may return to previous values.

Because of these unique thermal features in the Steamboat Hills, the BLM established the 40-acre Steamboat ACEC on a portion of the Main Terrace to protect the hot springs and geysers. A more detailed discussion the Steamboat ACEC is presented below in Section 4.11, Land Use.

In 1986 it became evident that the springs on the Main Terrace were undergoing a systematic decline, although the decline may have begun earlier. By early 1986, only one (1) spring was discharging and water levels continued to decline through mid-1986 (Sorey and Colvard, 1992). Water levels then began to rise and springs started to discharge again. Then there was another period of declining water levels that, with some minor fluctuations, has continued until the present (Sorey and Colvard, 1992). Discharge from the last flowing spring ceased in 1989. The decline in the spring discharge and the water levels in the thermal area is believed to have been caused by several factors, as presented in the discussion of the ground water and geothermal systems in Section 4.4.2.

4.4.2. Ground Water

Ground water in the Steamboat Hills area, and the Truckee Meadows in general, is abundant and highly utilized. The ground water is characterized by both geothermal aquifers and non-geothermal (fresh-water) aquifers.

4.4.2.1. Fresh Waters

Fresh ground water is derived principally from the alluvial materials which overlie fractured igneous and metamorphosed volcanic rocks. The fresh waters in the alluvial material provide water supplies to South Truckee Meadows General Improvement District (STMGID) wells in the Whites Creek/Thomas Creek fan areas, to Westpac Utilities wells within the valley floor, and to numerous individual domestic wells. Recharge to this alluvial aquifer originates from four (4) sources: direct percolation of precipitation at higher elevations in upper fan areas; infiltration of surface waters from mountain streams; upward and lateral leakage from underlying and adjacent fractured granitic and metamorphosed volcanic rocks; and secondary recharge from unlined ditches and canals as well as from land application of irrigation water.

The chemical quality of the ground water derived from the alluvial fan aquifers of the Thomas/Whites Creek fan complex north to northwest of the Steamboat Hills is generally good. Total Dissolved Solids (TDS) ranges between approximately 100 to 300 milligrams per liter. Northeast of Steamboat, in the Virginia Foothills area, the chemical quality of the fresh water is affected by elevated levels of iron, manganese, arsenic and boron.

4.4.2.2. Geothermal Waters

Several studies of the geothermal system have been conducted, either to better understand the geothermal system or assess the impacts to the system perceived to be resulting from the development of the geothermal resource. In general, these past studies have concentrated on the geothermal system, and do not view the system in a more regional hydrogeologic setting. This section summarizes the past geothermal system investigations, and the results of the Nork Report (Nork, 1992; Appendix C of this EA), which analyzes the geothermal system as part of the regional hydrogeologic system. The recently completed USGS report which studies the hydrology of the Steamboat Hills area through 1989 is also cited in this section (Sorey and Colvard, 1992; Appendix D of this EA).

4.4.2.2.1. Previous History of Reservoir Interpretation

Production well testing and pressure monitoring of the available surrounding monitoring wells and hot springs (termed reservoir pressure interference monitoring in this discussion) for the Steamboat Hills Project was first performed subsequent to the drilling of the first production well, well No. SB#1 (21-5), in 1979 (Goranson and others, 1990). The well and reservoir testing program was continued by the Steamboat Hills Project developers through time as other production, injection and monitor wells were drilled, completed and made available for testing purposes. The analyses of production well temperature, pressure and chemistry data, along with reservoir pressure interference data, indicated that a large, high temperature (410°F-450°F), highly productive geothermal reservoir underlaid the Steamboat Hills area, and that a shallower, lower temperature (<350°F) geothermal system was directly to the north and northeast of the high temperature system.

Modelling of the geothermal reservoir conducted in the early 1980's for Western States Geothermal for the original Steamboat Hills Project was based on data which indicated that the Steamboat Hills deep geothermal reservoir intersected by the production and injection wells was not directly connected to either the shallow geothermal area or the ground water system located north of the Steamboat Hills Project area, nor were the Steamboat Hills Project geothermal wells hydraulically connected to the Steamboat Hills hot springs area (Yeamans, 1984). Interference well testing had indicated that well No. Cox I-1 was in hydraulic communication with the Steamboat Hills Project production area, but not with the nearby shallow (<1,000 feet) monitor wells (Goranson and others, 1990). The nature of the caprock over the geothermal reservoir in the northern area was uncertain at that time; however, analysis of the reservoir pressure data obtained to that date indicated that the shallow (<1,000 feet) monitor wells located in the main Steamboat Hills Project production area and in the area of the Steamboat Hills Project injection well were not hydraulically connected to the deeper Steamboat Hills Project production and injection zone (Yeamans, 1984).

While these reservoir analyses attempted to determine the properties of the high and low temperature geothermal reservoir system(s), the analyses were somewhat ambiguous with respect to the relationship of the geothermal system(s) to the local hot springs area and the overall ground water system. As a result, the BLM and the NDEP determined that a reservoir test, using wells planned for use in power plant production and injection operations, would be necessary prior to either agency acting on the permit applications for the original Steamboat Hills Project. The reservoir test was necessary to determine the reservoir behavior, the influence of production and injection on the geothermal system and, in particular, the potential effects of the Steamboat Hills Project injection operations on the hot springs area and local ground water system.

In May-June, 1987, six (6) months prior to power plant start-up, the injection, production and interference reservoir pressure tests were performed. The measured test data and subsequent analyses of the test data by the consultants to the Steamboat Hills Project developer from the May-June 1987 reservoir test indicated that pressure communication existed between the Steamboat Hills Project production area and the Cox I-1 injection well (Goranson and van de Kamp, 1990). The Main Terrace area was monitored separately by the NDEP, the BLM and CPI personnel on a daily basis during the test for both changes in spring discharge and depth to water level in hot spring pools with no discharge. None of the changes that were noted at the springs could be correlated with the changes that would be anticipated from the potential pressure communication paths between the Steamboat Hills Project operation area and the hot springs area (Goranson and van de Kamp, 1990). No effects were also noted at monitor wells located to the south and north of the Steamboat Hills Project lease area. In addition, shallow monitor wells completed in the Steamboat Hills Project injection and production area to depths between 900-1,500 feet did not show any pressure communication with either the injection or production wells (Goranson and others, 1990). Therefore, no impacts from geothermal operations were expected on the ground water system surrounding the Steamboat Hills Project area (Goranson and van de Kamp, 1990).

As a result of the continuing BLM concern regarding the decline of hot spring and geyser activity in the Steamboat ACEC first observed in 1986, the BLM contracted the USGS to study the local hydrology and determine the factors affecting the flow of hot springs and geysers and the relative significance of each factor. The USGS contracted with California State University at San Diego (CSUSD) to do the principal field data collection. The CSUSD study resulted in the completion of a Master Thesis on the hydrology of the Steamboat Hills Area in 1990 (Collar Report) (Collar, 1990). The Collar Report concluded that, contrary to previous studies, the Steamboat Hills geothermal reservoir was connected to the Steamboat Springs aquifer, and the Steamboat Hills Project operations were the major contributing factor in the decline of the hot springs and geysers.

Following release of a draft of the Collar Report in 1989, additional analyses and reservoir modeling studies of the Steamboat Hills Project monitoring data were carried out by CPI consultants in July, 1989 using production, injection and monitoring data that had been obtained for the period February, 1988 to April, 1989 (van de Kamp and Goranson, 1990). Data was also obtained for the existing SBG Geothermal Project located approximately 1 mile to the north of the Steamboat Hills Project operations. All of the data (CPI and SBG) were incorporated into a reservoir model and used to calculate the effects of the combined SBG and Steamboat Hills Project operations on the geothermal system, the hot springs area and the nearby ground water system (van de Kamp and Goranson, 1990). This work again came to the conclusion that the

Steamboat Hills Project high-temperature production and injection area were not directly connected to either the shallow geothermal area or the ground water system located to the north of the Steamboat Hills Project production area, nor were the Steamboat Hills Project wells hydraulically connected to the hot springs area located at the Main Terrace.

Using the field data collected for the Collar Report, as well as additional data on geothermal and ground water usage and levels in the Steamboat Hills Project area and the results of previous studies, both the USGS, under contract with the BLM, and W.E. Nork, Inc., in support of the preparation of this EA, concurrently attempted to establish the parameters of the Steamboat Hills hydrologic system and determine the geohydrologic factors affecting the decline in the hot spring and geyser activity in the Steamboat Springs area. The results of both the USGS report (Sorey and Colvard, 1992) and the Nork Report (Nork, 1993) form the basis of the discussion presented below.

4.4.2.2.2. Current Interpretation of the Geothermal System

Geothermal waters generally reside in, and are derived from, the fractured granitic and metamorphosed volcanic rocks underlying the alluvium, with some exceptions. Hot springs and geysers of the Steamboat Hills issue from alluvial deposits at the Main and Low Terraces. These alluvial deposits are also tapped by a number of shallow, lower temperature geothermal wells. In some instances, the chemical quality of these shallow wells suggests mixing of the fresh and geothermal waters; in others, the low temperature wells tap water of purely geothermal origin.

Stable isotope studies suggest that the recharge source for the geothermal system is deeply circulating meteoric waters. The recharge area may be localized with the upper reaches of the Carson Range west to northwest of the Steamboat Hills in the area between Galena Creek and Evans Creek (Sorey and Colvard, 1992). Alternatively, since there are multiple geothermal manifestations in evidence along a broad stretch of the eastern slope of the Sierra Nevada north and south of Steamboat, it is conceivable that the Steamboat geothermal system is part of a much larger regional flow system.

System Morphology

The geothermal reservoir comprises fractured igneous rocks of granitic composition which have intruded metamorphosed sedimentary and volcanic rocks. Geothermal fluids in the southern portion of the reservoir are produced from wells which intersect steeply dipping north-northeasterly trending faults and fractures within the granitic rocks. In the northeastern part of the Steamboat Hills, producing fractures trend northwesterly, dipping about 75° to the north (Figure 4-2). Faults play a significant role in the occurrence and movement of geothermal fluids within the reservoir because the fractures related to faulting exhibit very high secondary permeability. The intervening unfractured rocks are relatively impermeable. Consequently, the movement of geothermal fluids normal to the faults is comparatively small. However, zero flow normal to the major fault conduits within the reservoir rocks is unlikely because fracturing is widespread.

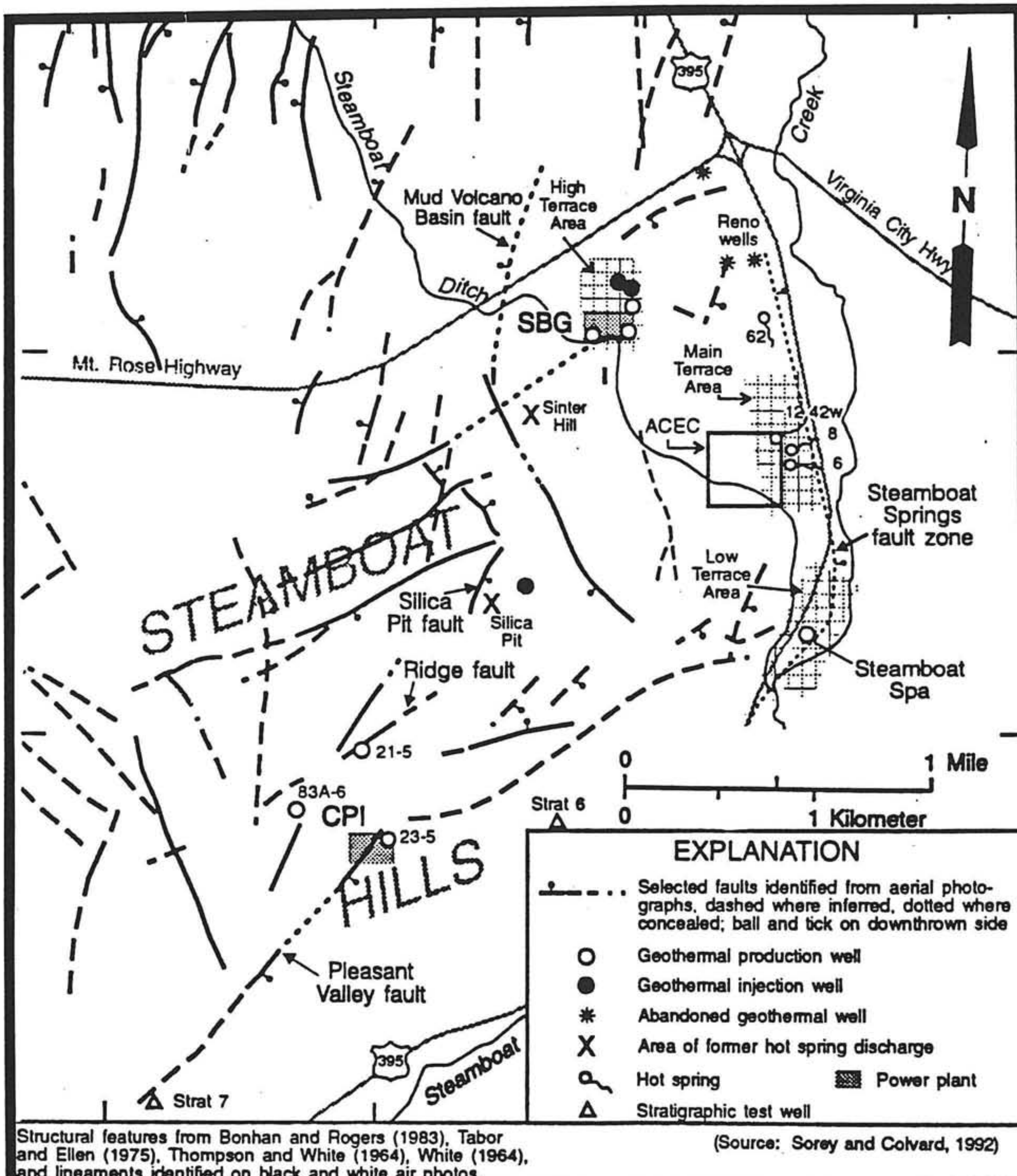


Figure 4-2: Location of Faults and Lineaments in the Steamboat Hills Area

Although hydrologic boundaries within the Steamboat Hills almost certainly exist, none have been conclusively identified through the testing conducted to date. The geothermal system is bounded by faults which behave as barriers to the movement of geothermal fluids. The Pleasant Valley fault bounds the Steamboat Hills on the southeast and restricts geothermal fluid movement in that direction.

Above depths of 2,000 to 3,000 feet below land surface in the Steamboat Hills Project field southwest of the Main Terrace and 400 to 600 feet in the northern part of the Steamboat Hills, the steeply dipping fractures are filled with mineral deposits. This lower-permeability horizon acts as a cap on the geothermal system, except where infrequent open faults and fractures extend to land surface as at the Main and Low Terraces.

The natural geothermal fluid flux through the system is also not known with a high degree of confidence. However, estimates based on assumed values of chloride concentration in the reservoir and measured chloride flux in Steamboat Creek suggest that the historic local geothermal discharge ranged from 1,110 to 1,385 gallons per minute (gpm)(Sorey and Colvard, 1992). The total flux through the system is not known because the relationship of the Steamboat Springs area to other geothermal occurrences along the eastern Sierra is unknown. Given that there are multiple geothermal occurrences aligned along the eastern slope of the Sierra Nevada, north and south of Steamboat, it is conceivable that the Steamboat Geothermal System is part of a larger regional flow system and the historic discharge rates may simply represent localized discharge of a larger system.

It is unclear whether the Steamboat Hills are underlain by a single geothermal reservoir or several isolated reservoirs which are independent of one another; different models to explain the observed data have been proposed (see System Models, page 4-22). The location of the geothermal heat source relative to the reservoir(s) is also unknown, and may be present at some remote location requiring the geothermal fluids to arrive at the Steamboat Hills via different flow paths.

Temperature and Chemistry

The hottest reservoir temperatures are encountered in the southern portion of the Steamboat Hills within the Steamboat Hills Project area. Temperatures in that area approach 420°F to 460°F at depths of 2,000 to 3,000 feet below land surface (3,200 feet elevation). In the northern portion of the Steamboat Hills, geothermal fluids with temperatures of 320°F to 360°F are found at depths of 400 to 600 feet below land surface. Low temperature geothermal waters (80°F to 180°F) are found in shallow alluvial deposits north and east of the Steamboat Hills.

Chemical geothermometers indicate a maximum reservoir temperature approaching 500°F. By comparison, Steamboat Hills Project production wells in the southern part of the Steamboat Hills yield temperatures of 420 to 460°F. The production wells for SBG in the northern part of the Steamboat hills yield temperatures of up to 340°F. The reservoir which feeds the hot springs may have a temperature of approximately 450°F.

In contrast to the good chemical quality of the fresh ground water in the alluvial deposits, the TDS of the geothermal fluid is greater than

2,000 mg/l and is a sodium chloride water type. The geothermal fluid derived from the SBG production area in the northern Steamboat Hills contains approximately 2,200 mg/l TDS. Because the collection of unflashed samples of the geothermal brine from the Steamboat Hills Project production area in the southern Steamboat Hills is not practical, exact values for TDS in that part of the reservoir have not been measured. Analytical results of "flashed" samples to date have yielded values ranging from approximately 2,100 to 3,055 mg/l TDS.

Permeability

Each production area exhibits very high permeability. The permeability-thickness product of the reservoir, "kh", has been estimated to range from approximately 500,000 to 3,000,000 millidarcy-feet on the basis of tests in both the southern and northern parts of the Steamboat Hills (Nork, 1992; Sorey and Colvard, 1992). A lack of observable boundaries is consistent with a highly permeable reservoir because the effect of a nearby barrier boundary occurs so quickly that its presence during testing is undetectable or indistinguishable from well bore influences.

Connection with Fresh Water System

The geothermal system is hydraulically connected to the local alluvial aquifer(s). Some wells completed in the alluvial aquifer, such as the Pine Tree Ranch, Brown School, and Herz (domestic) wells, suggest mixing of fresh and geothermal waters. As noted earlier, the hot springs located at the Main and Low Terraces of the Steamboat Springs area are associated with these alluvial aquifers. The details of this interconnection, however, are not known with any degree of certainty.

System Models

Although the hydrology of the Steamboat Hills geothermal system is complex, some general features of the system are known. Alternative models to explain the system have been suggested, though no single model clearly and unequivocally explains all of the observed phenomena all of the time.

One model of the geothermal system postulates that there are at least three (3) geothermal systems operating beneath the Steamboat Hills (Figure 4-3). Each system is described as hydraulically isolated from the other by pressure boundaries or impermeable rocks. The three (3) systems are: a deep, high-temperature system tapped by the Steamboat Hills Project production and injection wells; a shallow, moderate-temperature system tapped by the SBG wells; and the low-temperature system(s) related to the hot springs at the Main and Low Terraces and thermal ground water found in the alluvial aquifer (Goranson and others, 1990; van de Kamp and Goranson, 1990). Evidence cited as supporting this interpretation includes:

- Differences in elevation between the three (3) zones;
- Differences in temperature at each of the systems and the temperature gradient between the reservoirs;
- No convincing evidence of communication between the Steamboat Hills Project production/injection horizon and the hot springs; and

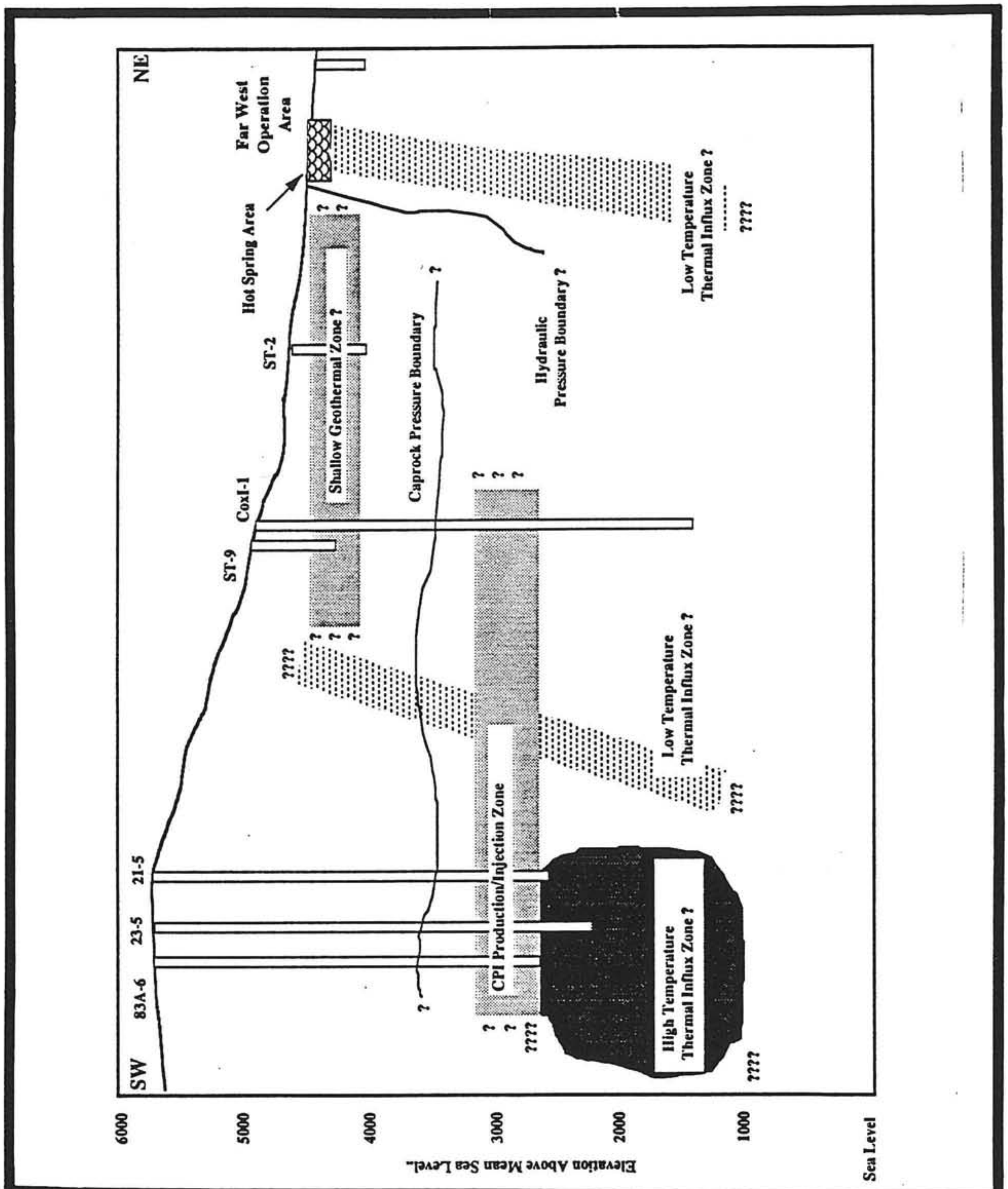


Figure 4-3: Schematic Cross Section Through the Steamboat Hills Geothermal Area Showing Postulated Isolated Geothermal Systems

- Observed pressure support in the Steamboat Hills Project reservoir due to injection.

A second model suggests that only one (1) geothermal system operates at Steamboat (see Figure 4-4). This model holds that regions of localized high permeability associated with faults and fractures exist within otherwise impermeable rocks and there is a degree of communication between some of these different systems. The model further suggests that upflow from the Steamboat Hills Project production horizons feeds the moderate temperature reservoir tapped by SBG and the Main Terrace (Sorey and Colvard, 1992). Evidence cited for this model includes:

- A perceived response at the hot springs to some Steamboat Hills Project production episodes; and
- General similarities in gross chemistry of the fluids from the different areas.

In reality, a conceptual model which depicts the Steamboat Hills geothermal system probably lies somewhere between the two (2) models discussed above. Given the highly fractured nature of the reservoir rocks and the extent of faulting, it is difficult to accept that there is zero movement of geothermal fluids vertically and in an easterly direction through the system. While there may be no movement between adjacent fault conduits near land surface where geologic data show the fractures to be filled with mineral deposits, it is possible that the various high permeability zones enjoy some degree of communication at depth.

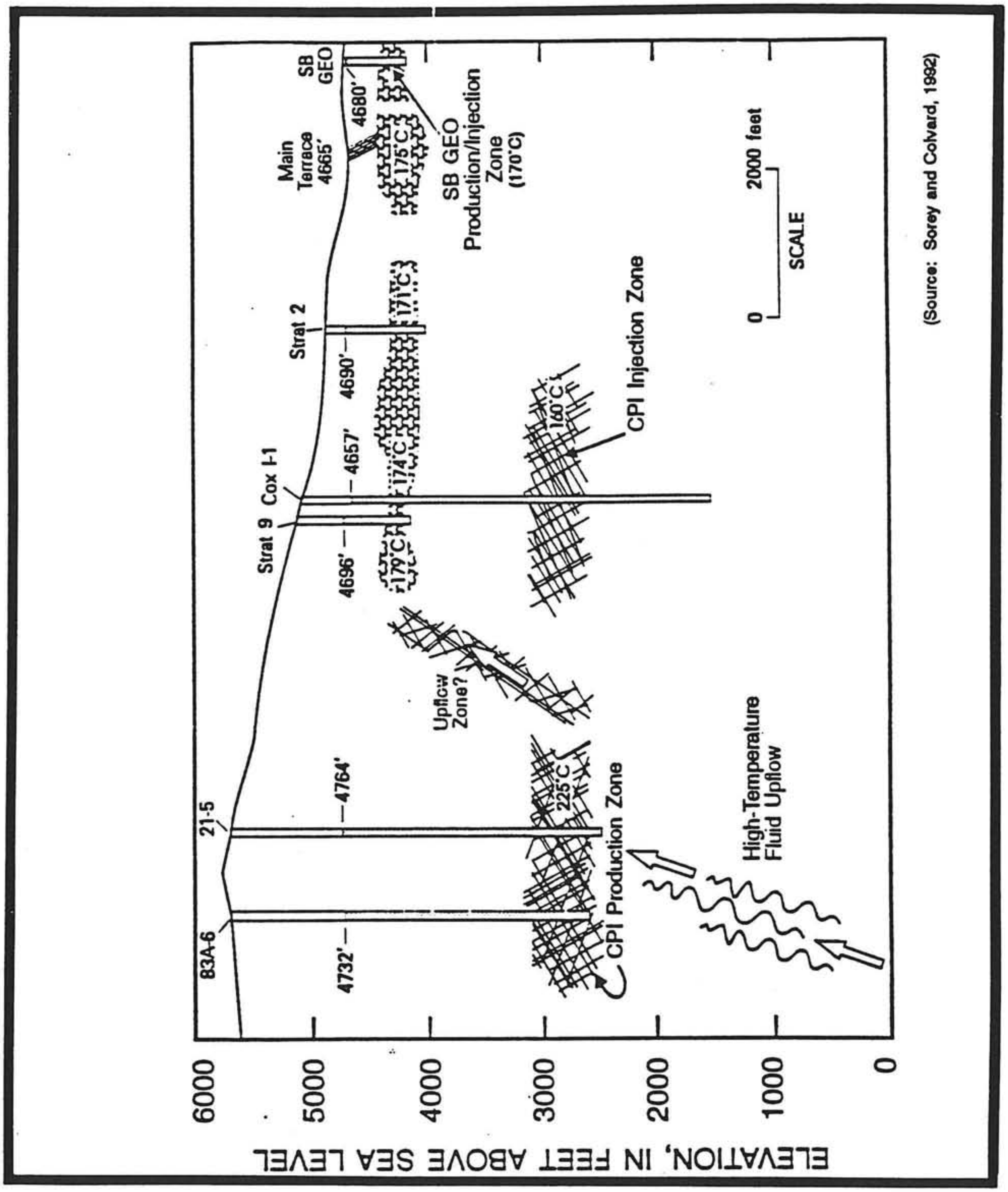


Figure 4-4: Schematic Cross Section Through Steamboat Hills Geothermal Area Showing Postulated Interconnected Geothermal System

The degree of pressure support to producing zones in the reservoir consequent to injection has been an issue in the past (Nork, 1992; Sorey and Colvard, 1992). In the SBG field an observed pressure decline of seven (7) to 10 psi in observation wells during the first three (3) years of operation is viewed as either reservoir drawdown or the influence of the current drought conditions. In the Steamboat Hills Project well field, there are no observation wells completed in the reservoir which have been monitored since before the Steamboat Hills Project came on line. Pressure data for production wells taken when they are occasionally shut in do not suggest a decline in reservoir pressure due to production. Recent analytical work, obtained during the shut-in of the production wells for maintenance in May and June of 1990, strongly suggests pressure support to the Steamboat Hills Project reservoir from injection in Cox I-1. The evidence for pressure support from injection to the hot springs appears inconclusive.

4.4.2.3. Current Trends

Between 1985 and 1990, water level declines of 17 to 27 feet have been observed in fresh ground water wells completed in the alluvial aquifer in the southwest Truckee Meadows. Similar declines have been noted in available data for hot springs on the Main Terrace and wells completed both in the high-temperature reservoir and cold-water aquifers in the Steamboat Hills. The total decline in the head of the reservoir supplying thermal water to the hot springs and geysers system was probably close to 17 feet in 1989, and estimated to be as much as 20 feet in 1990 (Sorey and Colvard, 1992). Significant reductions in the discharge of geothermal waters from the Steamboat Hills geothermal system have also been postulated (Collar, 1990), but this may simply reflect a diversion of geothermal waters into the shallow ground water system as ground water levels declined (Sorey and Colvard, 1992). The similarity in data trends for the different hydrostratigraphic units suggests that changes in water level in both the geothermal reservoir and alluvial aquifers may have a common cause or causes.

From 1985 to 1989, declines of 14 to 21 feet occurred in the wells monitoring the fresh water system. South Truckee Meadows General Improvement District (STMGID) withdrawals are less than half of the ground water withdrawals from this area, with Westpac Utilities and individual domestic wells making up most of the rest. The extended period of below normal precipitation is also a factor. Based on comparisons of seasonal freshwater production rates and monitoring wellwater levels, and aquifer modelling, perhaps as much as 12 to 24 feet of the decline in water levels in the alluvial aquifer near the Steamboat Hills from 1986 through 1991 (2 to 4 feet per year) may be attributable to ground water withdrawals for domestic and quasi-municipal use.

Water Quality measured in wells completed solely in the fresh water system have generally been stable despite dropping groundwater levels (DeRocher, 1993). However, the quality of the water monitored in wells completed in the mixed geothermal water/fresh water systems have typically shown increases in chloride, boron, arsenic and TDS (Coulter, 1993; DeRocher, 1993), which has been interpreted as a decreasing ratio of fresh water to geothermal water in the wells as the fresh water level has continued to decline (DeRocher, 1993). To date, no adverse impacts of geothermal production or injection operations on the fresh ground water regime in the Truckee Meadows, such as breakthrough of thermal effluent to potable water supply wells, have been documented. Seasonal and long-term water level fluctuations observed in the hot springs are believed to be influenced by ground water pumping from the alluvial aquifer. There is clear evidence that the reservoir feeding the hot springs and geysers and vents within the Main Terrace is hydraulically connected to the alluvial aquifer (see 4.4.2.2.2). Based on their analysis, Sorey and Colvard (1992) state that most (80 to 95 percent) of the long-term decline in the water table at the Main Terrace may be due to effects of declines in water levels in the shallow ground water system. Evidence also suggests that the specific impact of the Steamboat Hills Project's current operations on the thermal water levels under the Main Terrace (estimated to be 0.5 to 1.0 feet by Nork (1992) and 1.0 to 3.0 feet by Sorey and Colvard (1992)) has been small compared to the thermal water level declines created by other influences, such as the lowering of the non-thermal water table and the drought (Nork, 1992; Sorey and Colvard, 1992). Although the lowering of ground water tables is generally reversible (through increased recharge, decreased production, or manipulation of pressure gradients), based upon the observations to date, it is unlikely that discharge from the hot springs and/or geysers would resume even if production at the Steamboat Hills Project were to cease or be mitigated <u>and</u> recharge to the shallow ground water system from precipitation were to return to normal, because increased ground water withdrawals from the alluvial aquifer appear to be the major cause of thermal water level declines in the Main Terrace area (Sorey and Colvard, 1992).

4.5. Air Resources

4.5.1. Meteorology

The climate of the Steamboat Hills is characterized by warm, dry summers and cool, moist winters with local variations due to elevation and slope aspects.

Weather data collected at Reno Cannon International Airport, located approximately 8 miles north of the Steamboat Hills Project area, is summarized in Table 4-2.

Table 4-2: Summary of Available Weather Data for the Steamboat Hills Study Area

Month	Average Temperature (°F)	Total Precipitation (inches)	Wind Speed and Direction (miles per hour)	
January	32.2	1.24	5.6	S
February	37.4	0.95	6.2	S
March	40.6	0.74	7.8	WNW
April	46.4	0.46	8.2	WNW
May	54.6	0.74	7.9	WNW
June	62.4	0.34	7.6	WNW
July	69.5	0.30	7.0	WNW
August	66.9	0.27	6.5	WNW
September	60.2	0.30	5.8	WNW
October	50.3	0.34	5.3	WNW
November	39.7	0.60	5.5	S
December	32.5	1.21	5.2	SW
Annual	49.4	7.49	6.6	WNW

Data from 1951-1980, Source: NOAA, 1990

Because temperature generally decreases with elevation, the temperatures recorded at the Cannon International Airport monitoring station, on average, would be slightly higher than the actual temperatures around the Steamboat Hills study area. The elevation of the Cannon International Airport monitoring station is approximately 4,400 feet AMSL, while the elevation of the Steamboat Hills Project area is approximately 5,300 feet AMSL.

Most precipitation in western Nevada originates from frontal storms during the winter months, with some convectional storms occurring during the summer months (Houghton, et al, 1975). The greatest accumulations of precipitation (up to 60 inches per year) occur in the Carson Range. Lesser amounts (approximately 20 inches per year) accumulate in the Virginia Range, and less than 6 inches fall on the valley floor. The Steamboat Hills, Truckee Meadows, and Virginia Range all lie in the rain shadow of the Carson Range (Nork, 1992). The mean annual precipitation at the Cannon International Airport monitoring station was 7.49 inches for the period from 1951 through 1980 (USDI, 1987).

Since the 1984-85 precipitation year, drought conditions have existed in the region. Between 1984 and 1989, average annual precipitation was 6.39 inches, and in only one (1) year since 1984 was precipitation greater than the 7.49-inch historic average (NOAA, 1990). Other periods of drought conditions in the region have also existed in recent history, particularly during the 1940's and again during the 1970's (Sorey and Colvard, 1992).

4.5.2. Air Quality

The study area is located within hydrographic basin No. 87 (Truckee Meadows) and No. 88 (Pleasant Valley), which are also the numbers used by the NDEP to designate the air basins. NDEP monitoring of the Truckee Meadows basin has determined that the basin is in nonattainment status for PM_{10}, carbon monoxide and ozone. NDEP monitoring to determine the attainment or nonattainment status of the Pleasant Valley basin has not been conducted and, as such, this basin is considered "unclassified" in regards to attainment status. However, NDEP staff have indicated that the unclassified status of this basin can be construed to mean that the basin is an attainment area since it has not been proven to be nonattainment (McCleary, 1991).

National Ambient Air Quality Standards (NAAQS) established under the Federal Clean Air Act specify the maximum allowable concentration of a pollutant, or class of pollutants, in the atmosphere to provide for protection of public health and welfare from known or anticipated adverse effects. In addition, the state of Nevada and Washoe County have promulgated ambient air quality standards which are equal to or more stringent than the NAAQS. The Washoe County ambient air quality standard for H_2S, the principal pollutant emitted from the Steamboat Hills Project, is 5.0 parts per billion (ppb).

Air pollution levels in the study area are generally higher during the winter months, when temperature inversions trap pollutants near the surface. Most pollutants of concern in the study area are combustion emissions resulting from motor vehicle traffic and wood burning.

Air pollutant monitoring was conducted in the study area from mid-January to mid-June, 1986 as part of the baseline environmental data gathering that was conducted for the Steamboat Hills Project. The following are the maximum daily average concentrations for the pollutants monitored during that period: SO_2 - 8.93 ppb; NO - 6.19 ppb; NO_2 - 37.09 ppb; NO_x - 37.83 ppb;, and NH_3 - 69 micrograms per cubic meter ($\mu g/m^3$) (CH_2M Hill, 1986a and 1986b). H_2S was monitored during the same monitoring period, but was not detected.

The Steamboat Hills Project emits essentially no pollutants except for H_2S. The H_2S is emitted from the cooling tower and chemical abatement tower. The two-phase flow of geothermal production fluid currently delivered to the power plant contains approximately 20 to 24 lbs./hr. of H_2S, almost all of which ends up in the steam after flashing. After the steam is condensed in the condenser, almost all of the H_2S is ejected with the noncondensible gases, but a small portion remains with the condensate and is quickly released from the cooling tower. The Steamboat Hills Project power plant currently utilizes a chemical abatement system that scrubs the noncondensible gases exiting the power plant condenser in a packed tower to remove most of the H_2S entrained in the steam prior to release of the gases to the atmosphere. This chemical abatement tower system utilizes sodium hydroxide to scrub the noncondensible gases to remove approximately 95 to 97 percent of the H_2S prior to release to the atmosphere. The amount of H_2S currently released to the atmosphere during normal Steamboat Hills Project operations ranges from approximately 3.0 to 4.5 lb/hr. This amount is substantially less than the 5.5 lb/hr limit set by the Washoe County District Health Department. The previously approved modifications to the Steamboat Hills Project's H_2S abatement system (see Section 3.1.2) would reduce current average emissions of H_2S by approximately 50 to 70 percent. All operations for the Steamboat Hills Project are conducted in compliance with state and county air quality requirements.

Since the current H_2S abatement system was installed at the Steamboat Hills Project in 1988, there have been a few instances when local residents in Pleasant Valley recognized detectable H_2S levels. These observations could usually be correlated with malfunctions in the Steamboat Hills Project H_2S abatement system. As a result of these observations, CPI agreed to undertake a 90-day H_2S monitoring program which was initiated in June, 1992, at two (2) stations in

Pleasant Valley. One (1) station was located directly south of the Steamboat Hills Project and the other was located to the southeast. During the operation of this monitoring program, local residents noticed the odor of H_2S at times which were coincident with monitoring results of greater than 5.0 ppb H_2S equivalent. One (1) of these observations correlated with a malfunction in the Steamboat Hills Project H_2S abatement system.

4.6. Biological Resources

4.6.1. Vegetation Communities

The study area is located at elevations between 4,500 feet and 6,200 feet AMSL. A mixed shrub/forb/grass community with two (2) variations is dominant in the Steamboat Springs Unit Area. One of the variations is dominated by big sagebrush (*Artemisia tridentata*) with lesser amounts of low sagebrush (*Artemisia arbuscula*). The other variation is distinguished by desert needlegrass (*Stipa speciosa*) with lesser amounts of big sagebrush and Thurber needlegrass (*Stipa thurberiana*) (CH_2M Hill, 1986a). Other species present in the Steamboat Springs Unit Area are listed in Table 4-3.

Table 4-3: Partial Vegetation Resources Species List

Common Name		Scientific Name	Common Name		Scientific Name
GRASSES:	Cheat grass	*Bromus tectorum*	FORBS:		*Balsamorhiza sagittata*
	Douglas rabbitbrush	*Chrysothamnus nauseosus*			*Balsamorhiza hookeri*
	Great Basin wild rye	*Elymus cinereus*			*Crepis accuminata*
	Bottlebrush squirreltail	*Sitanion hystrix*		Cutleaf Filaree	*Erodium circutarium*
	Indian ricegrass	*Oryzopsis hymenoides*		Lupine	*Lupinus sp.*
	Sandberg bluegrass	*Poa secunda*			*Calochotus nuttalli*
		Stipa speciosa			*Eriogonum sp.*
		Stipa thurberiana			*Aster sp.*
	Bluebunch wheatgrass	*Agropyron spicatum*			*Medicago sativa*
	Crested wheat	*Agropyron cristatum*		Phlox	*Phlox sp.*
SHRUBS:	Big sagebrush	*Artemisia tridentata*	TREES:	Jeffrey Pine	*Pinus jeffreyi*
		Artemisia arbuscula		Singleleaf pinon	*Pinus monophylla*
	Antelope bitterbrush	*Purshia tridentata*			
	Rubber rabbitbrush	*Chrysothamnus nauseosus*			
		Ephedra nevadensis			
		Prunus andersoni			
	Broom snakeweed	*Gutierrezia sarothrae*			
		Lygodesmia spinosa			

Source: CH_2M Hill, 1986a and 1986b

Consultation with the Nevada Natural Heritage Program (NNHP) in 1989 (Appendix E) for records of endangered, threatened, rare, candidate or sensitive plant species revealed only the Steamboat buckwheat (*Eriogonum ovalifolium var. williamsiae*) within the study area. Consultation with the NNHP in 1993 (also Appendix E) identified records for an additional species, the altered andesite buckwheat (*Eriogonum robustum*), found within the study area. Additional information regarding these species is discussed below.

4.6.1.1. Altered Andesite Buckwheat

Altered andesite buckwheat (*Eriogonum robustum*), a.k.a. Lobb buckwheat (*Eriogonum lobbi var. robustum*), is a Federal category 2 candidate species, which means that there is some evidence of vulnerability, but without further research there is not enough data to support listing as Threatened or

Endangered. There is no Nevada State listing for the species, although the Northern Nevada Native Plant Society has placed the species on "watch" status, denoting a potentially vulnerable taxa in need of monitoring or further data to determine status (Morefield and Knight, 1991). The species is known to occur in Nevada in Carson City, Lyon, Storey and Washoe Counties.

The NNHP in 1993 documents populations of the altered andesite buckwheat within the study area in Section 32, Township 18 North, Range 20 East, and in 1989 and 1993 in Sections 26 and 35 in this same township, although outside of the study area. Additional individuals have also recently been identified in Sections 28 and 29 of Township 18 North, Range 20 East. This species is known to favor areas of acidic soil derived from historically hydrothermally altered andesite rock.

4.6.1.2. Steamboat Buckwheat

Steamboat buckwheat, Federally listed as an endangered species and statelisted as critically endangered, has been observed in Sections 28, 29, and 33, Township 18 North, Range 20 East (CH_2M Hill, 1986b). This species inhabits only those areas around the historically active and fossil hot springs on the Main, Low and High Terraces in the Steamboat Hills area. The species was proposed for Federal listing as endangered in 1985, and actually Federally listed as endangered in 1986, because of its limited range and potential threats to its continued existence through present or threatened destruction, modification, or curtailment of its habitat or range (USFWS, 1985; USFWS, 1986). Presently, the USFWS has not identified critical habitat for the species, and a recovery plan has not yet been prepared.

At the time the Steamboat buckwheat was listed, it was thought that most of the plants were concentrated on 20 acres of a total of 80 acres of BLM land, and on 40 acres of land owned by a private citizen, although the species was thought to have been more widespread in the past. It was also hypothesized that there was a relationship between the species' moisture requirements and hot springs flow, although it was acknowledged that little was known about the moisture requirements of the Steamboat buckwheat (Williams, 1982; CH_2M Hill, 1986b).

Under the Endangered Species Act, as amended, Federal agencies are specifically required to ensure that any action they authorize, fund or carry out are not likely to jeopardize the continued existence of the species. This includes any actions which may be taken on Federal lands on which the species is found, such as the BLM-managed 40-acre Steamboat ACEC located in the NE¼ of the NW¼ of Section 33 and the USFS-managed 40-acre parcel located in the SW¼ of the SW¼ of Section 28, as well as any other Federal actions which may directly or indirectly affect the species, whether located on private or Federal lands.

In 1987, the Steamboat buckwheat was state-listed as critically endangered under the Nevada statute for the Protection and Propagation of Selected Species of Native Flora (NRS 527.270). This listing required full protection for Steamboat buckwheat on all lands within the State of Nevada under NRS 527.260 to 527.300, inclusive, and required that the species not be removed or destroyed without a special permit. The state law brought full protection from direct impacts to the Steamboat buckwheat on private lands, which specifically included the remaining portions of Sections 28 and 33, as well as Section 29.

A 1986 survey in the Steamboat Hills area in connection with the proposed Steamboat Hills Geothermal Project mapped the occurrence of the Steamboat buckwheat and evaluated the various parameters of the Steamboat buckwheat habitat to determine the specific characteristics which make the Steamboat Hills area suitable as Steamboat buckwheat habitat (CH_2M Hill, 1986d). The study investigated soil chemistry and moisture, distribution of the plants relative to the active hot springs, and plant associations.

Mapping for the survey was conducted in an approximate 370-acre area within which almost all of the known Steamboat buckwheat occurs (see Figure 4-5). The areas shown on Figure 4-5 as "General Areas Covering Known Populations of Steamboat Buckwheat" have been generally drawn from data developed by the 1986 survey to show the basic distribution of the Steamboat buckwheat in 1986. These general areas contain all the identified Steamboat buckwheat populations, as well as areas of known Steamboat buckwheat habitat, potential future habitat and some areas that may not be habitat. Within these areas there were approximately 50 acres of actual Steamboat buckwheat populations. Each of these areas are apparently substantially larger than those first presumed by the USFWS when the species was listed.

The 1986 CH_2M Hill study concluded that the occurrence of Steamboat buckwheat was specific to soils which develop on decomposing siliceous sinter deposited by the hot springs and geysers. The sinter soils were relatively immature and undeveloped, and the Steamboat buckwheat was generally not found on deep soils or alluvial soils. It appeared that the hot springs and geysers did not supply the moisture requirements of the species, but that the Steamboat buckwheat was largely dependent on natural precipitation.

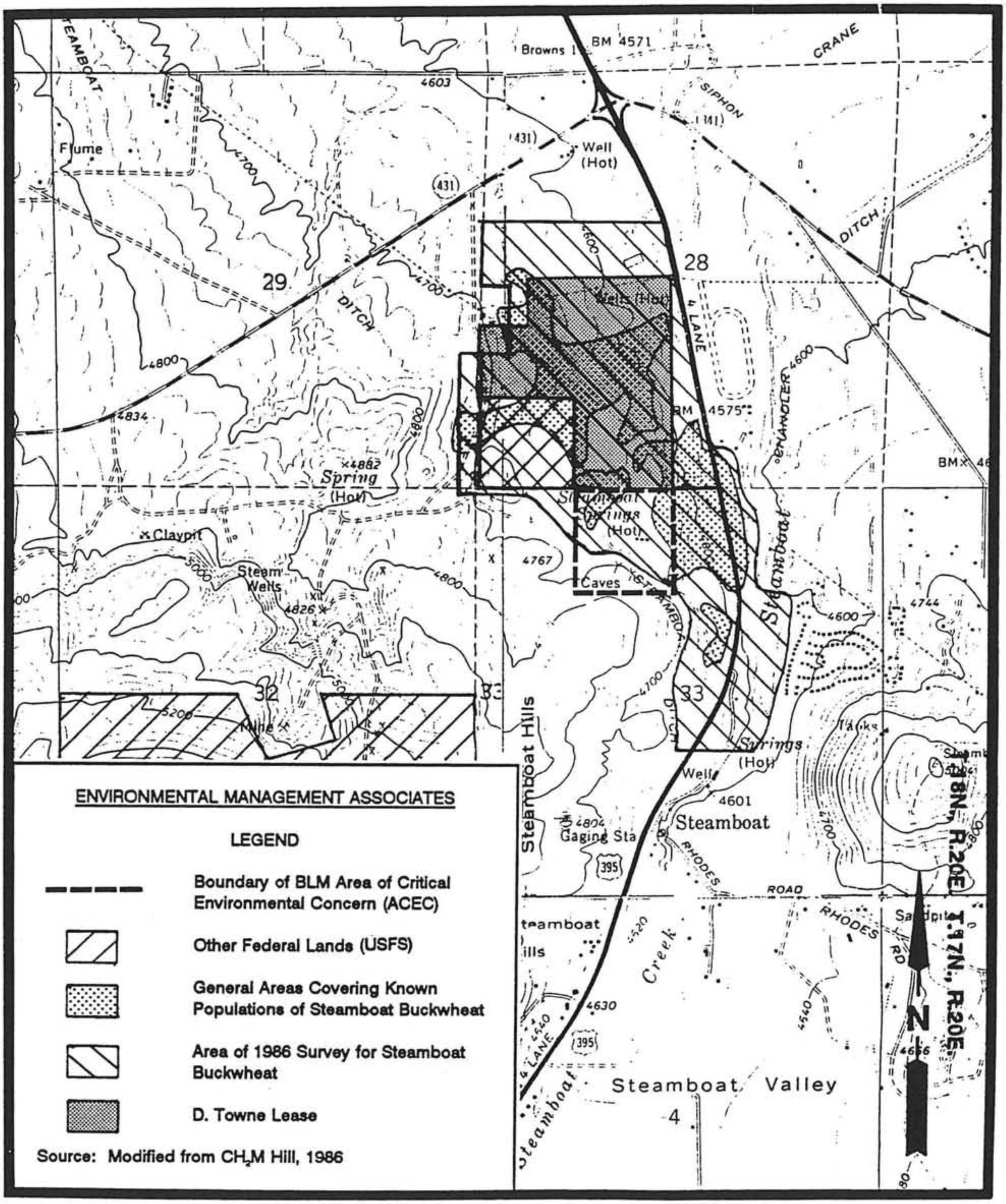


Figure 4-5: Location Map of the General Occurrence of Steamboat Buckwheat in the Steamboat Hills

Steamboat buckwheat also appeared to be intolerant of the high soil moisture conditions and the high mineral levels of the geothermal fluids at the hot springs (CH_2M Hill, 1986d). For example, healthy populations of Steamboat buckwheat have been found on the High Terrace (see Figure 4-2 and Figure 4-5) although, as indicated in Section 4.4.1.2, there have been no spring flows historically (for at least 120 years), and probably much longer. This study concluded that the Steamboat buckwheat was endemic to, and was the colonizing species of, the sinter soils. It appeared to be the first plant to adapt to the slowly maturing soil as conditions for plant growth became less harsh through the leaching of soluble chemicals from the sinter. Over time, with continued soil development, other plants were able to occupy the site, possibly out-competing the Steamboat buckwheat, which may cause it to decline or die out completely at a given site.

As part of the approval of the 1987 Steamboat Hills Geothermal Project POO/POU, formal consultation with the USFWS (USFWS, 1987), under Section 7 of the Endangered Species Act, as amended, was conducted because the then-proposed activities were presumed to have the potential to directly or indirectly affect the Steamboat buckwheat. The analysis of potential impacts in the USFWS Biological Opinion concluded that no direct impacts would occur, but that indirect impacts from the Steamboat Hills Project could possibly develop if the Steamboat Hills Project altered the hydrologic regime of Steamboat Springs. However, the Biological Opinion concluded that the then proposed Steamboat Hills Project would not likely jeopardize the continued existence of the endangered Steamboat buckwheat as a result of alteration of the hydrologic regime. Monitoring of the hydrology of the surface water, ground water and hydrothermal features was to be conducted to determine if significant adverse impacts were occurring. If alteration of the hydrologic regime were to occur as a result of the proposed Steamboat Hills Project, then mitigation measures were to be implemented to minimize the impact.

Since the USFWS Biological Opinion was issued in 1987, a number of factors have interacted on the hydrology of the Steamboat Springs, causing the hot springs and geysers to cease flowing in 1989. These factors are, in order of believed importance: increased ground water withdrawals for domestic and municipal consumption; the extended regional drought; and the production and injection of geothermal fluids, all of which are fully discussed in Section 4.4, Hydrology.

Because the hot springs and geysers are currently not flowing (see Section 4.4.1.2), siliceous sinter is currently not being deposited on the Main or Low Terraces. If the springs and geysers continued to not flow for a long period of time, and sinter continued to not be deposited, eventually the development of sinter soils would slow and, ultimately, stop as all available deposits of sinter were weathered to soil. The existing sinter soils would mature to the point that the Steamboat buckwheat would likely be pushed out by plants more competitive in the deeper, more mature soils. However, as described in Sections 4.3 and 5.3, because of the large areal extent and thickness of the existing sinter deposits, and the very slow rate at which the sinter weathers to soil, an appreciable reduction in the sinter available for weathering to soil is not considered likely for tens of thousands to hundreds of thousands of years. In the short term (hundreds of years to tens of thousands of years), if the springs do not flow and the sinter continues to not be deposited, the rate of development of sinter soil may actually increase, because all deposited sinter would be available for weathering, and none would be covered by actively depositing sinter. This would result in increased habitat for the Steamboat buckwheat over this time period, both because of the increase in immature sinter soils for the Steamboat buckwheat to colonize, and because no geothermal fluids, in which the Steamboat buckwheat apparently cannot grow (CH_2M Hill, 1986d), would be discharged to the surface to reduce the available sinter soils.

In 1991 a detailed, intensive survey of the Steamboat buckwheat on approximately 110 acres of private land in the southwestern portion of Section 28, Township 18 North, Range 20 East, MDB&M, was conducted as part of the SBG 2 and 3 expansion project for the Nevada Division of Forestry (NDF) Conditional Permit (Nelson, 1991). This survey identified two (2) major populations, as well as several smaller, more fragmented populations, of Steamboat buckwheat in Section 28 (see Figure 4-5). The locations of these populations were generally consistent with those identified in the 1986 survey. Although the 1986 and 1991 surveys were conducted using different field methods, and comparisons may not be accurate, the two (2) major populations identified in the 1991 survey each appear to cover a significantly greater area than those identified in the 1986 survey. The smaller populations identified in the 1991 survey are also greater in areal extent than those identified in the 1986 survey. The exception to this is in the area in the NE¼ of the NE¼ of the SW¼ of Section 28, where the population identified in 1986 appears to have largely died out.

In October of 1991, the NDF issued a Conditional Permit for Disturbance or Destruction of Critically Endangered Species for the SBG Steamboat Power Plant Expansion (SBG 2 and 3), which was to be constructed on a 110-acre private geothermal lease containing significant Steamboat buckwheat habitat and populations (see Figure 4-5). Among other requirements, the permit required that a conservation agreement be "validated" prior to construction activities, and a management plan for the Steamboat buckwheat be developed and implemented within one (1) year from the date of permit issuance. SBG contracted with The Nature Conservancy to manage and implement the required mitigation measures, and in December of 1991, as part of the construction of the SBG 2 and 3 expansion projects in Section 28, approximately 17,000 individual Steamboat buckwheat plants were removed from the SBG 2 and 3 project area and either transplanted to other areas in Section 28 or to greenhouses for study. This transplantation disturbed approximately 0.15 acres of Steamboat buckwheat populations.

Currently, the University of Nevada-Reno greenhouses, the May Arboretum and the NDF have some of the transplanted Steamboat buckwheat (The Nature Conservancy, Knight, 1993). All three (3) facilities will be conducting experiments with various methods of transplanting, propagating, seed production and germination and grow-out gardening in both native and introduced soils. This information can then be incorporated into any recovery plan prepared by the USFWS for the Steamboat buckwheat.

A thirty-year Steamboat buckwheat management plan is currently being written by The Nature Conservancy for the 110-acre SBG 2 and 3 geothermal lease, which will include monitoring methods and techniques for the long-term protection of the existing Steamboat buckwheat populations, as well as the mitigated areas, inside the 110-acre SBG 2 and 3 geothermal lease area. This plan will be available for public review and implementation in 1993 (Knight, 1993).

4.6.2. Wildlife Resources

A variety of wildlife species inhabit the study area. Biological surveys conducted as part of the environmental baseline data gathering for the Steamboat Hills Project provide most of the information available of wildlife within the study area.

Mammals typical of the study area include mule deer, coyote, jackrabbit, cottontail, and various rodents. Mule deer which utilize the study area are resident Nevada deer which summer in the Carson Range, west of the Steamboat Hills Project area, and winter in the foothills, including the study area, as well as in the Virginia Hills, east of the study area (CH_2M Hill, 1986c). Three (3) key mule deer range sites were located within the study area to the south and west of the Steamboat Hills Project power plant site. The overall average deer density on these key range sites was approximately 103 deer per square mile, and approximately 90 percent of the plants in these areas showed signs of hedging (browsing) (CH_2M Hill, 1986b). Mule deer use of other portions of the study area appear to be limited. No mule deer migration corridors have been identified in the Steamboat Springs Unit Area.

Raptors observed within the study area during the environmental baseline data collection include the red-tailed hawk, American kestrel, golden eagle, northern harrier, barn owl, and Swainson's hawk. No raptor nests were identified during the data collection period (CH_2M Hill, 1986b and 1986c). The study area is also used by numerous songbird and breeding bird species.

Consultation with the Nevada Natural Heritage Program in 1989 (Appendix E) and 1991 (Kolar, 1991) revealed no records of endangered, threatened, rare, candidate or sensitive wildlife species in the study area.

4.7. Wilderness

The designated wilderness nearest to the study area is the Mount Rose Wilderness Area, located approximately 5 miles west of the Steamboat Hills Project area. There are currently 102 units of public land managed by the BLM in Nevada which are classified as Wilderness Study Areas (WSAs) (USDI, 1986b). The BLM has conducted studies for each WSA to recommend to the Secretary of the Interior which WSAs are suitable or unsuitable for inclusion in the National Wilderness Program System. The nearest WSA to the study area is the Burbank Canyons WSA, located approximately 40 miles southeast of the study area. The Steamboat Hills Project is not directly visible from any Wilderness Areas or WSAs.

4.8. Cultural and Paleontological Resources

4.8.1. Cultural Resources

The Steamboat Hills Project is located in a region which is abundant in cultural resources due to the diversity of prehistoric and historic activities which have taken place there. Prehistorically, the Steamboat Hills Project area was used as a sinter quarry and winter village area, while Steamboat Creek was a site of almost constant occupation. Historical activities included mining and the occupation of the Steamboat Springs area during the last half of the 19th century (USDI, 1987). Cultural resources clearance has been granted to all areas which have been previously disturbed as a result of project development activities.

4.8.2. Paleontological Resources

No paleontological resources are known to exist within the Steamboat Hills Project area; however, any paleontological resources which would exist within the Steamboat Hills Project area would most likely be very common for the region and the state of Nevada.

4.9. Visual Resources

The visual resources of the Steamboat Hills Project area have been investigated using methods outlined in Section 8400 of the BLM Manual (USDI, 1986a). Using these methods, the resources are analyzed by considering the scenic quality, viewer sensitivity and the distance between the viewer and the proposed modification of the landscape. The BLM Visual Resource Management (VRM) system, which was developed by the BLM for identifying, evaluating and classifying visual resources for land management resources, assigns a management class rating from I through IV by inventorying and evaluating both scenic quality and the sensitivity of a landscape (Table 4-4). The Steamboat Hills Project area is located in a Class III and Class IV VRM area. A Class III VRM rating means that changes in the landscape may be evident in the characteristic landscape but should remain subordinate to the visual strength of the existing character. A Class IV VRM rating means that the proposed changes in the landscape may subordinate the original character of the landscape.

Table 4-4: BLM Visual Resource Management Classes

Class	Description
I	The objective of this class is to preserve the existing character of the landscape. This class provides for natural ecological changes; however, it does not preclude very limited management activity. The level of change to the characteristic landscape should be very low and must not attract attention.
II	The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen, but should not attract the attention of the casual observer. Any changes must repeat the basic elements of form, line, color and texture found in the predominant nature features of the characteristic landscape.
III	The objective of this class is to partially retain the existing character of the landscape. The level of change to the characteristic landscape should be moderate. Management activities may attract attention, but should not dominate the view of the casual observer. Changes should repeat the basic elements found in the predominant natural features of the characteristic landscape.
IV	The objective of this class is to provide for management activities which require major modification of the existing character of the landscape. The level of change to the characteristic landscape can be high. Management activities may dominate the view and be the major focus of viewer attention. However, every attempt should be made to minimize the impact of these activities through careful location, minimal disturbance, and repeating the basic element.

Source: USDI, 1986a

The landscape of the Steamboat Hills Project area, as well as the study area and the surrounding area, consists of north-south trending mountain ranges interspersed with valleys. Vegetation consists of shrubs and grasses. Browns and tans are the dominant vegetation and landscape colors in the area, although some small areas of grays or greens are apparent. The Steamboat Hills Project facilities are generally located on the hilltops, while the surrounding valleys are generally occupied by residences.

Existing Steamboat Hills Project facilities are most visible to travelers on US 395. Those traveling southbound on the highway can intermittently see some Steamboat Hills Project facilities, such as pipelines, roads and the transmission line. The Steamboat Hills Project facilities are most visible to those traveling northbound on

US 395, especially from the top of Washoe Hill, which is located to the south of the Steamboat Hills Project area. Views from this point include the existing power plant and cooling tower facility, as well as pipelines, roads and wellsites. The existing vapor plume, which emanates from the cooling towers, is most visible during the winter months. Lighting at the power plant facility is directed so as to not be directly visible to viewers from the highway or residences.

4.10. Noise

The existing Steamboat Hills Project is located in a moderately populated rural area, with the nearest residence located approximately 0.5 miles southwest of the existing power plant site. Some man-made sources of noise within the Steamboat Hills Project area include the operation of the existing Steamboat Hills Project, aircraft (the Steamboat Hills Project area is located under a major flight path for the Reno-Cannon International Airport) and vehicle traffic on nearby US 395. Ambient noise levels were monitored as part of the environmental baseline data collection for the Steamboat Hills Project from numerous sites within and around the Steamboat Hills Project area. Measurements from a site located approximately 1,000 feet northwest of the power plant site indicate that hourly L_{eq} measurements ranged from approximately 30 decibels (DBA) during nighttime periods to peak levels of approximately 65 DBA during peak traffic periods (CH_2M Hill, 1986a, 1986b, 1986c and 1987).

Noise level standards are generally set to protect human and wildlife receptors from undue health effects, interference and annoyance. Under Geothermal Resources Operations Order No. 4, all Federal geothermal lessees must comply with Federal occupational noise exposure levels or state standards for protection of personnel, whichever are the more restrictive. Unless a more restrictive level is set by the BLM authorized officer, the maximum noise exposure levels are set at an energy-equivalent noise level (L_{eq}) of 65 DBA for all geothermal-related activity, as measured at the lease boundary or at 0.8 kilometers (one-half mile), whichever is greater.

4.11. Land Use

The Steamboat Hills Project is located within the Steamboat Springs Unit Area within the Steamboat Springs KGRA on Federal and private lands. As of July 1, 1988, all Federal lands in the area, except for the 40-acre Steamboat ACEC, were transferred from the BLM to the USFS, and are currently administered by the USFS, although all geothermal-related development within the Steamboat Springs Unit Area requires the approval of the BLM with the concurrence of the USFS, pursuant to the Geothermal Steam Act of 1970, as amended. The Steamboat Hills Project, a 12.5 MW electric geothermal power plant which is operated by CPI, has been in operation since February of 1988. A 6.8 MW electric binary geothermal power plant which is owned by SBG is located approximately 1 mile north of the Steamboat Hills Project.

The Steamboat Hills Project area is within Washoe County and is zoned A1 and A4. Within this zoning, geothermal development is authorized under a Special Use Permit. As stated above, the Federal lands in the Steamboat Hills Project area are either within the Toiyabe National Forest or the BLM Lahontan Resource Area. The development of the geothermal resource is consistent with the Forest Plan and the Resource Area Management Plan, respectively. Geothermal development is permitted through a POO/POU issued by the BLM.

Other land uses within and/or around the study area, apart from geothermal development, include residential uses, transportation, agriculture, livestock grazing, and vehicle-oriented recreation. There are no established grazing allotments within or immediately around the Steamboat Hills Project area. The nearest residence is approximately 0.5 miles southeast of the existing power plant site.

Several historic mining operations, which produced gold, silver, lead, zinc, mercury, sulfur, cinder, clay and aggregate, are located within and around the study area. An active quarry operation is located approximately 0.5 miles northwest of the Steamboat Hills Project.

The BLM's Steamboat ACEC is located in the NE¼ of the NW¼ of Section 33, Township 18 North, Range 20 East, MDB&M, approximately 0.5 miles northeast of the Steamboat Hills Project. This 40-acre parcel was designated as a "Hot Springs Reserve" in 1963 because of the geothermal features present on the parcel. This designation allowed for the implementation of BLM management measures which afforded some protection to the geothermal features of the ACEC area. As a result of authorities granted under FLPMA, the BLM developed the Reno Management Framework Plan (RMFP) which, among other things, determined the need for designation of an ACEC on the 40-acre parcel, to more fully protect the geothermal features of the area (USDI, 1983).

The Steamboat ACEC was officially created by the BLM on January 19, 1983. During the BLM's development of the Steamboat ACEC, the Steamboat buckwheat was identified as a new variety of *Eriogonum ovalifolium*. Populations of Steamboat buckwheat were identified in the hot springs areas of the Steamboat Hills, and within the 40-acre "Hot Springs Reserve", specifically. As a result of this discovery, the BLM management plan for the Steamboat ACEC, which was completed in March, 1983, was expanded to also include the protection of the Steamboat buckwheat. Detailed discussions of the geothermal-related features and the Steamboat buckwheat are located in Sections 4.4.1.2 and 4.6.1.2, respectively, of this EA. As part of the development of the Steamboat ACEC, the BLM entered into an agreement with Washoe County for Washoe County to develop a park within the Steamboat ACEC. The plan for interpretive sites and recreational facilities in the park is part of the goal of the Steamboat ACEC, as identified in the RMFP, which would allow for greater recreational access to the Steamboat ACEC area while protecting the geothermal features of the Steamboat ACEC.

4.12. Socioeconomics

4.12.1. Population

The Steamboat Hills Project is located in southern Washoe County within northwestern Nevada. The nearest population center is the Reno/Sparks metropolitan area, which is located approximately 5 miles north of the Steamboat Hills Project area. The official population counts for Washoe County are presented in Table 4-5:

Table 4-5: Official Population Counts for Washoe County, Nevada

City/County	1980 Population[a]	1990 Population[b]	Percent Increase
Reno	100,756	133,850	33%
Sparks	40,780	53,367	31%
Balance of County	52,087	67,450	29%
Washoe County (total)	193,623	254,667	32%

[a]Source: NOCS, 1985
[b]Source: USBC, 1991

4.12.2. Economy

The service industry is the major employer in Washoe County, with hotel, gaming, and recreation services dominating. In 1989, 41.1 percent of all wage and salary jobs in Washoe County were in the service industry, with trade and the government sector also leading as employers, with 23.0 and 12.3 percent, respectively, of all wage and salary earners (NOCS, 1990). The 1990 annual average unemployment rate for Washoe County was 4.8 percent, a slight increase over the 1989 rate of 4.7 percent. During the same period, state average unemployment rates dropped slightly to 4.9 percent, down from 5.0 percent in 1989 (Benson, 1991).

4.12.3. Housing

There were 112,193 total housing units in Washoe County in 1990. Of these, 49.3 percent were owner-occupied, 41.9 percent were renter-occupied, and 8.8 percent were vacant. The median value of an owner-occupied unit in Washoe

County was $111,200.00, while the median cash rent in the county was $429.00 (USBC, 1991).

4.12.4. Services

Electricity in most of Washoe County is provided by Sierra Pacific Power Company. Natural gas is supplied to the Reno-Sparks area by Westpac Utilities, while other areas are supplied by Southwest Gas. Other home heating fuels in use in the area include LP gas, fuel oil and wood (NOCS, 1985).

Law enforcement in the unincorporated areas of Washoe County is provided by the Washoe County Sheriff's Department. Fire protection services for the Steamboat Hills Project area are provided by the NDF. Road maintenance is provided by the governmental division (state, county, or city) otherwise responsible for each particular road.

The Washoe County School District provides primary and secondary education for Washoe County students. School enrollment has greatly increased due to the general population increase during recent years. Enrollment in the district from the 1988-1989 school year to the 1989-1990 school year increased approximately four (4) percent, and increased 17.6 percent from 1983 to 1989 (NOCS, 1990).

Three (3) hospitals, Washoe Medical Center, St. Mary's Regional Medical Center, and Sparks Family Hospital, serve the Reno-Sparks area and Washoe County. Ambulance service in the Truckee Meadows area is provided by REMSA, the regional emergency transport service provider. Air ambulance service is provided by Care Flight.

4.13. Miscellaneous Resources

There are no prime and unique farmland, floodplains, wild and scenic rivers or areas with Native American religious concern within or adjacent to the study area.

5. ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION

5.1. Physiography

The Proposed Action would have no impacts to the physiography of the area.

5.2. Geology and Mineral Resources

5.2.1. Geology

Seismicity in the vicinity of the Project area is historically moderately high and a large earthquake is a possibility over the expected 30-year life of the increased fluid production. Peak horizontal ground accelerations of 0.4 to 0.5 g are predicted at the project from the largest earthquake likely to occur, which was translated into a ground shaking intensity of VII as expressed on the Modified Mercalli Scale (USDI, 1987). Design and construction of existing facilities in conformance with criteria of the Uniform Building Code requirements should prevent the Project facilities from suffering major structural damage as a result of VII intensity shaking. Because the Proposed Action calls for injection of the geothermal fluids into the geothermal aquifer at geologically shallow depths, between approximately 1,700 and 3,000 feet, and because injection pressures would be low, there is no reason to believe that the increase in geothermal fluid injection would induce seismic events.

5.2.2. Mineral Resources

Under the Proposed Action, the extraction of heat from the additional production and injection of geothermal fluids may increase the rate at which the reservoir is cooling. However, once project operations cease, which is anticipated to be in 30 years, the accelerated cooling will stop, and the reservoir is expected to return (over a few years to a few tens of years after cessation of operations) to essentially pre-production thermal conditions, resulting in no long-term impacts to the mineral (geothermal) resources of the area (see Section 5.4.2).

5.3. Soils

Because there would be no new surface disturbance associated with the Proposed Action, there would be no direct impacts to the soil resources in the study area from implementation of the Proposed Action.

As previously stated in Section 4.3, the Main and Low Terraces are currently not receiving the addition of new siliceous material, as has historically occurred, because the hot springs and geysers are not flowing. The cessation of deposition of silicious sinter by the hot springs will eventually indirectly impact the soils created by the weathering of the silicious sinter, since eventually all the available silicious sinter will weather to mature soils and none will be left to weather into new silicious sinter soil. However, the process of weathering silicious sinter to sinter soil is a very slow process, one which requires hundreds to tens of thousands of years, such that the available supply of existing sinter would not be exhausted for a very long time.

Implementation of the Proposed Action, if not correctly mitigated, may slightly increase the existing drawdown of the thermal water table below the Steamboat hot springs (see Section 5.4.2). However, because the Steamboat hot springs and geysers have already ceased flowing, and because other factors have been judged to be the primary reason for this cessation of flow of the springs, the Proposed Action will not have an effect on the now-ceased flow of the Steamboat hot springs and/or geysers, and thus on the deposition of silicious sinter and, ultimately, the formation of silicious sinter soil, until and unless the effects of the other factors are first reversed (see Section 5.4.2).

Should the adverse effects of the other hydrologic factors be reversed, such that the springs would be able to flow again except for any effects of the Proposed Action, any effect the Proposed Action may have on the hot springs and geysers system, and ultimately the deposition of silicious sinter and the weathering of the sinter to soil, would only last for the duration of the Project and a short time (a few years to a few tens of years) after operations cease. As a result, implementation of the Proposed Action could, at worst, have a small, short-term, indirect impact on the silicious sinter soils, and would not have a long-term indirect impact to these sinter soils associated with the hot springs and geysers (see Section 5.4.2).

5.4. Hydrology

5.4.1. Surface Water

No direct impacts to the surface waters of the area are anticipated from implementation of the Proposed Action. The potential for indirect impacts to surface waters as a result of increased or reduced discharge of thermal waters to Steamboat Creek from the hot springs from the increased production and injection of geothermal fluid is discussed in Section 5.4.2.

As discussed in Section 4.4.1.2, the last hot spring on the Main Terrace ceased to flow in approximately 1989. Because of the complexities of the geothermal system at the Steamboat Hills, it cannot be determined with absolute certainty to what extent each factor, including the current production for the Steamboat Hills Project, has contributed to the thermal and fresh water level declines observed in the vicinity of the Steamboat ACEC and hot springs and geysers since 1986 (see Section 4.4.2.3). However, modelling of the hydrothermal system and the regional hydrology indicate that the relative contribution of the Steamboat Hills Project to the current decline in the thermal water table in the area of the hot springs appears to be small (from less than 1 foot to 3 feet), compared to regional water level declines of approximately 25 feet since 1985 (Sorey and Colvard, 1992; Nork, 1992).

Implementation of the Proposed Action may as much as double the possible existing drawdown of the thermal water table from the Steamboat Hills Project (see Section 5.4.2), although the predicted drawdown from the other stresses on the hydrologic system, including the other geothermal projects and extensive ground water developments, are predicted to be substantially greater (Sorey and Colvard, 1992; Nork, 1992). However, because the hot springs and geysers have already ceased flowing, and other factors have and will contribute much more than the Proposed Action to this water table drawdown, the Proposed Action will not have an effect on the flow of the Steamboat hot springs and/or geysers until and unless the effects of the other factors are first reversed (see Section 5.4.2). Should the adverse effects of the other hydrologic factors on the hot springs be reversed, and should any residual, unmitigated adverse hydrologic effects of the Steamboat Hills Project (including the Proposed Action) still be great enough to prevent the springs from flowing again in the short-term, there should be no long-term impacts (beyond a few years to a few tens of years after cessation of operations) to the geothermal reservoir, and thus the flow of the Steamboat hot springs and geysers, from implementation of the Proposed Action, because these residual effects of the Steamboat Hills Geothermal Project production and injection activities are reversible over this time period (see Section 4.4.1.2).

5.4.2. Groundwater

The Proposed Action would increase geothermal fluid production in the Steamboat Hills project area from the current levels of 1.6×10^6 lb/hr to a maximum of 3.8×10^6 lb/hr, and increase the actual consumption of geothermal fluid from the current approximately 0.16×10^6 lb/hr to as much as 0.38×10^6 lb/hr, or an approximate doubling of each rate. To investigate the possible changes to the hydrologic system as a result of these increases, Nork (1992) modelled the geothermal system, including the total production, injection and consumption of the Steamboat Hills Project and the other existing and proposed geothermal projects (see Section 9.3.1), using a modified version of the computer code VARFLOW. Although the geothermal reservoir is obviously more complex than the modelled system, using a simplified computer code, such as VARFLOW, is useful to understand possible gross effects to the hydrologic system from these proposed changes, and the available data for the geothermal system are insufficient to justify the use of a more complex model.

The results of the modelling suggest that doubling the production rate of geothermal fluid to 3.8×10^6 lb/hr, and the actual consumption of geothermal fluid to 0.38×10^6 lb/hr, could be expected to produce as much as a one (1) psi pressure decline in the geothermal reservoir under the Steamboat hot springs, which translates into a thermal water table decline of approximately 0.5 feet (Nork, 1992). This compares to the 20 psi pressure decline predicted to occur as a result of the operation of all of the current and proposed geothermal projects (see Section 9.3.1).

An alternative, but more simplistic, method of estimating the possible impact of doubling the geothermal fluid production and consumption rate is to assume that the changes to the geothermal reservoir will be linear with the changes to the stresses to the system; that is, doubling the production/consumption rate would double the decline in the thermal water table. Given that the estimates for the decline in the thermal water table under the Steamboat Hills hot springs that has been produced by the existing Steamboat Hills Geothermal Project range from 0.5 to 3 feet, it would follow that a doubling of the production/consumption rate could double the declines in the thermal water table, adding an additional 0.5 to 3 feet to the current thermal water table decline.

The projected life of the Proposed Action is anticipated to be 30 years. At the end of the project life, the operation of the power plant and the production and injection wells would cease, thus ending the Project's utilization of the geothermal resource. Because any effects that the production and injection activities were having on the thermal reservoir are judged to be reversible over time (see Section 4.4.1.2), these effects would begin to dissipate, first at the production and injection areas, then propagating to the other areas of the geothermal reservoir. As a result, there should be no long-term impacts (beyond a few years or a few tens of years after cessation of operations) to the geothermal reservoir and hydrology of the area from implementation of the Proposed Action, even if there are some short-term impacts.

5.5. Air Resources

Aerial emissions of H_2S would change only slightly from current rates as a result of the increase in fluid flow through the power plant associated with the Proposed Action. The increased H_2S produced with the geothermal fluid under the Proposed Action (to as much as nearly 240 percent of current rates), when combined with the planned decrease in current H_2S emissions from the installation of the gas injection system (a decrease of 50 to 70 percent over current emission rates), would result in no H_2S emissions over the 5.5 lb/hr limit set by the Washoe County District Health Department.

The potential for upset emissions from the increased use of geothermal fluid by the Project also exists, although any such emission would be very rare. No significant degradation of the existing ambient air quality should occur as a result of the Proposed Action, and project emissions should not exceed local, state and Federal standards. There would be no direct impacts to any Class I airsheds as a result of implementation of the Proposed Action.

5.6. Biological Resources

5.6.1. Vegetation Communities

Implementation of the Proposed Action will not directly impact any vegetation communities, including any direct impact to any altered andesite or Steamboat buckwheat populations or altered andesite or Steamboat buckwheat habitat, or any indirect impacts to any altered andesite populations or habitat.

As discussed in Section 4.6.1.2, the Steamboat buckwheat is endemic to, and the colonizing species of, the silicious sinter soils derived from the silicious sinter deposited over time by the hot springs and geysers of Steamboat springs. It grows on soils derived from the sinter which are relatively young and immature, but is intolerant of high soil moisture conditions and the high mineral levels of the geothermal fluids at the hot springs themselves. Thus, the Steamboat buckwheat is directly dependent on the silicious sinter soils, but only indirectly dependent on the silicious sinter itself, from which the soils very slowly form, and even more indirectly dependent on the flow of the hot springs and geysers, which slowly deposit silicious sinter which slowly breaks down into the sinter soil upon which the Steamboat buckwheat is dependent.

As previously discussed in Section 4.4.1.2, the Steamboat hot springs and geysers are currently not flowing, and siliceous sinter is not being deposited on the Main and Low Terraces. As stated in Section 4.3, the continued cessation of deposition of silicious sinter by the hot springs will eventually indirectly impact the soils created by the weathering of the silicious sinter, since eventually all the available silicious sinter will weather to mature soils and none will be left to weather into new silicious sinter soil. However, the process of weathering silicious sinter to sinter soil is a very slow process, one which would require hundreds to tens of thousands of years, such that the available supply of existing sinter would not be exhausted for a very long time. Thus, it follows that the potential for any impact to the Steamboat buckwheat from the cessation of flow of the hot springs is extremely unlikely in the short term (hundreds to thousands of years), and low in the long term (hundreds to thousands of years and more).

As discussed more fully in Section 5.3, implementation of the Proposed Action may slightly increase the existing drawdown of the thermal water table below the

Steamboat hot springs if not properly mitigated. However, because the Steamboat hot springs and geysers have already ceased flowing, and because implementation of the Proposed Action may create only a relatively small additional decline in the thermal water table feeding the Steamboat hot springs reservoir compared to other factors, implementation of the Proposed Action will not have an effect on the flow of the Steamboat hot springs and/or geysers, the deposition of silicious sinter, the formation of silicious sinter soil, and thus the Steamboat buckwheat, until and unless the effects of the other hydrologic factors are first reversed (see Section 5.3). Should the adverse effects of the other hydrologic factors on the springs be reversed, and the adverse hydrologic effects of the Steamboat Hills Project (including the Proposed Action) still be great enough to prevent the springs from flowing again, the potential for any impact to the Steamboat buckwheat from the cessation of flow of the hot springs, as explained above, is extremely unlikely in the short term (hundreds to thousands of years), and low in the long term (hundreds to thousands of years and more).

As also discussed more fully in Section 5.3, any effect implementation of the Proposed Action may have on the hot springs and geysers system, and ultimately the deposition of silicious sinter and the weathering of the sinter to soil, would only last for the duration of the Steamboat Hills Project and a short time (a few years to a few tens of years) after operations cease. As a result, implementation of the Proposed Action could, at worst, have a small, short-term, indirect impact on the silicious sinter soils, and thus an even smaller potential indirect impact on the Steamboat buckwheat, and would not have any long-term impact to these sinter soils associated with the hot springs and geysers or the Steamboat buckwheat. The BLM has initiated Formal Section 7 Consultation with the USFWS concerning the Steamboat Buckwheat (Appendix F). This consultation is currently ongoing.

Formal Consultation with the USFWS for the Proposed Action concluded with the USFWS issuance of their Biological Opinion that the Proposed Action was "not likely to jeopardize the continued existence of Steamboat buckwheat in the Steamboat Hills area in the foreseeable future." (USFWS, 1993). This same Biological Opinion stated that the USFWS did not believe that implementation of the Proposed Action would result in any incidental take of Steamboat buckwheat, and made three (3) "conservation recommendations" to the BLM. The 1993 USFWS Biological Opinion is attached as Appendix G to this EA.

5.6.2. Wildlife Resources

Because no changes are expected to result from the implementation of the Proposed Action which would reduce or alter wildlife habitat in the project area, no impacts to wildlife are expected from implementation of the Proposed Action.

5.7. Wilderness

Because the nearest Wilderness Area is located approximately 5 miles west and up hydrologic gradient from the project area, no direct or indirect impacts to wilderness are expected. No impacts to any WSA area are anticipated.

5.8. Cultural and Paleontological Resources

5.8.1. Cultural Resources

Because the Proposed Action does not include any surface disturbing activities or construction of any additional structures, no direct or indirect impacts to any known or undiscovered cultural resources would result.

5.8.2. Paleontological Resources

Because the Proposed Action does not include any surface disturbing activities or construction of any additional structures, no direct or indirect impacts to any known or undiscovered paleontological resources would result.

5.9. Visual Resources

Because the Proposed Action does not include any surface disturbing activities or construction of any additional structures, no visual impacts would result from these type of activities. However, the increased throughput of geothermal fluid in the project's existing cooling tower may result in some small, incremental increase in the size, and possibly the visibility, of the cooling tower water vapor plume. The vapor plume is visible only in the daylight hours during cold weather, and any possible increase in the visibility of the plume would be limited and insignificant.

5.10. Noise

Implementation of the Proposed Action may result in some small, incremental increase in the noise generated by the Steamboat Hills Project. However, any increase would likely be insignificant and indiscernible from the noise currently generated by the Steamboat Hills project, and other existing noise generated by activities surrounding the Steamboat Hills Project Area.

5.11. Land Use

The Proposed Action is: compatible with the existing land uses in and around the project area; compatible with the Washoe County General Plan; compatible with the

BLM Resource Management Plan and the Toiyabe Forest Plan; consistent with the designation of the Steamboat Springs KGRA; consistent with creation of the Steamboat Springs Unit Area; and compatible with the management objectives for the Steamboat ACEC. Also, the Proposed Action is consistent with the current Washoe County zoning designations for the area of operations. The Project is not expected to interfere with any known mining claims or the future expansion of US 395.

As discussed in Section 5.4.1, implementation of the Proposed Action, if not properly mitigated, is predicted to increase possible existing drawdown of the thermal water table from the Steamboat Hills Project. However, because the hot springs and geysers have already ceased flowing, and other factors have contributed much more than the existing Steamboat Hills Project or Proposed Action to this water table drawdown, the Proposed Action will not have an effect on the now-ceased flow of the Steamboat hot springs and/or geysers, and thus the Steamboat ACEC, until and unless the effects of the other factors are first reversed. If these effects of the other hydrologic factors are reversed, any unmitigated residual effects that the Steamboat Hills Project (including the Proposed Action) production and injection activities would have on the thermal reservoir are reversible over time, so there should be no long-term impacts (beyond a few years to a few tens of years after cessation of operations) to the geothermal reservoir, the flow of the Steamboat hot springs and geysers, and thus the Steamboat ACEC, from implementation of the Proposed Action.

5.12. Socioeconomics

Because the implementation of the Proposed Action would not result in any net increase or decrease in the number or type of employees at the Steamboat Hills

Project, no appreciable direct impacts to the area's economy, housing or government services would be expected. However, because increased production of geothermal resources would result in increased royalties being paid to private lessors and the Federal government (which returns one-half of these royalties to the state), some indirect economic benefits would result.

5.13. Miscellaneous Resources

The Proposed Action would have no impacts to prime and unique farmland, floodplains, wild and scenic rivers or areas with Native American religious concern.

6. MITIGATION MEASURES

This chapter discusses mitigation measures recommended to be included as part of the approval of the Proposed Action. Certain environmental impact reduction measures have already been included by Yankee/Caithness as part of the Proposed Action, as outlined in Section 3.2. These measures are not discussed further in this chapter. Mitigation measures are not considered necessary for the following resources: Physiography; Geology and Mineral Resources; Air Resources; Wildlife Resources; Wilderness; Cultural and Paleontological Resources; Visual Resources; Noise; and Socioeconomics, and are not further discussed in this chapter.

6.1. Soils

Because the only potential for impacts to soils from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Section 6.2.2 are considered necessary.

6.2. Hydrology

6.2.1. Surface Water

Because the only potential for impacts to surface water hydrology from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Section 6.2.2 are considered necessary.

6.2.2. Ground Water

The Proposed Action would increase geothermal fluid production in the Steamboat Hills Project area from the current levels of 1.6×10^6 lb/hr to 3.8×10^6 lb/hr, and increase the actual consumption of geothermal fluid from the current approximately 0.16×10^6 lb/hr to as much as 0.38×10^6 lb/hr, or an approximate doubling of each rate. The results of the modelling conducted by Nork (1992) suggests that implementation of the Proposed Action could be expected to produce as much as a one (1) psi pressure decline in the geothermal reservoir under the Steamboat hot springs, which translates into a thermal water table decline of approximately 0.5 feet, which compares to the 20 psi pressure decline predicted to occur as a result of the operation of all of the current and proposed geothermal projects. A more simplistic estimate of the possible impact of the Proposed Action is that it could add an additional 0.5 to 3 feet to the current thermal water table decline under the hot springs.

However, it is also recognized that the available hydrologic data regarding the geothermal and ground water hydrologic systems does not allow the unequivocal determination of the precise cause-and-effect relationships between the various possible stresses to these hydrologic systems and the observed, or predicted, hydrologic responses.

As discussed in Section 3.1.3, to help develop better hydrologic data, the BLM has directed CPI to modify and expand the hydrologic monitoring program originally approved under the 1987 POO/POU. With this additional hydrologic data, which is now being collected, it should be possible to both verify the accuracy of the impacts analysis for the Proposed Action, and allow the definition, implementation and evaluation of suitable mitigation measures for any hydrologic impacts which may occur as a result of the implementation of the Proposed Action.

The expanded monitoring program would specifically: 1) monitor Steamboat Hills Project geothermal reservoir performance in order to better predict future behavior and best manage the resource under use; 2) better understand ground water responses to changes in recharge, precipitation, withdrawal and production and injection operations at the Steamboat Hills Project geothermal field; and 3) obtain data on the hydrology of the area to understand the potential for impacts, and the mitigation of impacts, to the Steamboat hot springs from the operation of the Steamboat Hills Project. This expanded program is specifically designed to ensure that the data collected will be adequate for its intended purposes for both the existing and proposed expansion (the Proposed Action) of the Steamboat Hills Project. Under the approval of this expanded hydrologic monitoring program, the authorized officer has specifically reserved the right to require the CPI to amend the hydrologic monitoring program to alter the monitoring locations, data collected, monitoring frequency or reporting requirements if such an amendment is necessary to ensure the collection of data of acceptable quality which meets the objectives of the program.

The objective of the proposed hydrologic mitigation program for the Proposed Action is defined as the elimination of any of the potential hydrologic changes to the geothermal reservoir which feeds the Steamboat hot springs area which may result from any operations conducted by the Steamboat Hills Project, including the Proposed Action. The proposed mitigation program consists of two (2) parts. The first part is a monitoring program which, as described above, can establish the nature and extent of the actual or impending hydrologic impacts, and can allow the definition, implementation and evaluation of suitable mitigation measures for the identified hydrologic impacts. It is recognized that implementation of a monitoring program is not actually mitigation *per se*, but a collection of data necessary to implement and evaluate mitigation measures. Based upon the design and intent of the Steamboat Hills Project expanded hydrothermal monitoring program, this program appears sufficient to accomplish the objectives of the proposed monitoring program for the Proposed Action, and no additional monitoring appears necessary at this time.

The second part of the proposed mitigation program is the definition and implementation of the actual mitigation measures. A number of geothermal wellfield techniques are possible to accomplish the mitigation of potential impacts (some of which have been previously discussed in Section 3.3). The choice of which mitigation measures to implement must rely on the full range of hydrologic monitoring data available at the time, and upon its quality and consistency. This is one of the reasons that it is difficult to set specific "triggers" for the implementation of any specific mitigation measure.

Given the above analysis, the following actions are proposed to be taken to mitigate any of the hydrologic changes to the geothermal reservoir which feeds the Steamboat hot springs area which result from any operations conducted by the Steamboat Hills Project, including the Proposed Action, which are determined necessary by the BLM authorized officer to eliminate significant adverse hydrologic impacts:

1) The operator shall comply with all conditions of approval of the hydrologic monitoring program, including any subsequent modifications or amendments required by, or approved by, the authorized officer.

2) If the authorized officer determines that the available monitoring information indicates that:

   (a) Pressure, temperature, and/or chemical changes or trends are occurring within the Steamboat Hills Project geothermal production or injection field substantially in excess of the anticipated variations;

   (b) Pressure, temperature, and/or chemical changes or trends are occurring within the monitoring wells as a result of the operation of the Steamboat Hills Project substantially in excess of the anticipated variations; or

   (c) Steamboat Hills Project operations may produce an unacceptable impact to the existing conditions or the trend of activities of the hot springs and geysers system at the Main or Low Terraces,

   the operator shall, as required by the authorized officer, implement one (1) or more of the following mitigation actions:

   (i) Temporarily modify the production and/or injection of geothermal fluids within the Steamboat Hills Project field and monitor the reservoir response. Modification could include one or more of the following:

   - change fluid volumes or pressures in one (1) or more production or injection well(s);
   - discontinue use of one (1) or more production or injection well(s);
   - change the depth of some or all of the injection;
   - relocate one (1) or more production or injection well(s); or
   - any other measures as directed by the authorized officer, or

   (ii) Permanently modify the production and/or injection of geothermal fluids within the Steamboat Hills Project field and monitor the reservoir response.

3) If the authorized officer determines that the available monitoring information indicates that Steamboat Hills Project operations have produced an unacceptable impact to the existing conditions or the trend of activities of the

hot springs and geysers system at the Main or Low Terraces, the operator shall, as required by the authorized officer, implement one (1) or more of the following mitigation actions:

(a) Temporarily modify the production and/or injection of geothermal fluids within the Steamboat Hills Project field and monitor the reservoir response. Modification could include one or more of the following:

(i) Change fluid volumes or pressures in one (1) or more production or injection well(s);

(ii) Discontinue use of one (1) or more production or injection well(s);

(iii) Change the depth of some or all of the injection; or

(iv) Relocate one (1) or more production or injection well(s).

(b) Permanently modify the production and/or injection of geothermal fluids within the Steamboat Hills Project field and monitor the reservoir response.

(c) Reduce or eliminate the consumption of geothermal fluids and monitor the reservoir response.

(d) Reduce or discontinue production of geothermal fluids and monitor the reservoir response.

4) The operator shall establish a mechanism to ensure that the mitigation actions described above will be implemented in a timely manner. The mechanism shall be developed by the operator in consultation with the authorized officer.

The mitigation measures presented above have been defined to ensure that any changes to the hot springs and geysers system in the Main and Low Terrace areas produced by the Proposed Action which are determined to be unacceptably adverse by the authorized officer are mitigated and appropriate remedial actions taken, as necessary.

As a requirement of approval of this amended POO/POU, the operator would be required to comply with the requirements of the approved expanded monitoring program. Monitoring results from the production, injection and monitoring wells and all other monitoring data collected under the expanded hydrologic monitoring plan would be analyzed by the BLM to determine if changes or trends in pressure, temperature, and/or chemistry have been created by operations of the Steamboat Hills Project have occurred outside of the range of anticipated variations.

Although significant adverse impact to the geothermal reservoir feeding the Steamboat hot springs and geysers is not predicted by the various models and is considered unlikely under the current circumstances, if the BLM determined that the monitoring information indicated that Steamboat Hills Project operations may produce an unacceptable impact to the existing conditions or the trend of activities of the hot springs and geysers system at the Main or Low Terraces, the BLM could require the operator to implement one or more wellfield mitigation measures, several of which are specifically identified.

The selection of the proper geothermal wellfield reservoir management technique or techniques to be implemented (from those listed, or others, as appropriate) would depend upon the exact nature of the change in the geothermal reservoir detected by the expanded monitoring program, and the other information provided by the entire hydrologic monitoring program. These reservoir management techniques have been proven generally effective in other geothermal, oil and gas, and ground water fields, and there is every reason to believe that they will be effective in these situations. Most are relatively simple in concept, in that they attempt to modify the hydraulic (pressure) regime of the geothermal reservoir to alter the flow of the geothermal fluid. The BLM authorized officer has the authority to require the lessee to implement any necessary wellfield operation changes as mitigation measures under the Geothermal Steam Act of 1970, the Act's implementing regulations, and the Federal geothermal leases.

If the BLM determined that the monitoring information indicated that Steamboat Hills Project operations actually produced a significant unacceptable impact to the existing conditions or the trend of activities of the hot springs and geysers system at the Main or Low Terraces, the BLM would require the operator to implement one or more wellfield mitigation measures, most of which are the same as previously discussed. Again, the selection of the proper reservoir management technique or techniques (from those listed, or others, as appropriate) would depend upon the nature of the significant adverse impact to the hot springs and geysers system in the Main or Low Terraces detected. The BLM would also consider the reduction or elimination of the consumption of geothermal fluid by the Steamboat Hills Project (of which approximately ten (10) percent of the produced fluid is consumed as cooling tower makeup water), or the curtailment or discontinuance of the production of geothermal fluids.

Because of the nature of the geothermal operations, there is every reason to believe that implementation of standard geothermal reservoir management techniques will be effective in correcting any significant adverse hydrologic effects which may be determined likely to occur, or have occurred, to the geothermal reservoir which feeds the Steamboat hot springs. However, there is no question that if such adverse effects created by the operation of the Steamboat Hills Project are not corrected by standard wellfield techniques, cessation of all geothermal production operations will succeed in correcting the problems. If implemented, cessation of all geothermal fluid production operations would first reverse these adverse effects at the production and injection areas, then propagate the recovery to the other areas of the geothermal reservoir, such that there should be no residual long-term impacts to the geothermal reservoir and hydrology of the area. Although total recovery under worst case situations may require as many as a few tens of years after cessation of operations, most of the recovery would occur within a very short period of time, probably less than one (1) year.

Finally, the proposed mitigation measures require the operator to develop, in coordination with the BLM, a mechanism to ensure that the mitigation measures which may be required by the BLM can and will be able to be timely implemented. This could include, for instance, a program to plan, schedule or obtain any long lead-time permits to alter the geothermal wellfield.

No additional mitigation measures are considered necessary.

6.3. Biological Resources - Vegetation Communities

Because the only potential for impacts to vegetation communities, and specifically the Steamboat buckwheat, from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Section 6.2.2 are considered necessary.

6.4. Land Use

Because the only potential for impacts to land use, and specifically the Steamboat ACEC, from implementation of the Proposed Action results from the potential impacts to the ground water hydrology of the study area, no mitigation measures beyond those discussed in Section 6.2.2 are considered necessary.

7. UNAVOIDABLE ADVERSE IMPACTS/IRREVERSIBLE OR IRRETRIEVABLE COMMITMENT OF RESOURCES

Implementation of the Proposed Action, mitigated as necessary by the hydrologic mitigation measures proposed in Chapter 6, would result only in relatively minor unavoidable adverse impacts to hydrologic and mineral resources, since all of these impacts would be restricted to only the Steamboat Hills Project geothermal reservoir. There will be a short-term decrease in the temperature, and alteration in the pressure distribution, of the Steamboat Hills Project geothermal reservoir; however, these impacts would begin to reverse and would eventually be eliminated once the utilization of the geothermal resource ended. Up to a maximum of an additional 0.19×10^6 lb/hr of geothermal fluids would be consumed by evaporation from the cooling tower. This additional net consumption of water reduces the quantity of water in the geothermal system, and could also result in an alteration in the pressure distribution of the Steamboat Hills Project geothermal reservoir. This would also begin to reverse, and would eventually be eliminated, once the utilization of the geothermal resource ended.

The only irreversible or irretrievable commitments of resources resulting from the implementation of the Proposed Action would be the net consumption of water resources y the Project for the cooling of the power plant, which would increase to a maximum of 0.38×10^6 lb/hr.

8. ENVIRONMENTAL CONSEQUENCES OF THE NO ACTION ALTERNATIVE

The No Action Alternative would occur if the BLM rejected the Proposed Action and did not approve the 1991 POO/POU. The Steamboat Hills Project would not operate at either design or maximum electrical generation capacity with increased geothermal fluid production and injection rates. Implementation of the No Action Alternative would not affect operation of the existing Steamboat Hills Project facilities to produce and inject up to 1.9×10^6 lb/hr of geothermal fluid, nor affect construction and operation of the binary power plants, nor effect the ability of the BLM to mitigate any adverse effects of the existing Steamboat Hills Project.

Implementation of the No Action Alternative would result in none of the environmental impacts discussed in Chapter 5, Environmental Consequences of the Proposed Action, of this EA. Implementation of the No Action Alternative would limit further additional utilization of the identified geothermal resources within the Steamboat Springs Geothermal Unit, and additional electricity would not be generated by these geothermal resources from projects within the Unit. Additional electrical energy would likely be generated from some alternative source, most likely accompanied by some adverse environmental impacts, and the positive indirect economic effects of the Proposed Action to Washoe County and its residents would also not occur.

9. CUMULATIVE IMPACTS

9.1. Introduction

This chapter briefly summarizes the cumulative impacts from activities in the Steamboat Hills area on the environmental resources of concern, and the potential incremental increase in cumulative impacts to those resources which could result from the implementation of the Proposed Action. Cumulative impacts are those effects on the resources of an area or region caused by the combination of existing, proposed and reasonably foreseeable projects which may be individually minor but together potentially significant. An analysis of the cumulative impacts of a project are required under the BLM's procedures and regulations for implementation of NEPA. The area of the cumulative impact analysis for this EA (Steamboat Hills area) is generally considered the Steamboat Hills and surrounding valleys (Figure 9-1). The specific area of cumulative analysis for each resource of concern can vary, based on the characteristics of the resources, but generally includes: the southern-most portion of the Truckee Meadows; the Steamboat Hills; Steamboat Valley; Pleasant Valley; and the Callahan Ranch Road area.

As a result of the BLM review of the 1991 POO/POU, public comment on the IP Letter and the issues of concern identified in previously prepared environmental documents for other projects in the study area, certain resources have been determined to need a cumulative analysis. These resources include: water resources, specifically ground water; air resources, specifically air quality; and biological resources, specifically the Steamboat buckwheat. Impacts to other resources were not considered cumulatively significant and, therefore, the analysis of the impacts to those other resources in Chapter 5 was considered sufficient.

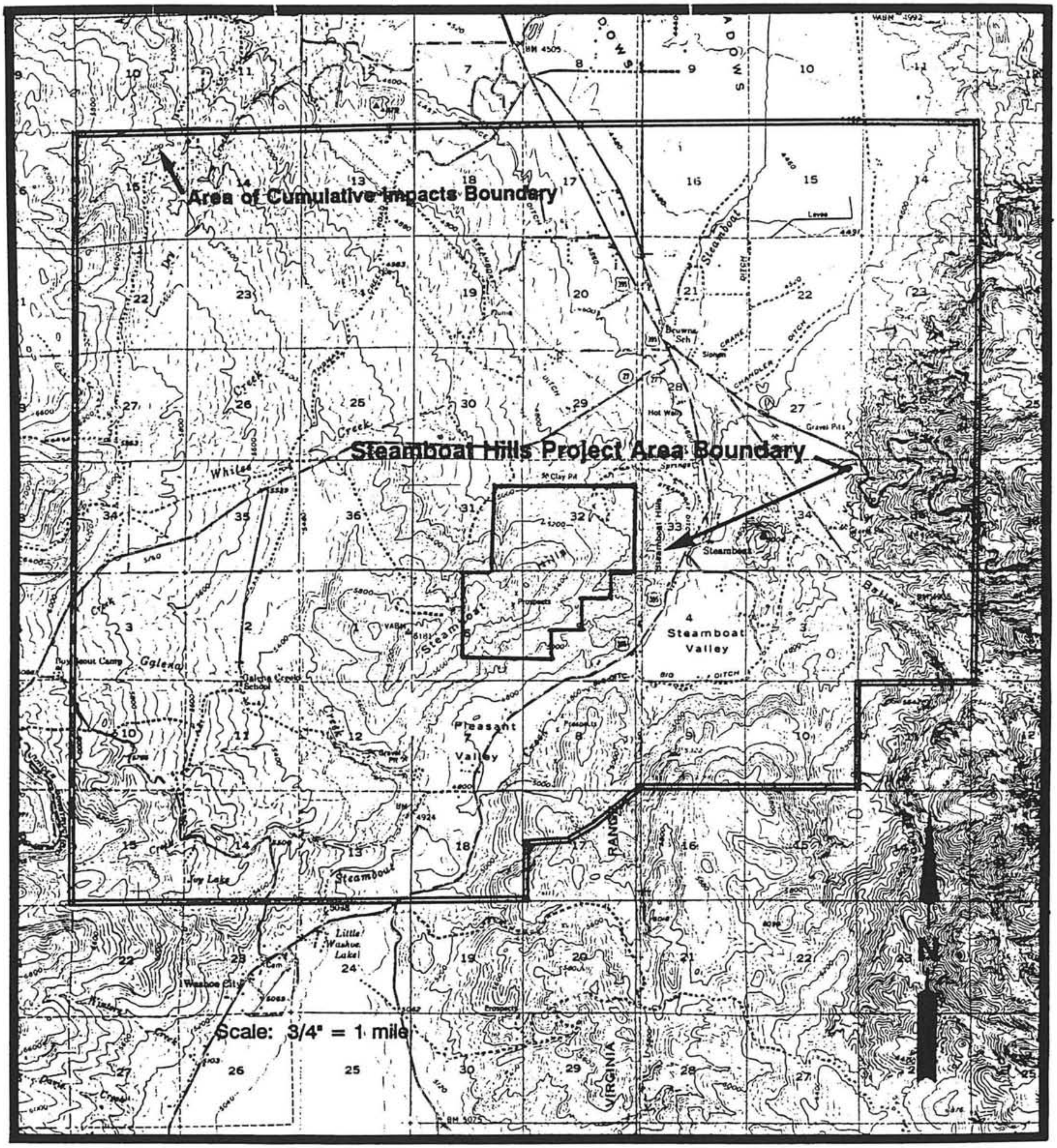
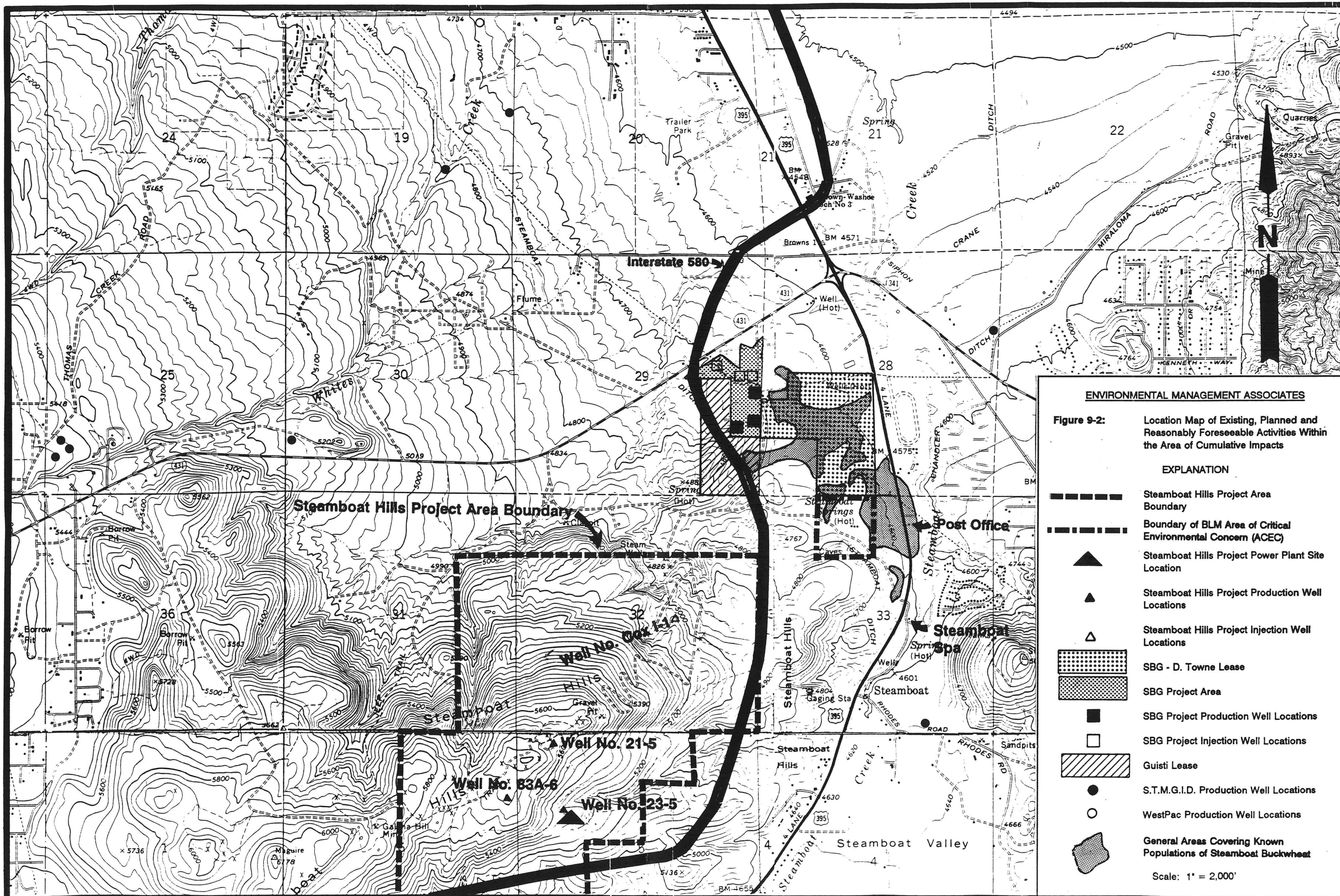


Figure 9-1: Location Map of the General Boundary of the Area of Cumulative Impacts

The reasonably foreseeable future scenario is based on an analysis of the actions of the geothermal and other ground water development projects, and other activities, that may affect the resources of concern in the Steamboat Hills area over a 15-year time-frame. The 15-year time frame for the reasonably foreseeable future scenario is from 1992 through 2006. The operations predicted in this scenario are anticipated to commence within the 15-year time frame, and are to be completed by, or extend beyond, the year 2006. The life of the geothermal power generation projects in the study area are expected to be 30 years; however, the 15-year time frame for the foreseeable future was chosen because a reliable estimation of all of the other activities in the study area could not be extended beyond 15 years.

A number of environmental documents have previously been completed for projects located in the Steamboat Hills area. The "US 395 From Winters Ranch North to South Virginia/I-580 Connection, Washoe County, Nevada, Final Environmental Impact Statement" (US 395 FEIS) evaluated the impacts of the planned construction of the freeway between Reno and Carson City (USDOT, 1983). The right-of-way for the freeway passes to the east and south of the Steamboat Hills Project area (Figure 9-2). The BLM prepared an EA for the existing Caithness Steamboat Hills Geothermal Project in 1987 (1987 EA) (USDI, 1987), which evaluated the impacts associated with the original Steamboat Hills Project, including impacts to the geothermal reservoir, ground water, and the Steamboat buckwheat. Environmental evaluations were conducted in conjunction with the Special Use Permit applications and UEPA permit applications for SBG's 1, 1A, 2, and 3 Projects, which are located to the north of the Steamboat Hills Project area (Figure 9-2) (OESI, 1987; Steamboat Development Corp., 1991). The analysis of impacts for the resources of concern in this chapter of the EA that were addressed in the previously prepared environmental documents are specifically referenced in Section 9.3,



ENVIRONMENTAL MANAGEMENT ASSOCIATES
Figure 9-2: Location Map of Existing, Planned and Reasonably Foreseeable Activities Within the Area of Cumulative Impacts
EXPLANATION
Steamboat Hills Project Area Boundary
Boundary of BLM Area of Critical Environmental Concern (ACEC)
Steamboat Hills Project Power Plant Site Location
Steamboat Hills Project Production Well Locations
Steamboat Hills Project Injection Well Locations
SBG - D. Towne Lease
SBG Project Area
SBG Project Production Well Locations
SBG Project Injection Well Locations
Guisti Lease
S.T.M.G.I.D. Production Well Locations
WestPac Production Well Locations
General Areas Covering Known Populations of Steamboat Buckwheat
Scale: 1" = 2,000'
N
Interstate 580
Steamboat Hills Project Area Boundary
Post Office
Steamboat Spa
Well No. 21-5
Well No. 83A-6
Well No. 23-5
Trailer Park
Flume
Steamboat Hills
Steamboat Valley
Steamboat
Gaging Sta
Borrow Pit
Gravel Pit
Quarries
Sandpits
CRANE
MIRALOMA
KENNETH
WAY
RHODES RD
DITCH
SIPHON
4 LANE
Creek
Whites
24
19
20
21
22
25
30
29
28
36
31
32
33
4

Environmental Consequences, and the analysis in this chapter incorporates the analysis conducted in the previously prepared documents by reference.

9.2. Existing, Proposed and Reasonably Foreseeable Future Projects

Geothermal development and other ground water development projects are ongoing in the Steamboat Hills area. As previously discussed in this EA, CPI is currently utilizing the geothermal resource for electrical power generation. In addition, SBG operates an electrical power generation facility north of the Steamboat Hills Project area that utilizes the geothermal resources (SBG 1 and 1A), and is now completing an expansion of this power plant. Direct utilization of the geothermal resource is currently conducted at the Steamboat Spa, east of the Steamboat Hills Project area, adjacent to U.S. Highway 395 (Figure 9-2). In addition, some of the private land owners in the surrounding Steamboat Hills area utilize the geothermal resources for home space heating. Washoe County has completed several ground water wells in the Steamboat Hills area and utilizes them to supply drinking water to residents in the area. In addition, there are a number of small water supply companies in the Steamboat Hills area, as well as individual domestic wells, which utilize the ground water. Other existing operations or activities include the commercial and residential development in the Steamboat Hills area, the water skiing facility and other governmental projects.

Proposed activities include the previously discussed CPI expanded use of the geothermal resource for electrical power generation (the Proposed Action). SBG is also completing a new facility (SBG 2 and 3) which includes two (2) power generation plants on the Towne Lease adjacent to their existing power operations (Figure 9-2). Other proposed activities include the Sierra Reflections Resort, the construction of

I-580 through the Steamboat Hills, expansion of the SPPC substation, and the county park in the Steamboat ACEC.

Reasonably foreseeable future activities include the development of the Guisti Lease for geothermal power production and the pumping of additional ground water for domestic purposes.

9.2.1. Activities Using the Geothermal Resource for Electrical Generation

These activities include: the Steamboat Hills Project existing and proposed operations; the existing SBG power plant and expansion at this facility; the SBG Towne Lease power plants (SBG 2 and 3); and the foreseeable activities at the Guisti Trust property. There are no other reasonably foreseeable operations that would utilize geothermal fluids for power generation in the Steamboat Hills area.

The existing Steamboat Hills Project power plant is fully described in Section 3.1.1. Currently, the Steamboat Hills Project produces approximately 1.6×10^6 lb/hr of geothermal fluid at approximately 460° F from three (3) production wells. Approximately 10 percent, 0.16×10^6 lb/hr, of this fluid is consumed and the remainder, approximately 1.44×10^6 lb/hr, is injected in one (1) injection well. The Steamboat Hills Project proposed expansion of the geothermal fluid production and injection rates (the Proposed Action) is fully discussed in Section 3.2. The Proposed Action would increase the production and injection rates for the existing power plant up to a total of approximately 3.8×10^6 lb/hr of geothermal fluid. Of the total produced, a maximum of approximately 0.38×10^6 lb/hr of geothermal fluid would be consumed and a minimum of approximately 3.42×10^6 lb/hr of geothermal fluid would be injected into one (1) or more injection wells. There is no additional proposed surface disturbance in conjunction with the Steamboat Hills Project expansion.

The existing SBG geothermal power plant facility (SBG 1 and 1A) is located in the NE¼ of the SE¼ of Section 29, Township 18 North, Range 20 East (Figure 9-2). The power plant currently generates approximately 6.8 MW of electricity from seven (7) binary fluid generating modules. Approximately 3,600 gpm (1.63 x 10^6 lb/hr) of geothermal fluid are produced from three (3) production wells at a temperature of 325° F. The spent geothermal fluid is injected into one (1) of the two (2) existing injection wells, at a temperature of approximately 190° F. The SBG 1 and 1A Project area covers approximately 28 acres, approximately 3.4 acres of which have been disturbed as a result of the SBG 1 and 1A Project. In addition, production and injection at this facility is planned to increase by 5,200 gpm (2.35 x 10^6 lb/hr) to 8,800 gpm (3.98 x 10^6 lb/hr). There would continue to be no net consumption of water and there would be no additional surface disturbance.

SBG has recently completed the development of a 24 MW power plant (SBG 2 and 3) on the Towne Lease adjacent to the existing SBG power plant that consists of two (2) binary power plants located in Section 28, Township 18 North, Range 20 East, MDB&M (Figure 9-2). Each power plant has a single binary system using the closed-loop Rankine cycle. Approximately 14,000 gpm (6.28 x 10^6 lb/hr) of geothermal fluid is produced from up to nine (9) new production wells, at a temperature of approximately 340° F. All the fluid is injected in up to three (3) injection wells and there is no net consumption of geothermal fluid. The SBG 2 and 3 project area covers approximately 110 acres, approximately 40 acres of which is disturbed by the SBG 2 and 3 project.

To the southwest of the SBG operations is the Guisti Trust Lease. Because of the identified geothermal resources on the property, it is reasonably foreseeable to assume the development of a power plant on the site that would produce and inject approximately 3,000 gpm (1.36×10^6 lb/hr) of geothermal fluid. Surface disturbance associated with this project would be approximately five (5) acres. Table 9-1 provides a summary of the cumulative geothermal fluid use for electrical energy production in the Steamboat Hills area.

Table 9-1: Summary of Cumulative Geothermal Fluid Use for Electricity Production

Project	Production Rate ($\times 10^6$ lb/hr)	Injection Rate ($\times 10^6$ lb/hr)	Consumptive Use ($\times 10^6$ lb/hr)
Steamboat Hills Project (current)	1.60	1.44	0.16
Steamboat Hills Project (increased)	2.20	1.98	0.22
Subtotal - Steamboat Hills Project	3.80	3.42	0.38
SBG 1 and 1A Project (current)	1.63	1.63	0.00
SBG 1 Project (expanded)	2.35	2.35	0.00
SBG Towne Lease - 2 and 3 Project	6.28	6.28	0.00
Guisti Trust Lease Project	1.36	1.36	0.00
Subtotal - Other Geothermal Electric	11.62	11.62	0.00
Total - Geothermal Electric	15.42	15.04	0.38

9.2.2. Activities Directly Using the Geothermal Resource

The Steamboat Hills area has a number of private homes which utilize the geothermal resource for domestic heating. The other direct use of the geothermal resources in the Steamboat Hills area is the Steamboat Spa, which is located on the east side of U.S. Highway 395, on the Low Terrace (Figure 9-2). The spa utilizes geothermal fluid from one (1) production well for hot baths and spas. The fluid is discharged to the surface and flows into Steamboat Creek. These activities consume approximately 38 AFA (0.01 x 10^6 lb/hr) of geothermal fluid. There are no proposed or reasonably foreseeable expansions of these types of operations.

9.2.3. Activities Using the Fresh Ground Water

The major user of ground water in the Steamboat Hills area is the STMGID, which pumps ground water from seven (7) wells in the area to supply potable water to the residents and businesses in the area (Figure 9-2). Approximately 1,144 AFA (0.35 x 10^6 lb/hr) of ground water was produced in 1990. In addition to STMGID, there are approximately 300 wells within the 40-square mile area surrounding the Steamboat Hills that supply domestic water to the private land owners in the Steamboat Hills area that are not otherwise supplied by STMGID. It is estimated that approximately 1,518 AFA (0.47 x 10^6 lb/hr) of ground water is consumed from these wells (Nork, 1992). Other uses of ground water in the Steamboat Hills area include the water-skiing facility east of U.S. Highway 395, which consumes approximately 30 AFA (0.01 x 10^6 lb/hr) of ground water. All of this production of ground water results in an equivalent net consumption.

Proposed or reasonably foreseeable residential development in the Steamboat Hills area includes the Sierra Reflections resort/hotel development in the south

Pleasant Valley area. Domestic water for this project would be supplied by STMGID at a rate of approximately 130 AFA (0.04 x 10^6 lb/hr). Water for irrigation and landscaping would be from decreed surface waters in Steamboat Creek, at a rate of approximately 220 AFA (0.04 x 10^6 lb/hr). The Truckee Meadows Regional Plan identifies the policies and action plans for water use in the south Truckee Meadows as: (1) develop the ground water in the Thomas and Whites Creeks area to supply the water requirements for the area; (2) ensure that existing and proposed water companies (save Sierra Pacific Power Company) are operated and maintained by Washoe County; and (3) require all new projects to be annexed into STMGID. Therefore, it is foreseeable that water requirements for all future development in the Steamboat Hills area would be supplied by the STMGID water supply system. It is projected that the population in the southern Truckee Meadows will triple in the next 15 years, and ground water consumption by STMGID will increase by 6,780 AFA (2.10 x 10^6 lb/hr) (Nork, 1992). Table 9-2 provides a summary of the cumulative ground water use.

Table 9-2: Summary of Cumulative Ground Water Use

Project	Consumptive Use (x 10^6 lb/hr)
CURRENT GROUND WATER USERS	
STMGID	0.35
Other Water Wells	0.47
Water Ski Facility	0.01
Subtotal - Current Ground Water Users	0.83
FUTURE GROUND WATER USERS	
Sierra Reflections Hotel	0.04
STMGID	2.10
Subtotal - Future Ground Water Users	2.14
Total - Ground Water Users	2.93

9.2.4. Activities With a Direct Impact on the Steamboat Buckwheat

Past and present development within the general area of the Steamboat Hills geothermal area, and the hot springs area specifically, has impacted the Steamboat buckwheat (*Eriogonum ovalifolium var. williamsiae*) and its habitat, and has the potential to continue to impact the Steamboat buckwheat through direct disturbance of the area where the Steamboat buckwheat grows. Development that has impacted the Steamboat buckwheat has been conducted by the Federal government, state government and private companies, as well as individuals. This includes: the new U.S. Post Office, east of U.S. Highway 395; the expansion of

U.S. Highway 395; the private residence formally owned by Ms. Dorothy Towne; the construction of the SPPC substation located in the SBG 1 Project area and, the SBG 1 Project (Figure 9-2). All these activities occurred prior to, or could not be included in, the 1986 Steamboat buckwheat study. The total amount of surface disturbance from these activities is estimated to be approximately 7.1 acres, and the area of Steamboat buckwheat populations directly impacted by these activities is estimated to be approximately 3.28 acres.

There are also a number of proposed and reasonably foreseeable activities that may or would impact the Steamboat buckwheat. The Nevada Department of Transportation is in the middle of a long-term construction project for the completion of Interstate 580 (I-580) between Reno and Carson City. The planned route of I-580 will be through the Steamboat Hills area (Figure 9-2). Construction of the portion of I-580 south of State Route 431 in the Steamboat Hills is planned to commence in 1998. Initial work will consist of the preparation of the subgrade for the six-lane freeway and the installation of all drainage structures. This work is scheduled for completion in 2001. The completion of the freeway base, surfacing, signing, lighting and signals is planned to start in 2003 and to be completed in 2005. This would result in the disturbance of approximately 70 acres between the Mt. Rose Highway and a point just south of the existing Steamboat Hills Project power plant. Approximately 9.2 acres of this disturbance would occur within the 370-acre Steamboat buckwheat area surveyed by CH_2M Hill, and an estimate of approximately 1.84 acres of Steamboat buckwheat populations would be directly impacted.

The SBG power plants (2 and 3) on the Towne Lease are located to the south and east of the existing SBG 1 Project (Figure 9-2). The total proposed surface disturbance associated with this project is approximately 40 acres. Of the 40 acres, approximately 0.15 acres of Steamboat buckwheat populations has been directly impacted.

SPPC plans to expand their substation located in the SE¼ of Section 29. The expansion would disturb approximately 1.5 acres, and directly impact an estimated 0.30 acres of Steamboat buckwheat populations.

To the southwest of the SBG operations is the Guisti Trust Lease. Because of the identified resources on the property, it is reasonably foreseeable to assume the development of a power plant on the site that would have approximately 5.0 acres of associated surface disturbance, which includes an estimate of approximately 1.0 acres of direct impact to Steamboat buckwheat populations. There are also a number of other private land parcels in the area of Steamboat buckwheat occurrence. Though nothing is currently proposed in the Steamboat buckwheat area, development on the private lands in the area for residential or commercial facilities could potentially cause additional disturbance to the areas where Steamboat buckwheat populations occur. However, any such development would require the issuance of a Conditional Permit from the NDF to disturb or remove Steamboat buckwheat.

The BLM's Steamboat ACEC is located in the NE¼ of the NW¼ of Section 33, Township 18 North, Range 20 East, MDB&M (Figure 9-2). Through an agreement between the BLM and Washoe County, a proposed development of the ACEC by Washoe County includes a park with an interpretive site and recreation facilities. The surface disturbance associated with this project would be approximately 1.5 acres. The Carson City District Office has indicated that none of the disturbance would occur in areas with Steamboat buckwheat populations (Loomis, 1993).

9.3. Environmental Consequences

Environmental consequences of implementing the Proposed Action, which is the expansion of the Steamboat Hills Project, were evaluated in Chapter 5 for each resource. Only ground water hydrology, vegetation resources and air resources are considered to have potential impacts which are appropriate for cumulative impact assessment in conjunction with the Proposed Action. Affects to the other resources would not result in unavoidable adverse impacts that could be cumulatively important, and are not evaluated in this chapter of the EA.

9.3.1. Ground Water Hydrology

The cumulative (existing, proposed and reasonably foreseeable) consumptive use of ground water, both fresh water and geothermal fluids, is presented in Table 9-3. The increased production of geothermal fluid under the Proposed Action (2.20×10^6 lb/hr) represents approximately twelve (12) percent of the total ground water produced under the reasonably foreseeable future scenario, while the additional consumptive use of geothermal fluid under the Proposed Action (0.22×10^6 lb/hr) represents approximately six and one-half (6½) percent of the total amount of ground water consumed. The cumulative production of approximately 15.43×10^6 lb/hr of geothermal resources represents approximately eighty-four (84) percent of total cumulative production of ground water resources under the reasonably foreseeable future scenario, but the cumulative consumption of 0.39×10^6 lb/hr of geothermal resources represents only eleven and one-half (11½) percent of the cumulative consumption of total ground waters.

Table 9-3: Summary of Cumulative Geothermal Fluid and Ground Water Use

Project	Production Rate (x 10⁶ lb/hr)	Percent of Subtotal	Percent of Total	Consumptive Use (x 10⁶ lb/hr)	Percent of Subtotal	Percent of Total
Steamboat Hills Project (current)	1.60	10.37	8.70	0.16	41.03	4.76
Steamboat Hills Project (Proposed Action)	2.20	14.26	11.96	0.22	56.41	6.55
Other Electric Projects	11.62	75.31	63.15	0.00	0.00	0.00
Direct Use Projects	0.01	0.06	0.05	0.01	2.56	0.30
Subtotal - Geothermal Fluid Use	15.43	100.00	83.86	0.39	100.00	11.61
Current Ground Water Users	0.83	27.95	4.51	0.83	27.95	24.70
Future Ground Water Users	2.14	72.05	11.63	2.14	72.05	63.69
Subtotal - Ground Water Use	2.97	100.00	16.14	2.97	100.00	88.39
Total - Geothermal and Ground Water Use	18.40	N/A	100.00	3.36	N/A	100.00

Because of the complexity of the ground water system and the geothermal system, as well as the limited amount of data on specific aspects of the geothermal system, it is difficult to quantify the impacts specific operations have had on the water table and surface flows from the hot springs. However, based on the limited data, some interpretations have been made on the relative effect specific operations have on the water table (Sorey and Colvard, 1992; Nork, 1992). These analyses indicate that the relative contribution of the Steamboat Hills Project appears to be small, and the up-to-25-foot regional decline in the ground water table appears to be predominately associated with the increased withdrawals of ground water for domestic use in the southwest Truckee Meadows, and current drought conditions. Extending this analysis for the cumulative production and use of the geothermal fluid only (that is, ignoring the consumptive use of the fresh ground water), the computer code VARFLOW provides results which suggest that reservoir pressures in the vicinity of Spring 6 in the Steamboat ACEC could be reduced by as much as 20 psi. Of this amount, the Proposed Action for the Steamboat Hills Project may account for less than a one (1) psi decline. The operations at the SBG Towne Lease (SBG 2 and 3) account for approximately one-half of this amount; SBG 1 and Guisti Trust operations are the remainder (Nork, 1992). These estimates are qualitatively consistent with those of Sorey and Colvard (1992).

As stated above, based upon existing conditions, it is unlikely that discharge from the hot springs and geysers would resume even if production at the Steamboat Hills Project were to cease and recharge from precipitation were to return to normal, because increased ground water withdrawals from the alluvial aquifer appear to be the major cause of water level declines in the Main Terrace area (Sorey and Colvard, 1992; Nork, 1992). Given the relative magnitude of the predicted increases in consumptive use of freshwater from the alluvial ground water aquifer (see Table 9-3), and the increased production from the other geothermal power projects proposed for the Steamboat Hills area adjacent to the Steamboat ACEC, it appears that this statement would remain true for the reasonably foreseeable future scenario as well.

9.3.2. Vegetation Resources

As previously discussed, Steamboat buckwheat populations occur within an approximately 370-acre area on the High, Main and Low Terraces. Based on the 1986 survey, within this area there are approximately 53 acres of Steamboat buckwheat populations (if the estimated 3.28 acres of Steamboat buckwheat populations impacted by known pre-1986 activities are included). The cumulative (existing, proposed and reasonably foreseeable) surface disturbance from all activities in the 370-acre area is approximately 64.6 acres; however, only 6.57 acres of actual Steamboat buckwheat populations would be directly impacted. As there is no planned surface disturbance under the Proposed Action, there would be no direct incremental impact to Steamboat buckwheat populations or its potential habitat as a result of the implementation of the Proposed Action.

The regional drought, land use development and use of the ground water as a potable water source, as well as the development and use of the geothermal resource, appears to have had the effect of lowering the water table and a subsequent decrease in, and/or elimination of, surface flows from the hot springs and geysers. Details on how and why the water table has lowered are discussed in Sections 4.4.2.2 and 5.4.2. The elimination of surface flows from the hot springs and geysers may eventually have an indirect effect on the Steamboat buckwheat habitat through the elimination of the deposition of silicious sinter, which could ultimately effect the future formation of the sinter soil on which the Steamboat buckwheat is dependent. The way in which the changes in the flow from the hot springs and geysers may impact the Steamboat buckwheat habitat is discussed in Sections 4.6.1.2 and 5.6.1. Any incremental increase that the Proposed Action may have on the indirect impacts to the Steamboat buckwheat are generally proportionally related to the Proposed Action's effect on the water table, as discussed in Section 9.3.1, and are short-term in nature.

The cumulative 6.57 acres of direct impact to Steamboat buckwheat population includes the estimated 3.28 acres that occurred prior to, or were not included in, the 1986 survey. Therefore, only 3.29 acres of direct impact would occur to the Steamboat buckwheat under proposed or foreseeable future activities. To mitigate the direct impacts to the Steamboat buckwheat as a result of the SBG 2 and 3 Project, SBG has entered into an agreement with The Nature Conservancy to protect the Steamboat buckwheat within the SBG 2 and 3 Project area. This agreement covers approximately 110 acres of private land in the SW¼ of Section 28. SBG also agreed to transplant the 0.15 acres of Steamboat buckwheat populations that would have been directly impacted to other areas within the 110-acre SBG 2 and 3 Project area. To conduct the transplanting, SBG applied for, and the NDF issued, a Conditional Permit to disturb the Steamboat buckwheat. The permit contains specific conditions to ensure minimal disturbance of the Steamboat buckwheat. Should the plants survive the transplanting, any direct impact to the species would be avoided. This type of mitigation or avoidance should also be considered for the other proposed and foreseeable projects which could have a direct impact on Steamboat buckwheat populations, such as the construction of I-580, the expansion of the SPPC substation, and the construction associated with the Guisti Lease. If these mitigation measures are implemented and are successful, then the species and habitat could be managed to minimize any losses beyond those that occurred prior to 1986.

All development in the study area that may affect the Steamboat buckwheat is subject to state and possibly Federal requirements to assure survival of the species. Of the approximately 50 acres of existing Steamboat buckwheat populations identified in the 1986 survey, an estimated 65 percent, or 33 acres, are either on Federal lands or on SBG lands subject to a Steamboat buckwheat protection agreement with The Nature Conservancy. Therefore, a majority of the known populations of the species is located on land where it is or can be managed to ensure protection. Any development on the other 35 percent, or 17 acres of land, would be subject, at a minimum, to NDF permit requirements that could be made as rigorous as those in the SBG permit.

9.3.3. Air Resources

Cumulative impacts to the air quality of the Steamboat Hills Project area are principally a result of regional emissions from internal combustion engines and smoke from wood burning stoves, and emissions from the Steamboat Hills Project flash power plant. The primary emissions of concern from internal combustion engines and wood burning stoves are CO, NO_x and SO_x. The activities under the Proposed Action would not increase any CO, NO_x or SO_x emissions, and would, therefore, not contribute to any incremental increase in these pollutants. The Steamboat Hills Project facility is the only activity in the area which emits H_2S. As stated in Section 5.5, the H_2S emissions from the Proposed Action would result in only a slight change in the amount of H_2S emissions. However, the total H_2S emissions from the Steamboat Hills Project facility under the Proposed Action would remain below the 5.5 lb/hr limit set by the Washoe County Department of Health.

10. COORDINATION AND CONTACTS

The following individuals, organization, and agency representatives were contacted during the preparation of this assessment. Where appropriate, specific communications are identified as a reference (see Section 12, References).

Public Agencies

Federal Agencies

National Oceanic and Atmosphere Administration, Reno, Nevada:

Larry Jensen

U.S. Geological Survey - Water Resource Division:

Rita Carmen

State of Nevada Agencies

Nevada Division of Wildlife, Reno:

Pat Coffin

Nevada Division of Environmental Protection:

Gay McCleary

Private Organizations

Nevada Natural Heritage Program:

Glen Clemner
Kris Kolar
James Morefield

11. QUALIFICATIONS OF PREPARERS

This Environmental Assessment (EA) was prepared by Environmental Management Associates, Inc. (EMA) under a contract with Yankee\Caithness Joint Venture, L.P., under the management and control of Mr. Richard Hoops of the Bureau of Land Management, Nevada State Office in Reno, Nevada and Ms. Maureen Joplin of the U.S. Forest Service Toiyabe National Forest Office in Sparks, Nevada. The following is a list of individuals responsible for preparation of the EA.

Dr. Dwight L. Carey
Principal
D.Env. Environmental Science and Engineering, 1982, University of California, Los Angeles
M.S. Geology, 1976, University of California, Los Angeles
B.S. Geology, 1972, California Institute of Technology

Environmental professional who has managed various types of projects over 20 years, including:

- Environmental Impact Statements, Environmental Impact Reports, and Environmental Assessments
- Waste Discharge Requirement Applications, including Underground Injection Control Applications

EA principal areas of responsibility: quality control, proposed action, air resources and geothermal resources.

Richard F. DeLong
Senior Environmental Specialist
M.S. Geology, 1986, University of Idaho
M.S. Environmental Management, 1984, University of Idaho
B.A. Geology, 1980, California State University, Chico

Six (6) years of experience in environmental analysis, environmental baseline data collection and assessment, and regulatory analysis, including:

- Comprehensive and focused Environmental Assessments and Environmental Impacts Statements
- Technical reports including regulatory impact analysis, visual impact analysis and noise impact analysis
- Permitting activities for a number of natural resource development projects

EA principal areas of responsibility: NEPA compliance, introduction, alternatives, geology, soils, biology, water resources, land use and cumulative impacts.

Ellen D. Leavitt
Environmental Specialist
M.S. Geology, 1980, University of Oregon
B.A. Geology, 1975, Middlebury College

Four (4) years of experience as an environmental specialist for various projects including:

- Environmental Assessments and Environmental Impact Statements
- Regulatory Compliance Analysis
- Preparation of Federal, State and Local Permit Applications for Natural Resource Development Projects
- Coordination of Environmental Baseline Surveys

EA principal areas of responsibility: soils and quality control.

Jill C. Pitts
Environmental Analyst
B.A. Political Science, 1988, University of Nevada, Reno

Four (4) years of experience as an environmental specialist for various projects including:

- Environmental Assessments
- Preparation of Federal, State and Local Permit Applications for Natural Resource Development Projects
- Conducting Environmental Baseline Surveys

EA principal areas of responsibility: noise, visual, socioeconomics.

Lynda Peck Nelson

Associate
M.S. Range Management and Biology, 1988, University of Nevada, Reno
B.S. Plant, Soil, and Water, 1980, University of Nevada, Reno

Ten (10) years experience as range scientist, botanist and endangered plant specialist, including:

- Botanical expertise for Environmental Assessments
- Wetlands Delineations
- Threatened and Endangered Plant Surveys

EA principal areas of responsibility: vegetation resources, Steamboat buckwheat.

12. REFERENCES

Benson, B., 1991: Nevada Employment Security Department Research, Carson City, Nevada, Personal Communication.

Bonham, H.F., 1969: Geology and Mineral Deposits of Washoe and Storey Counties, Nevada; Nevada Bureau of Mines and Geology, Bulletin 70, 140p.

Caithness Power, Inc., 1993: Proposed Expanded Hydrologic Monitoring Program for the Steamboat Hills Project.

CH_2M Hill, 1986a: Steamboat Springs Environmental Baseline Study, First Quarter.

________, 1986b: Steamboat Springs Environmental Baseline Study, Second Quarter.

________, 1986c: Steamboat Springs Environmental Baseline Study, Third Quarter.

________, 1986d: Factors Affecting the Distribution of Eriogonum Ovalifolium var. Williamsiae at Steamboat Springs.

________, 1987: Steamboat Springs Environmental Baseline Study, Fourth Quarter.

Collar, ,1990: ,Unpublished Masters Thesis, California State University San Diego, p.

Colter, D., 1993: Washoe County District Health Department, Environmental Section, Reno, Nevada, Personal Communication.

DeRocher, T, 1993: Hydrological Monitoring Report, Caithness Power, Inc., Steamboat Hills, Nevada, January 1 - June 30, 1993.

Fenneman, A., 1938: Physiography of the Western U.S.; McGraw-Hill Co., New York, New York.

Goranson, C. and van de Kamp, P., 1990: An interpretation of the relationship between the local ground water system and the shallow isolated moderate temperature geothermal areas in the Steamboat Springs geothermal and South Truckee Meadows area; unpublished report, 8p.

Goranson, C, van de Kamp, P., and DeLong, T., 1990: Geothermal injection and monitoring program history at the Caithness Power, Inc. flash steam power plant, Steamboat Springs, Nevada; Geothermal Resources Council Annual Meeting, 1990.

Houghton, J.G., C.M. Sakamoto and R.G. Geffard, 1975: Nevada's Weather and Climate; Nevada Bureau of Mines and Geology , Special Publication 2, 78 p.

Husband, J.J., 1975: Earthquake Epicenter Map of Nevada, 1868 Through 1972; Nevada Bureau of Mines and Geology, Map 43.

Iwasaki, I, 1962: Geochemical investigation of geysers in Japan; Tokyo Institute of Technology, Bulletin 46, 60p.

Knight, T., 1993: The Nature Conservancy, Las Vegas, Nevada, Personal Communication.

Koenig, H., 1989: Recent Geyser Activity at Steamboat Springs, Nevada; Geyser Observation and Study Association, Volume 1, pp 243-254.

Kolar, K., 1991: Nevada Natural Heritage Program, Carson City, Nevada, Personal Communication.

Lincoln, 1923: Mining Districts and Mineral Resources of Nevada; Stanley Palmer, Reno, Nevada.

Loomis, D., 1993: Bureau of Land Management, Carson CIty District Office, Carson City, Nevada, Personal Communication.

McCleary, G., 1991: Nevada Division of Environmental Protection, Carson City, Nevada, Personal Communication.

Morefield, J.D. and Knight, T.A., editors, 1991: Endangered, Threatened, and Sensitive Vascular Plants of Nevada; published by the Nevada State Office of the Bureau of Land Management, Reno, February, 1992.

Nelson, L.S., 1991: Survey for Steamboat Buckwheat, Eriogonum Ovalifolium var. Williamsiae at Steamboat Springs, Nevada; JBR Consultants Group, Reno, Nevada.

NDEP, 1987: Nevada Air Quality 1986 Annual Report; Nevada Division of Environmental Protection.

NOCS, 1985: Washoe County Nevada Profile; Nevada Office of Community Services.

_____, 1990: Nevada Statistical Abstract 1990, September, 1990.

NOAA, 1990: Local Climatological Data, Annual Summary with Comparative Data, Reno, Nevada, 1990; National Oceanic and Atmospheric Administration.

OESI, 1987: Washoe County Special Use Permit Application, 1987.

Petty, S. and Adair, R.G., 1993: Assessment of the Byers wells as a monitoring site for the Steamboat Hills Area of Critical Environmental Concern.

Sorey, M. and Colvard, E., 1992: Factors Affecting the Decline in Hot-Springs Activity in the Steamboat Springs Area of Critical Environmental Concern, Washoe County, Nevada; Administrative Report for the Bureau of Land Management, Menlo Park, California, 106p.

Steamboat Development Corp., 1991:

Stewart, J.H., 1980: Geology of Nevada; Nevada Bureau of Mines and Geology, Special Publication 4, 136p.

USBC, 1991: Census of Population and Housing, 1990: Summary Tape File 1A Data on CD-ROM (Nevada); U.S. Bureau of the Census.

USDI, 1986a: Visual Resource Management System; BLM Manual 8400 Series.

_____, 1986b: State of Nevada Wilderness Status Map; Bureau of Land Management, Reno, Nevada.

_____, 1987: Proposed Steamboat Hills Geothermal Project, Draft Environmental Assessment; Bureau of Land Management, Carson City, Nevada.

_____, 1988: National Environmental Policy Act Handbook, BLM Handbook H-1790-1, 1-1547, October 15, 1988; Bureau of Land Management.

USDOT, 1983: US 395 from Winters Ranch North to South Virginia/I-80 connection, Washoe County, Nevada, Draft Environmental Impact Statement; FHWA-NV-EIS-77-02.2-F; U.S. Department of Transportation.

U.S. Fish and Wildlife Service, 1985: Proposed Rule: Proposed Endangered Status for *Eriogonum Ovalifolium Var. Williamsiae* (Steamboat Buckwheat), Federal Register, V.50, No. 177, September 12, 1985, pp. 37252-37255.

__________________________, 1986: Final Rule: Proposed Endangered Status for *Eriogonum ovalifolium var. williamsiae*, Federal Register, V.51, No. 130, August 7, 1986, pp. 24669-24672.

__________________________, 1987: Memorandum to the State Director, Bureau of Land Management, regarding Formal Section 7 Consultation on the Steamboat Buckwheat for the Proposed Chevron Resources Company Geothermal Project.

2________________________, 1993: Memorandum to the State Director, Bureau of Land Management, regarding Biological Opinion for the Proposed Expansion of Steamboat Hills Geothermal Project: Amendment for Geothermal Fluid Rate Increase.

van de Kamp, P. and Goranson, C., 1990: Summary of the hydrogeologic characteristics of the Steamboat Hills area, Nevada; unpublished report, 13p.

Williams, M.J., 1982: Status Report: <u>Eriogonum</u> <u>ovalifolium</u> var. <u>williamsiae</u> (reveal), Submitted to the U.S. Fish and Wildlife Service, Portland, Oregon, 30p.

White, D.E., 1967: Some principles of Geyser Activity, Mainly from Steamboat Springs, Nevada; American Journal of Science, Volume 265, pp. 641-684.

__________, 1968: Hydrology, Activity, and Heat Flow of the Steamboat Springs Thermal System, Washoe County, Nevada; U.S. Geological Survey, Prof. Paper 458-C.

White, D.E., G.A. Thompson, and C.H. Sandberg, 1964: Rocks, Structure, and Geologic History of Steamboat Springs Thermal Area, Washoe County Nevada; U.S. Geological Survey, Prof. Paper 458-B.

Yeamans, F., 1984: Hydrology of the Steamboat Springs Geothermal System, 1984; unpublished report.

APPENDIX A

Interested Parties Letter

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
Nevada State Office
850 Harvard Way
P.O. Box 12000
Reno, Nevada 89520-0006

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

Steamboat Unit
3280/1792

AUG 15 1991

Dear Interested Parties:

Reference: Environmental Scoping for the Amendment to the Plan of Operation/Plan of Utilization for the Steamboat Hills Geothermal Project, Steamboat Springs Unit Area, Washoe County, Nevada

On June 28, 1991, Yankee/Caithness Joint Venture, L.P. (as owner) and Caithness Power, Inc. (as operator) submitted to the Nevada State Office, Bureau of Land Management (BLM), an Amendment to the Plan of Operation/Plan of Utilization (POO/POU) for the Steamboat Hills Geothermal Project, Steamboat Springs Unit Area, Washoe County, Nevada. A copy of the amendment to the POO/POU is enclosed.

The initial POO/POU for the Steamboat Hills geothermal project, which was approved on June 26, 1987, authorized Caithness Power Inc. (CPI) to operate the present 12.5 MW (net) single-flash condensing turbine power plant and geothermal wellfield. As part of the approval, the total wellfield production rate was limited to 1.9 million pounds per hour. In the amendment, CPI has requested approval to increase the maximum total geothermal fluid production and injection rates from the Unit participating area from the current geothermal wellfield production level of 1.9 million pounds per hour up to a maximum of 3.8 million pounds per hour. The increased production would be obtained from existing or already approved but as yet unconstructed geothermal wells. Therefore, the amendment does not propose any surface disturbance of federal lands not otherwise previously approved. The increased wellfield production would be used to operate three binary power plant units with a total generation capacity of 12 MWs. The binary units would be located on private land in the Unit and have already received a Special Use Permit from Washoe County. CPI must receive approval from BLM of a Plan for Production (PFP) to be submitted at a later date before the binary units would be placed into operation. Upon BLM approval of the PFP, the electrical generation capacity of the CPI geothermal project would increase to a total of 25 MWs.

The Steamboat Hills Project area of operations includes both private and federal land covering all of Sections 5 and 6 and the N ½, Section 7, T.17N., R.20E.; and all of Sections 31 and 32, and the SW ¼ Section 28, S ½ Section 29 and the W ½ Section 33, T.18N., R.20E. Access to the project is via an existing paved secondary road from the Mt. Rose Highway (State Route 431).

The BLM is the lead agency of the federal government responsible for regulating the development of geothermal resources located on federal lands which have been leased for geothermal resource development. The U.S. Forest Service administers the surface of the federal lands located within the project area, and therefore will act as a cooperating agency during the review of the proposed amendment. In accordance with the Geothermal Steam Act of 1970 and 43 CFR 3262.4, 3262.4-1 and 3262.4-2, the principal authorization granted by the BLM as approval of these geothermal resource operations is the POO/POU. Although the BLM does not exercise similar regulatory authority over the development of geothermal resources found on private or state lands, the BLM is responsible for ensuring the conservation, and preventing the waste, of the geothermal resources found within all lands of the federal Unit.

The BLM, in cooperation with the Forest Service, will be preparing an environmental document to evaluate the possible environmental consequences of the proposed production rate increase. Scoping of the issues related to the proposed Amendment is an initial part of the environmental analysis preparation. Comments received from interested parties will play an important role in identifying issues and determining their significance.

You are invited to send written comments to the BLM Nevada State Office (address below). All comments will be given serious consideration in the preparation of the environmental document and conditions of approval. All comments concerning the proposed action should be sent no later than September 13, 1991 to the following address:

Mr. Richard Hoops
Bureau of Land Management (NV-920)
850 Harvard Way
Reno, NV 89502

If you would like any additional information, please contact Richard Hoops at (702) 785-6568.

Sincerely,

Thomas V. Leshendok
Deputy State Director,
Mineral Resources

2 Enclosures
1. Plan of Operations/Plan of Utilization Amendment
2. Interested Parties Notified

APPENDIX B

Public Comments on the Interested Parties Letter

DISTRICT HEALTH DEPARTMENT

September 16, 1991

Richard Hoops
Bureau of Land Management (NV-920)
850 Harvard Way
Reno, Nevada 89502

RE: Environmental Scoping for the Amendment to the Plan of Operation/Plan of Utilization for the Steamboat Hills Geothermal Project; E91-101

Dear Mr. Hoops:

This Department has reviewed the referenced proposal with regard to sewage disposal, domestic water supply, solid waste, vector control, water quality, and air pollution. We have the following comments:

1. The Air Quality Management Division of the Washoe County District Health Department is monitoring emissions from the Yankee Caithness facility. Emissions are not currently exceeding the permitted limit of 5.5 lb/hr.

2. The Nevada Division of Environmental Protection is overseeing a continuing groundwater monitoring program in the Pleasant Valley area in response to concerns that the geothermal power operation may impact groundwater quality. No degradation of groundwater quality has been observed.

Please address any questions regarding the foregoing to me at 328-2430.

Sincerely,

Bryan W. Tyre
Environmental Engineer
Environmental Health Services

BWT:sw

cc: Carl R. Cahill
Chris Ralph, Washoe County Air Quality Management Division
Don Young, Washoe County Department of Development Review

United States Department of the Interior

FISH AND WILDLIFE SERVICE

FISH AND WILDLIFE ENHANCEMENT
Reno Field Station
4600 Kietzke Lane, Building C-125
Reno, Nevada 89502-5093

September 13, 1991
File No.: 1-5-91-I-246

Memorandum

To: Deputy State Director, Mineral Resources, Bureau of Land Management, Reno, Nevada (Attention: Richard Hoops)

From: Field Supervisor, Reno Field Station, Reno, Nevada

Subject: Environmental Scoping for the Amendment to the Plan of Operation/Plan of Utilization for the Steamboat Hills Geothermal Project, Steamboat Springs Units Area, Washoe County, Nevada (3280/1792)

The Fish and Wildlife Service (Service) has reviewed your letter dated August 15, 1991, regarding the intent to prepare an environmental document for the above referenced project. The document will evaluate the possible environmental consequences of a proposed increase in the production rate of the Steamboat Hills Geothermal Project well field. The increased production would be obtained from existing or already approved but as yet unconstructed geothermal wells. According to the Environmental Assessment dated May 30, 1987, expansion of the project from the original 12.5 megawatt power plant would require new permits and would be subject to compliance with the National Environmental Policy Act.

Endangered Species

The original 1.5 megawatt geothermal power plant project was the subject of formal consultation with the Service in 1987 pursuant to section 7 of the Endangered Species Act (Act) of 1973, as amended (File No.: 1-5-87-F-101). The Service determined that the project was not likely to jeopardize the continued existence of the endangered Steamboat buckwheat (*Eriogonum ovalifolium* var. *williamsiae*). Informal consultation was completed between the Service and the Forest Service in 1990 on a proposal to re-enter an existing well (File No.: 1-5-90-I-15). The Service concurred with the Forest Service that the action was not likely to adversely affect the listed species.

The Service's primary concern is the impact of the proposed increase in production rate on the Steamboat buckwheat. The Bureau of Land Management must make a determination whether this new action will affect the listed plant. Should you determine the plant may be affected, then you must consult with the Service as required by section 7 of the Act. Attachment A specifies your requirements in further detail.

Although the proposed action will not result in additional surface disturbance to Federal lands, the environmental document should address direct and indirect project impacts to biological resources on public and private lands as well as cumulative impacts. The timing of anticipated effects should also be addressed.

An important issue with this project is the potential for increased geothermal fluid production to affect the hydrology in and around the Steamboat Hills project area. The environmental document should present monitoring and other data and analyses to show anticipated effects of the proposal, if any, on hydrology in the area. The relationship of this hydrology to the habitat of the Steamboat buckwheat also should be presented.

Wildlife Populations and Habitat

Positive and negative impacts, both direct and indirect, to terrestrial and aquatic wildlife and habitats should be identified for each alternative, including ancillary facilities such as the three binary power plant units, if not addressed in previous environmental documents or if new information is now available to make reassessment appropriate. Negative impacts to be addressed should include, but not be limited to, destruction or alteration of breeding, nesting, cover, and foraging habitat for wildlife. Descriptions of habitat should include both qualitative and quantitative information. Areas with sensitive resources such as endangered species, wetlands, and riparian habitats should be identified.

Water Quality and Quantity

Impacts to water quality from each alternative should be addressed. This should include a discussion of measures to reduce impacts in the event of a well blowout that may result in a geothermal water surface discharge. The potential for such a discharge to negatively affect sensitive habitat areas, if any, should be discussed if this issue has not been addressed in previous documents. We note that the December 1986 Plan of Operation/Utilization for the project indicated that a detailed spill prevention and control plan would be prepared prior to start up of the power plant. This plan should be updated and available for public review as part of the environmental document review process.

Cumulative Effects

The document should include an analysis of cumulative impacts on biological resources as well as air and water quality in the area. Incremental impacts of increased production of the Steamboat Hills geothermal project as well as impacts from past, present, and reasonably foreseeable future mining and other actions in the vicinity of the project and on adjacent private lands should be considered in this analysis. This should include an analysis of the potential for cumulative impacts of other geothermal projects in the area on the Steamboat buckwheat.

The project proponent should continue monitoring the ground water system in the area to ensure that impacts to the Steamboat buckwheat do not occur.

Besides providing comments on the draft and final environmental document, we may comment on any public notice issued for a permit from the Nevada Division of Environmental Protection.

We appreciate the opportunity to comment on the notice of intent to prepare an environmental document for this project. We look forward to continued coordination in association with endangered species issues. If you have any questions regarding our comments, please contact Mary Jo Elpers at FTS 470-5227 or (702) 784-5227.

for David L. Harlow

Attachment

cc:
Assistant Regional Director, Fish and Wildlife Enhancement, Portland, Oregon (AFWE)
State Director, Bureau of Land Management, Reno, Nevada
Forest Supervisor, Toiyabe National Forest, Sparks, Nevada
Administrator, Nevada Division of Environmental Protection, Carson City, Nevada
Regional Manager, Nevada Department of Wildlife, Fallon, Nevada

MELPERS:dj:9/13/91

ATTACHMENT A

FEDERAL AGENCIES' RESPONSIBILITIES UNDER SECTIONS 7 (a) and (c) OF THE ENDANGERED SPECIES ACT

SECTION 7 (a): Consultation/Conference

Requires:

1) Federal agencies to utilize their authorities to carry out programs to conserve endangered and threatened species;

2) Consultation with FWS when a Federal action may affect a listed endangered or threatened species to insure that any action authorized, funded or carried out by a Federal agency is not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat. The process is initiated by the Federal agency after determining the action may affect a listed species;

3) Conference with FWS when a Federal action is likely to jeopardize the continued existence of a proposed species or result in destruction or adverse modification of proposed critical habitat.

SECTION 7 (c): Biological Assessment - Major Construction Activity 1/

Requires Federal agencies or their designees to prepare a Biological Assessment (BA) for major construction activities. The BA analyzes the effects of the action on listed and proposed species. The process begins with a Federal agency requesting from FWS a list of proposed and listed threatened and endangered species. The BA should be completed within 180 days after its initiation (or within such a time period as is mutually agreeable). If the BA is not initiated within 90 days of receipt of the list, the accuracy of the species list should be informally verified with the FWS. No irreversible commitment of resources is to be made during the BA process which would foreclose reasonable and prudent alternative to protect endangered species. Planning, design, and administrative actions may proceed; however, no construction may begin.

We recommend the following for inclusion in the BA:

1. An onsite inspection of the area affected by the proposal which may include a detailed survey of the area to determine if the species or suitable habitat are present.

2. A review of literature and scientific data to determine species distribution, habitat needs, and other biological requirements.

3. Interviews with experts, including those within FWS, State conservation departments, universities, and others who may have data not yet published in scientific literature.

4. An analysis of the effects of the proposal on the species is terms of individuals and populations, including consideration of cumulative effects of the proposal on the species and its habitat.

5. An analysis of alternative actions considered.

6. Documentation of the results, including a discussion of study methods used, any problems encountered, and other relevant information.

7. Conclusion as to whether or not a listed or proposed species will be affected.

Upon completion, the BA should be forwarded to our office.

1/ A construction project (or other major undertaking having similar physical impacts) which is a major Federal action significantly affecting the quality of the human environment as referred to in NEPA (42 U.S.C. 4332 (2) C).

SIERRA CLUB

Toiyabe Chapter - Nevada and Eastern California
P.O. Box 8096, Reno, Nevada 89507

September 13, 1991

Richard Hoops
Bureau of Land Management (NV-920)
850 Harvard Way
Reno, NV 89502

HAND DELIVERED

Dear Mr. Hoops,

On behalf of the Toiyabe Chapter of the Sierra Club, I am sending you comments in reference to the environmental scoping for the Amendment to the Plan of Operations for the Steamboat Hills Geothermal Project in Washoe County, Nevada.

In general, we found the information in the scoping documents to be inadequate. The notice dated Aug. 15, 1991, does not reveal what environmental process is being scoped for. Is the Bureau conducting an amendment to the 1987(?) Environmental Assessment? Is it a new EA? If not, how will the Bureau comply with the requirements of NEPA? Please clarify.

The details in the scoping document are vague, referencing other documents and data which are not available to the public. Our primary concern is that the expanded level of pumbping will adversely affect Steamboat Hot Springs, an Area of Critical Environmental Concern and site of an endangered plant. We are also concerned about increased air pollution from expanded operations.

It is our observation that the flows from Steamboat Hot Springs have greatly diminished since the mid-1980's. We do not know if the lessened flows are a result of the drought as argued by the applicant or of the geothermal extraction activities. Did flows in the Hot Springs similarly diminish during the other severe droughts experienced in the Truckee Meadows, especially in the 1930's when Washoe Lake also dried up? Does the Bureau have access to the flow rates for the Hot Springs?

While the document entitled "Amendment..." refers to flow tests made in May and June of 1987 with the Nevada Division of Environmental Protection as documentation of its claim that there is no connection between the geothermal reservoirs underlying the Hot Springs and the extraction wells, no evidence is presented to support this claim. When we called the NDEP, agency personnel could not locate flow test data nor give us [illegible] tests, other than that 750 gpm were taken out and about 600 gpm were reinjected. We would like to formally request a copy of the referenced flow test data from the Bureau.

If the NDEP information is accurate, then 600 and 750 gpm are only small fractions of the maximum rate allowed now (3,300 gpm). Therefore, the existing referenced flow test is far from a test under production conditions.

There is no information in the documents on the geochemistry of waters from the Hot Springs and extraction wells. Are they identical or significantly different?

Given that the applicant proposes to expand production to 7,600 gpm, ten times higher than the flow test, we question whether the flow test could be adequate for assessing impacts on the surface springs. New flow tests must be conducted, at least at the level of existing production and modelled for higher extraction rates.

We queston whether the applicant's proposal to reinject fluids at 160 degrees F, significantly lower than extraction temperatures, will adversely affect the temperatures of the surface springs.

Other information which should be disclosed is the geological stratigraphy of the upper production zone and the injection and lower zone wells, since the applicant asserts that the reservoirs are not linked.

The documents vaguely refer to "monitoring" which has occurred since the 1980's of flow rates at Steamboat Springs. The document should clearly disclose the extent and results of all monitoring conducted on Steamboat Hot Springs as well as <u>who</u> conducted the monitoring.

In addition, we would like to see monitoring data on air quality impacts of the present operation disclosed since 1987 as well as anticipated future hydrogen sulfide emissions from expanded operations.

We reqeust that uou include monitoring data on flows and air quality from the other geothermal operations adjacent to Steamboat Hot Springs for analysis purposes. An EA should examine the cumulative impacts of the various permitted operations on Steamboat Hot Springs.

In conclusion, an EA should thoroughly examime the relationship between the applicant's present operations and the flows at Steamboat Hot Springs, as well as the asertion that the expanded operations will have zero effect. The Bureau must not approve the proposed amendment if the expanded operation will destroy what is left of Steamboat Hot Springs, and, presumably, the endangered Steamboat buckwheat dependent on the Springs. If the expanded operatons will adversely affect the surface springs, then the Bureau must require mitigation for adverse affects.

In any event, there is a tremendous lack of information about the impacts of the existing operation, much less any reasonable supporting documentation that expanded operations will not result in decreased surface spring flows. We request the Bureau to hold a public hearing in which more of the information would be available and questions from the public would be answered.

Sincerely,

Rose Strickland

Rose Strickland, Chair
Public Lands Committee

9/10/91

Dear Mr. Hoops:

This letter is in response to the materials I received in late August concerning the project by the Yankee/Caithness Joint Venture, LP. Steamboat Hills Geothermal Project.

There is clear misinformation in the materials provided by the Ammendment to the plan of operation.

On page 13 the following is stated: "Modelling of the geothermal reservoir utilizing all of the available data indicates that the Steamboat Hills deep geothermal reservoir intersected by the production and injection wells is not directly connected to either the shallow geothermal area or the groundwater system located north of the Caithness project area, nor are the Caithness geothermal wells hydraulically connected to the Steamboat Hot Springs area. Therefore, There will not be any adverse effects ion these hydrologic features from the increase in production."

If you buy this I've got a bridge for sale!!

Simply put; from the moment of the start of the project Steamboat Springs ceased to exist as a geothermal phenomenon. The second largest geyer area in the United States has no more geysers. The water is almost completely gone.

I assume the Bureau of Land Management has been monitoring the project so you know the veracity of my statement.

There is still a small amount of water in the Steamboat Springs area and hopefully the silica walls of the features maintain some integrity. Certainly any more water loss will completely destroy a piece of our national heritage.

The application for increase in water use must be denied.

The wole project must be carefully looked at again due to the resource it is so obviously destroying.

Thank you for your close attention,

Allan Friedman
2301 Ward St.
Berkeley, CA
94705

United States Department of the Interior

FISH AND WILDLIFE SERVICE
FISH AND WILDLIFE ENHANCEMENT
Reno Field Station
4600 Kietzke Lane, Building C-125
Reno, Nevada 89502-5093

September 13, 1991
File No.: 1-5-91-I-246

Memorandum

To: Deputy State Director, Mineral Resources, Bureau of Land Management, Reno, Nevada (Attention: Richard Hoops)

From: Field Supervisor, Reno Field Station, Reno, Nevada

Subject: Environmental Scoping for the Amendment to the Plan of Operation/Plan of Utilization for the Steamboat Hills Geothermal Project, Steamboat Springs Unite Area, Washoe County, Nevada (3280/1792)

The Fish and Wildlife Service (Service) has reviewed your letter dated August 15, 1991, regarding the intent to prepare an environmental document for the above referenced project. The document will evaluate the possible environmental consequences of a proposed increase in the production rate of the Steamboat Hills Geothermal Project well field. The increased production would be obtained from existing or already approved but as yet unconstructed geothermal wells. According to the Environmental Assessment dated May 30, 1987, expansion of the project from the original 12.5 megawatt power plant would require new permits and would be subject to compliance with the National Environmental Policy Act.

Endangered Species

The original 1.5 megawatt geothermal power plant project was the subject of formal consultation with the Service in 1987 pursuant to section 7 of the Endangered Species Act (Act) of 1973, as amended (File No.: 1-5-87-F-101). The Service determined that the project was not likely to jeopardize the continued existence of the endangered Steamboat buckwheat (*Eriogonum ovalifolium* var. *williamsiae*). Informal consultation was completed between the Service and the Forest Service in 1990 on a proposal to re-enter an existing well (File No.: 1-5-90-I-15). The Service concurred with the Forest Service that the action was not likely to adversely affect the listed species.

The Service's primary concern is the impact of the proposed increase in production rate on the Steamboat buckwheat. The Bureau of Land Management must make a determination whether this new action will affect the listed plant. Should you determine the plant may be affected, then you must consult with the Service as required by section 7 of the Act. Attachment A specifies your requirements in further detail.

Although the proposed action will not result in additional surface disturbance to Federal lands, the environmental document should address direct and indirect project impacts to biological resources on public and private lands

APPENDIX C

Summary of the Hydrology of the Steamboat Hills and Vicinity

A SUMMARY OF THE HYDROGEOLOGY OF THE STEAMBOAT HILLS AND VICINITY

A SUMMARY OF THE HYDROGEOLOGY OF THE STEAMBOAT HILLS AND VICINITY

TABLE OF CONTENTS

LIST OF FIGURES

page

A SUMMARY OF THE HYDROGEOLOGY OF THE STEAMBOAT HILLS AND VICINITY

1. INTRODUCTION

WILLIAM E. NORK, INC. (WEN) was retained by Environmental Management Associates, Inc. (EMA) to review a broad range of available records, publications and commentary and from these data, to summarize the highly complex hydrogeology of the Steamboat Hills and vicinity. The geographic area of investigation is depicted in Figure 1. As part of this investigation WEN assessed the hydrologic impacts which may have occurred consequent to all operations and activities in the area, including Caithness Power, Inc.'s (CPI) existing geothermal operations, and evaluated the potential future impacts, if any, resulting from CPI's proposed amendment to its Plan of Operations/Plan of Utilization (POO/POU) to increase the geothermal fluid production and injection rate, as well as the cumulative hydrologic impacts resulting from all past present and reasonably foreseeable future operations. This cumulative investigation looked at the existing and future impacts on the hydrologic system which could be ascribed to neighboring geothermal operations, fresh groundwater users, surface water irrigators and natural phenomena such as the current and protracted drought conditions prevalent in this part of Nevada. Figure 2 depicts the identity and location of the principal existing and proposed geothermal resource operations, municipal groundwater users and their spacial relationship to CPI.

This report utilizes the previous investigations of White, et al. [1964], White [1968], Nehring [1980]; the more recent studies by Sorey and Colvard [1991] and the variety of publications and documents prepared by CPI's consultants; records, reports and information from the files of the Nevada Divisions of Environmental Protection and Water Resources; Steamboat Ditch flow records from the Federal Water Master; monitoring data by Yeamans and Broadhead [1988]; current pumping records provided by the Washoe County Utility District (WCUD) for the South Truckee Meadows General Improvement District (STMGID); and projected future (non-geothermal) fresh groundwater usage as estimated in the Washoe County Comprehensive Plan [1991].

Notwithstanding the extreme complexity of the hydrogeologic system at Steamboat Hills and vicinity, this report provides plausible, sometimes alternative, explanations for the already observed declines in water levels and spring discharges and the potential future impacts which may be manifest consequent to the cumulative and conjunctive use of geothermal, fresh groundwater and surface water in the Steamboat Hills area.

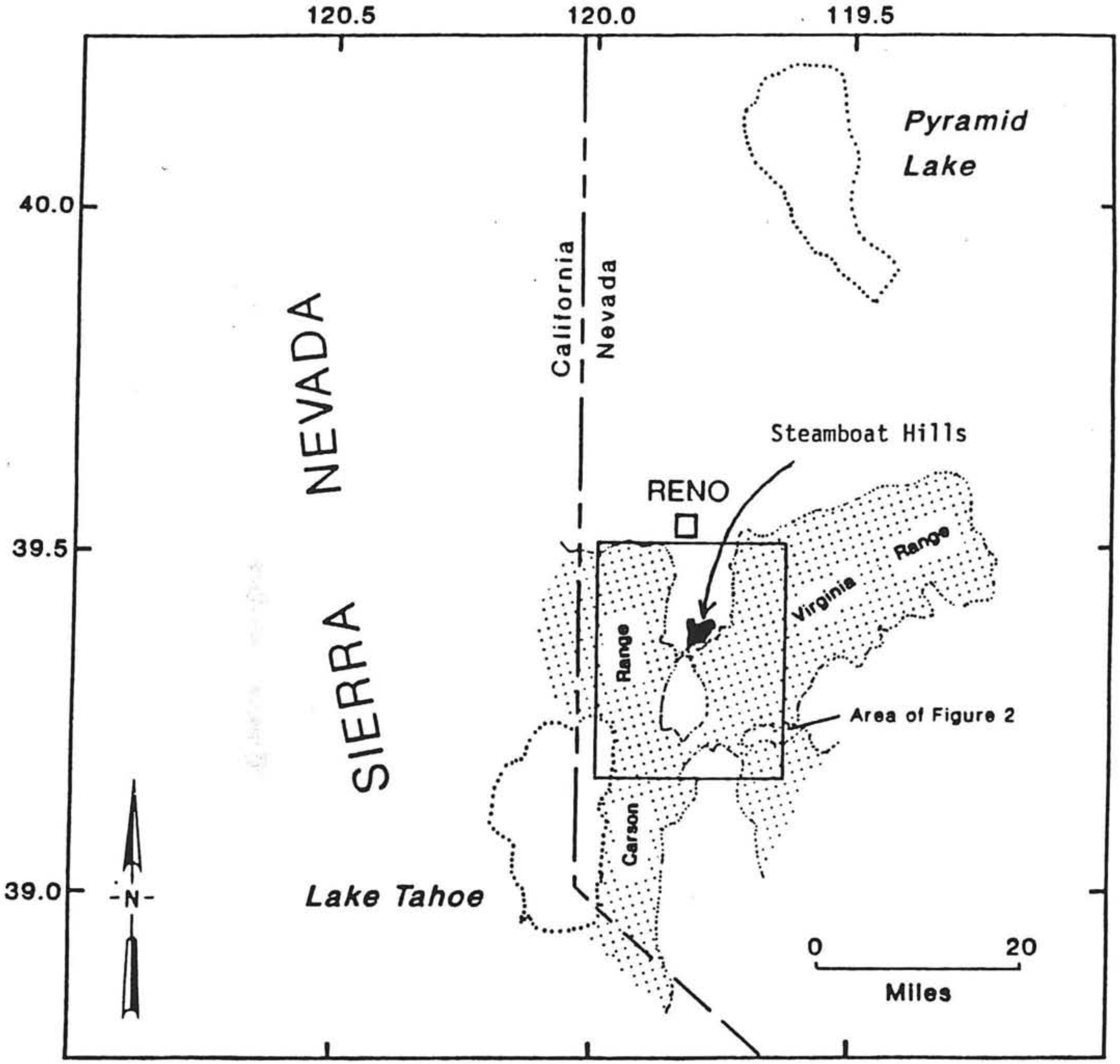


Figure 1. Location map.

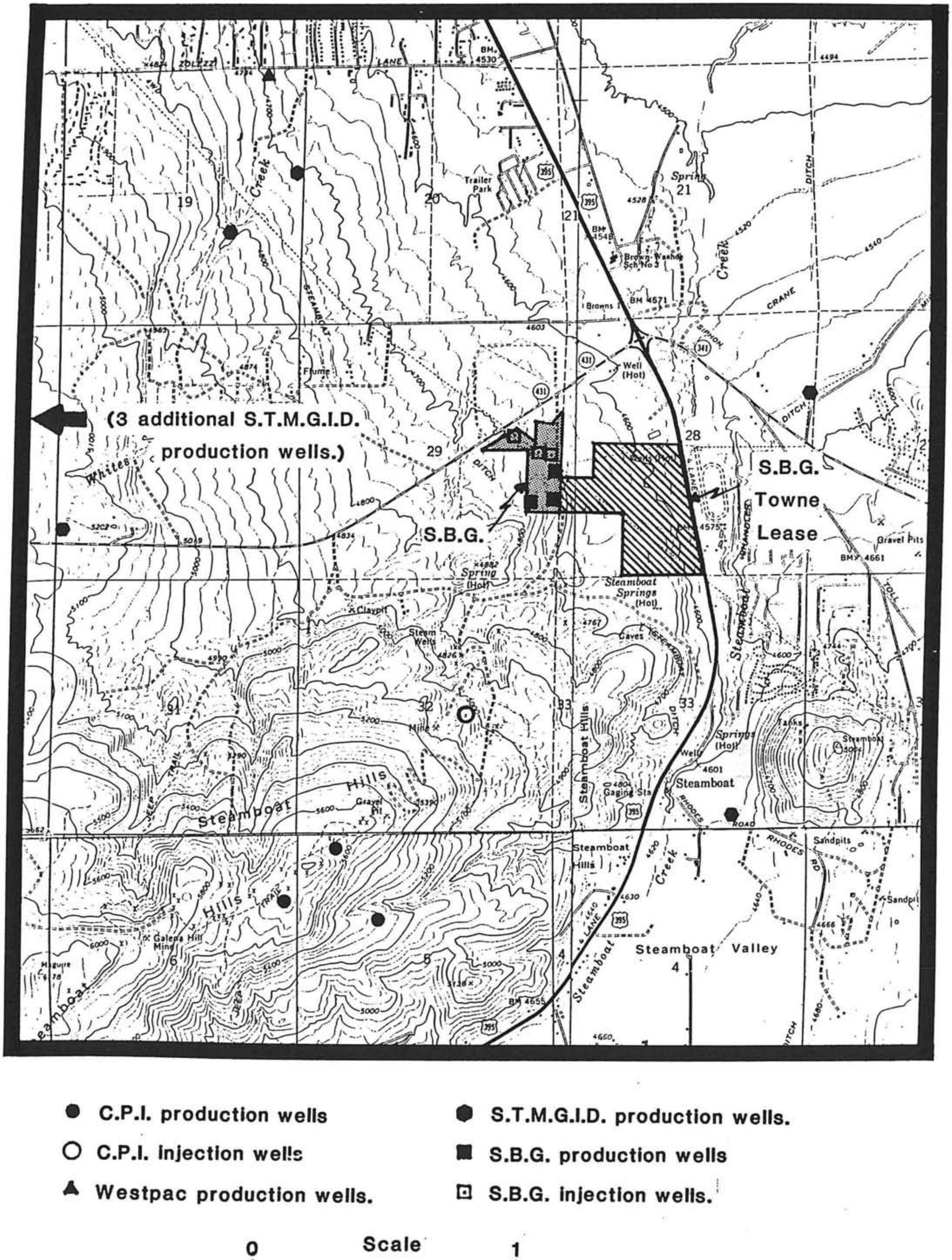


Figure 2. Locations of geothermal projects and other water users in the South Truckee Meadows.

2. HYDROGEOLOGY

2.1. Geology

The following discussion of the geology in the vicinity of the Steamboat Hills is based on the work by White, et al. [1964] and published and unpublished work by CPI's consultants. For more detailed description of the geologic units the reader is invited to review the work of White, et al. [1964]. More recent unpublished and published work by CPI's consultants greatly expands on the earlier geologic investigations. The distribution of geologic units in the vicinity of the Steamboat Hills is depicted in Figure 3.

The oldest geologic unit in the Steamboat Hills comprises Triassic-Jurassic Age metavolcanic rocks, presumably of the Peavine Sequence. These intensely folded rocks are exposed on the southern flank of the hills.

The metavolcanic rocks are intruded by Jurassic-Cretaceous Age rocks of granodioritic composition which crop out in the northern part of the hills. The contact between these two major lithologic units dips steeply and strikes in an easterly direction. Its irregular nature is evidenced by repetitive sequences of alternating igneous and metamorphic rocks penetrated by some wells (Figure 4). The granitic rocks show very little structural character other than faults, fractures, and joints. Near the faults and fractures, the granodiorite is highly altered.

An unconformity separates Mesozoic rocks from younger geologic units. Tertiary Age (Miocene-Pliocene) Alta and Kate Peak Formations are volcanic rocks which were extruded and overlie the older metamorphic and igneous rocks which were exposed by erosion during a 60-million year hiatus in deposition. The Alta Formation comprises soda trachyte lava flows and associated pyroclastic rocks and breccias. The Kate Peak Formation comprises several hundred feet of andesitic lava flows and tuff breccias. These units are commonly hydrothermally altered.

A second unconformity separates the Kate Peak Formation from Pliocene Age Lousetown Formation. The Lousetown Formation comprise basaltic andesite flows and a series of rhyolite domes. The domes are oriented along a northeasterly trend which extends for several miles. Recent detailed geologic mapping of the area shows that the basaltic andesite does not blanket the northern Steamboat Hills. Rather, it comprises a series of localized eruptions along steeply dipping faults. Flow banding in these rocks help locate faults and fractures from which the volcanics were extruded (Goranson, et al., 1990; van de Kamp, 1991, personal communication).

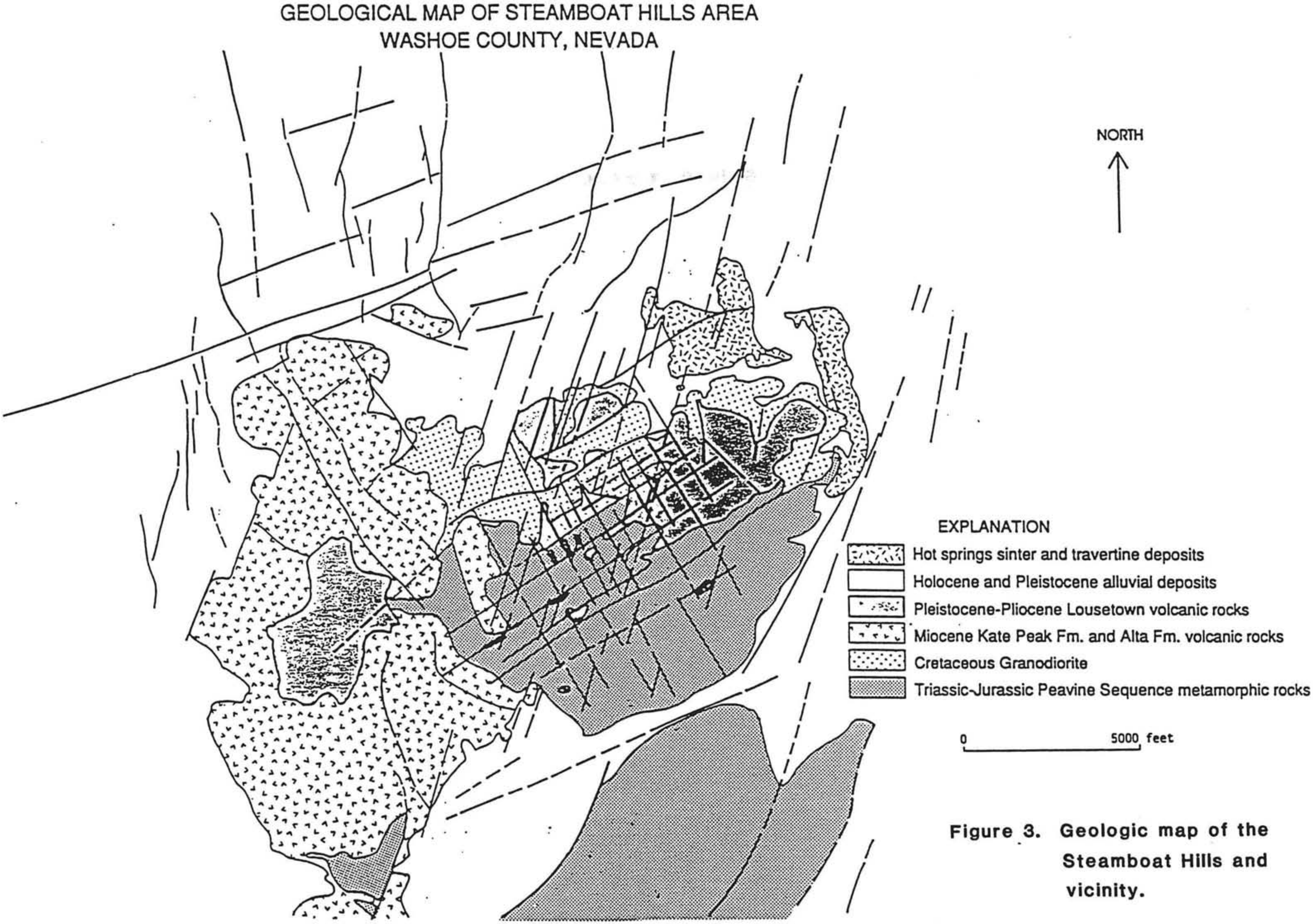
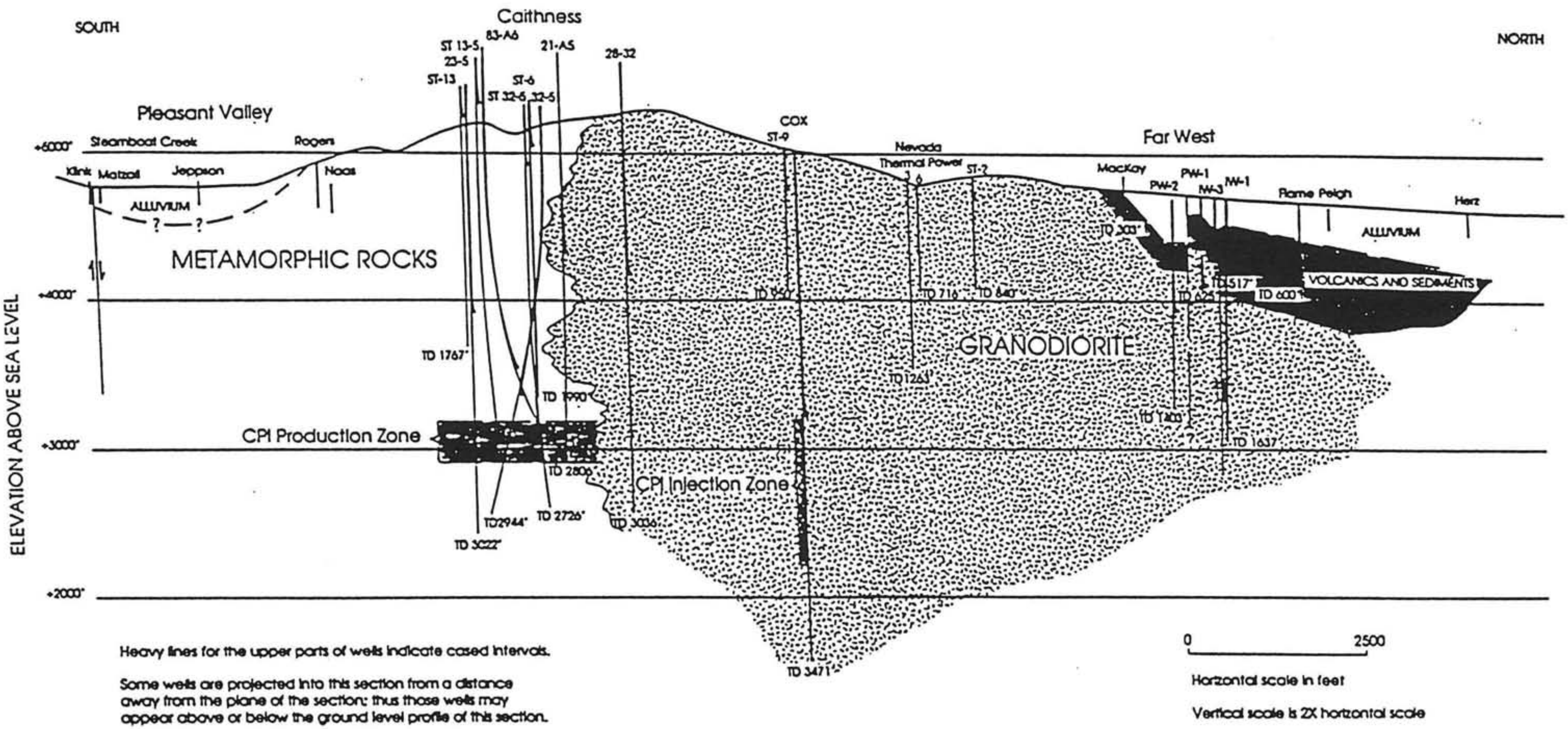


Figure 3. Geologic map of the Steamboat Hills and vicinity.

(urc ior on. l 0)



(source: Goranson, et. al., 1990)

Figure 4. Geologic cross section through the Steamboat Hills.

Alluvial deposits mantle the underlying units along the north and northeastern margin of the Steamboat Hills. These deposits, which originated from erosion of the surrounding highlands, are locally cemented by silica sinter. Three distinct terraces have been formed in the alluvial deposits by hot spring deposition: namely, the High Terrace, the Main Terrace, and the Low Terrace. The High Terrace was formed by ancient hot spring activity which is now extinct (White, 1968). The Main and Low Terraces are the site of present-day hot spring activity.

The Steamboat Hills are positioned at a transition between the Sierra Nevada Batholith located to the west and the Basin and Range Physiographic Province to the east. The Walker Lane, a large-scale right lateral strike slip fault zone passes east of the Steamboat Hills. The Steamboat Fault system is probably related to this major structural trend.

The Steamboat Hills represent a structural block in the shape of a parallelogram which is approximately 1,800 feet higher in elevation than the valley floor. Three fault trends dominate the structure. The block is bounded to the north and south by faults which trend N50° to N60°E. The faults which delimit the Steamboat Hills on the west and east trend north to north-northeast. The third major fault trend is oriented in a northwesterly direction (Figure 3).

2.2. Hydrology

The Steamboat Hills are located within the Truckee Meadows Hydrographic Basin. Elevations within the basin range from more than 10,000 feet in the Carson Range to the west, up to 7,700 in the Virginia Range to the east, and approximately 4,400 feet on the valley floor of the Truckee Meadows to the north. By comparison, the elevation of the highest point in the Steamboat Hills is 6,178 feet.

Precipitation in the basin is derived principally from storms which occur November through March. The greatest accumulations of precipitation (up to 60 inches per year) occur in the Carson Range (Kleiforth, unpublished data). Lesser amounts (approximately 20 inches annually) accumulate in the Virginia Range, and less than six inches fall on the valley floor. The Steamboat Hills, Truckee Meadows, and Virginia Range all lie in the rain shadow of the Carson Range.

At higher elevations within the basin some of the precipitation percolates directly into the ground, some is lost through evapotranspiration, and the remainder runs off as surface water. Generally, little to none of the precipitation falling on the valley floor or at elevations below 5,000 feet contributes as recharge to the groundwater system except where groundwater levels are at or near land surface. Similarly, where groundwater levels are shallow, some secondary recharge from both surface and groundwater irrigation use occurs. For the most part, however, the principal source of groundwater recharge is direct percolation of precipitation at higher elevations and infiltration of surface water within the alluvial fans below the mountain front and above the valley floor.

Since 1938, nearly one-half of the precipitation years have been at or above average annual rates (see Figure 5). Since 1985, however, and with the exception of 1986 (the result of one major short duration storm), precipitation has been below average, particularly at higher elevations. Also, since 1968, there is a general downward trend in average precipitation both at high elevations and within the lower elevations of the Truckee Meadows Basin (Figure 5).

2.2.1. Surface Water

The principal streams in the vicinity of the Steamboat Hills are Thomas and Whites Creeks to the north, Galena Creek to the west and south, and Steamboat Creek. Whites, Thomas, and Galena Creeks all drain the Carson Range to the west. Infiltration of surface water from these influent streams is a major source of groundwater recharge to the alluvial aquifers within the Truckee Meadows. The creeks are all tributary to Steamboat Creek which, in turn, is tributary to the Truckee River. The principal surface water sources and average annual flow are:

CREEK/CANAL	FLOWS (AFA[1])
Steamboat (including 7,800 AFA from Galena Creek)	10,900
Steamboat Ditch	6,500
White	4,700
Thomas	4,300

[1] AFA = Acre-feet per annum (ref. Cooper and Associates, 1983)

Steamboat Creek is an effluent stream in the South Truckee Meadows. As such, it receives inflow from the groundwater system via upward seepage through the stream bottom along its length. A portion of the groundwater discharged to the

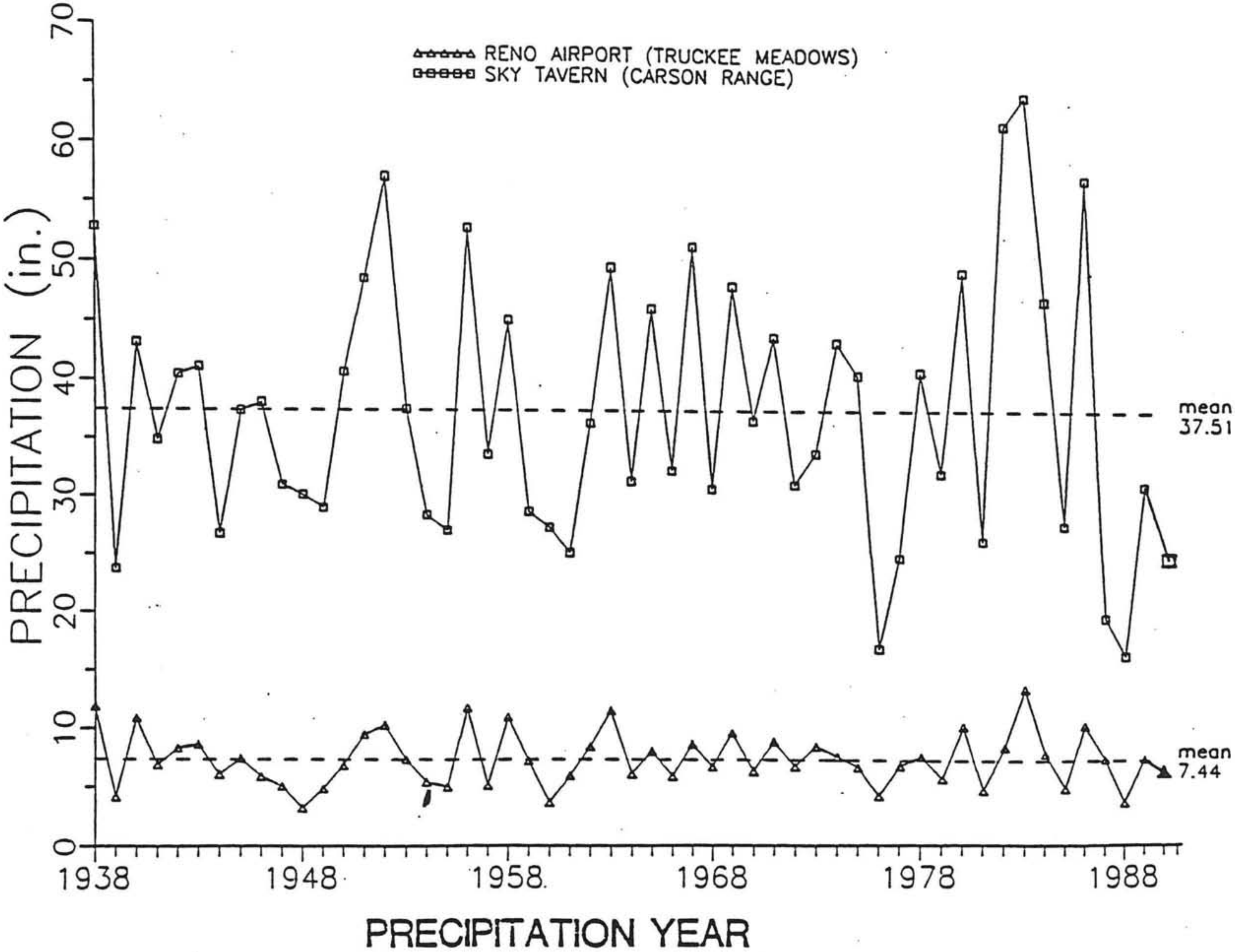


Figure 5. Annual precipitation for the Reno and Sky Tavern stations, 1938 to 1989. (Each precipitation-year runs from July to June.)

creek originates as outflow from the geothermal system. White [1968] estimated the discharge from the Steamboat geothermal system to be approximately 1,800 AFA (1,100 gpm). Of this amount, hot springs along the Main Terrace have historically discharged 48 to 96 AFA or 30 to 60 gpm (ibid.).

There are also a number of irrigation ditches and canals within the area which derive water from either the Truckee River or one or more of the aforementioned creeks. These mostly unlined ditches and canals behave as local influent streams and contribute to groundwater recharge, especially when running full.

2.2.2. Groundwater

The groundwater system in the Steamboat Hills area comprises both fresh (non-geothermal) waters and geothermal waters.

2.2.2.1. Fresh Water System

Fresh groundwater is derived principally from the alluvial materials which overlie fractured igneous and metavolcanic rocks. The fresh waters in the alluvial material provide water supplies to STMGID wells in the Whites Creek/Thomas Creek fan areas, to Westpac Utilities wells within the valley floor, and to numerous individual domestic wells. Recharge to this alluvial aquifer originates from four sources: direct percolation of precipitation at higher elevations in upper fan areas, infiltration of surface waters from mountain streams, upward and lateral leakage from underlying and adjacent fractured granitic and metavolcanic rocks, and secondary recharge from unlined ditches and canals as well as from land application of irrigation water.

The chemical quality of the groundwater derived from the alluvial fan aquifers of the Thomas/Whites Creek fan complex north to northwest of the Steamboat Hills is generally good. Total Dissolved Solids (TDS) ranges between approximately 100 to 300 milligrams per liter (Cooper and Associates, et al., 1983). Northeast of Steamboat, in the Virginia Foothills area, the chemical quality of the groundwater is affected by elevated levels of iron, manganese, arsenic and boron (ibid.).

2.2.2.2. Geothermal System

Geothermal waters generally reside in and are derived from the fractured granitic and metavolcanic rocks underlying the alluvium, with some exceptions. Hot springs of the Steamboat Hills issue from alluvial deposits at the Main and Low Terraces. These alluvial deposits are also tapped by a number of shallow, lower temperature geothermal wells. In some instances, the chemical quality of these shallow wells suggests mixing of the fresh and geothermal waters; in others, the low temperature wells tap water of purely geothermal origin.

Stable isotope studies suggest that the recharge source for the geothermal system is deeply circulating meteoric waters. The recharge area may be localized with the upper reaches of the Carson Range west to northwest of the Steamboat Hills in the area between Galena Creek and Evans Creek [Nehring, 1980]. Alternatively, since there are multiple geothermal manifestations in evidence along a broad stretch of the eastern slope of the Sierra Nevada north and south of Steamboat, it is conceivable that the Steamboat Geothermal System is part of a much larger regional flow system.

System Morphology

The geothermal reservoir comprises fractured igneous rocks of granitic composition which have intruded metavolcanic rocks. Geothermal fluids in the southern portion of the reservoir are produced from wells which intersect steeply dipping north-northeasterly trending faults and fractures within the granitic rocks (Goranson et al., 1990). In the northeastern part of Steamboat, producing fractures trend north-northeasterly, dipping about 80° to 85° to the west (Goranson, 1991). Faults play a significant role in the occurrence and movement of geothermal fluids within the reservoir because the fractures related to faulting exhibit very high secondary permeability. The intervening unfractured rocks are relatively impermeable. Consequently, the movement of geothermal fluids normal to the faults is comparatively small. However, zero flow normal to the major fault conduits within the reservoir rocks is unlikely because fracturing is widespread. Flow occurs exclusively along faults and fractures.

Spinner surveys and a Schlumberger Formation Microscanner (FMS) log have been run in the CPI injection well, Cox I-1. A spinner survey performed while injecting at a rate of 3,500 gpm (at 290°F) indicated that

60% of the total flow exits the well bore in a zone between 1,800 and 1,820 feet below land surface. Several other zones below this depth also accept fluid. The FMS log run in this high permeability zone of the reservoir indicated near-vertical fractures (dipping at 85-90°) striking north-northeasterly. One other well has been logged with the FMS tool and it, too, yielded north-northeasterly trending permeable fracture zones (Goranson, et al., 1990). This orientation is consistent with surface expressions of faults on the Main Terrace manifested by hot springs and vents.

Above depths of 2,000 to 3,000 feet below land surface in the CPI field southwest of the Main Terrace and above 400 to 600 feet in the northern part of the Steamboat Hills, the steeply dipping fractures are filled with mineral deposits (Goranson, et al., 1990), which acts as a lower-permeability horizon cap on the geothermal system, except where infrequent open faults and fractures extend to land surface at the Main and Low Terraces.

The natural state of geothermal fluid flux through the system is not known with a high degree of confidence. An estimate based on assumed values of chloride concentration in the reservoir and measured chloride flux in Steamboat Creek suggests that the local geothermal discharge approaches 1,130 gallons per minute (White, 1968). The total flux through the system is not known because the relationship of the Steamboat area to other geothermal occurrences along the eastern Sierra is unknown. Given that there are multiple geothermal occurrences aligned along the eastern slope of the Sierra north and south of Steamboat, it is conceivable that the Steamboat Geothermal System is part of a larger regional flow system and the 1,130 gpm alluded to above may simply represent localized discharge of a larger system.

It is unclear whether the Steamboat Hills are underlain by a single geothermal reservoir or several isolated reservoirs which are independent of one another. The location of the geothermal heat source relative to the reservoir(s) is unknown and may be present at some remote location requiring the geothermal fluids to arrive at the hills via different flow paths (Goranson, 1992, personal communication).

Temperature and Chemistry

The hottest reservoir temperatures are encountered in the southern portion of the Steamboat Hills. Temperatures in that area approach 420°F to 460°F at depths 2,000 to 3,000 feet below land surface (3,200 feet elevation). In the northern portion of the Steamboat Hills, geothermal fluids with temperatures of 320°F to 360°F are found at depths of 400 to 600 feet below land surface. Low temperature geothermal waters (80°F to 180°F) are found in shallow alluvial deposits north and east of the Steamboat Hills (Goranson, et al., 1990).

Chemical geothermometers indicate a maximum reservoir temperature approaching 500°F (Goranson, 1992, personal communication). By comparison, CPI production wells in the southern part of the Steamboat Hills yield temperatures of 420 to 460°F (Goranson, et al., 1990). The production wells for SBG Geothermal Project in the northern part of the Steamboat hills yield temperatures of up to 340°F (GeothermEx, 1989; Goranson, et al., 1991a). The temperature of the reservoir which feeds the hot springs may have a temperature of approximately 450°F (Nehring, 1980).

In contrast to the chemical quality of the fresh groundwater in the alluvial deposits, the TDS of the geothermal brine is greater than 2,000 mg/l and is a sodium chloride water type. The geothermal brine derived from the SBG production area in the northern Steamboat Hills contains approximately 2,200 mg/l TDS (Goranson, 1991a). Because unflashed samples of the geothermal brine have not been collected from the CPI production area in the southern Steamboat Hills, exact values for TDS in that part of the reservoir have not been measured. Analytical results of these "flashed samples" to date have yielded values ranging from approximately 2,100 mg/l (Thermo Chem, 1988) to 3,055 mg/l (NDOH, 1991).

Nehring [1980] observed that the chemistry of the geothermal fluids from springs and shallow (<700 ft.) wells at the main and low terraces, as well as several shallow (<200 ft.) wells north of the terraces at Steamboat, could be accounted for by conductive cooling and boiling. No data from the CPI Lease were available for that study. More recent comparison of fluid analyses from the Steamboat Hills shows that although the gross chemistry of the geothermal fluids derived from the different production areas is similar, silica concentrations are not identical, indicating the fluids from the different production areas may have equilibrated at different temperatures or have divergent histories (Bobbie Gollan, 1992; personal communication). So, processes other than simple boiling and conductive cooling may be at work.

Permeability

Each production area exhibits very high permeability. The permeability-thickness product of the reservoir, kh, has been estimated to range from 1,000,000 to 3,000,000 millidarcy-feet on the basis of tests in both the southern and northern parts of the Steamboat Hills (GeothermEx, 1989; Goranson, 1992, personal communication).

The geothermal system is bounded by faults which behave as barriers to the movement of geothermal fluids. The Pleasant Valley fault bounds the Steamboat Hills on the southeast and restricts geothermal fluid movement in that direction.

Although hydrologic boundaries within the Steamboat Hills almost certainly exist, none have been identified through testing conducted to date. A lack of observable boundaries is consistent with a highly permeable reservoir because the effect of a nearby barrier boundary occurs so quickly that its presence during testing is undetectable or indistinguishable from well bore influences.

Connection with Fresh Water System

The geothermal system is hydraulically connected to the local alluvial aquifer(s). Some wells completed in the alluvial aquifer, namely the Pine Tree Ranch, Browns School and Herz (domestic) wells (refer to Figure 9), suggest mixing of fresh and geothermal waters. (Goranson, et al., 1990; van de Kamp, 1991, personal communication). And, as noted earlier, the hot springs located at the Main and Low Terraces of the Steamboat area are associated with these alluvial aquifers. The details of this interconnection are not known with any degree of certainty.

2.2.2.3. Hydrologic Models for the Geothermal System

The hydrology of the Steamboat Geothermal System is complex. While some general features of the system are known and alternative models have been suggested, no single model clearly and unequivocally explains all of the observed phenomena all of the time.

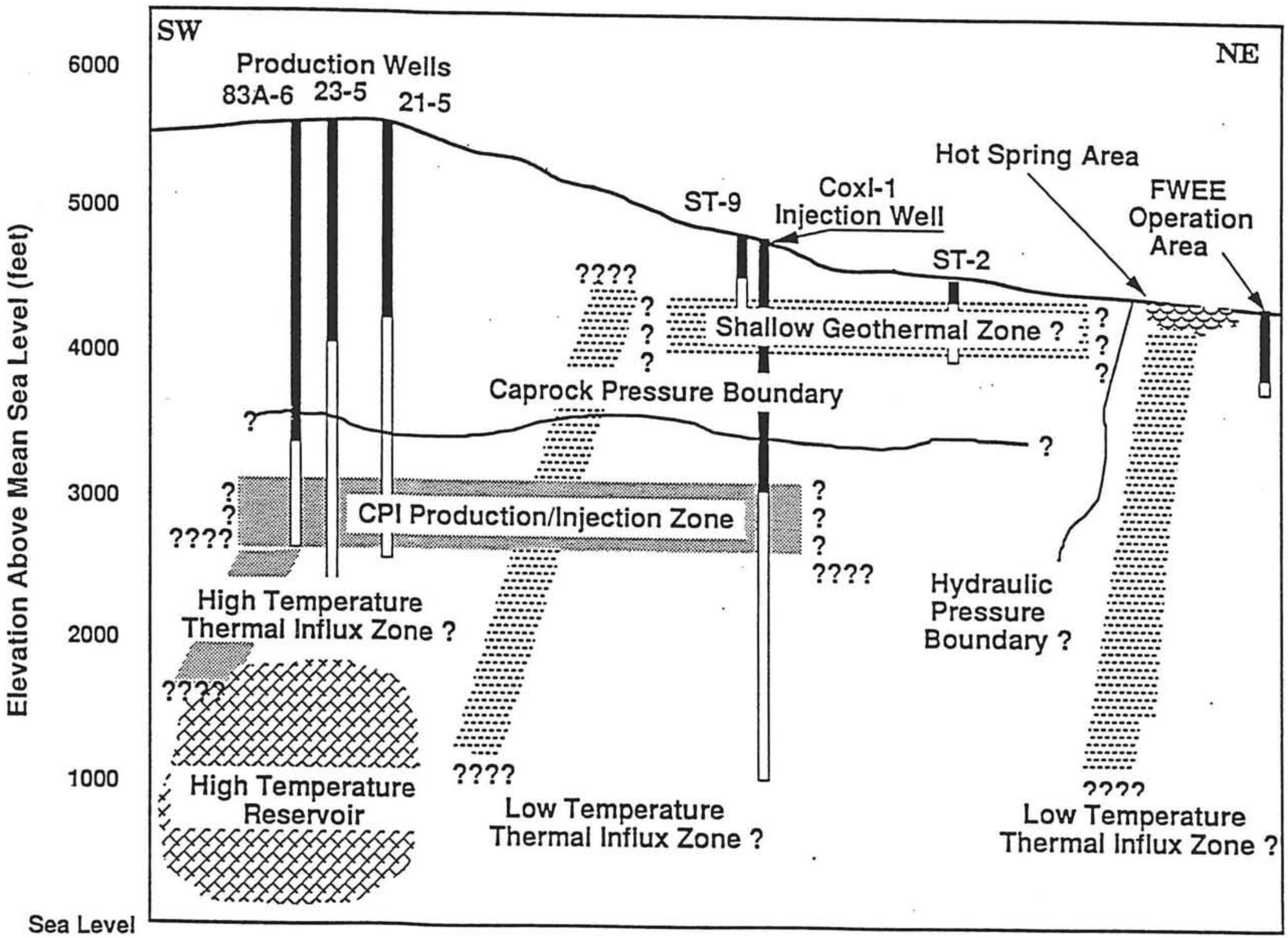


Figure 6. Schematic cross section through the Steamboat Hills showing separation between isolated zones.

One model of the geothermal system postulates that there are at least three geothermal systems operating beneath the Steamboat Hills (Figure 6). Each system is described as hydraulically isolated from the other by pressure boundaries or impermeable rocks. The three areas are: a deep high temperature system tapped by the CPI production and injection wells, a shallow moderate temperature system tapped by the SBG wells, and the low temperature system(s) related to the hot springs at the Main and Low Terraces and thermal groundwater found in the alluvial aquifer (Goranson, et al., 1990; van de Kamp and Goranson, 1990). Support for this interpretation includes:

- differences in elevation between the three zones,

- differences in temperature at each of the areas and the temperature gradient between the reservoirs,

- no convincing evidence of communication between the CPI production/injection horizon and the hot springs.

- observed pressure support in the CPI reservoir due to re-injection.

A second model (Sorey & Colvard, 1991) suggests that only one geothermal system operates at Steamboat. Regions of localized high permeability associated with faults and fractures exist within otherwise impermeable rocks and there is a degree of communication between some of these different areas (Figure 7). The model suggests that upflow from the CPI production horizons feeds the moderate temperature reservoir tapped by SBG and the Main Terrace. Little pressure support to the CPI reservoir from re-injection is recognized.

Evidence cited for this model includes:

- A perceived response at the hot springs to some CPI production episodes.

- No clear indication of injection support in the CPI well field.

- General similarities in gross chemistry of the fluids from the different areas.

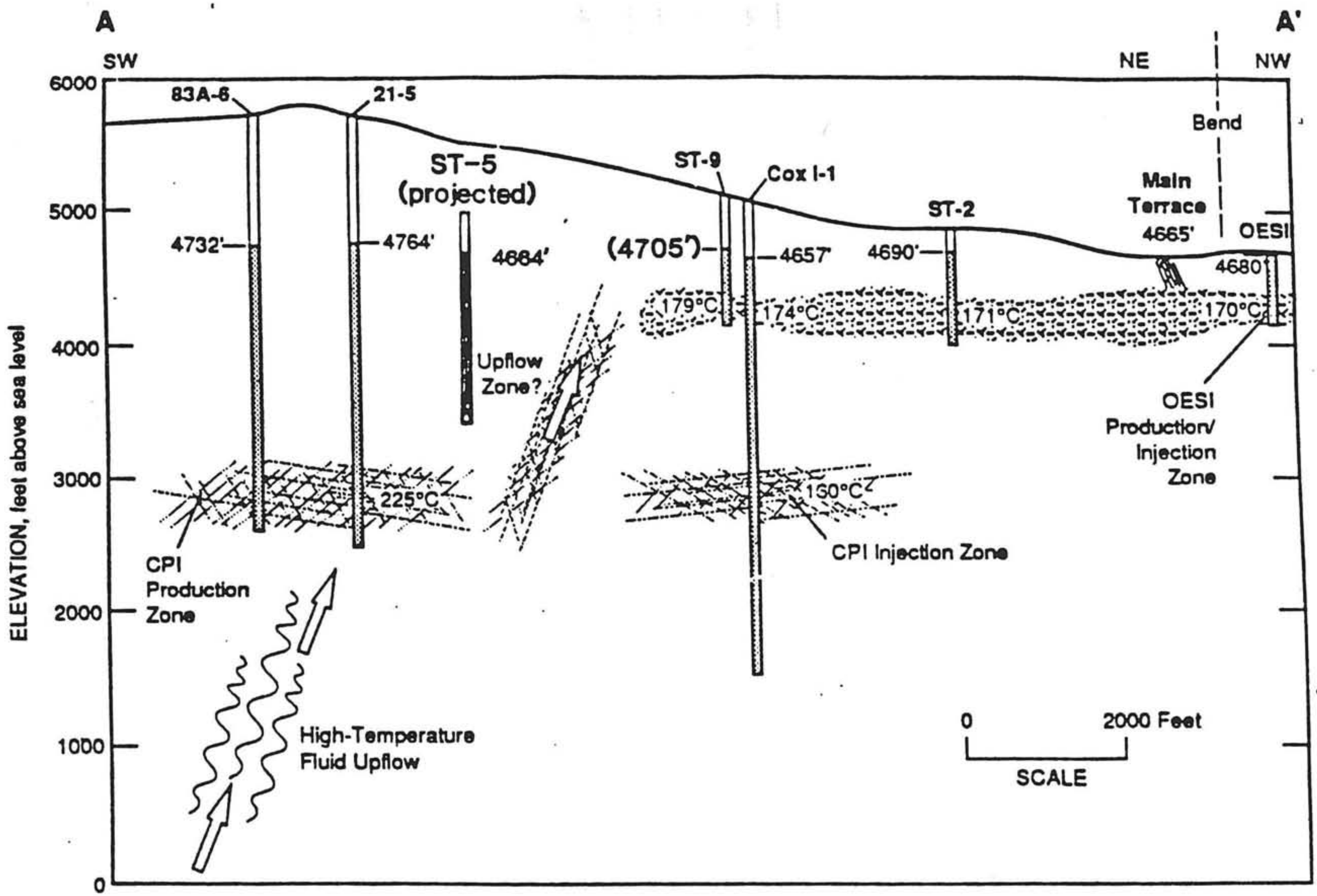


Figure 7. Schematic cross section through the Steamboat Hills showing possible relationships between temperature zones.

In order to verify which, if either, of the two models for the geothermal system is more correct, it would be necessary to further stress the system and observe the results. This approach has not been successful at Steamboat to date because there are outside influences acting on the system and some data are lacking for critical areas and time periods. There is no guarantee that the same approach would be successful in the future, either.

In reality, a conceptual model which depicts the Steamboat Geothermal System probably lies somewhere between two models discussed above. Given the highly fractured nature of the reservoir rocks and the extent of faulting, it is difficult to accept that there is zero movement of geothermal fluids vertically and in an easterly direction through the system. While there may be no movement between adjacent fault conduits near land surface where geologic data show the fractures to be filled with mineral deposits, it is possible that the various high permeability zones enjoy some degree of communication at depth, however tortuous.

Whichever of the two models is more correct, on a gross scale, the reservoir must be highly anisotropic. Intuitively, the major transmissivity tensor in the CPI production area might be aligned with the north-northeasterly structural trend and permeable fractures identified through FMS logs in the Steamboat Hills. The minor axis would be oriented in an east-west direction. Indirect evidence of low permeability in an east-west direction is suggested by the relatively small quantity of geothermal water discharged into Steamboat Creek. Given a head difference of approximately 100 feet between the Main Terrace and Steamboat Creek, the discharge to the creek would be enormous unless the overall permeability in an east-west direction is small.

The anisotropic character of the Steamboat area, in a gross sense, is further indicated by a lack of a clear response to re-injection in the hot springs area. Recent analytical work (Petty, 1992) clearly documents pressure support to the CPI reservoir from re-injection in Cox I-1. If as the second model implies, there is communication between the CPI production area and the Main Terrace, and the reservoir benefits from pressure support from injection as the first model implies, then the hot springs might be expected to experience an increase in water levels or discharge during the first years of operation because the injection well is closer to the springs than the production wells. The evidence for pressure support at the hot springs is inconclusive. Water levels measured for Spring 6 appear to have declined at a rate less than the regional trend. Perhaps this is a consequence of pressure support. However, TH-1, a temperature gradient well drilled on the Main Terrace north of Spring 6 shows a water level of approximately 30 feet below land surface (Goranson, 1992, personal communication) suggesting that the declines observed in Spring 6 may be greater than the 12 feet that some investigators (Collar, 1990; Sorey and Colvard, 1991) suspect has occurred.

As noted above, kh of the reservoir is as much as 3,000,000 md-ft. In an anisotropic reservoir, the average permeability is equivalent to the geometric mean of the major and minor permeability tensors. Assuming kh parallel to the fractures is 10 times that normal to the fractures, then the value of kh parallel to the fracture is

$$kh_y = kh_{av.} / 0.316 = 3{,}000{,}000 \text{ md-ft} / 0.316 = 9.5 \times 10^6 \text{ md-ft}$$

If boundaries exist, but are "transparent", then kh would be higher still.

The precise nature of the reservoir is almost irrelevant from a production standpoint because, for all practical purposes, it is infinitely permeable. As a consequence, pressure decline in the reservoir necessary to sustain the high production rates is small compared to the amount of pressure drawdown available to the production wells.

The degree of pressure support to producing zones in the reservoir consequent to re-injection has been an issue in the past (Collar, 1990; Sorey and Colvard, 1991). In the SBG field an observed pressure decline of seven to 10 p.s.i. in observation wells during the first three years of operation is viewed as either reservoir drawdown (GeothermEx, 1989) or the influence of the current drought conditions (Goranson, 1991a.).

In the CPI well field, there are no observation wells completed in the reservoir which have been monitored since before the project came on line. Pressure data for production wells taken when they are occasionally shut in do not suggest a decline in reservoir pressure due to production. Evidence for pressure support in the CPI field was obtained from shut-in of the production wells for maintenance in May and June of 1990. Data from well 28-32 (originally completed as a production well, but not currently used as such) during and following the shut-in period clearly document pressure support (Petty, 1992).

Given kh equal to 3,000,000 md-ft and close proximity of production and injection wells in both the CPI and SBG well fields, breakthrough of injectate to the production wells should have been experienced soon after re-injection commenced. That no thermal breakthrough in the presence of injection support has been observed indicates a pressure connection between the production and injection horizons but no hydraulic connection at the current production and injection rates. Density differences could propel the injectate downward in the near-vertical fault/fracture conduits away from the production wells. Support of this argument is also found in the experience at the CPI well field during the May-June, 1990 shut-in period. Water samples from the CPI injection well, Cox I-1, taken when it was flow tested soon after the well was taken off line showed no trace of the injectate despite continuous injection at high rates for a period of three years and a contrast in the chemistry between the injectate and ambient geothermal fluids in this area. The conclusion drawn was that the injectate must be moving vertically away from the well at high velocity (Goranson, 1992, personal communication).

2.3. Current Utilization of Water Resources

2.3.1. Surface Waters

There are no unappropriated surface waters in the South Truckee Meadows except for a few isolated springs. With the exception of losses due to evapotranspiration from native vegetation, virtually all surface water use in this area has been for agricultural purposes. Agricultural use of surface water has declined since the early 1980's, partly due to the current drought conditions and, in part, due to a change in land use from agriculture to housing. As an illustrative example, Figure 8 illustrates the decrease in the annual deliveries via the Steamboat Ditch. A consequence of this change in land use is reduced secondary recharge from irrigation to the groundwater system because of a decrease in the volume of irrigation water applied to the land. An anticipated result of this loss of secondary recharge is a decline in groundwater levels. Long range planning for the South Truckee Meadows suggests this trend will continue.

2.3.2. Groundwater

Groundwater withdrawals from the fresh water aquifers within the entire Truckee Meadows Hydrographic Basin for the 1989-90 water year are estimated by the Nevada Division of Water Resources (NDWR) [1991] at 17,000 AFA. This amount is less than the total of 21,000 AFA for the 1988-89 water

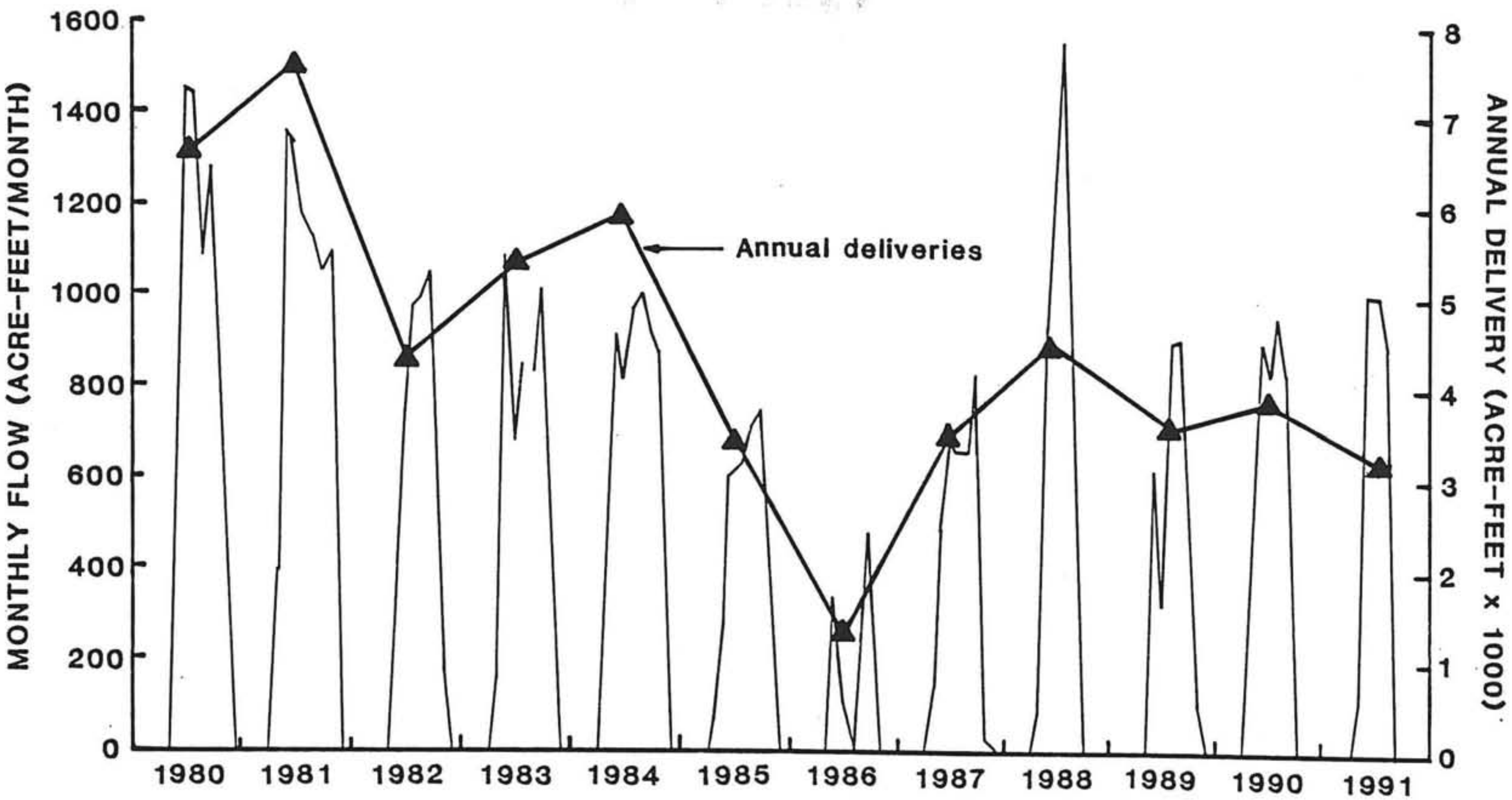


Figure 8. Steamboat Ditch water deliveries.

year (NDWR, 1990) presumably as a result of water conservation efforts brought about by increased public awareness of the current drought conditions. These withdrawals compare to an estimated average annual groundwater recharge to the basin of 27,000 AFA (Van Denburgh, 1973). The Nevada State Engineer has committed approximately 41,000 AFA of groundwater rights for use.

2.3.2.1. Fresh Water System

Groundwater resources in the Whites Creek/Thomas Creek fan and the Steamboat Hills areas are exploited by the South Truckee Meadows General Improvement District (STMGID), Westpac Utilities, and numerous individual domestic well owners. Withdrawals from the alluvial aquifer by STMGID (Wells 1 through 6 and the Thomas Creek Well) totalled 1,144 AFA for 1990 (Washoe County Utility Division, 1991). Individual domestic water supply wells withdrew an estimated 1,518 AFA in 1990 (Washoe County Department of Comprehensive Planning, 1991), bringing the total withdrawals from the alluvial aquifer north to northwest of the Steamboat Hills by these two groups of users alone to approximately 2,662 AFA.

2.3.2.2. Geothermal System

The Nevada State Engineer has permitted and certificated more than 18,000 AFA of geothermal consumptive water rights in addition to the 41,000 AFA of groundwater withdrawals. At present, consumptive use of geothermal waters by geothermal resource users is relatively small even though large quantities of fluids are diverted. SBG diverts approximately 3,600 gpm (5,670 AFA) from the geothermal reservoir. Consumptive use by SBG is zero because all fluids are re-injected into the reservoir. An additional 38 AFA are withdrawn and consumed by individual geothermal well owners and the Steamboat Spa (Bruce McKay, 1991, personal communication).

Caithness Power, Inc. (CPI) operates a 13 MWe (megawatts of electricity, net) single flash steam driven geothermal power plant. Production at CPI is from three wells. These are designated 21-5, 23-5, and 83A-6. Re-injection takes place via one injection well, referred to as Cox I-1 (Figure 9). Full-scale geothermal production at CPI began in early 1988. Prior to this time, the wells were periodically flowed with or without the benefit of re-injection. Production, re-injection, and net production versus time are plotted in

Figure 10. The large variations in rates experienced during the first year of production were caused by wellbore scaling.

CPI is presently permitted to withdraw and re-inject up to 1,900,000 pounds per hour (lb/hr) of geothermal fluids (the equivalent of 3,800 gpm of water at 68°F) to supply the 13 MWe single-flash plant. Three binary units have also been approved for power generation but have not been constructed. These additional units will utilize spent brine from the flash plant and generate an additional 12 MWe, bringing the total power generation capacity to 25 MWe. At present, the combined geothermal fluid flow from the three CPI production wells is approximately 1,600,000 lb/hr (3,200 gpm or 5,122 AFA of water at 68.8°F). Of this amount, approximately 90 percent (2,880 gpm or 4,608 AFA) on average is re-injected via a single well. The remainder (512 AFA) is consumed as steam condensate/cooling tower evaporation (Goranson, et al., 1990).

Therefore, the total estimated consumptive use of the geothermal fluids is 550 AFA. This equates to less than three per cent of the total groundwater withdrawals from the Truckee Meadows hydrographic basin, and only 16 percent of the groundwater consumption in the southwestern Truckee Meadows.

2.3.3. Discussion of Current Trends from Groundwater Use

A consequence of the exploitation of the geothermal resources at the Steamboat KGRA was the implementation of a network to monitor the surrounding groundwater and geothermal systems for changes which might be caused by geothermal development. Figure 9 shows the locations of the monitoring stations. Both SBG and CPI participate in monitoring programs. Many of the wells in the monitoring network are completed in the alluvial aquifer. Data collected from these wells are therefore useful in documenting changes in the Truckee Meadows groundwater system, as well as the low temperature alluvial aquifer associated with the hot springs at the Main Terrace. The monitoring network does not involve the high temperature reservoir at the CPI production area. However, data from the monitoring network may be helpful in identifying influences common to both systems.

Based upon the data collected under the existing hydrologic monitoring program, the BLM directed CPI to modify and expand the hydrologic monitoring program. Under the expanded monitoring program, the

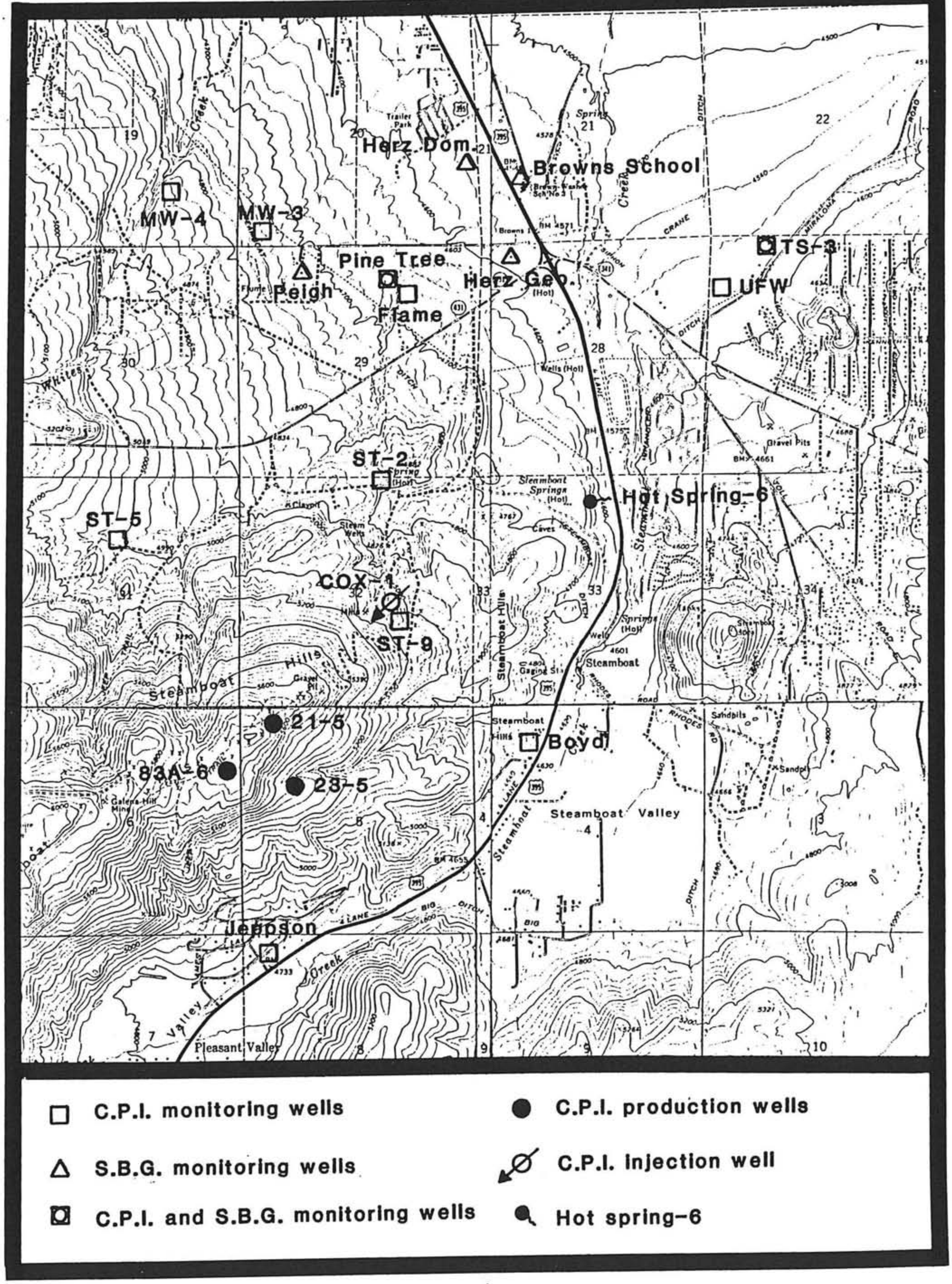


Figure 9. Location of wells monitored by C.P.I. and S.B.G.

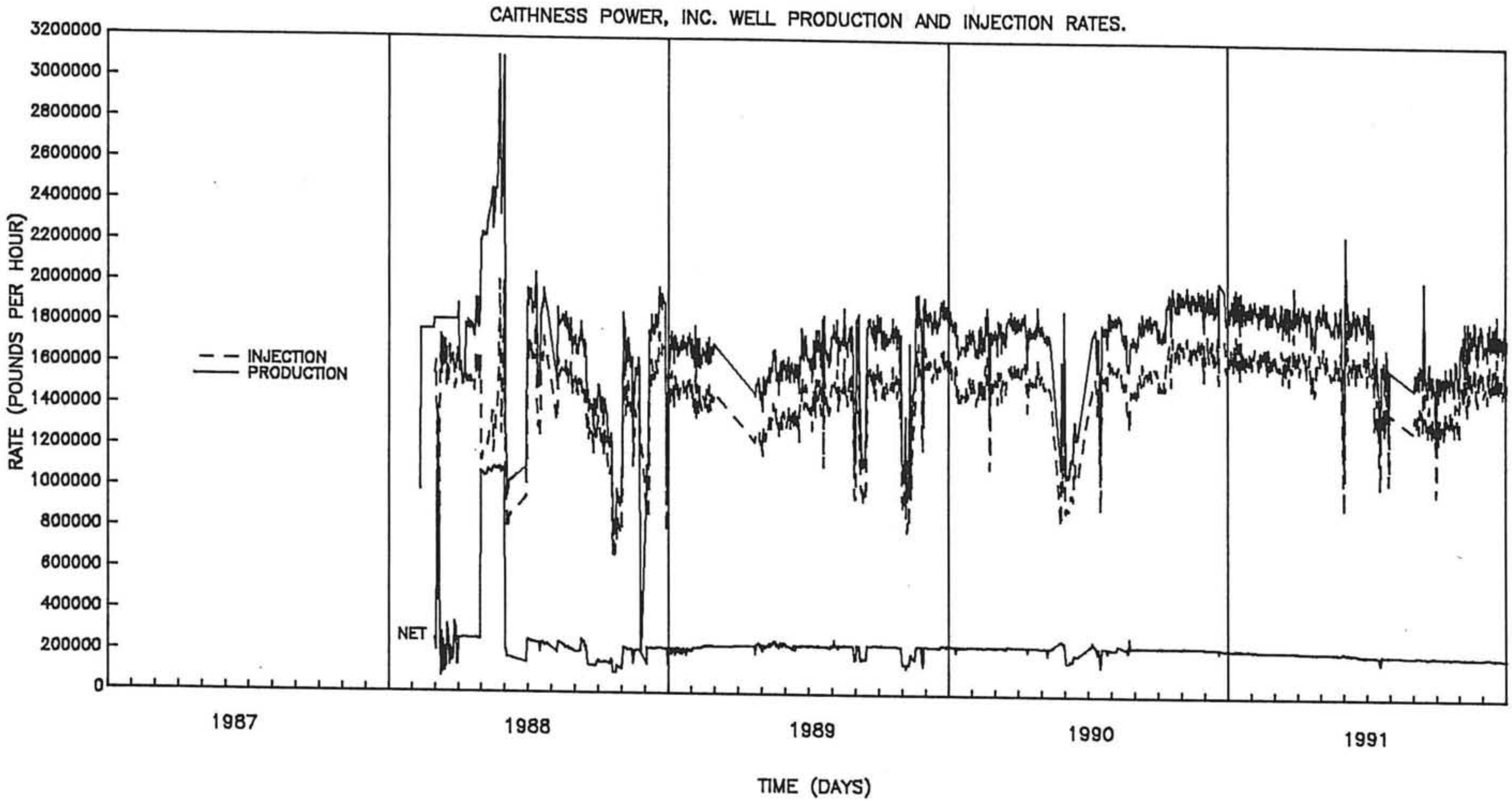


Figure 10. C.P.I. production, injection, and net production versus time.

production wells in the CPI field will be monitored for pressure, temperature, total fluid produced, and brine chemistry. Wells adjacent to the production zone will be monitored for water level and pressure. Wells positioned near and at the boundaries of the Steamboat Hills Project geothermal field will be monitored for water level and pressure. Hot springs activity, if any, will be visually monitored at the Main Terrace, along with water level and chloride concentration from a well previously completed within the Steamboat ACEC. Water levels and chemistry will also be monitored in several domestic and geothermal wells and surface water points in the region surrounding the Steamboat Hills.

2.3.3.1. Fresh Water System

To date, no adverse impacts on the fresh groundwater regime in the Truckee Meadows such as breakthrough of thermal effluent to potable water supply wells have been documented. A rise in temperature and increased chloride levels in some of the monitoring wells has been observed, but was linked to a decrease in the amount of high quality recharge to the alluvial aquifer as a consequence of the current drought conditions (Yeamans and Broadhead, 1988).

Between 1985 and 1990, water level declines of 17 to 26 feet have been observed in wells completed in the alluvial aquifer in the southwest Truckee Meadows. Similar declines have been noted in data for hot springs on the Main Terrace and wells completed both in the high-temperature reservoir and cold-water aquifers in the Steamboat Hills. The similarity in data trends for the different hydrostratigraphic units suggests that changes in water level in both the geothermal reservoir and alluvial aquifers may have a common cause or causes.

The alluvial aquifer was examined in detail in an attempt to identify the reason(s) behind these declines principally because the hydrogeology of the alluvial aquifer is simpler than that of the geothermal reservoir. If outside influences could be identified through analysis of the alluvial aquifer, then the potential impact on water levels due to geothermal development might be quantified. This analysis complements the exhaustive investigation of various influences on the water levels at the hot springs by Collar [1990] and Sorey and Colvard [1991]. The water level decline in the alluvial aquifer and geothermal system has in large part been ascribed (Goranson & van de Kamp, 1990; Goranson, et al., 1990; Sorey and Colvard, 1991; Petty, 1992) to a reduction in groundwater recharge associated with a regional decline in

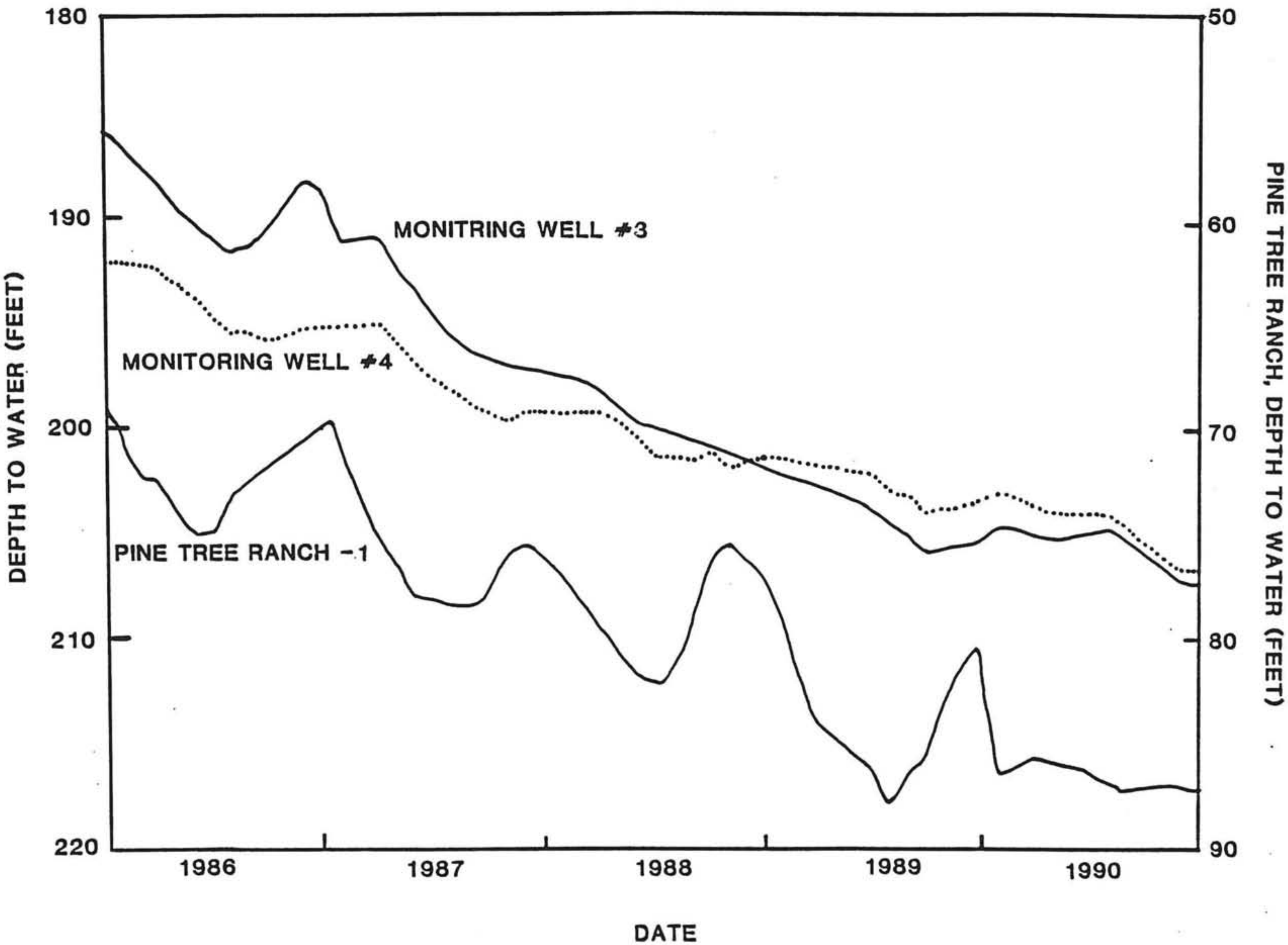


Figure 11. Hydrographs for STMGID MW-3 and MW-4 and Pine Tree Ranch Well No. 1.

precipitation beginning in 1985 (Figure 5) and increases in groundwater withdrawals from wells in the south Truckee Meadows. Water level declines, as noted earlier, may also be related to changes in land use from agricultural to residential use, which has reduced the amount of groundwater recharge in the area by infiltration from ditches and irrigation and the increase in domestic water users in the area. Water level data for one of the monitoring wells, Pine Ranch No. 1 (PTR-1, Figure 11), which is located near irrigated land, provide an illustrative example of the effect secondary recharge may play on water levels.

A typical irrigation water application in the Truckee Meadows is four acre-feet per acre. As much as 25 percent may provide secondary recharge to the shallow alluvial deposits. Assuming a porosity of 20 per cent, one foot per acre of secondary recharge from irrigation could account for a local rise in near surface unconfined alluvial deposits of as much as five feet. This hypothetical rise compares closely with the annual excursions in water level for PTR-1 (Figure 6).

The time for secondary recharge to reach the water table was examined assuming a vertical hydraulic conductivity of one tenth the average horizontal hydraulic conductivity for the alluvial deposits, and a unit vertical gradient.

$$v = (K\ i\ A)/\phi = (0.5\ \text{ft/day} \times 1\ \text{ft/ft} \times 1\text{ft}^2)\ /\ 0.20 = 0.5\ \text{ft/day}/0.2 = 2.5\ \text{ft/day}$$

Given a depth to water at PTR-1 of 90 feet below land surface, the travel time is

$$90\ \text{ft}\ /\ 2.5\ \text{ft/ day} = 36\ \text{days}.$$

Comparison of Figure 8 (Steamboat Ditch deliveries) and Figure 6 shows water levels in PTR-1 start to recover approximately one month after the onset of the irrigation season. The foregoing discussion suggests that the annual fluctuations in water level in PTR-1 are related in large part to secondary recharge from irrigation, a conclusion which is consistent with the opinion of Yeamans and Broadhead [1988].

By comparison, annual excursions in the water levels in STMGID monitoring wells MW-3 and MW-4 are smaller than those for PTR-1, particularly for the period after 1986 (Figure 11). In 1986, precipitation was greater than normal (see Figure 5). The two monitoring wells are completed to greater depth than PTR-1 (which is only 110 feet deep). It is unlikely that the effect of local secondary recharge from irrigation would be propagated deeper because, as depth increases, there is a greater cumulative thickness of low permeability materials which would further impede downward movement of secondary recharge. As a result, seasonal fluctuations observed in the STMGID monitoring wells probably have another cause.

One possible explanation of the seasonal fluctuation in the STMGID monitoring wells relates to withdrawals of groundwater from the alluvial aquifer. This effect was investigated by calculating the drawdown in the vicinity of MW-3 and MW-4 which might be attributable to pumping by STMGID, alone. Figure 12 shows the annual distribution of pumping by STMGID. Assuming an infinite, uniform aquifer with a transmissivity of 20,000 gallons per day per foot width (Mike Widmer, personal communication), and a specific yield of 0.10, drawdown was calculated for wells located 3,000 and 4,000 feet from a hypothetical well discharging near the centroid of pumping in the STMGID well field using the computer code WHIP (Hydro-Geo Chem, 1990) which is, in effect, a "Theis"-type analysis which easily accommodates variable flow rates.

Figure 13 shows the cyclical drawdown in MW-3 and MW-4 which might be expected using the above noted aquifer properties and groundwater withdrawals by STMGID. Analytical results show annual fluctuations of one-half to 1.5 feet per year. While the results do not fully simulate the observed data for these two wells, they clearly indicate that seasonal variations in groundwater withdrawals from the alluvial aquifer almost certainly contribute to some of the fluctuation of water levels observed in the alluvial deposits.

The hydrographs for STMGID monitoring wells MW-3 and MW-4 and PTR-1 (Figure 11) also show an overall downward trend beginning well before the onset of geothermal production at Steamboat. Water levels in PTR-1 have declined 25 feet. MW-3 and MW-4 have experienced 17 to 27 feet of decline. Groundwater pumpage in the South Truckee Meadows may also contribute to this downward trend. Comparison of current groundwater extractions in the area (approximately 2,600 AFA) to the estimated 784 AFA which was withdrawn from the Thomas/White Creek fan area in 1980 (Cooper and Associates, et al., 1983) indicate current withdrawals are more than 300 percent of what they were in 1980.

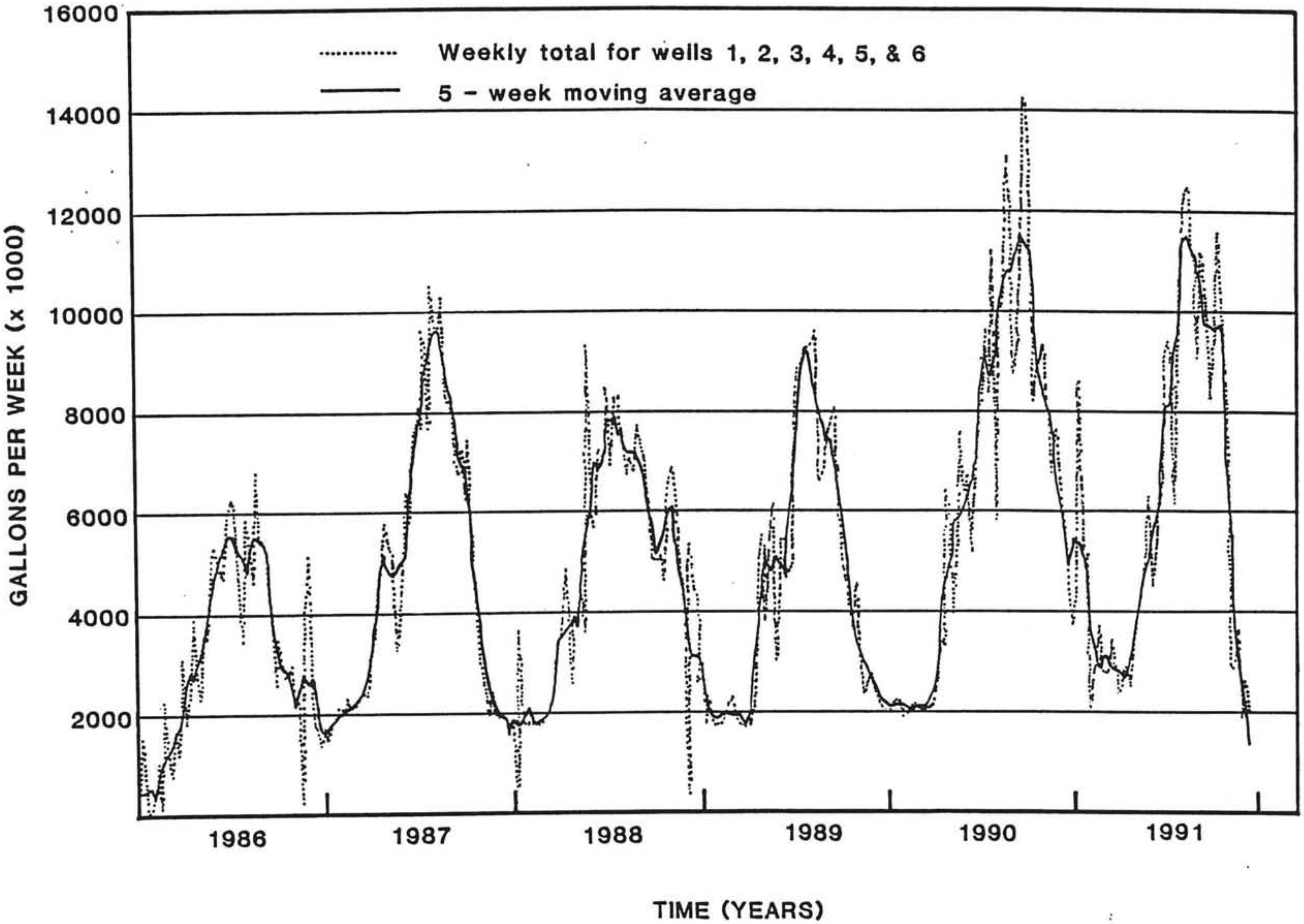
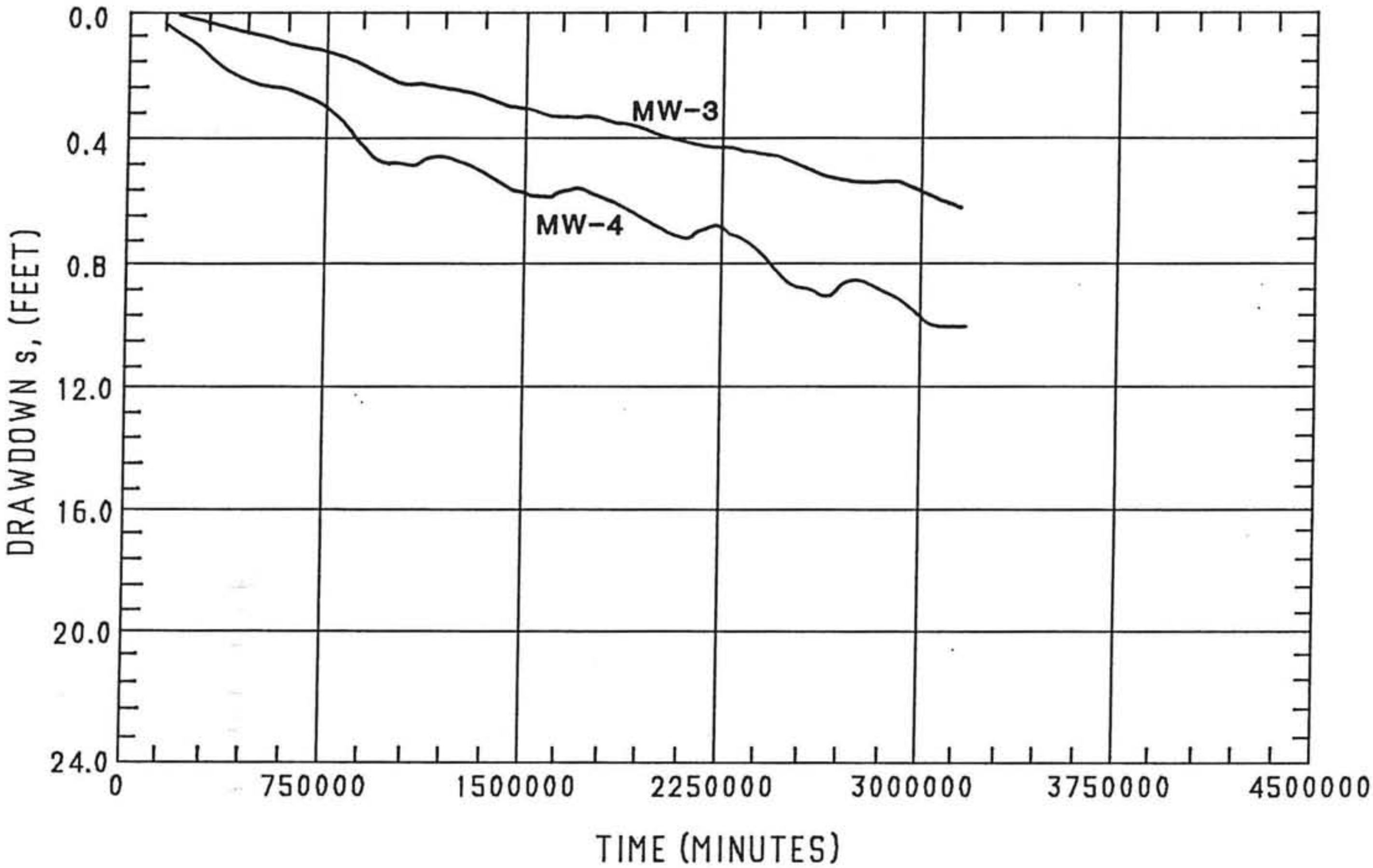


Figure 12. Annual groundwater withdrawals by STMGID well field.



Transmissivity = 0.270E+04 FT^2/DAY Storativity = 0.100

Figure 13. Calculated drawdown at STMGID MW-3 and MW-4.

The analysis discussed above also illustrates the cumulative drawdown which might be attributable to STMGID. As much as six to ten feet of cumulative drawdown in the alluvial aquifer since 1985 might be accounted for by pumping these same STMGID wells located on the Whites/Thomas Creek fan. Obviously, STMGID is not the only entity which extracts groundwater from the South Truckee Meadows and, therefore, is not the only contributor. Westpac Utilities operates a quasi-municipal well approximately two miles north of the STMGID well field. Groundwater extractions by this well were not included in the analysis. Individual domestic well consumption was not included either because the well owners do not maintain detailed records of water use and, therefore, their contribution cannot be so easily identified. As a consequence, these results serve only to illustrate that declines in water levels in the basin might be caused in large part by increased groundwater withdrawals in this part of the Truckee Meadows.

STMGID withdrawals are less than half of the groundwater withdrawals from this area. As a result, an additional six to 10 feet or more of cumulative drawdown might be expected to be generated by the other users. That residential and quasi-municipal groundwater withdrawals are impacting water levels in the south Truckee Meadows is further illustrated in Figure 11. A 19 percent reduction in groundwater extractions in 1989-90 (Figure 12) was accompanied by a decrease in the rate of water level decline as measured in MW-3, MW-4, and PTR-1 for the same period.

The conclusion which can be drawn from the foregoing discussion is that perhaps as much as 12 to 24 feet of the decline in water levels in the alluvial aquifer near the Steamboat Hills from 1986 through 1991 (two to four feet per year) may be attributable to groundwater withdrawals for domestic and quasi-municipal use.

More insight into the effect of groundwater withdrawals on the alluvial aquifer is likely to be gained when a numerical model of the Southwest Truckee Meadows aquifer which is currently under development by WCUD is completed.

2.3.3.2. Geothermal Producers

An analysis of the affect CPI's operations have on the geothermal system is illustrated through reservoir modelling utilizing a modified version of the computer code VARFLOW (IDO, 1982). The model calculates pressure drawdown due to withdrawals from and buildup due to injection in an infinite and uniform reservoir. While the geothermal reservoir is complex, employing a simple model to represent a complex system is justified because:

- Reservoir testing to date has not identified any hydrologic boundaries,
- The reservoir appears to behave as an equivalent porous media,
- Reservoir permeability-thickness products for the two principal production areas (CPI and SBG) are similar although they are far apart, and
- Data available to date are insufficient to justify the use of a very complex model of the system.

Specific assumptions for the calculations are:

- Production is from a well located in the center of the CPI well field. The discharge rate is 1,600,000 lb/hr
- Re-injection takes place in Cox I-1. The injection rate is 1,440,000 lb/hr.
- The permeability-thickness product of the reservoir is 3,000,000 md-ft and storativity is 0.004 psi/ft.
- The reservoir is isotropic.
- Reservoir drawdowns are calculated for a hypothetical well located at Spring 6, a distance of 9,500 feet from the discharging well and 5,100 feet from the injection well.
- No recharge to the reservoir occurs.

The analyses results depicted in Figure 14 illustrate that for the first four years of operation (1988 through 1991) at CPI, the water levels at the Main Terrace are expected to have risen initially, then gradually decline to background levels by the end of the fourth year. For the same period, assuming a regional water level decline of approximately two to four feet per year due to reduced recharge and increased groundwater withdrawals from the south Truckee Meadows, water levels at the hot springs would have declined at least eight feet, in the absence of any influence from CPI.

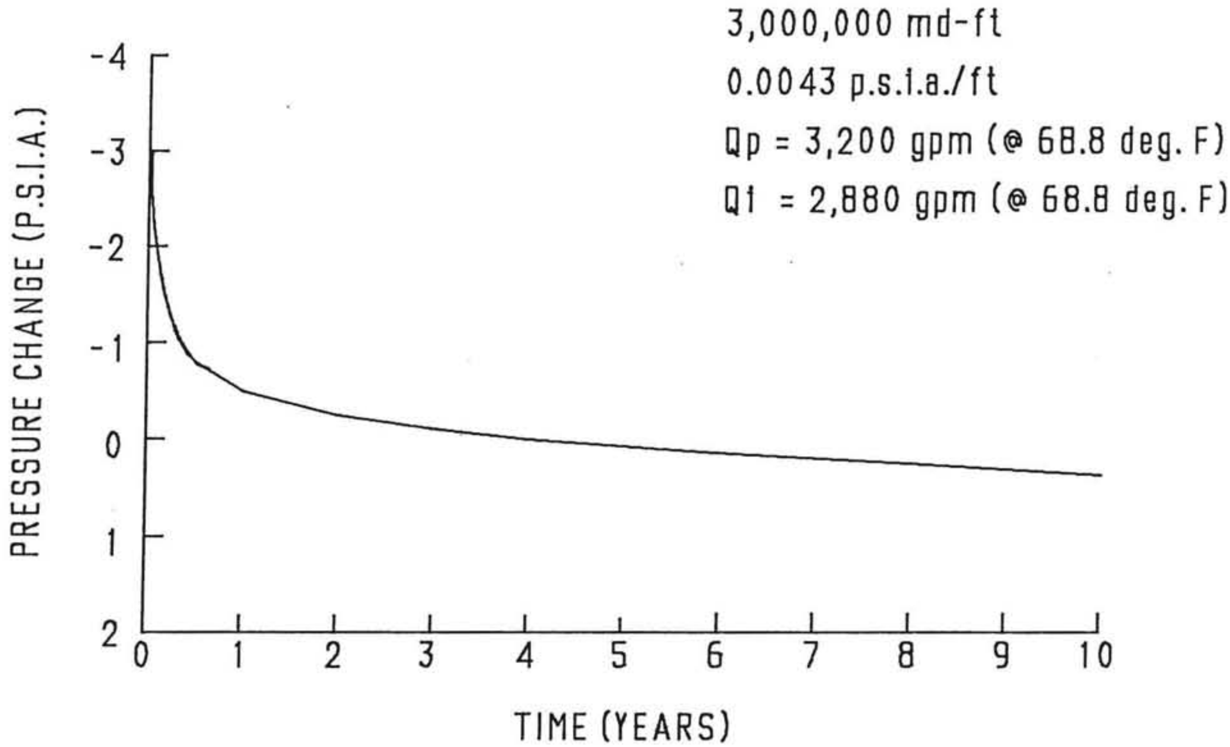


Figure 14. Calculated drawdown at Spring 6, assuming radial flow in an infinite reservoir.

By comparison, the water levels in Spring 6 declined approximately three feet, much less than the regional trend for the same period of time. Perhaps the difference represents indirect evidence of pressure support at the hot springs due to re-injection by CPI as the VARFLOW model predicts. Alternatively, the lesser observed water level declines in the springs could result from truncation of the peaks of the spring hydrographs which would occur when the water level in the spring reached the elevation of the orifice, thus potentially artificially reducing the actual water level decline.

Clearly, the water levels in hot springs and vents within the Main Terrace have responded to outside influences. However, the foregoing discussion suggests that as of the end of the fourth year of full-scale operations by CPI in 1991, the impact of CPI's operations on water levels near the Main Terrace has been negligible compared to other probable outside influences which have resulted in water level declines in some springs of as much as 12 feet.

A corollary to the aforementioned conclusion is the observation that discharge from the hot springs would not resume flowing even if production at CPI were to cease. Moreover, because increased groundwater withdrawals from the alluvial aquifer appears to be a major cause of water level declines in this area, even if recharge returns to "normal", activity at the Main Terrace will not recover to pre-development conditions.

Because of the complexities of the geothermal system at the Steamboat Hills, it can not be determined with absolute certainty to what extent production at CPI has contributed to water level declines in the vicinity of the ACEC since geothermal power production began in February 1988. The relative contribution appears to be small, much less than one foot as noted above, compared to regional water level declines approaching 30 feet since 1985. This regional trend appears to be associated with the current drought conditions and increased withdrawals of groundwater for domestic use in the southwest Truckee Meadows. If, as the data suggest, changes in hot spring activity at the Main Terrace primarily result from outside influences, no change in operations by CPI will initiate a resumption of hot spring activity.

The CPI production zone clearly receives pressure support from re-injection (Petty, 1992). Consequently, if the springs react to production, then they should also react in a predictable manner to re-injection. It follows that if a pressure connection between the CPI production well field and the Main

Terrace exists, a rise in water level at the hot spring area should have been observed for the first four years of operation at CPI.

Figure 15 is a plot of temperature versus time for the CPI production wells. Note that there has been a slight decline in temperature of produced fluids with time. This decline is a result of operation of the wells and does not represent a decline in the reservoir temperature. Periodic temperature survey data for the wells do not show a decrease in reservoir temperature (Goranson, 1992, personal communication).

Recent estimates of chloride flux in Steamboat Creek have been used as evidence that production at CPI has reduced the geothermal outflow to the alluvial aquifer by an amount coincidental with net production (Collar, 1990). However, since CPI does not consume chloride in its operation, it should not effect chloride flux. Therefore, chloride flux relationships appear to be misleading.

The geothermal system does not appear to be immune from water level declines resulting from outside influences. For example, observation wells at SBG have recorded a decline of up to 15 p.s.i. (Goranson, 1991b). Because all fluids withdrawn by SBG production wells are re-injected and this drop is consistent with the regional trend, this decline is attributed to the drought.

2.3.3.3. Hot Springs

Seasonal and long-term fluctuations observed in the hot springs may also be influenced by groundwater pumpage from the alluvial aquifer in addition to the annual fluctuations observed by White [1968]. Hot springs located on the Main Terrace intermittently ceased to discharge at land surface beginning in 1986 and ceased altogether in 1987. Because large-scale testing of the CPI wells started in 1986, considerable effort has been expended attempting to link operations at CPI to changes in spring activity at the Main Terrace (Collar, 1990). Specific examples of apparent cause and effect include:

- A two month test of 23-5 at a rate of 815 gpm was performed 3/21 through 5/15/86 (Figure 16). Coincidentally, the flow in Spring 6 declined until flow ceased and water levels at the spring orifice continued to decline until after testing was terminated. After the test, the water level in Spring 6 rose and it ultimately resumed flowing. A

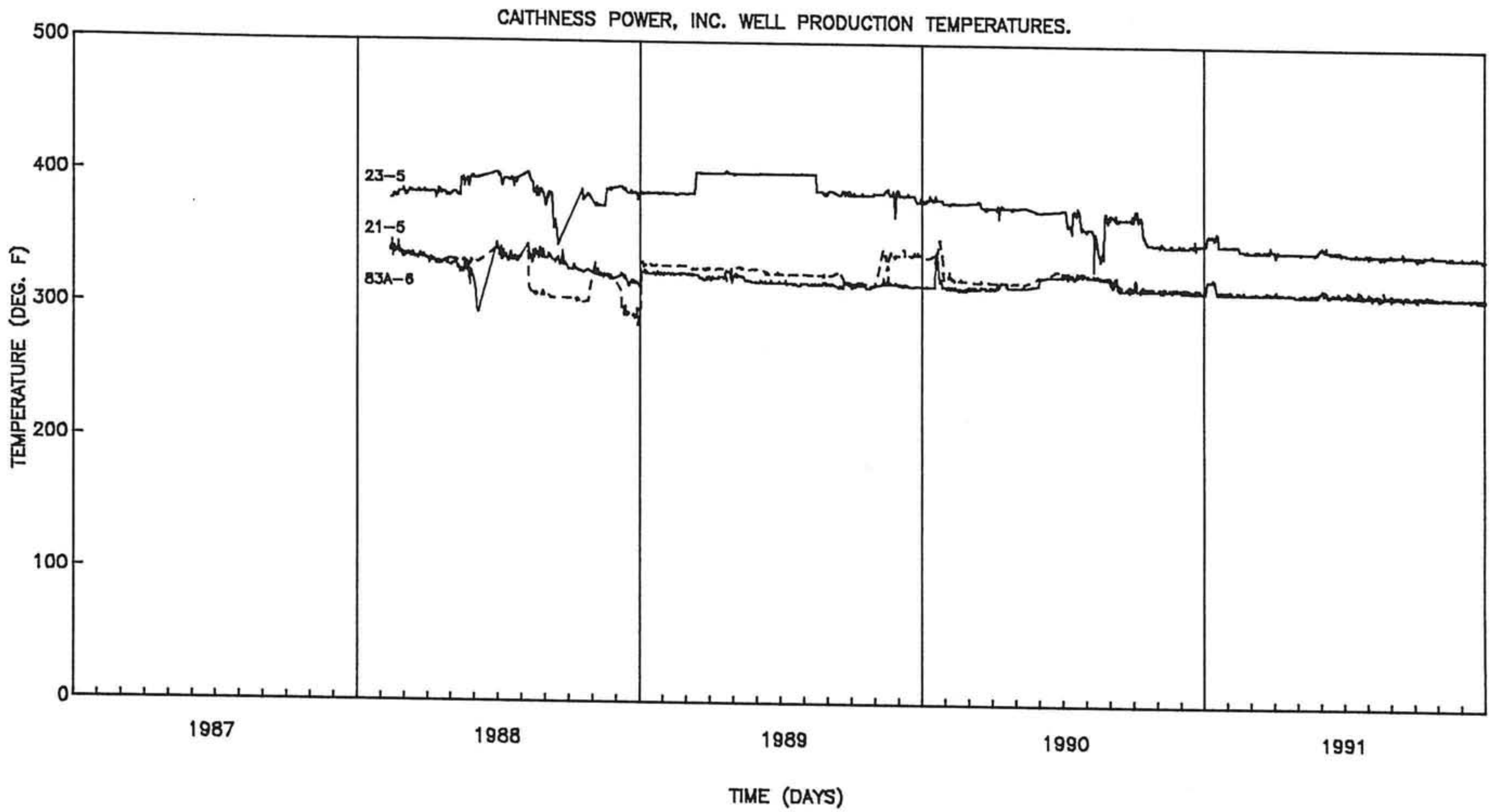


Figure 15. C.P.I. well discharge temperature versus time.

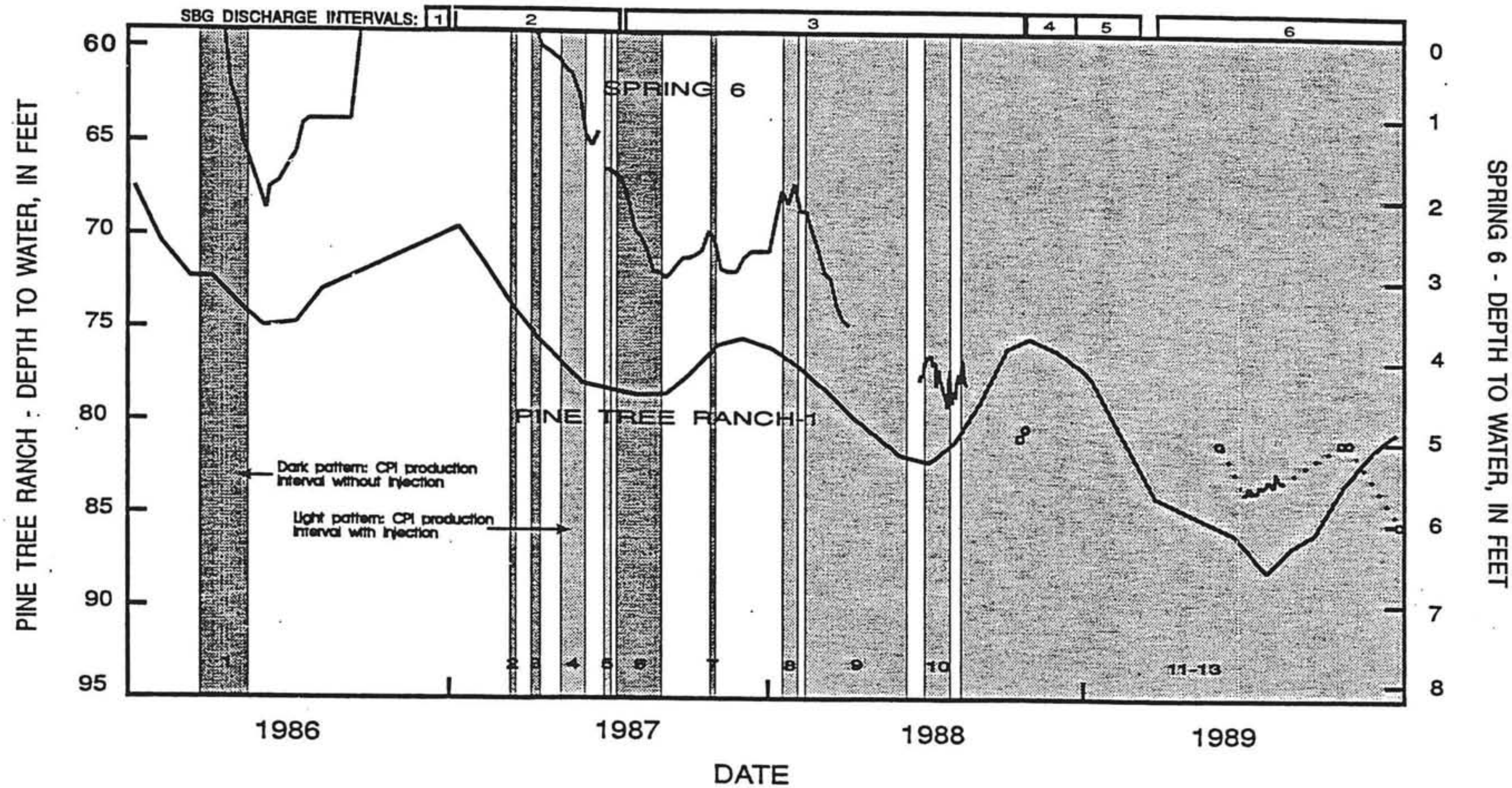


Figure 16. Spring 6 hydrograph (hydrograph for P.T.R.-1 plotted for ease of comparison).

clear correlation, however, between the two events is not evident. The general trend in spring flow and water levels just as easily correspond to the typical annual fluctuations observed in the alluvial aquifer. Similar annual fluctuations were observed by White [1968] in the vent for Spring 35.

- A series of tests with and without the benefit of re-injection were conducted in 1987 (Figure 16). Coincidental with these tests, a decline in the flow and water levels were observed in Spring 6, followed by recovery after testing was terminated. The general shape of the Spring 6 hydrograph may also reflect the regional water level trend in the alluvial aquifer, with one exception. Well 83A-6 was flowed without the benefit of re-injection at rates of 970 to 2460 gpm 10/14-30/87. Concurrent with this test period a "reversal" of the annual recovery trend of the water level in Spring 6 was observed. Of all the data, this singular and short-term test interval suggests a possible pressure connection between the CPI well field and the Main Terrace. However, these data are inconclusive because the relationship does not appear to repeat nor is there any other clear evidence of pressure support from re-injection in the area of the hot springs.

- Fluctuations in water levels in Spring 6 observed 6/27/88 through 8/15/88 appear to correlate with variation in CPI well field operations. However, they also appear to correlate with changes in stage measured for Steamboat Ditch (Figure 17) which meanders along the Main Terrace. The data suggest that changes in loading on the terrace may influence spring behavior. However, for these changes to represent loading influences, the reservoir beneath the high terrace must be unconfined. Moreover, the rate of change in ditch stage to effect the observed change in spring level is so large as to be unrealistic. These observations, then, are also inconclusive.

A hydrograph for Spring 6 is plotted in Figure 16. The Spring 6 data follow the same general trend as PTR-1. The hot springs are clearly located within cemented alluvial deposits. Therefore, the processes effecting the hot springs may be the same as those which are influencing water levels elsewhere in the alluvial aquifer. The hydrograph for Spring 6 also bears a resemblance to that for Stratigraphic Test Well No. 5 (Strat-5; Figure 18) which is a warm-water well. This coincidence tends to further support the above-noted conclusions.

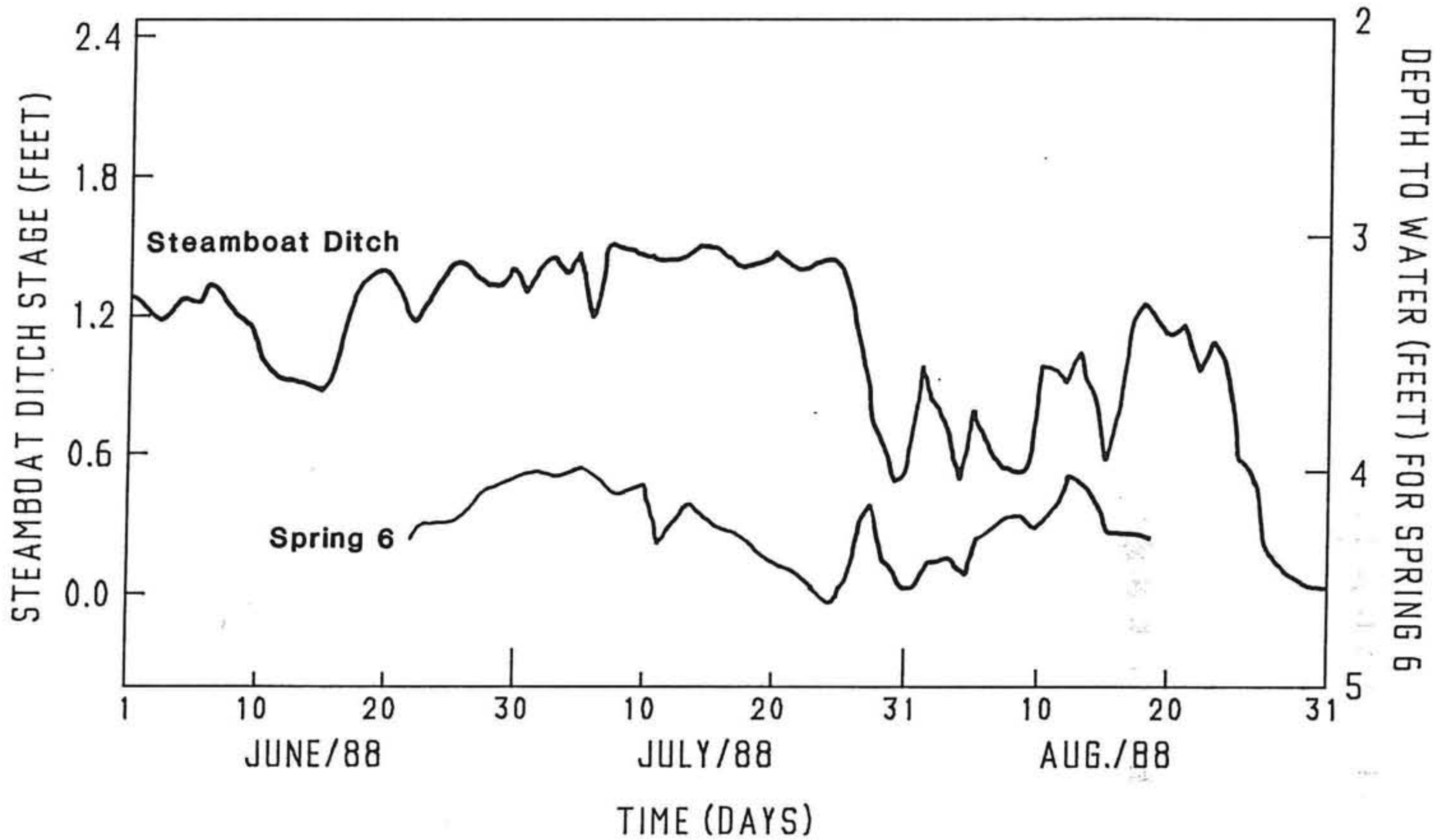


Figure 17. Comparison of water levels in Spring 6 to Steamboat Ditch stage.

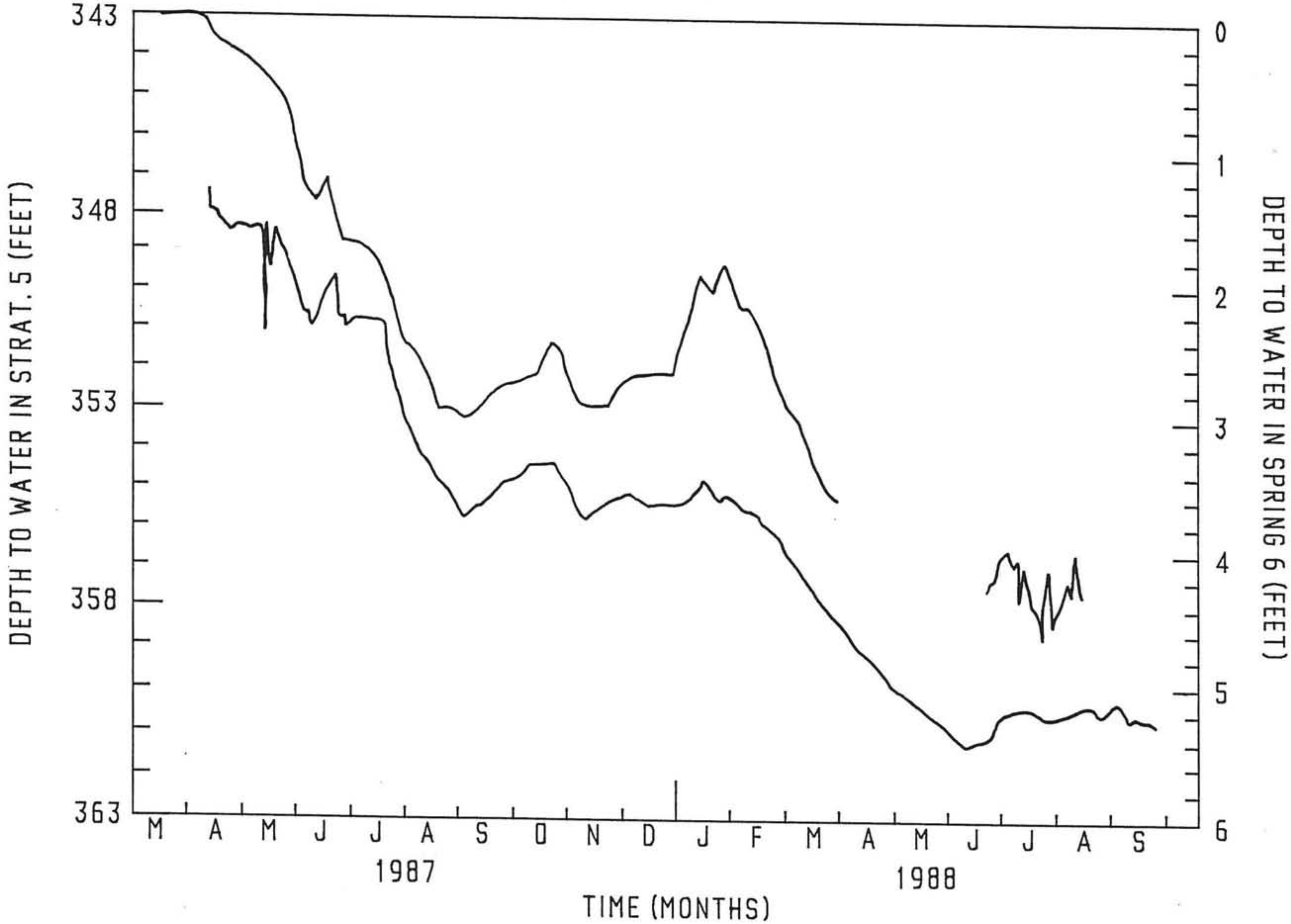


Figure 18. Hydrograph of spring 6 and strat. 5, March, 1987, to September, 1988.

3. CONSEQUENCES OF FUTURE WATER RESOURCE DEVELOPMENT

3.1. Summary of Current Development

Between 1985 and 1990, water level declines of 17 to 26 feet have been observed in wells completed in the alluvial aquifer in the southwest Truckee Meadows. Similar declines have been noted in data for hot springs on the Main Terrace and wells completed both in the high-temperature reservoir and cold-water aquifers in the Steamboat Hills. The similarity in data trends for the different hydrostratigraphic units suggests that changes in water level in both the geothermal reservoir and alluvial aquifers may have a common cause or causes.

Perhaps as much as 12 to 24 feet of the decline in water levels in the alluvial aquifer near the Steamboat Hills from 1986 through 1991 (two to four feet per year) may be attributable to groundwater withdrawals for domestic and quasi-municipal use. STMGID withdrawals are less than half of the groundwater withdrawals from this area.

Seasonal and long-term fluctuations observed in the hot springs may also be influenced by groundwater pumpage from the alluvial aquifer in addition to the annual fluctuations observed by White [1968].

To date, no adverse impacts on the fresh groundwater regime in the Truckee Meadows, such as breakthrough of thermal effluent to potable water supply wells, have been documented.

There is clear evidence that the water levels in hot springs and vents within the Main Terrace have responded to outside influences. The impact of CPI's operations on water levels near the Main Terrace has been negligible compared to other probable outside influences, which have resulted in water level declines in some springs of as much as 12 feet.

3.2. CPI's Proposed Action

Given the temperature of geothermal fluids presently derived from CPI production wells, higher production rates than are presently experienced by the plant are necessary. Approximately 2,900,000 lb/hr (5,800 gpm) are now required for the plant to operate at its maximum electrical generation capacity (CPI, 1991). At least two new production wells are needed. These wells may be drilled on Federal lands administered by the Bureau of Land Management (BLM) and the Forest

Service (USFS). CPI requested an amendment to the Plan of Operations/Plan of Utilization (POO/POU) from the BLM which will allow as much as 3,800,000 lb/hr (7,600 gpm) to be diverted and re-injected. The surplus well discharge and injection rate above the rate of 2,900,000 lb/hr is sought to ensure that the plant can operate at full capacity in the event that the temperature of the geothermal fluid produced by the CPI well field declines as exploitation of the geothermal resource expands (ibid.).

As previously stated, if CPI is currently having a minor impact on the hot spring area, increasing net production (consumption) from the current levels of 160,000 lb/hr to 380,000 lb/hr, will increase these impacts. The best estimate indicates that the new rates of production and re-injection would decrease the pressure in that area by less than one p.s.i. (approximately 0.5 feet) (Section 3.3 discusses this further).

3.3. Cumulative Impacts

Because the geothermal and potable groundwater aquifers interact with each other, the impacts due to expanded exploitation of the two systems may be cumulative. At this time, the details of the hydrogeology of the two systems are poorly understood and the consequences of further exploitation cannot be evaluated with a high degree of accuracy.

Long range planning for Washoe County predicts that the population of the southwest Truckee Meadows will increase from approximately 10,000 residents in 1990 to as many as 32,000 by the year 2007 (Washoe County Department of Comprehensive Planning, 1991). This increase in population is expected to increase groundwater withdrawals in the southwest Truckee Meadows from 2,662 to 9,442 AFA.

In addition to CPI's planned increase in production, Steamboat Development (SBG) has recently increased the capacity of its existing facility, producing and injecting 8,800 gpm (up from 3,600 gpm). With a new operation on the Towne Lease, SBG may be producing and injecting a total of 14,000 gpm. In both cases, SBG net consumption will be zero, i.e., all fluids will be re-injected. In addition to geothermal power generation projects currently on line or planned for the near future, lands controlled by the Guisti Trust southwest of the SBG production area and north of the CPI production area have the potential for power generation. A test well completed on the property encountered high permeability fractures and temperatures of 320°F. If the Guisti property is developed, the cumulative production rates from all geothermal projects may approach 33,000 gpm. Net consumption by all users of the geothermal reservoir(s) will be approximately 690 to 900 gpm, depending on the operation of CPI. The total power production from the Steamboat Hills within the foreseeable future could approach 69 MWe.

Given the large quantities of geothermal fluids scheduled to be produced and injected, some local changes in reservoir pressure are anticipated from the cumulative development of the geothermal system. These changes to the system were investigated using the computer code VARFLOW. Assumptions in this investigation include:

- permeability-thickness product, kh, equal to 3,000,000 md-ft

- storativity of 0.002 psi/ft*

- pumping rates of:

  9,000 gpm at CPI
  8,800 gpm at SBG
  14,000 gpm at SBG Towne Lease
  3,000 gpm at Guisti

- injection rates of:

  8,100 gpm at CPI
  8,800 gpm at SBG
  14,000 gpm at SBG Towne Lease
  3,000 gpm at Guisti

(* Note - this value was selected to be consistent with interference calculations made by Goranson, 1991b.)

Results of the analysis suggest that reservoir pressures in the vicinity of Spring 6 in the ACEC will be reduced by as much as 20 p.s.i by the cumulative development of the geothermal resource. Of this amount, approximately one-half this amount will result from operations at the SBG Towne Lease (Goranson, 1991b). CPI may account for less than one p.s.i. decline at the hot spring area, which is less than five per cent of the total impact. The remainder is accounted for by SBG and Guisti production.

4. MONITORING AND MITIGATION MEASURES

A major, if not the major, shortcoming of investigations to date which have attempted to link geothermal production at Steamboat to changes in hot spring activity is the lack of reliable monitoring stations on the Main Terrace and within the geothermal reservoir. Because the hot springs have ceased to flow or have dried up altogether, they are no longer useful as observation points to monitor future changes in the geothermal system, regardless of their cause. Constructing a monitoring well on the Main Terrace as suggested by Sorey and Colvard [1991] would provide useful data regarding changes in head associated with geothermal production of other causes. Such a monitoring well should be equipped with a continuous recording pressure transducer to collect high-quality reservoir pressure data. This may alleviate inaccuracies associated with the periodic measurement of water levels in open springs which are at or near boiling. The modified and expanded hydrologic monitoring program which the BLM directed CPI to implement is designed to monitor a well on the Main Terrace, as well as monitor geothermal reservoir performance and obtain the necessary data on the hydrology of the Steamboat Springs area to better understand the potential for impacts, and the mitigation of impacts, to the Steamboat ACEC from the operation of the Steamboat Hills Project.

If the data from this monitoring well, combined with all of the other monitoring data, shows that production by CPI is a substantial contributor to unacceptable reservoir pressure changes at the hot springs, then the Steamboat Hills Project could be modified to reduce or eliminate these CPI-induced changes. These Project modifications or changes could include one or a combination of the following:

- relocating one or more geothermal production wells to minimize the impact of geothermal fluid production from the Project on the hot springs reservoir;
- relocating an injection well to a location which would minimize impacts on hot spring activity which could be clearly attributed to CPI production;
- reducing net geothermal fluid production or ceasing geothermal fluid production altogether;

However, it is premature to specifically detail what Project modifications may be appropriate or necessary to implement until the nature, degree and extent of any possible impact is better documented and understood.

5. SOURCES OF INFORMATION

Collar, R.J., 1990. Causes for decline of hot spring and geyser activity, Steamboat Springs, Nevada: M.S. Thesis, San Diego State University, California, 327p.

Cooper & Associates, CH2M/HILL, and CES, INC., 1983. South Truckee Meadows Washoe Valley water/waste water facility and management plan.

CPI, Inc., 1991. Amendment to the plan of operations/plan of use.

GeothermEx, Inc., 1989. Assessment of geothermal resource potential of the ORMAT Leasehold at Steamboat Springs, Washoe County, Nevada: consulting report prepared for Westinghouse Credit Corp.

Goranson, C., 1990. Summary of the hydrogeologic characteristics of the Steamboat Hills area, Nevada: consulting report prepared for Caithness Power, Inc. and Yankee-Caithness Joint Venture L.P., 13p.

Goranson, C., 1991a. Summary and interpretation of six years of groundwater monitoring data and four years of geothermal production and injection well operations at the SB GEO, Inc. geothermal binary power plant Steamboat Springs, Nevada: consulting report prepared for SB GEO, Inc.

Goranson, C., 1991b. Letter Report on the predicted behavior of the northern Steamboat Hills geothermal system to increased geothermal development, Steamboat Springs, Nevada: prepared for Steamboat Development Corp.

Goranson, C. and P. van de Kamp, 1990. An interpretation of the relationship between the local groundwater system and the shallow isolated moderate temperature geothermal areas in the Steamboat Springs geothermal and South Truckee Meadows area: consulting report prepared for Caithness Power, Inc. 8p.

Goranson, C., P. van de Kamp, and T. DeLong, 1990. Geothermal injection and monitoring program history at the Caithness Power, Inc. flash steam power plant Steamboat Springs, Nevada: Proceedings of the Symposium on Subsurface Injection of Geothermal Fluids, October 1990, Santa Rosa, California.

Hydro-Geo Chem, 1990. Computer code WHIP.

IDO, 1982. Low-to-moderate temperature hydrothermal reservoir engineering handbook; U.S. Ept. of Energy, Idaho Operations Office, IDO-10099, vol. II.

Nehring, N.L., 1980. Geochemistry of Steamboat Springs, Nevada: M.S. Thesis, San Jose State University, 61p.

Petty, S., 1992. Discussion of USGS report on Steamboat Hot Springs; (Draft) Consulting report prepared for Caithness Power, Inc.van de Kamp, P.C. and C.B.

White, D.E., 1968. Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County Nevada: USGS Prof. Paper 458-C, 109p.

White, D.E., G.A. Thompson, and C.H. Sandberg, 1964. Rocks, structure, and geologic history of the Steamboat Springs thermal area, Washoe County Nevada: USGS Prof. Paper 458-B, 63p.

Yeamans, F. and R. Broadhead, 1988. Statistical analysis of ORMAT's water quality monitoring data, Steamboat, Nevada: report prepared for the Nevada Division of Environmental Protection and ORMAT Systems, Inc., 98p.

Other Sources:

Bobbie Gollan, 1991, personal communication
Colin Goranson, 1992, personal communication
Bruce McKay, 1991, personal communication
Peter van de Kamp, 1991, personal communication
Mike Widmer, 1991, personal communication

Nevada Division of Water Resources Basin Summaries
Washoe County Utility Division pumpage records
Washoe County Department of Comprehensive Planning
Comprehensive Plan

APPENDIX D

Factors Affecting the Decline in Hot-Springs
Activity in the Steamboat Springs Area of
Critical Environmental Concern, Washoe County, Nevada

FACTORS AFFECTING THE DECLINE IN HOT-SPRING ACTIVITY IN THE STEAMBOAT SPRINGS AREA OF CRITICAL ENVIRONMENTAL CONCERN, WASHOE COUNTY, NEVADA

U.S. GEOLOGICAL SURVEY

Administrative Report for the Bureau of Land Management

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary
U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:
Regional Hydrologist
U.S. Geological Survey
345 Middlefield Road, MS 470
Menlo Park, CA 94025

Copies of the report can be purchased from:
U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Bldg. 810
Box 25425
Denver, Colorado 80225

FACTORS AFFECTING THE DECLINE IN HOT-SPRING ACTIVITY IN THE STEAMBOAT SPRINGS AREA OF CRITICAL ENVIRONMENTAL CONCERN, WASHOE COUNTY, NEVADA

By Michael L. Sorey and Elizabeth M. Colvard
U.S. Geological Survey

U.S. GEOLOGICAL SURVEY

Administrative Report for the Bureau of Land Management

Menlo Park, California

1992

Contents

Illustrations

Tables

Conversion Factors, Vertical Datum, and Abbreviations

Multiply	By	To obtain
feet (ft)	0.305	meters
mile (mi)	1.61	kilometers (km)
feet squared per day (ft /day)	7.481	gallons per day per foot (gpd/ft)

Abbreviations used:

δ - standard delta notation (isotopic ratios)
o/oo - parts per thousand, or per mil (isotopic ratios)
D - deuterium
^{18}O - oxygen-18
mg/L - milligrams per liter (chemical concentration)
ppm - parts per million (chemical concentration)
gal/min - gallons per minute (volumetric flow rate of wells)
MW_e - megawatts of electric power

Terms used:

The hydraulic head in a reservoir is given by the height of the water column above an arbitrary datum in a well tapping the reservoir. Hydraulic head, or head, is related to fluid pressure by the equation:

Hydraulic head = (pressure/specific gravity) + elevation above arbitrary datum

Piezometric surface - the surface to which the water from a given reservoir or aquifer will rise under its full head.

Storage coefficient - a dimensionless measure of the water released from storage due to compression of the reservoir rock and expansion of water per unit volume and unit decline of head.

Transmissivity - a measure of the volumetric flow rate of ground water per unit width of reservoir for a unit hydraulic gradient. It is equal to reservoir hydraulic conductivity times reservoir saturated thickness.

^{14}C activity - the amount of radioactive decay of the carbon-14 isotope

FACTORS AFFECTING THE DECLINE IN HOT-SPRING ACTIVITY IN THE STEAMBOAT SPRINGS AREA OF CRITICAL ENVIRONMENTAL CONCERN, WASHOE COUNTY, NEVADA

by Michael L. Sorey and Elizabeth M. Colvard
U.S. Geological Survey

ABSTRACT

A study was begun in 1988 to delineate the factors affecting hot-spring activity in the Steamboat Springs geothermal system in western Nevada. Hot springs formerly flowed primarily in the Steamboat Springs Area of Critical Environmental Concern (ACEC), which occupies the southern part of the main silica terrace adjacent to Highway 395. Significant declines in spring flows and water levels in non-flowing spring vents at the main terrace were first noted during the spring of 1986 and the spring of 1987. All spring flow ceased in 1987 and water levels in spring vents have generally declined since then. Short periods of rising water levels in many vents, lasting for weeks to months, have occurred within the longer-term period of decline. The available evidence indicates that the principal factor causing the reduction in spring activity is the water-level decline in the shallow ground-water system in the South Truckee Meadows, which between 1985 and 1989 exceeded 20 feet in places. The decline in ground-water level has been caused by increased ground-water use from wells and by reductions in ground-water recharge associated with successive years of below-normal precipitation beginning in 1986-87. A secondary factor affecting spring activity is production from geothermal wells. Following periods of well testing in 1986, full-scale production and injection began in January 1987 at the SB GEO geothermal well field located 0.5 miles northwest of the ACEC. Full-scale production began in February 1988 at the Caithness Power Incorported (CPI) geothermal well field, located 1.5 miles southwest of the ACEC.

By 1989, the hydraulic head beneath the ACEC had declined by about 17 feet. It is difficult to determine how much of this total decline to attribute to different factors because each has caused similar types of effects and because certain key hydrologic aspects of the problem are not adequately known. Most important in this regard are the location and hydraulic properties of permeable zones that may connect the hot springs with the developed geothermal reservoirs in the Steamboat Hills and with alluvial aquifers in the South Truckee Meadows, and the level of drawdown in the CPI well field. Records are available on changes in spring flow and water level at the main terrace, changes in water level in observation wells, and fluid production and injection at the geothermal well fields. From this information we estimate that most (80-95 percent) of the decline in spring activity at the main terrace may be attributable to water-level declines in the shallow ground-water system. Approximately 1-3 feet (5-20 percent) of the total may be attributable to the effects of production and injection from the Caithness well field; operations at the SB GEO well field appear to have caused less effect on the hot springs than have the CPI well-field operations.

Observation wells completed in the CPI production reservoir and in the reservoir that supplies the springs on the main terrace are needed to provide more accurate determinations

of the effects of the above-mentioned factors on hot-spring activity. Water-level data collected from such wells during interference tests or temporary shut-downs at the geothermal well fields could allow the degree of hydraulic communication between these fields and the hot springs to be better quantified. Such monitoring could also detect water-level rises that might accompany a return to normal precipitation conditions in the Steamboat area. However, it is unlikely that mitigation measures that might be carried out at the CPI and SB GEO well fields would be effective in returning the springs to their former flowing conditions because other factors, such as continued ground-water pumping in the South Truckee Meadows and geothermal production from sites currently being developed near the northern boundary of the ACEC, are likely to have significant negative effects on the hot springs.

INTRODUCTION

Background

The Steamboat Springs geothermal area is located approximately 9 miles south of the city of Reno, in and around the Steamboat Hills in western Nevada (figs. 1 and 2). The geothermal area includes numerous historically active hot springs and geysers at the northeastern end of the Steamboat Hills. The Steamboat Hills trend northeast, almost transverse to the nearby Carson Range, which is separated from the Sierra Nevada by the Lake Tahoe basin.

Because of the unique occurrence of a large number of hot springs and geysers in the Steamboat area, the U.S. Geological Survey did an extensive study of the Steamboat geothermal system between 1945 and 1952. During this study, existing thermal wells were evaluated, eight new wells were drilled and tested within the Steamboat Springs geothermal area, and physical aspects of the hydrology and thermal activity of the spring system were investigated (White, 1968). The study involved detailed documentation of the activity of 74 springs in two major areas, referred to as the main terrace and the low terrace (fig. 3 and plate 1). White (1968) noted that of 46 springs on the main terrace, 13 erupted as geysers and 6 were pulsating springs. Three springs discharged continuously from June 1945 to August 1955. Of the 20 springs on the low terrace, 9 erupted as geysers, 2 were pulsating springs, and 6 springs discharged continuously from June 1945 to August 1952. The total flow from hot springs on the main and low terraces averaged 65 gal/min and ranged from 30 to 80 gal/min during this period.

In 1975 the Steamboat Springs Known Geothermal Resources Area (KGRA) was delineated (fig. 3), thus initiating exploration for, and development of, geothermal resources there (Chevron Resources, 1987). Numerous companies have been involved in geothermal exploration programs at Steamboat since 1975, including Phillips Petroleum, Chevron Resources, Yankee-Caithness, Caithness Power, Ormat Energy Systems, and Far West Capital. During this exploration period, Nehring (1980) studied the evolution and origin of thermal ground water in the Steamboat Springs geothermal area, utilizing chemical analyses of various thermal and non-thermal springs and wells, sampled mostly in 1977. Current geothermal power production consists of 7 MW_e from the SB GEO Binary Power Plant (SBG in fig. 3) on private land northeast of the Steamboat Hills and 12 MW_e from the Caithness Power Incorporated single-flash power plant (CPI in fig. 3) on a combination of private and federal land near the crest of the Steamboat Hills. Full-scale operations began in January 1987 at the SBG field and in February 1988 at the CPI field.

In an effort to preserve and protect the unique natural thermal features at Steamboat Springs, a 40-acre parcel of public land was designated an Area of Critical Environmental Concern (ACEC) in 1983. This ACEC (fig. 3) encompasses the southern part of the main terrace spring area delineated by White (1968) and is under the jurisdiction of the BLM's Carson City District Office. Protected under the ACEC designation are both the hot springs and geysers and the federally listed endangered steamboat buckwheat, which grows in the silica-rich soils surrounding the main terrace.

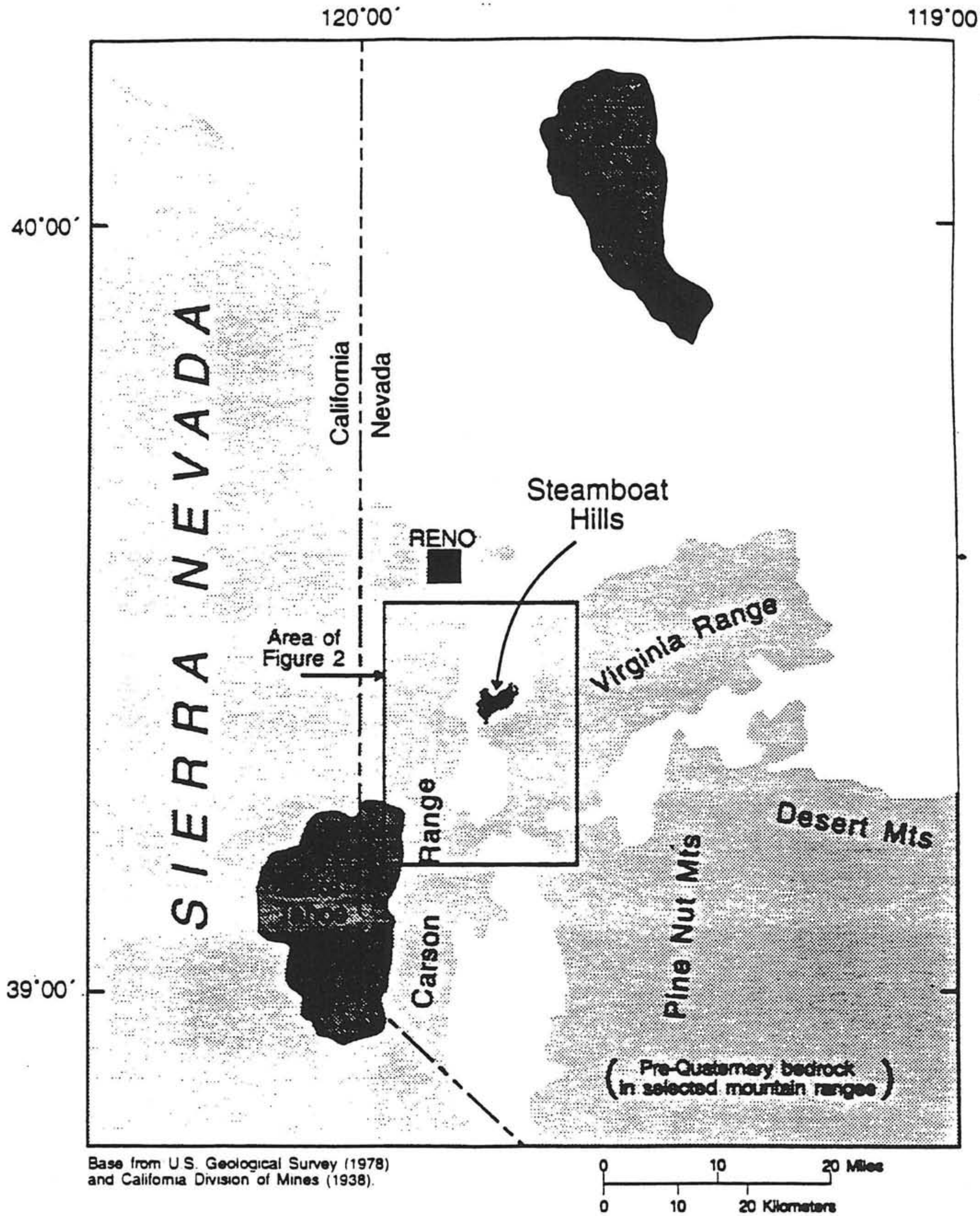


Figure 1. Location of the Steamboat Hills and adjacent ranges in western Nevada and eastern California.

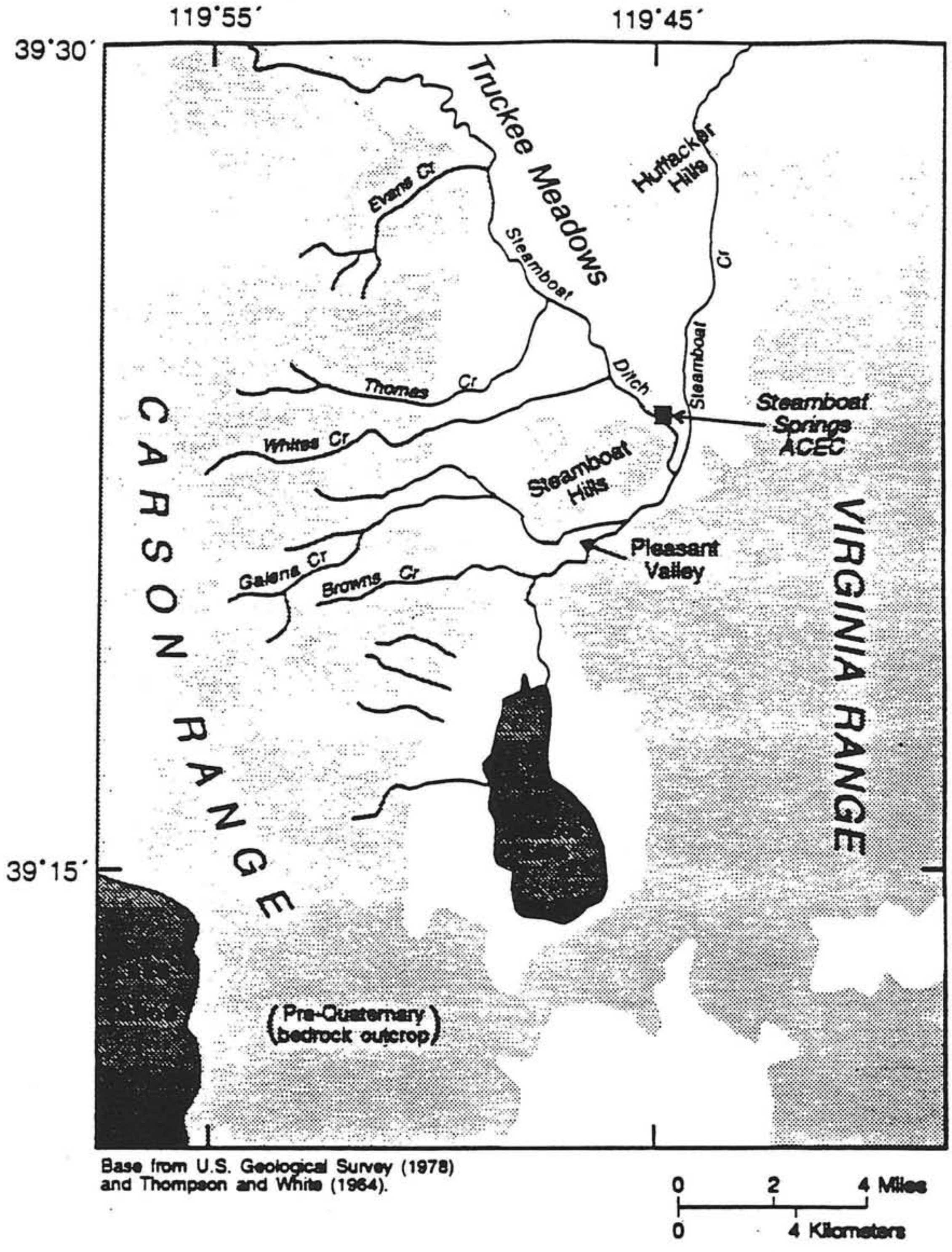


Figure 2. Location of Steamboat Hills and Steamboat Springs Area of Critical Environmental Concern (ACEC).

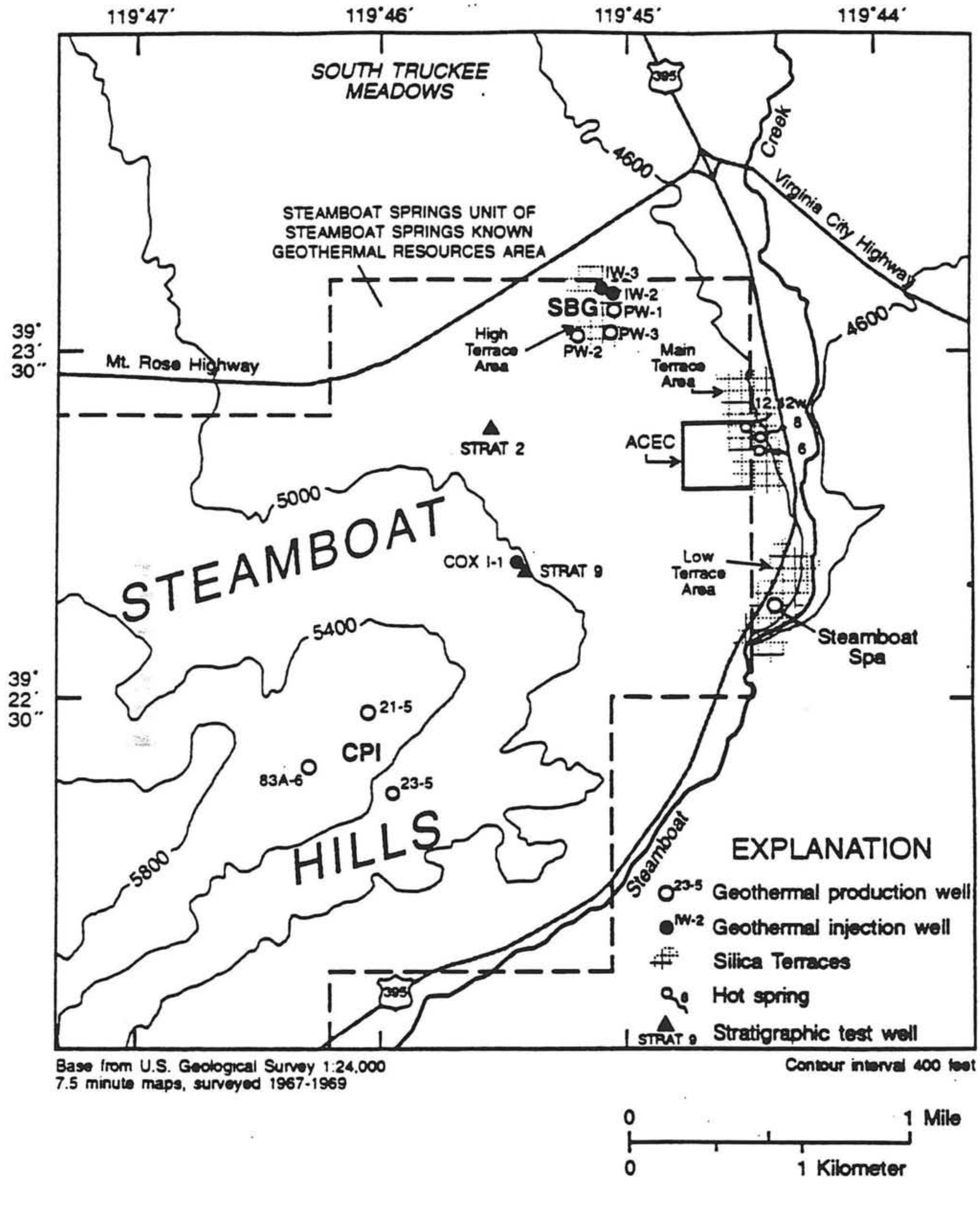


Figure 3. Location of Steamboat Springs Area of Critical Environmental Concern (ACEC) within the Steamboat Springs unit of the Steamboat Springs Known Geothermal Resources Area, which includes the Caithness Power, Inc. (CPI) and SB GEO (SBG) geothermal well fields.

In April, 1986 the BLM was contacted by the Geyser Observation and Study Association (GOSA). GOSA noted that on a recent visit to the main terrace, spring and geyser activity was greatly reduced; water levels in many springs had decreased to the point that there was no flow, some springs were dry, and the geysers were inactive. GOSA considered that the decline in spring activity might be related to the discharging of a geothermal well approximately one and a half miles to the southwest, at the crest of the Steamboat Hills. Hudson (1987a), based on observations of main-terrace spring and geyser activity during the spring and summer of 1986, noted that hot-spring water levels fell within a few weeks of the start of the well discharge and recovered within 3 weeks of the end of the well discharge. In June, 1986, the BLM began weekly to bi-weekly visits to the main terrace, noting geyser activity, periods of spring discharge, and depths to water in many non-flowing springs. These observations, along with those made by GOSA, D.M. Hudson, and the Nevada Division of Environmental Protection (NDEP) were compiled from BLM files and are presented in Appendix A. Monitoring of several main-terrace springs also began in June 1986 on behalf of Caithness and resulted in a series of reports by Yeamans (1986a, 1986b, 1987a, and 1987b). Included in these data are the only quantitative estimates of total flow from springs on the main terrace since those reported by White (1968). The total flow from six springs was estimated to vary from about 10 gal/min to 30 gal/min over the period June 1986 to April 1987, although discharge was noted from other springs not monitored (Yeamans, 1987a).

An Environmental Assessment (EA) of the proposed development of the CPI well field and power plant southwest of the main terrace was completed in May, 1987. This document addressed, in part, the potential impact on the springs and geysers of the main terrace ACEC from geothermal fluid production and injection in the federally authorized CPI well field (Chevron Resources, 1987). Potential effects of geothermal production and injection on spring and geyser activity were judged to be insignificant based on reinjection of "95 percent of the proposed rate of withdrawal of fluids" and preliminary results from a one-month production/injection test begun in May 1987 (Yeamans, 1987c, included in Chevron, 1987). A by-product of the Environmental Assessment was a ground- and surface-water monitoring program to be implemented by CPI. This plan was agreed upon by both the BLM and NDEP as satisfying the objectives of each agency. One objective of the monitoring plan was to observe, assess, and correct adverse effects on the hot springs of the ACEC. The Environmental Assessment also discussed possible measures to be undertaken in order to mitigate impacts to the ACEC springs caused by the CPI well field, including adjusting production and injection well rates, drilling additional injection wells, and closing the facility (Chevron Resources, 1987).

Springs on the main terrace began a systematic decline in flow and water level in 1987; as of July 1987 only one main-terrace spring (spring 8) was discharging (Appendix A). Locations of springs referred to in this report are shown on plate 1 and selected spring locations are shown in figure 3. Figure 4 shows hydrographs for the three springs with the most complete records over the 1986-1989 period. More detailed hydrographs for all monitored springs are included in Appendix A. The spring numbers follow those designated by White (1968). The hydrographs have been constructed predominantly from depth-to-water measurements presented in Appendix A. Because spring discharge was only visually estimated since 1986, periods of active discharge are simply plotted as zero depth to water. Periods of decreasing spring discharge, therefore, are not apparent on these plots.

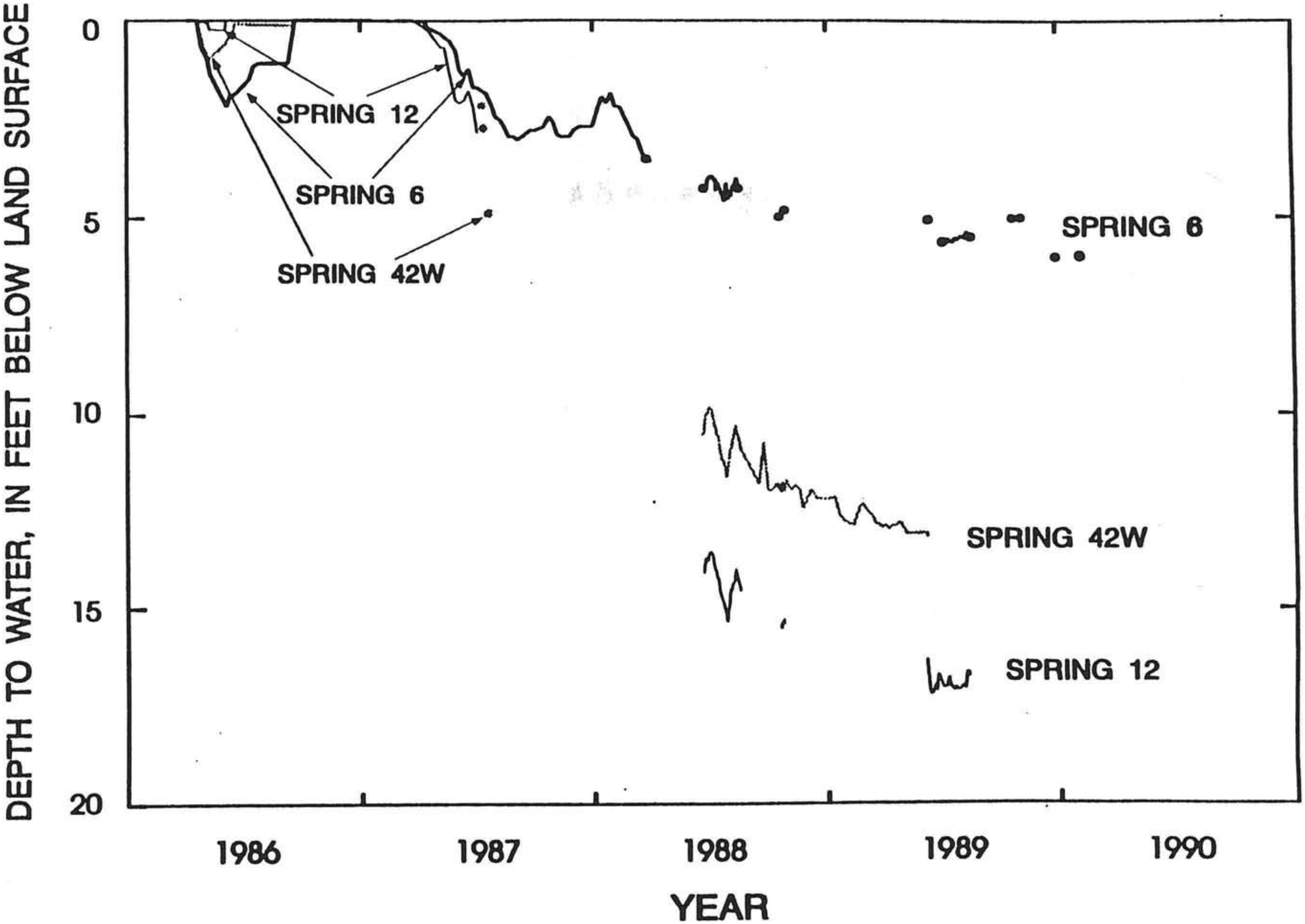


Figure 4. Hydrographs for springs 6, 12, and 42w on the main terrace at Steamboat Springs. Dots represent measured water-levels. Depth-to-water reference is the land surface at each spring.

Springs on the main terrace ceased flowing in early 1986 (except for spring 8) and water levels in the spring vents declined until mid-1986. This was followed by a period of rising water levels and renewed spring discharge, and then by another period of declining water levels that has continued with minor fluctuations until the present. Spring 8, one of the few springs that discharged continuously during the 1945-52 period, ceased flowing in March 1988. This recent decline in main-terrace spring activity is unprecedented when compared to White's (1968) seven-year study. An extreme example of the magnitude of the recent decline in spring activity is spring 12; this spring last discharged in March 1987 and in August 1988 it had a measured depth to water of slightly less than 17 feet (fig. 4).

White (1968) estimated the total rate of thermal-water discharge from the Steamboat geothermal system at 1110 gal/min in 1955, from measurements of chloride flux in Steamboat Creek, spring flow from the terraces, and estimates of well discharge on and near the terraces. We used measurements of chloride flux in Steamboat Creek in 1988 and 1989 to estimate the total natural discharge from the system as 500-700 gal/min. An average of 400 gal/min of thermal water is consumptively used at the CPI power plant, but this usage does not involve a loss of dissolved chloride from the geothermal reservoir.

Declines in thermal-water outflow, spring discharge, and spring water levels can be caused by a variety of factors. White (1968) described changes in spring discharge and water level caused by barometric pressure changes, variations in precipitation, earthquakes, and other natural influences. Determination of the primary factors responsible the recent decline in spring activity is complicated by the fact that the 1987 precipitation year (July 1986-June 1987) was the first in a series of five below-average precipitation years in the region encompassing the Steamboat Hills. The effects of this drought on water levels in the shallow ground-water system of the Steamboat region have been magnified by increased ground-water pumpage for domestic uses. An additional factor that could influence hot-spring activity is geothermal well production and injection at the CPI and SB GEO well fields and of production from the Steamboat Spa well at the low terrace (fig. 3).

Scope of the Study

This report was prepared by the U.S. Geological Survey, in cooperation with the Carson City District Office of the Bureau of Land Management (BLM), as part of a study of the Steamboat Springs, Nevada geothermal area. The study described in this report was a joint effort of the United States Geological Survey (USGS) and San Diego State University (SDSU), and was undertaken to determine the causes for the decline in hot spring and geyser activity within and surrounding the Steamboat Springs Area of Critical Environmental Concern (ACEC). The specific objectives of the study, as contained in the Intra-Agency Agreement No. NV950-IA8-002, were to:

1. Describe the hydrogeologic setting of the Steamboat basin and the natural processes that affect the thermal features of the ACEC.

2. Describe the relations of geothermal-fluid production and injection on public and private lands to the thermal features within the Steamboat ACEC, with particular emphasis on the relation of federally authorized production and injection to the ACEC.

3. Review the existing monitoring plans being implemented by BLM, the State of Nevada, and the geothermal operators. Evaluate and report on the ability of the monitoring efforts to detect changes in the hydrothermal system and to determine cause and effect relations. Make recommendations for changes to the monitoring plans, if necessary, including recommendations for monitoring wells.

4. Recommend methods to mitigate any effects to the thermal features from federally authorized geothermal production and injection.

A fifth objective, initially proposed by the BLM, was to recommend thresholds for determining significant changes to the thermal features of the ACEC that can be measured through the monitoring plan. This objective was not considered in the study because significant changes in the thermal features of the ACEC occurred before the study began and the existing monitoring plan no longer includes the collection of data from the ACEC or main terrace.

This report described the methods used to meet the stated objectives of the study, including (1) photo-interpretation of available imagery covering Steamboat Hills and surrounding areas to delineate fracture patterns, (2) compilation of a geologic map of Steamboat Hills and surrounding areas, (3) detailed monitoring of water levels in accessible hot spring vents and wells, (4) calculation of the thermal-water discharge in Steamboat Creek from measurements of stream discharge and chemical concentrations, (5) compilation and analysis of existing confidential and publicly-available geologic and hydrologic data, and (6) development of a conceptual hydrogeologic model of the Steamboat Springs geothermal system. We emphasize that it was not the intent of this study or of this report to provide a complete description of all hydrologic aspects of the Steamboat area, but rather to evaluate the existing information in terms of cause-and-effect relations and the relative effects of various stresses on hot-spring activity. Further, we have made suggestions for additional data collection to allow a better quantification of effects of different factors on the ACEC hot springs rather than recommendations for mitigation measures.

Permission was granted to the USGS and SDSU to review confidential data contained in NDEP files regarding the SB GEO facility. Confidential data regarding the CPI facility was furnished by Caithness and their consultants and was also accessed through the files held by the BLM and NDEP. Publicly available data are contained in graduate theses and published reports by the USGS and others, and in aerial photographs. Examples of data that may be considered confidential include temperature and pressure surveys in wells and calculations and interpretations contained in unpublished reports by consultants. Much of this information is included in five appendices to this report.

Acknowledgments

The authors wish to thank Daniel L. Jacquet of the Bureau of Land Management for his encouragement and coordination of the administrative aspects of this study. This report is based in part on field work, data collection, and interpretations presented in the M.S. thesis by R.J. Collar. The contributions of Collar, now with CH2M Hill, and David Huntley of San Diego State University are gratefully acknowledged. Jacquet and Richard Hoops (BLM) provided access to reports and data in BLM files. Valuable records of hot-spring observations were obtained from Terry Knight of the BLM and Paul Strasser and Heinrich Koenig of the Geyser Observation and Study Association. Douglas Zimmerman of the Nevada Division of Environmental Protection provided access to well-field and monitoring data furnished to the State of Nevada. Many other people provided information and assistance during this study, including Donald E. White of the U.S. Geological Survey, Frank Yeamans of the Cardinal Point Company, Donald M. Hudson, an independent geological consultant, Nelson Duchesneau of the International Community of Christ Church, Becky Weimer of the Nevada Bureau of Mines and Geology, Hal Kleiforth of the Desert Research Institute, Dennis T. Trexler and Thomas Flynn of the University of Nevada Las Vegas, Division of Earth Sciences, George Curti and family, the Damonte family, the Bella Vista Ranch, the Redfield Estates, Bruce MacKay, and other land and home owners in the study area. The contributions of Colin Goranson, a consulting geological engineer, Peter van de Kamp of the Cornelius Corporation, and Susan Petty of Susan Petty Consulting in providing data and critical suggestions regarding their interpretation are also acknowledged.

HYDROGEOLOGIC SETTING OF THE STEAMBOAT AREA

In the Steamboat area, thermal fluids are encountered at the surface on silica terraces north and northeast of the Steamboat Hills, in bedrock aquifers within the Steamboat Hills, and in alluvial deposits of the South Truckee Meadows. Possible relations between these thermal-water occurrences are discussed in this section of the report, following a summary of the important geologic and structural features of the area. A more detailed discussion of the hydrogeologic setting of the Steamboat area is given by Collar (1990), based on reports by Thompson and White (1964), White and others (1964), White (1968), Tabor and Ellen (1975), Cohen and Loeltz (1964), and Bonham and Rogers (1983).

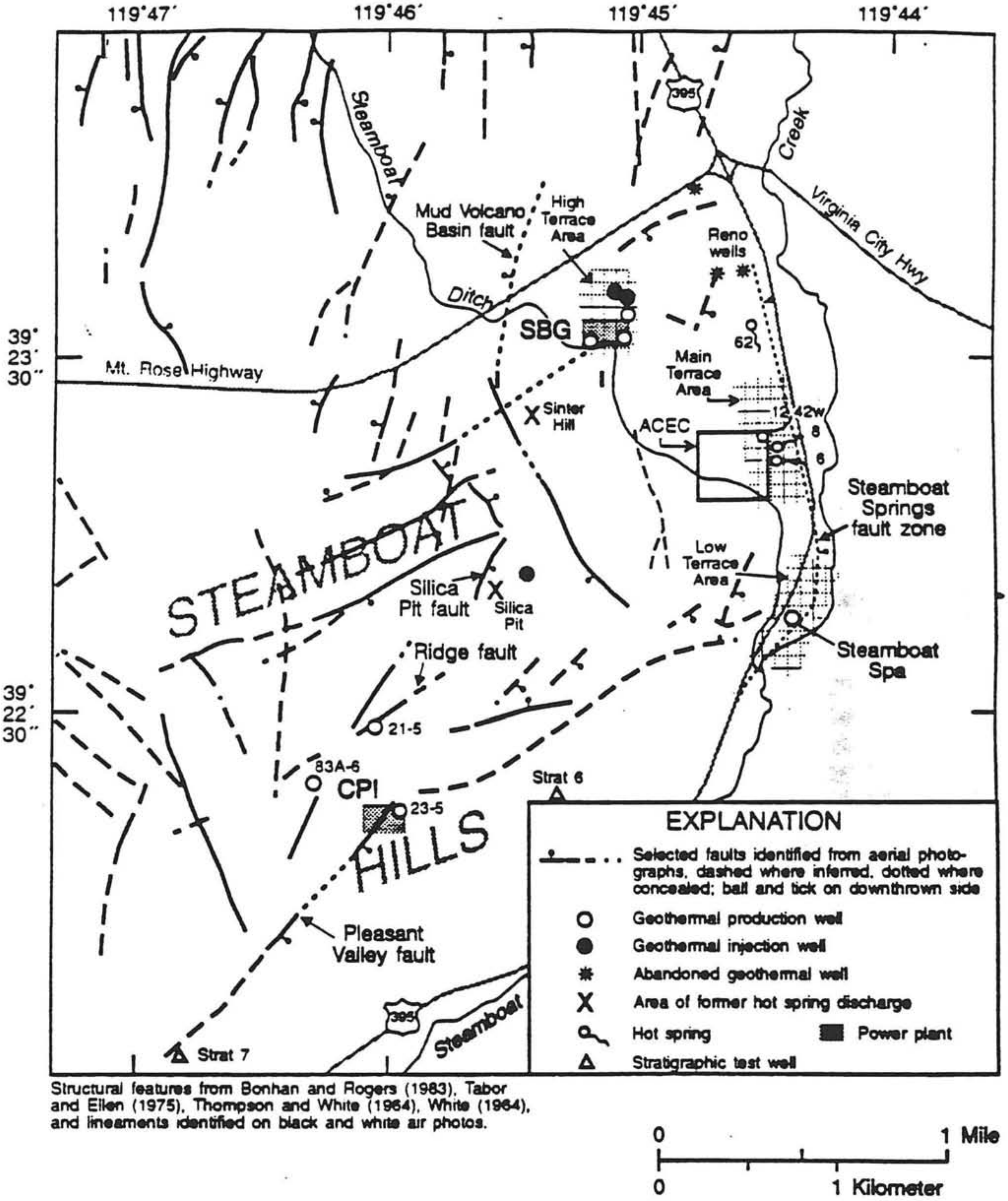
Geology and Structure

The Steamboat Hills consist of a topographically prominent bedrock high surrounded by unconsolidated deposits (plate 2). The southern part of the hills are composed of Triassic and Jurassic metamorphic rocks; these rocks are intruded by Jurassic and Cretaceous granodiorite along a steeply dipping contact that strikes in an eastward or northeastward direction near the crest of the hills. North and west of the crest of the hills the metamorphic rocks are overlain by Tertiary volcanic rocks and younger sediments. A geothermal exploration well drilled north of the hills near the center of section 21, T18N, R20E (plate 2) encountered 1,966 feet of unconsolidated deposits, primarily lacustrine sediments, with minor interbedded basalt flows (Desormier, 1984).

The youngest volcanic rocks in the Steamboat area are 1.14 to 1.21 m.y. old Steamboat Hills Rhyolite and the 2.52 to 2.55 m.y. old basaltic andesite flows described by Silberman and others (1979). The Steamboat Hills Rhyolite crops out in three domes (Qsr in plate 2), one of which occurs at the southwestern end of the Steamboat Hills. These domes, together with the Washington Hill Rhyolite dome eight miles northeast of the main terrace (not shown), form a northeast-southwest-trending volcanic lineament. Flows of basaltic andesite erupted along this lineament midway between the dome of Steamboat Hills Rhyolite at the southwest end of the hills and the main terrace. Many authors (for example, White and others, 1964; Silberman and others, 1979) have associated the hydrothermal activity at Steamboat Springs with magma reservoirs that supplied these Pleistocene eruptions.

Extensive deposits of silica sinter (opal and chalcedony) exist on the high, main, and low terraces (plates 1 and 2, and fig. 5). The sinter has been deposited primarily from discharging hot-spring waters and thermal ground water saturated with amorphous silica. In general, the sinter overlies unconsolidated alluvium and glacial outwash, but it may also cement these deposits. Drill-hole information indicates that the sinter is as thick as 80 feet at the main terrace, the top of which sits about 100 feet above the level of Steamboat Creek (plate 1).

Active hot springs occur only at the low and main terraces. However, hot springs formerly discharged at several other areas within the Steamboat Hills, as evidenced by silica deposits and hydrothermally altered rock (for example, Sinter Hill and Silica Pit in fig. 5 and plate 3). Hydrothermal eruption breccia along the Mud Volcano Basin fault west of the high terrace and near the Mount Rose Highway (State Highway 431) indicates hot-water upflow and probable seismically activated phreatic eruption activity in the middle or late Pleistocene



Structural features from Bonhan and Rogers (1983), Tabor and Ellen (1975), Thompson and White (1964), White (1964), and lineaments identified on black and white air photos.

Figure 5. Map of the Steamboat Hills and surrounding areas showing faults and lineaments identified from aerial photographs, selected wells, and general locations of silica terraces. CPI stands for Caithness Power Incorporated; SBG stands for SB GEO.

(White, 1955; White and others, 1964). The distribution of these features, along with data from geothermal wells discussed below, suggests an extensive geothermal system within the Steamboat Hills involving upflow of thermal fluid beneath the crest of the hills and outflow to the north and northeast. The piezometric surface corresponding to the present-day geothermal system beneath the Steamboat Hills is at depths of 300-1,000 feet below land surface.

The Steamboat Hills structural block was uplifted approximately 2,000 feet above adjacent areas to the east, west, and north along E-NE and N-NE trending normal faults. Faults of unknown displacement but E-NE and N-NE orientations cut through the hills and could provide zones of enhanced permeability for fluid flow at depth. Faults and lineaments identified from black and white areal photographs, as described by Collar (1990), are shown in figure 5 and plate 3. Many more lineaments were noted than actually appear on these maps; only those lineaments with distinct topographic expressions are shown.

White and others (1964) noted that fault traces within the Steamboat Hills fall into three categories: north-trending, east-northeast-trending, and northwest-trending. North-trending faults are the most common in the unconsolidated deposits surrounding the hills. Included in this set is the Steamboat Springs fault zone denoted by White and others (1964) and White (1968) as controlling the occurrence of hot springs at the main and low terraces (fig. 5 and plate 3). Control on the dip of this fault is based largely on drill-hole data and gravity surveys (Thompson and Sandberg, 1958). These data indicate at least 1,000 feet of vertical displacement across the fault zone. Additional evidence for extensions of this fault zone to the north and south of the terraces is discussed by Collar (1990). Also significant are the Mud Volcano Basin fault referred to previously and the Silica Pit fault, both of which appear to have been associated with surficial hydrothermal activity in the past. The north-trending faults (and faults with N-NE and N-NW orientations) are the most recently active faults in the Steamboat Hills (White and others, 1964) and are probably related to the dominant north-south structural trend of the Basin and Range province.

Northwest-trending structures are largely restricted to the bedrock of the Steamboat Hills. These include a fault mapped in two mine adits in the ACEC and faults forming a small graben approximately a mile west of the ACEC (fig. 5 and plate 3). The westernmost fault vertically offsets basaltic andesite by at least 100 feet and forms a prominent scarp; the easternmost fault forms a low scarp recognizable on areal photographs. A northwestward extension of this fault intersects the Mud Volcano Basin fault west of Sinter Hill.

The E-NE trending structures are most prominent west of the ACEC and north of Silica Pit, where three parallel faults have been mapped (White and others, 1964). One of these faults appears to offset the previously mentioned northwest-trending graben. To the south of these faults, a few east-northeast lineaments can be identified at the crest of the Steamboat Hills. These may be related to the Ridge fault shown on the map of Thermasource (1987), but no evidence for faulting was found in this area during this study. The steeply dipping contact between metamorphic and granitic bedrock also occurs along the crest of the hills and strikes in an east-northeast direction. Several of the Caithness wells drilled along this trend penetrate an alternating sequence of metamorphic and granitic rocks, indicating intrusive tonguing along an irregular contact (fig. 6). It is not known whether significant offset has

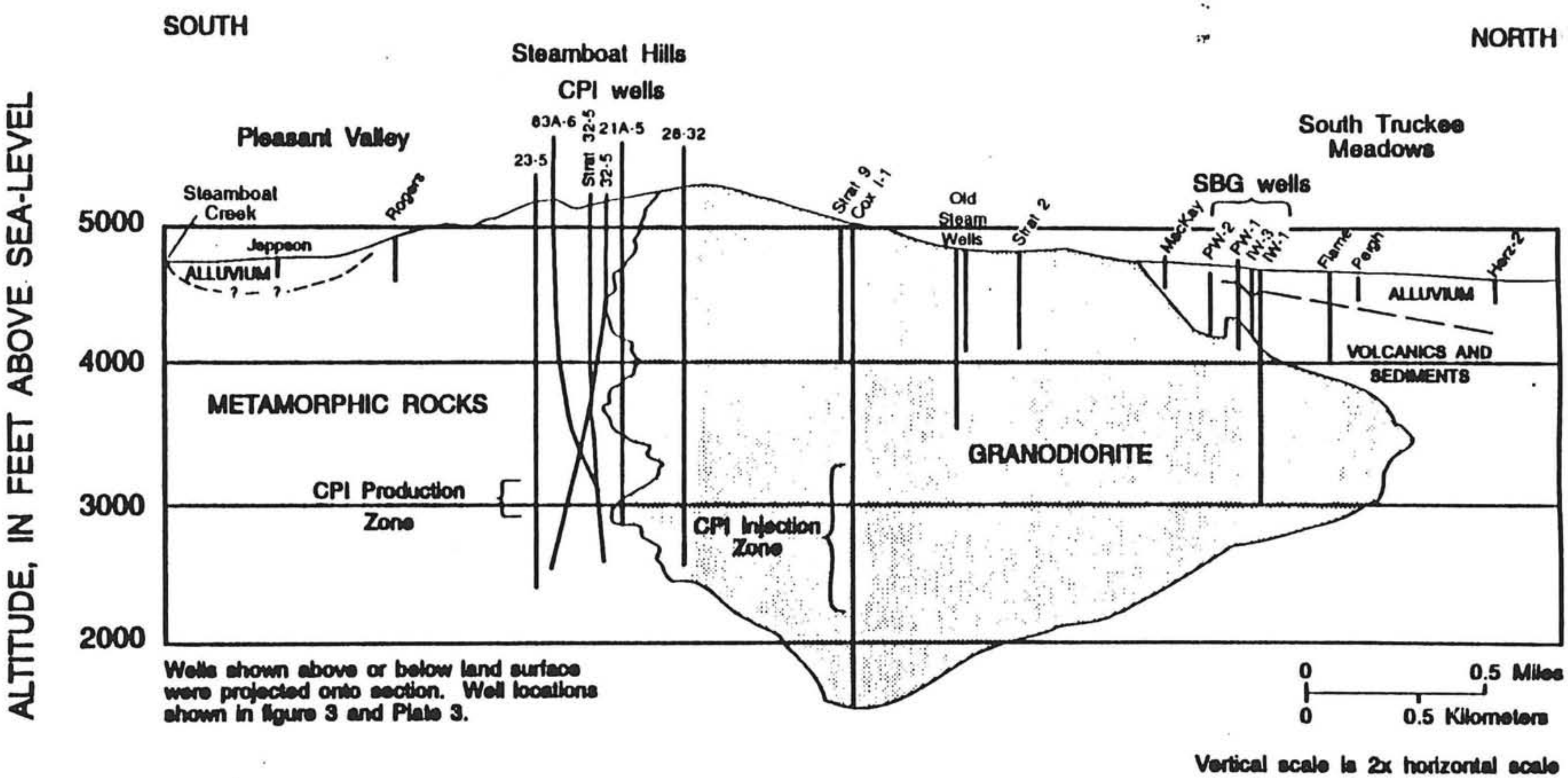


Figure 6. Generalized north-south lithologic section through the Steamboat Hills (modified from Goranson and others, 1990) and positions of selected wells. CPI stands for Caithness Power Incorporated; SBG stands for SB GEO.

occurred along this contact or to what extent production zones in these wells are related to the hypothesized Ridge fault. Near vertical fractures (85°-90 dip) striking in a north-northeast direction have been identified by borehole logging techniques in permeable zones encountered in the Cox I-1 injection well and one other (unspecified) CPI well (Goranson and others, 1990). These authors suggest that a southward extension of the Mud Volcano Basin fault provides a major structural control on permeability within the CPI production and injection reservoirs (C. Goranson, oral communication, 1991; P. van de Kamp, written communication, 1992).

To the south of the CPI production wells, the Pleasant Valley fault may form a boundary between the geothermal system within the Steamboat Hills and the ground-water system in Pleasant Valley (Yeamans, 1984). Stratigraphic test wells strat 6 and strat 7 are completed in bedrock at depths of 1500-1900 feet on the south, or hanging wall side of the Pleasant Valley fault (fig. 5), and encounter bottomhole temperatures of 80 -90°C. These temperatures are considerably cooler than temperatures in wells drilled into bedrock on the north side of the fault. This fault is shown in plate 3 and figure 5 as a combination of faulted segments and lineaments following the location in Thompson and White (1964). However, Tabor and Ellen (1975) depict the fault as continuing on its same trend from the vicinity of CPI well 23-5 toward the Silica Pit fault. No field evidence was found to support locating the continuation of the Pleasant Valley fault in either of the above positions (Collar, 1990).

Geothermal System Characteristics

Regional Flow

Several lines of evidence suggest that thermal waters encountered in fractured bedrock at depths of 1,000-3,000 feet in the Steamboat Hills, in hot springs and associated reservoirs beneath the silica terraces, and in alluvial aquifers in the South Truckee Meadows are hydrologically connected within a regional-scale geothermal system. These include similarities in chemical characteristics of thermal water (for example, Cl/B ratios), systematic decreases in hydraulic head and reservoir temperature to the north and east of the CPI production reservoir, and regional-scale E-NE and N-NE fault orientations. The study by White (1968) indicates that fluid discharge from this geothermal system and from the associated regional ground-water system occurs predominantly as seepage into Steamboat Creek. It has proven very difficult, however, to delineate the actual flow paths for thermal water and the degree of hydraulic (pressure) communication between features spaced a few miles or even a few thousand feet apart.

The age of thermal water from hot springs at Steamboat was estimated from its C activity as about 40,000-43,000 years (Flynn and Ghusn). The estimated error in these determinations is large (standard deviation 12,000 years) because the ^{14}C activity is near minimum detection limits and approaches background. In contrast, thermal waters discharging from hot springs in the Moana geothermal area northwest of Huffacker Hills (just north of the latitude 39° 30' in figure 7) show carbon ages of about 8,000 years (Flynn and Ghusn, 1983). Although the C activities in these waters indicate that they are relatively old, there are several sources of error that are difficult to properly account for in age determinations of this type. Principal among these is the addition of dead carbon from

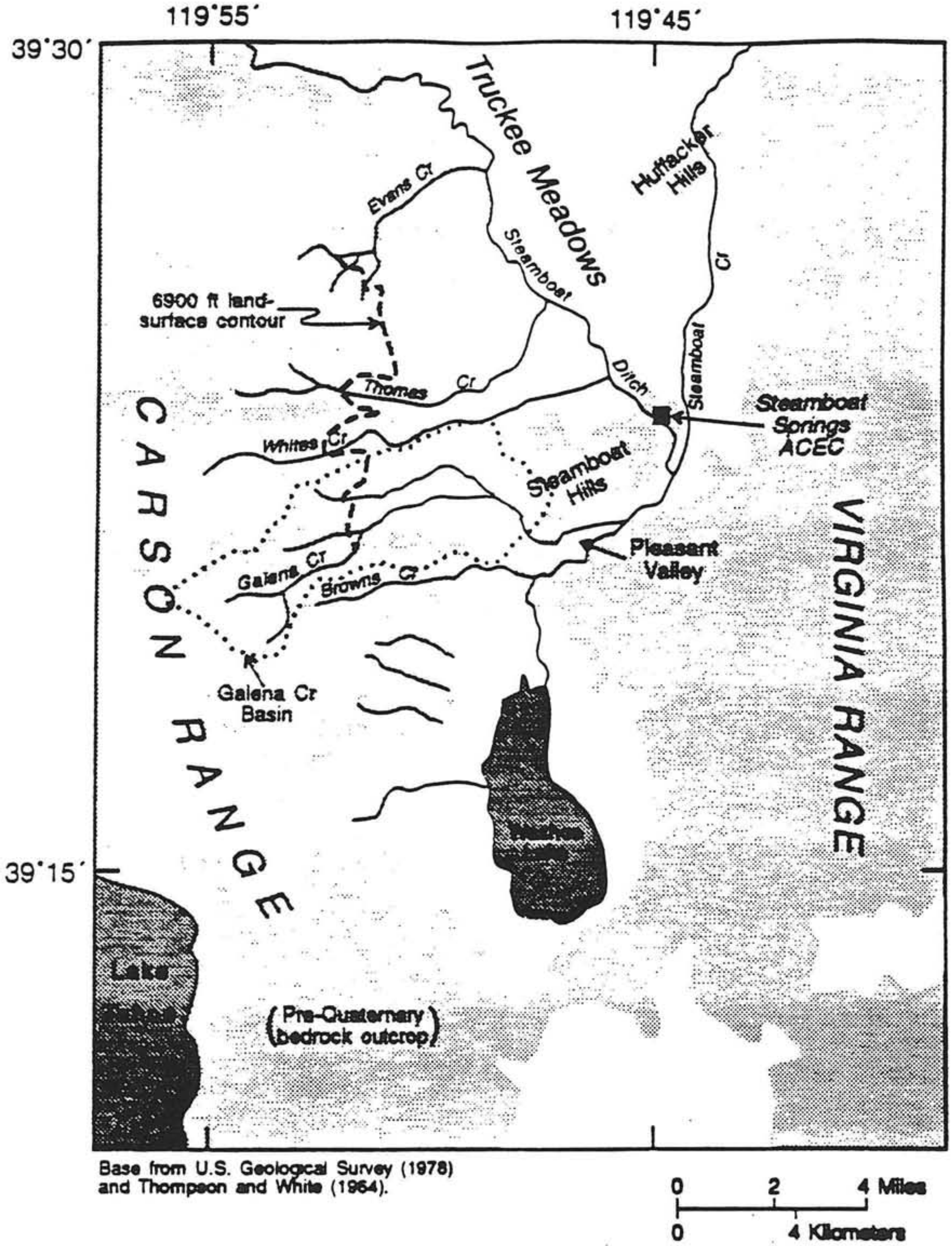


Figure 7. Map of Steamboat Hills area showing locations of Galena Creek drainage basin and 6,900 foot land-surface contour (sea-level datum) in the Carson Range, between Galena Creek and Evans Creek.

calcareous rocks. An alternative estimate of the age of thermal waters discharging from the Steamboat system is obtained by calculating the travel time through an assumed volume of the geothermal system. For a system volume of 6 mi^3 (width 3 miles, thickness 1,000 feet, length 10 miles), the travel time from recharge to discharge area would be close to 2,000 years for an average rock porosity of 0.05 and a total flow of 1,100 gal/min. This estimate of the total flow through the system matches that calculated from measurements of chloride-flux in Steamboat Creek, as discussed in subsequent sections of this report. The travel-time calculation demonstrates that unreasonably large system volumes would be required to yield thermal-water ages close to 40,000 years, and implies that the actual age of the thermal water may be closer to a few thousand years.

Possible areas of recharge to the Steamboat geothermal system have been delineated from differences in stable isotopes of oxygen and hydrogen in thermal and nonthermal waters in different parts of the Steamboat region. The isotope data from Nehring (1980) show that the hot spring waters are isotopically enriched in ^{18}O relative to the meteoric water line due to high-temperature water-rock reactions, but that the deuterium value of meteoric water recharging the hot springs matches the deuterium value for present-day precipitation at elevations near 6,900 feet in the Carson Range (fig. 8). Nehring's isotope data would further narrow the likely recharge area to the region between Galena Creek in the south and Evans Creek in the north (fig. 7), provided the isotopic characteristics of precipitation in this area are the same now as they were when recharge took place. This assumption would be valid for recharge occurring several thousand years ago, but would be questionable for water that is 40,000 years old. The isotope data of Flynn and Ghusn (1983), which show deuterium values of -120 to -130 o/oo for the Moana thermal waters, lead to the inference that these waters were recharged at higher elevations in the Carson Range than were the thermal waters discharging at Steamboat.

We have augmented the stable-isotope data from Nehring (1980) with two values for geothermal wells - one representing the average value for six samples collected over a one-week period in the summer of 1980 from well SB-1 (from Yeamans, 1984) and one representing the average of total flow samples collected in November 1991 from several production wells in the SB GEO well field. These data plot along the trend line for the hot-spring waters, suggesting common origins. Isotope values for samples collected in November 1991 from the CPI production wells are not yet available, but should prove useful, along with the associated chemical analyses, in delineating relations between thermal waters in different parts of the Steamboat Region.

Katzer and others (1984) used a water-budget for the Galena Creek basin to calculate a loss of approximately 2,700 gal/min into the fractured bedrock beneath the basin. For comparison, White (1968) estimated the total thermal-water discharge from the Steamboat geothermal system to be 1,110 gal/min. Ground water discharges into Galena Creek as it flows eastward through the bedrock gorge between the Galena Creek basin and Pleasant Valley. Thus, any recharge from Galena Creek to the geothermal system must occur upstream of the Steamboat Hills. Locations of recharge and discharge areas for the geothermal system, and hydraulic head data discussed below, are consistent with an overall southwest to northeast flow within the geothermal system, parallel to the topographic axis of the Steamboat Hills and the east-northeast structural trends discussed above.

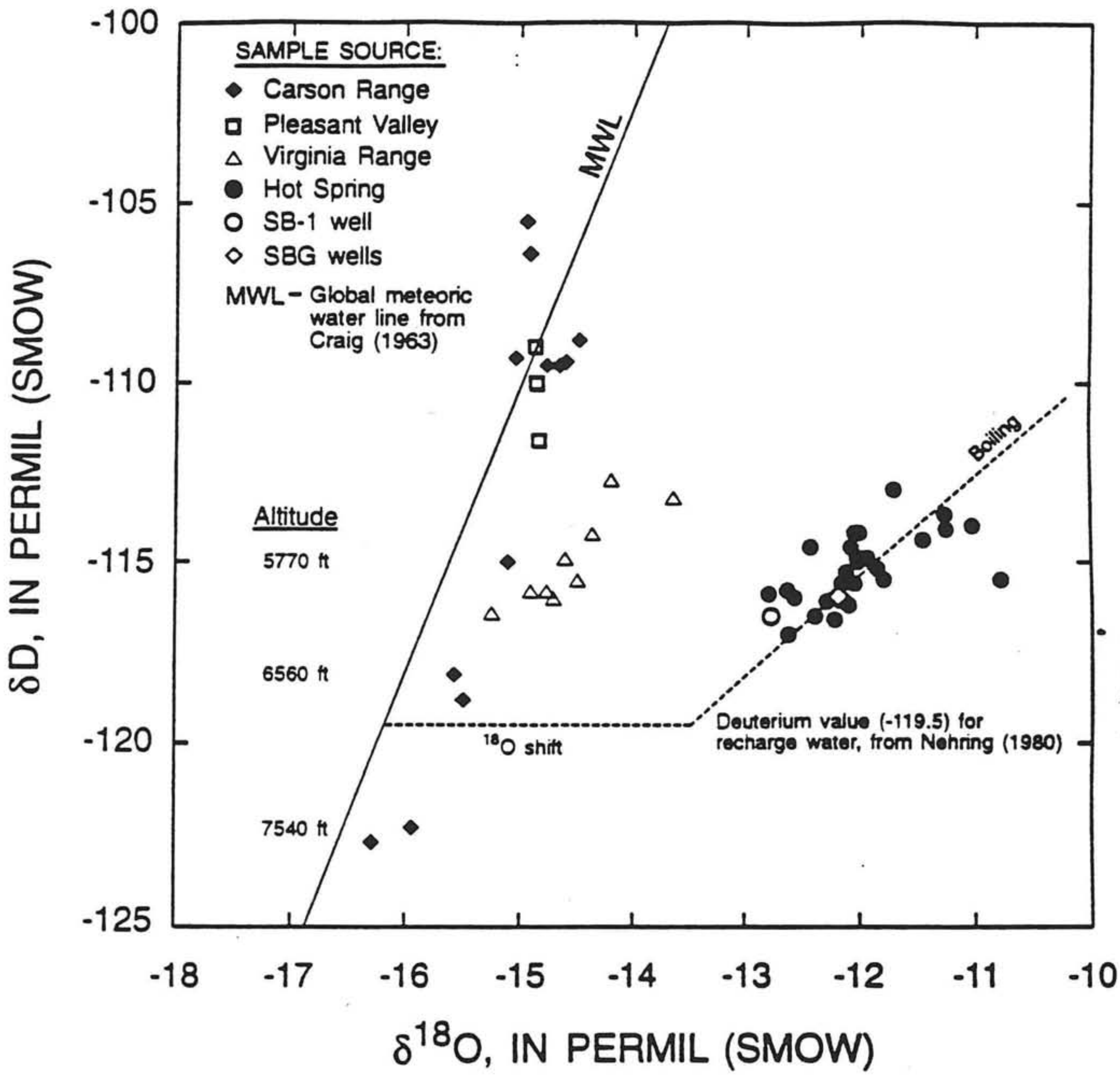


Figure 8. Stable water isotope values for waters from the Steamboat region showing the change in deuterium (D) with altitude in the Carson Range and how oxygen-isotope shift (from rock-water interactions) and boiling could account for the compositions of waters from hot springs on the main terrace and wells in the Caithness Power Incorporated (CPI) and SB GEO (SBG) well fields. All spring data is tabulated by (1980). SMOW stands for Standard Mean Ocean Water, used for reference.

The Steamboat geothermal system is part of a larger regional ground-water flow system that extends north of the Steamboat Hills toward the Truckee River (fig. 9). Contours of ground-water table altitude show that the general direction of flow in the unconsolidated deposits is from the valley margins (the Carson and Virginia Ranges) toward Steamboat Creek in the South Truckee Meadows. There is also a northward component of ground-water flow towards Huffacker Hills. Streamflow measurements made during this study and those reported by Shump (1985), White (1968), and Cohen and Loeltz (1964), show that Steamboat Creek is a gaining stream throughout the South Truckee Meadows and, consequently, a region of discharge of both thermal and nonthermal ground water. Piezometers installed in the bed of Steamboat Creek east of the main and low terraces show a hydraulic gradient for upward flow (Shump, 1985), also indicating ground-water discharge into the creek.

Steamboat Hills

Thermal water at temperatures of 50°-230°C is encountered in wells drilled in the Steamboat Hills. Goranson and van de Kamp (1989) and Goranson and others (1990) postulate that there are several isolated geothermal systems in the Steamboat region, including the high-temperature (210°-230°C) system tapped by the CPI production wells near the crest of the hills, the moderate-temperature (170°C) system tapped by the SB GEO wells on the northeast flank of the hills, and "several low-temperature systems" within the alluvial aquifers surrounding the Steamboat Hills that feed hot springs on the silica terraces and the surrounding valleys. The evidence cited for separate flow systems includes differences in altitudes between thermal reservoirs in each area, differences in reservoir temperature and in lateral temperature gradient between the CPI well field and strat 9 and between strat 9 and strat 2 (fig. 3), and a lack of convincing evidence of pressure communication between the CPI production and injection wells and various wells and hot springs. The degree of connection between thermal areas in the Steamboat region is clearly important to an assessment of the factors influencing changes in hot-spring activity on the main terrace. The information on system characteristics presented in this section does not in itself prove or disprove that there is hydraulic communication between any two areas. As in most geothermal settings, it is necessary to stress the system and measure subsequent changes to provide a clearer indication of cause and effect relations and hydraulic connections. This approach has not been fully successful at Steamboat because more than one stress has been in effect and the existing monitoring program has lacked adequate observation of pressure changes in production reservoirs and beneath the main terrace.

Production and injection zones in the various Caithness wells occur at similar altitudes, but at depths of 2,500-3,000 feet and about 2,000 feet, respectively (fig. 6). The altitudes of these zones are about 1,000 feet lower than that of the SB GEO production zone. The prevalence of normal faults of different orientations in the Steamboat Hills and temperature reversals in many of the thermal wells suggest that zones of thermal-water flow are related to fractures and perhaps fault intersections in the metamorphic and granitic bedrock. There are some data from core drilling and well logging indicating fracture control on production zones at the CPI and SB GEO well fields (Goranson and others, 1990 and 1991). However, the relations between permeable zones encountered in different wells are poorly understood. The maximum temperatures in the three CPI production wells vary from 210° to 230°C and temperature reversals below the main production zone in each well indicate hydraulic

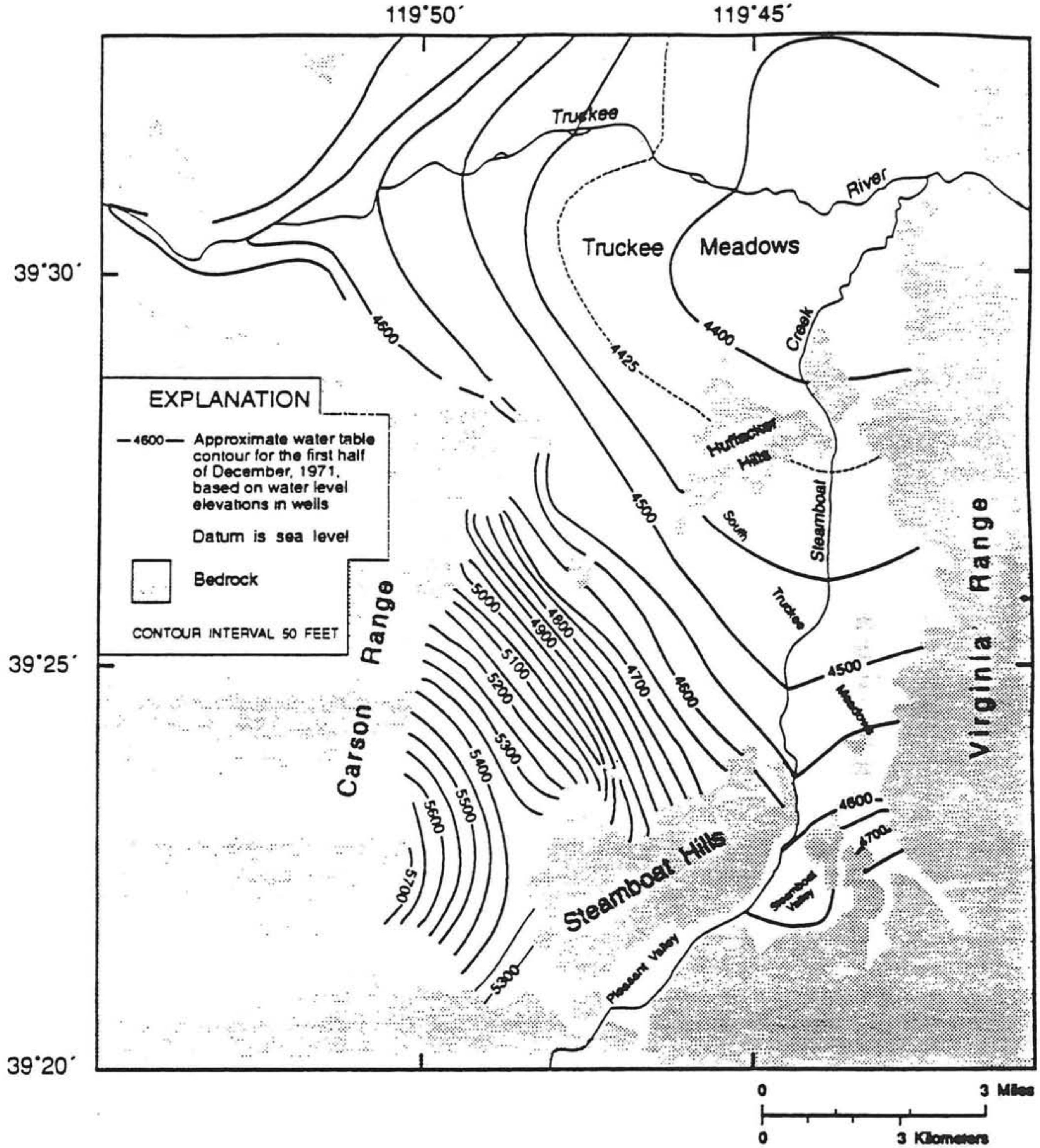


Figure 9. Water-table elevation map for the Truckee Meadows - Steamboat Hills area (from Cooley and others, 1971).

isolation of the fractures transmitting hot water to each well from deeper rocks. Somewhat surprisingly, pressure data from well interference tests indicate that the CPI and SB GEO reservoirs can be simulated as radial and homogeneous (Collar and Huntley, 1990; C. Goranson, written communication, 1991; and results discussed in subsequent sections of this report). Because the Caithness injection well (Cox I-1) is located closer to the main terrace than are the Caithness production wells (21-5, 23-5, and 83-A6), either heterogeneous reservoir conditions or a hydraulic boundary is required to explain the lack of evidence for pressure increases beneath the main terrace from operation of the CPI well field. At the SB GEO well field, injection wells IW-2 and IW-3 are located farther from the main terrace than are production wells PW-1, PW-2, and PW-3.

A schematic section drawn northeastward from the Caithness well field to the main terrace (fig. 10) illustrates relations between temperature and hydraulic head within the Steamboat Hills. Location of the section onto which various features were projected is shown in figure 11. The designated production and injection zones are based on drilling results which consistently show permeable fractures within these zones and low-permeability fractures and wall rocks above (and in some cases below) these zones. Although the permeable features penetrated by these wells may actually be related to steeply dipping faults, it appears that such structures are sealed by mineral deposits above altitudes of about 3,200 feet in the CPI well field and 4,300 feet in the SB GEO well field. Such sealing could be related to lower temperatures above the permeable zones. The injection zone in Cox I-1 must be hydraulically connected to the CPI production zone to the southwest because it appears to provide injection-pressure support, but must not be simply connected to the main-terrace hot springs because there is no evidence of rapid pressure increases beneath the main terrace from injection in Cox I-1. This matter is more fully discussed in subsequent sections of the report.

Piezometric-surface altitudes (hydraulic head) were calculated either from pre-production downhole pressure surveys (Caithness wells 83-A6 and Cox I-1) or water-level measurements. The pre-production water level in strat 9 was estimated at 375 feet below land surface, from measurements beginning in December 1987 and comparisons with hydrographs for strats 2 and 5 prior to that date. These data show consistent decreases in maximum temperature and head along this section, except that the injection zone in Cox I-1 is characterized by lower temperature and head than found at shallower depths at this site and lower head than that corresponding to spring altitudes at the main terrace. There is a suggestion from the data for strats 2 and 9 and Cox I-1 that each well penetrates a permeable zone containing thermal water at temperatures of 170°-180°C at similar altitudes near 4,300 feet. The altitude, temperature, and head of this zone are consistent with lateral flow of thermal water at this level toward the main terrace and the SB GEO well field. It is not known whether there is in, in fact, a continuous thermal aquifer connecting these areas, or whether hydraulic connections that may exist between these areas involve fracture-controlled flow along complex paths. White (1968) notes that temperatures below a depth of about 350 feet at the main terrace are relatively constant at about 175°C, lending support to the concept of hydrologic connection between the main terrace and a "shallow thermal-water flow zone" in the Steamboat Hills.

Hydraulic connection between the Caithness production zone and the hypothesized shallow thermal flow zone could be provided through an upflow zone between the production

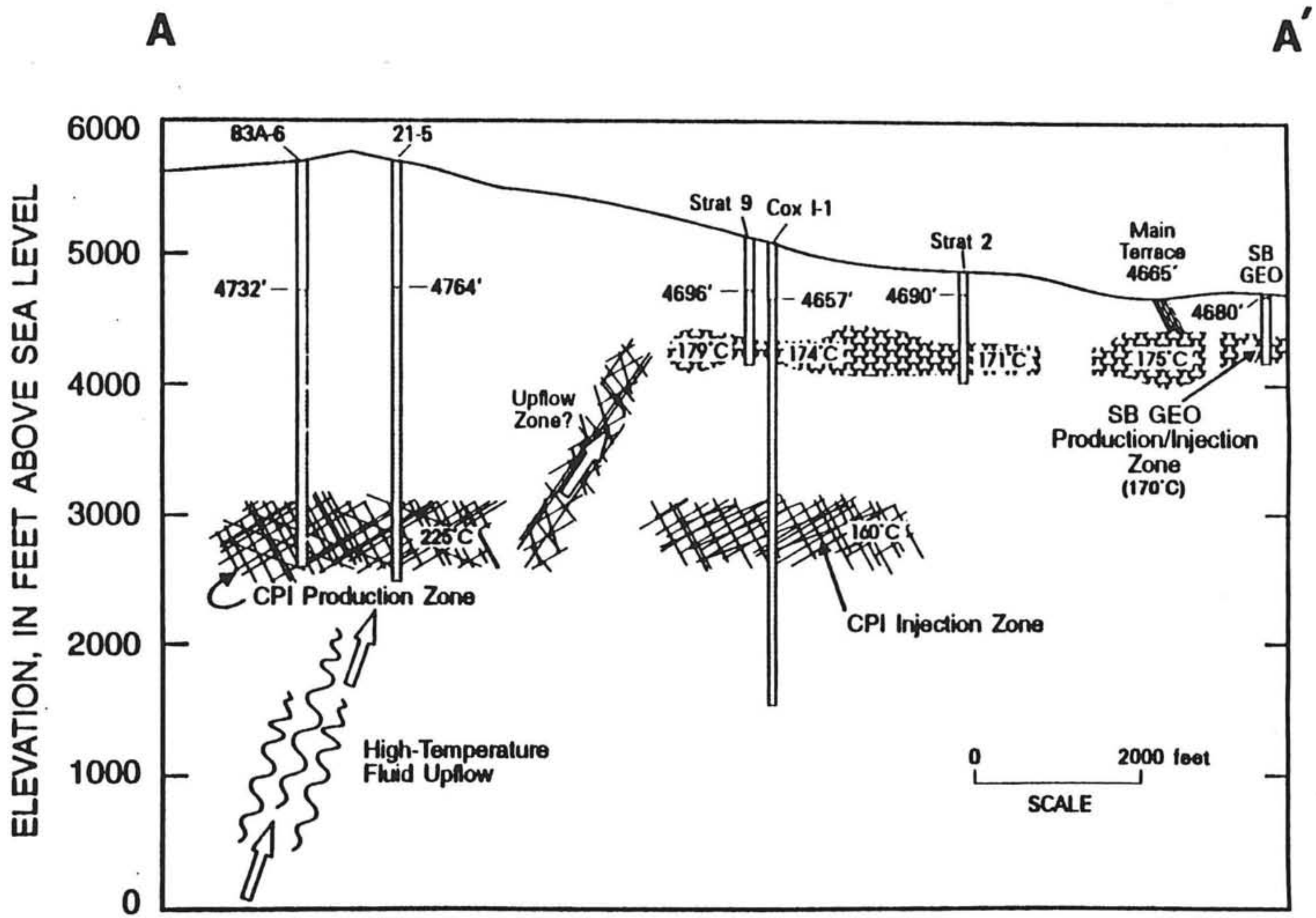
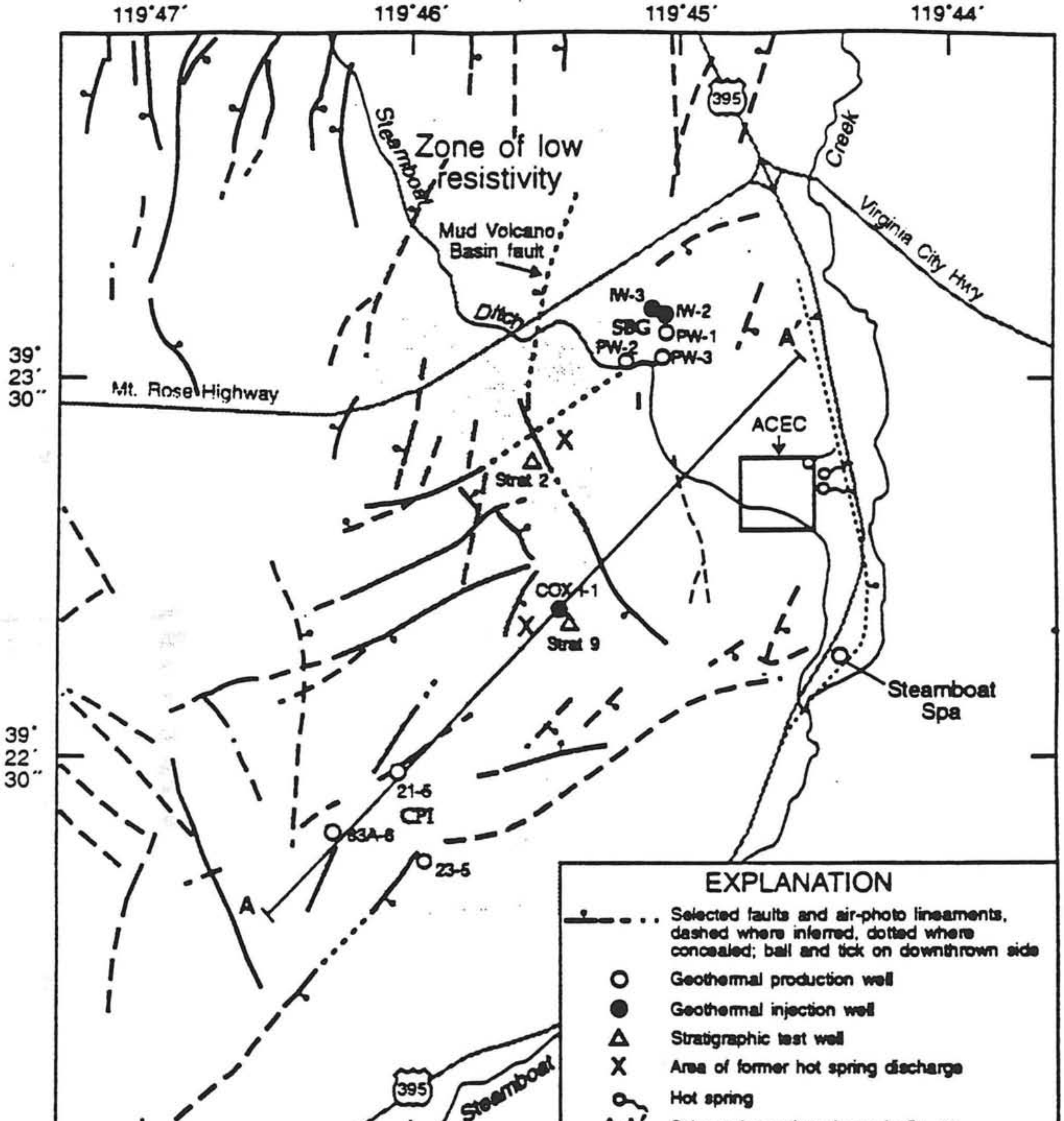


Figure 10. Schematic section through the Steamboat Hills geothermal area showing relations between zones of thermal-water flow (patterned) encountered in wells (labeled with well name). CPI stands for Caithness Power Incorporated. Measured temperatures are shown, along with altitudes of the piezometric surface determined from downhole-pressure surveys or water-level measurements. Section location shown, in figure 11.



Structural features from Bonhan and Rogers (1983), Tabor and Ellen (1975), Thompson and White (1964), White (1964), and lineaments identified on black and white air photos.

Figure 11. Zone of low electrical resistivity identified by telluric, audiomagnetic, and airborne electromagnetic surveys (Corwin and Hoover, 1979; Christopherson and others, 1980, Long and Brigham, 1975; and D.B. Hoover, written communication, 1991). Line A-A′ represents location of schematic section shown in figure 10. CPI stands for Caithness Power Incorporated; SBG stands for SB GEO; ACEC stands for Area of Critical Environmental Concern.

and injection wells. The existence of such a connection is not unreasonable, given the abundance of steeply dipping structures crossing the Steamboat Hills. Well interference data, discussed in a later section, do in fact demonstrate pressure communication between the CPI production wells and strats 2 and 9. For the purposes of this report, we will refer to a shallow thermal-water flow zone as existing beneath the Steamboat Hills and penetrated by strats 2 and 9 and the Cox I-1 well, recognizing the possible oversimplifications that this terminology may convey.

The production and injection zones at the SB GEO well field occur at similar altitudes and contain fluids with temperatures similar to those in permeable zones encountered in drill holes in the ACEC portion of the main terrace. However, higher hydraulic heads were indicated beneath the high terrace than beneath the main terrace under pre-development conditions, suggesting that thermal water did not flow directly from the main terrace to the high terrace. Electrical geophysical studies (discussed below) and well interference tests give some indications of thermal-water flow and hydraulic connections between the CPI well field and the SB GEO well field.

Goranson and others (1990) show a schematic section through the Steamboat Hills similar to that depicted in figure 10, but with "hydraulic pressure boundaries" separating the Caithness reservoir from the shallow thermal zone, the main terrace springs, and the SB GEO reservoir. In their conceptual model, each of these areas is fed by separate deep-seated upflow zones at different temperatures. No discharge points are indicated by these authors for thermal water flowing through either the Caithness reservoir or the shallow thermal reservoir. The existing subsurface information does not allow us to determine if either of these simplified models is close to reality. Although comparisons with other liquid-dominated geothermal systems suggests to us that a single, interconnected geothermal system is the simplest and most reasonable way to explain the occurrences of thermal waters within the Steamboat Hills area, the actual connections between areas may occur along deeper and more complex flow paths.

Regardless of which conceptual model is preferred, the response of different parts of the system to stresses such as those imposed by geothermal production and injection operations at two different well fields cannot be adequately predicted. Responses to stress must instead be measured after the fact because the hydraulic properties of the system are unknown, except in the immediate vicinity of the well fields. A further complication is that changes in water level in the ground-water system into which thermal water from beneath the main terrace flows could also affect heads and rates of hot-spring discharge at the main terrace. Hot springs in the ACEC are situated approximately 100 feet above the level of Steamboat Creek and may be particularly sensitive to such changes.

Geochemistry

The geochemistry of the main- and low-terrace springs and of the thermal ground water in the vicinity of the Steamboat Springs geothermal area has been studied by numerous authors (for example, Brannock and others, 1948; White, 1968; Bateman and Scheibach, 1975; Nehring, 1980 and Yeamans, 1984). As noted by these authors, the geochemistry of the hot-spring water and thermal ground water in the Steamboat Hills is distinctly different from other ground water in the vicinity of the Steamboat Hills and the South Truckee Meadows. Some characteristics of the thermal water include temperatures in excess of 20°C (Bateman and Scheibach, 1975), high total dissolved solids, elevated concentrations of arsenic, boron, and chloride ions, and a generally uniform chloride/boron ratio of about 18 (White, 1968).

The most characteristic and useful property for tracing thermal ground water from the Steamboat Springs geothermal area is chloride concentration, because it is high relative to the chloride concentration in nonthermal ground water and acts conservatively. White (1968) concluded that the most representative thermal ground water from the discharge part of the Steamboat Springs geothermal area has a chloride concentration of 820 mg/L. In contrast, chloride concentrations in nonthermal ground water from wells adjacent to the Steamboat Hills range from 0-30 ppm, but are generally less than 15 mg/L (Cohen and Loeltz, 1964; White, 1968; Bateman and Scheibach, 1975; Yeamans, 1984). Furthermore, surface water from streams draining the Carson Range and from Steamboat Creek upstream of the low terrace commonly has chloride concentrations of less than 10 ppm, though concentrations may be as great as 23 ppm (D. White, oral. commun., 1988). Cold springs in the region generally have chloride concentrations of <11 mg/L (White, 1968; Nehring, 1980). This marked difference in the chemistry of thermal and nonthermal waters can be used to identify areas of discharge from the Steamboat Springs geothermal system.

Representative chemical data for hot-spring and well waters are listed in table 1. For the CPI and SB GEO wells, the reported analyses were corrected for flash using the differences between cation and silica geothermometer temperature estimates to calculate the amount of boiling. Although total flow, or unflashed samples were collected from many of the geothermometer wells in November 1991, no analyses are as yet available for these samples. Such analyses would permit more detailed modeling of rock-water interactions and processes responsible for chemical differences in thermal water from different areas. Nevertheless, from the existing information the general similarity in thermal water chemistry between these waters is apparent, particularly in terms of the constancy of ratios of conservative elements such as Cl/B (18.6 ± 1.5, neglecting the Cox well) and Cl/Li (121.9 ± 9.4, neglecting the Cox well). In general, the hot spring waters are more concentrated than the waters from the geothermal production wells. Nehring (1980) also found the hot-spring waters to be more concentrated that waters from shallow wells completed in the granodiorite bedrock on the main terrace, and accounted for differences in Cl and enthalpy between the spring and well waters by a combination of conductive cooling and boiling of a source water at 230°C with a Cl concentration of 700 mg/L. This temperature was determined from cation geothermometer calculations for the spring waters. Although the flash-corrected chemistries for wells 83-A6 and 21-5 and the SB GEO production wells are close to that of this hypothesized source water, the flash-corrected analysis for well 23-5 appears more concentrated (Cl=790 mg/L). Well 23-5 taps a thermal zone with a measured temperature (238°C) and gas content (100 psi partial pressure) higher than those of the other CPI wells (221°C and 33 psi gas partial pressure), but each well is in hydraulic communication with the other (Faulder, 1987). It should also be noted that the calculated cation geothermometer temperatures for the CPI well samples reported in table 1 may be too high because of loss of Ca from the use of scale inhibitor.

Table 1. *Chemical data for thermal waters from the Steamboat Springs area*

[Results are given in milligrams per liter and are corrected for steam loss at amospheric flash, assuming constant enthalpy equal to that at production-zone temperature; --, no data]

Feature	Date	T_{WH}[1]	T_{DH}[2]	T_{Cation}[3]	pH[4]	SiO_2	Na	K	Ca	Mg	Li	HCO_3	CO_3	Cl	B	F	SO_4
CPI[5] 21-5	04/13/90	216	221	230	8.99	310	601	58	1.4	--	5.8	170	43	768	42	2.7	114
83A-6	04/12/90	221	221	237	8.74	323	537	63	2.0	--	5.5	181	30	697	38	2.5	102
23-5	04/18/90	232	238	256	8.82	420	594	88	2.0	--	6.8	212	34	793	44	2.5	91
COX 1-1	04/30/81	120	160	215	8.06	265	581	56	5.6	--	7.4	323	--	750	33	2.1	112
SBG[6] PW-1	12/90	170	170	212	--	237	531	51	13	0.7	--	235	--	697	36	1.7	101
PW-2	12/90	170	170	216	--	236	495	51	12	--	--	213	--	689	36	2.1	101
PW-3	12/90	170	170	216	--	252	526	53	11	--	--	200	--	697	37	2.1	102
Hot spring 6[7]	06/10/77	97	--	217	7.4	214	660	65	6.8	0.016	7.8	387	--	871	48	2.2	123
Well GS-5[8]	1950	--	173	--	--	--	--	--	--	--	--	--	--	820	--	--	--
Spring GS-5[9]	06/25/91	97	--	234	8.87	--	693	68	3	0	--	98	70	1000	53.1	2.7	151

[1]Temperature measured at well head, in degrees Celsius.
[2]Temperature measured downhole in production/injection reservoir, in degrees Celsius.
[3]Temperature calculation from Na-K-Ca geothermometer, in degrees Celsius.
[4]From lab measurement on flashed sample.
[5]Flashed sample analyses from University of Utah Research Institute (UURI) for Caithness Power Incorporated (CPI) production wells 21-5, 83A-6, and 23-5; Cox well sample analyzed by AMTEC.
[6]Flash sample analyses from Goranson (1991) for SB GEO (SBG) production wells PW-1, PW-2, and PW-3.
[7]Analysis from Nehring (1980).
[8]From White (1968).
[9]New seep adjacent to Well GS-5.

Electrical Geophysics

Various electrical geophysical surveys have been undertaken by the U.S. Geological Survey to delineate the distribution of thermal fluids beneath the Steamboat Hills. White and others (1964) summarize the results of resistivity measurements at the silica terraces, which show general correspondence between resistivity and depth to the saline water table and the thickness of relatively low porosity (and high resistivity) sinter. Self potential, telluric, audiomagnetotelluric (AMT), and airborne electromagnetic (AEM) surveys conducted in the 1970's (Corwin and Hoover, 1979; Christopherson and others, 1980; Long and Brigham, 1975; and D.B. Hoover, written communication, 1991) delineate a significant north-northeast trending conductive zone west of the main terrace (fig. 11). This zone of low resistivity is truncated south of the CPI well field, indicating a possible fault control to the southern extent of the geothermal system in the Steamboat Hills. Lower resistivities in the northern part of the anomaly (as low as 2 ohm-meters) could reflect a combination of thicker alluvial cover and shallower depths to hot-water. The telluric anomaly appears to extend northward toward Huffaker Hills but survey stations did not extend north of the intersection of Highway 395 and the Mt. Rose Highway (fig. 11). A corresponding zone of high self potential (SP) occurs along the eastern edge of the resistivity trough; high SP is also found along the main terrace.

These geophysical data indicate movement of thermal water along a major west-dipping structure associated with the Mud Volcano Basin fault west of the high terrace and its possible southward extension across the Steamboat Hills. However, more detailed studies of this type along with comparisons of surface geophysical measurements with borehole measurements of resistivity and temperature are needed to differentiate between the effects of thermal fluid flow, hydrothermal alteration, and fluid chemistry on these results.

Thermal-Water Discharge

Thermal water discharges in the Steamboat area from wells and springs and as seepage into Steamboat Creek. During the 1945-52 period, White (1968) estimated the total thermal-water discharge from the "Steamboat geothermal system" as 1,110 gal/min, 50 percent of which occurred as unseen seepage into the creek between Rhodes Road and Huffaker Hills (plate 4). During that period, thermal water discharged from springs at the main terrace (60 gal/min), the low terrace (5 gal/min), and in the South Truckee Meadows (85 gal/min). This latter group of springs (plate 4) includes Damonte Springs (SW 1/4, sec. 16, T18N, R20E), Drainage Ditch Springs (SW 1/4, sec. 15, T18N, R20E), Huffaker Springs (S 1/2, sec. 3, T18N, R20E), Double Diamond Springs (N 1/4, sec. 9, T18N, R20E), and the Zolezzi spring (SE 1/4, sec. 17, T18N, R20E). The total flow rate noted above for this group of springs is based on an assumed thermal-water component with Cl = 820 mg/L for each spring and represents the sum of the calculated component of high-chloride (820 mg/L) thermal water in their discharge. Measured chloride concentrations in these springs range from 94-130 mg/L (Zolezzi Spring) to 560 mg/L (Damonte Spring). Ratios of Cl/B for these spring waters and for water from Steamboat Creek north of Rhodes Road are similar to values for hot springs on the main terrace and thermal wells in the Steamboat Hills and South Truckee Meadows, leading White (1968) to suggest that thermal water originating in the Steamboat Springs geothermal area flows eastward and northward and discharges as springs and seepage into Steamboat Creek south of Huffaker Hills. This is consistent with the general direction of ground-water flow in the South Truckee Meadows (fig. 9) and with streamflow, conductivity, and chloride-flux measurements in Steamboat Creek by White (1968), Cohen and Loeltz (1964), Shump (1985), and those made during this study (Appendix F).

White (1968) used April 1955 measurements of stream discharge and chloride concentration upstream of the low terrace (Rhodes Road), at State Highway 341 (also known as the Virginia City Highway), and at Huffaker Hills to calculate a total seepage rate of 660 gal/min of thermal water with a chloride concentration of 820 mg/L. This rate was calculated by subtracting the rates of discharge from springs and wells entering the creek from the total rate of thermal-water entering the creek (1,110 gal/min from table 2). A similar calculation made by White (1968) for stream measurements made in April 1964 yielded a total discharge of 1,385 gal/min. White (1968) suggested that the greater chloride flux in 1964 could be due in part to input of chloride salts stored in shallow soils and mobilized with infiltration derived from a snow storm the previous week. Shump (1985) used averages for the 1981-82 period of measurements of stream discharge and specific conductance to estimate that 1,300 gal/min of thermal water discharged to Steamboat Creek. Shump's estimate of thermal-water discharge is considered less reliable that those of White because it is based on specific conductance measurements rather than chloride measurements and involves average values of streamflow and specific conductance instead of values from synoptic measurements, as discussed by Collar (1990). One important difference between conditions during the times of White's measurements and those of Shump is that geothermal wells discharged at significant rates at the north end of the main terrace and on the low terrace in the 1950's and 1960's, but had been abandoned or were little used before the 1980's. The general agreement between each set of results and comparisons with estimates of spring flow on the main terrace in 1916, as discussed in a later section, suggests that the discharge from these wells in the 1950's and 1960's (averaging about 300 gal/min) represents thermal water that would have flowed from springs on the main terrace, entered the creek as seepage, and/or flowed into alluvial aquifers in the South Truckee Meadows had the wells not been flowing. As such, it should be considered part of the natural discharge of thermal water from the Steamboat system.

Table 2. *Thermal-water discharge from different sources in the Steamboat Springs area*

Source and date of measurements	Well discharge[1] gal/min	Spring discharge from terraces[2] gal/min	Unseen discharge in Steamboat Ck above Virginia City Highway[3] gal/min	Discharge into Steamboat Ck below Virginia City Highway[4] gal/min	Total discharge from geothermal system gal/min
White (1968) 4/55	300	65	260	485	1110[5]
White (1968) 4/64	--	--	--	--	1385[6]
Collar (1990) 6/88	(380)	3	180[7]	340[7]	523[8]
Collar (1990) 8/88	(380)	3	150	--	--
Collar (1990) 3/89	(380)	3	230	430	663[8]

[1]For 4/55, discharge from wells occurred only at Reno, Mt Rose, and Steamboat Resort and flowed on the surface into Steamboat Creek. Value reported by White (1968) has been adjusted to a volumetric flow rate at 90°C. For this study, the value shown in parentheses is the average of the net production rate for the CPI well field, calculated for an evaporative fluid loss of 12 percent of an average production rate of 4,000 gpm and adjusted to a volumetric flow rate at 90°C with 820 mg/L Cl.

[2]Values from Collar (1990) are for spring 50 on the Low Terrace.

[3]From chloride flux measurements, assuming Cl in thermal and nonthermal water of 820 mg/L and 4 mg/L, respectively.

[4]Same as in 3 above, except that the totals include inflow from thermal springs (85 gpm for 4/55, and Damonte Springs in our study).

[5]Value listed differs from the 1125 value of White (1964) because of lower well discharge calculated for 90°C conditions.

[6]Based on chloride-flux measurements only.

[7]Values shown are averages of 160-190 gpm and 330-340 gpm ranges.

[8]Not counting net production from Caithness Power Incorporated (CPI) wells.

RECENT HYDROLOGIC CHANGES

Hydrologic changes that have occurred in the Steamboat area in recent years are discussed below. These changes include successive years of below-average precipitation (since 1986), general declines in water levels in the shallow ground-water system in much of the South Truckee Meadows and in many stratigraphic test wells in the Steamboat Hills, and cessation of discharge from hot springs at the main terrace (since 1987). Declines in water level in the shallow ground-water system, which have been observed since 1985, result from decreases in recharge from precipitation and seepage from the Steamboat Ditch and increases in pumpage of ground water for domestic use. Geothermal production and injection operations at the CPI and SB GEO well fields began in 1986, with the SB GEO power plant going on line in January 1987 and the CPI plant going on-line in February 1988. These changes are described in this section of the report and apparent cause-and-effect relations are noted. Other less significant influences on spring activity, such as barometric pressure changes and earthquakes, are also discussed in the following section.

Changes in Precipitation

Precipitation data were evaluated primarily for two stations in the Steamboat area - the Reno Airport and the Sky Tavern (fig. 12). The Sky Tavern site was chosen because it lies at an altitude of 7,620 feet in the Galena Creek basin, which is the postulated recharge area for the Steamboat geothermal system. In addition, precipitation records for three sites closest to Sky Tavern (Tahoe City, Truckee Ranger Station, and Boca weather station) with data extending back to the period of White's study were utilized to extend the record for the Sky Tavern site. The methods used are described by Collar (1990). For this purpose we consider a precipitation-year to extend from July to June to match the data tabulations obtained for most other sites. Annual precipitation at the Reno Airport and Sky Tavern sites for the period 1938-1990 is shown in figure 13.

White (1968) considered precipitation to be the most important natural influence on spring discharge during the 1945-1952 period of observation, and noted four scales of precipitation that could affect spring activity at Steamboat. These scales include (1) individual storms, (2) seasonal, (3) annual, and (4) long term. Effects of individual storms on spring discharge and water level were not clearly delineated by White (1968), in part because their effect is probably of short duration (days) and also because of differences in amounts of precipitation between individual storms in the immediate Steamboat area and at the Reno Airport, where most of the data were collected. Changes in precipitation on the scale of individual storms would not affect the overall decline in spring activity since 1987, but could possibly account for short-term changes in some vents.

Seasonal Variations

Significant seasonal variations in spring discharge at the main terrace were recorded during the 1945-52 period (fig. 14). On the basis of quarterly averages, White (1968) concluded that spring discharge was highest during the winter (January-March) and lowest during the summer (July-September). He also noted that weighted-average chloride concentration of this discharge was lowest during the winter and highest during the summer, suggesting that these seasonal variations were due to dilution of the spring discharge by precipitation (or inputs of nonthermal ground water entering the spring vents at shallow depths). White also recognized that warmer outside air temperatures during the summer could enhance evaporation and increase spring chloride relative to winter conditions.

Our review of the quarterly spring-discharge data from White (1968) indicates a pattern of seasonal variation in spring discharge, but little correlation between spring discharge and quarterly averaged

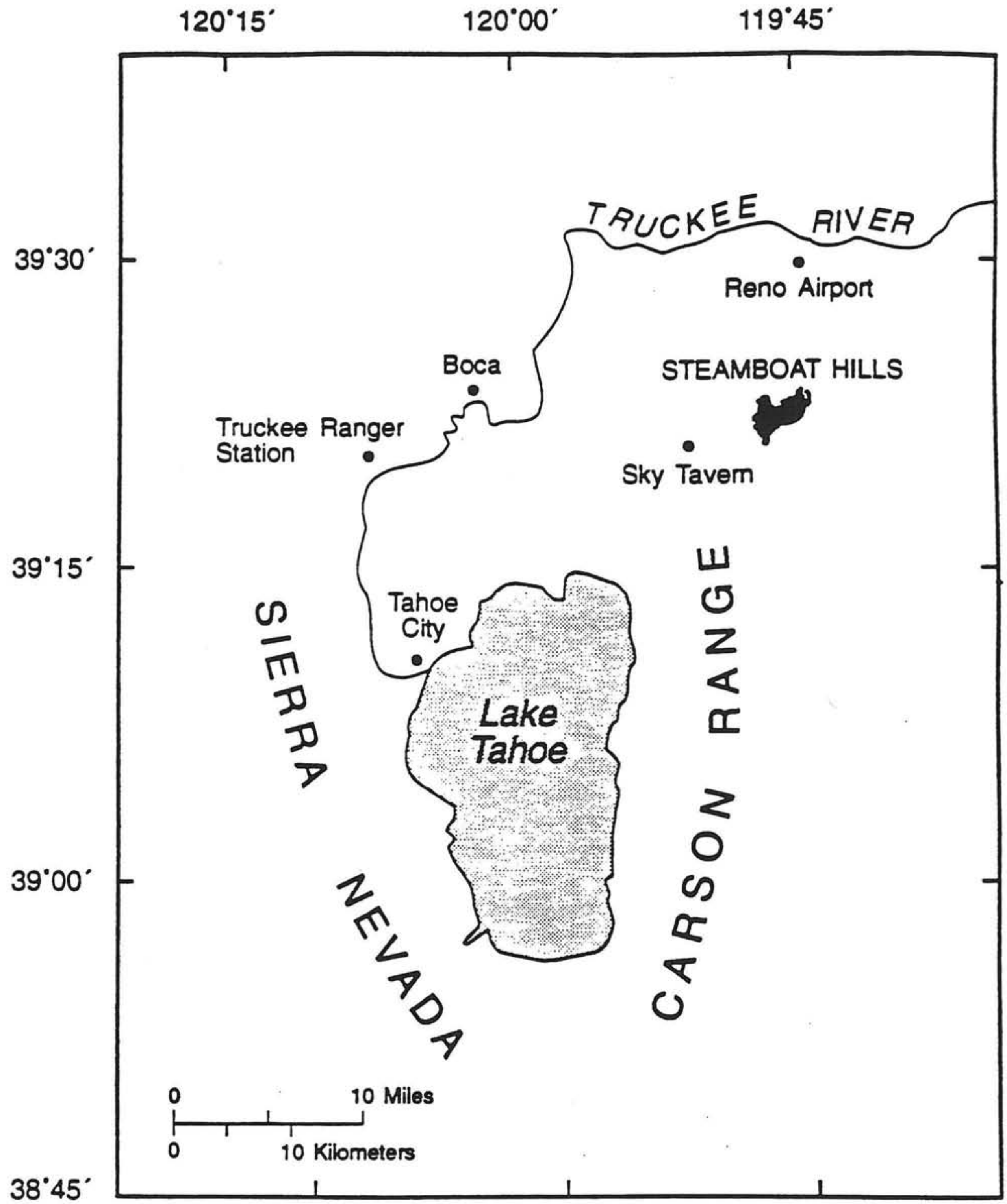


Figure 12. Location of selected precipitation-measurement stations in the vicinity of the Steamboat Hills for which data were used in this study.

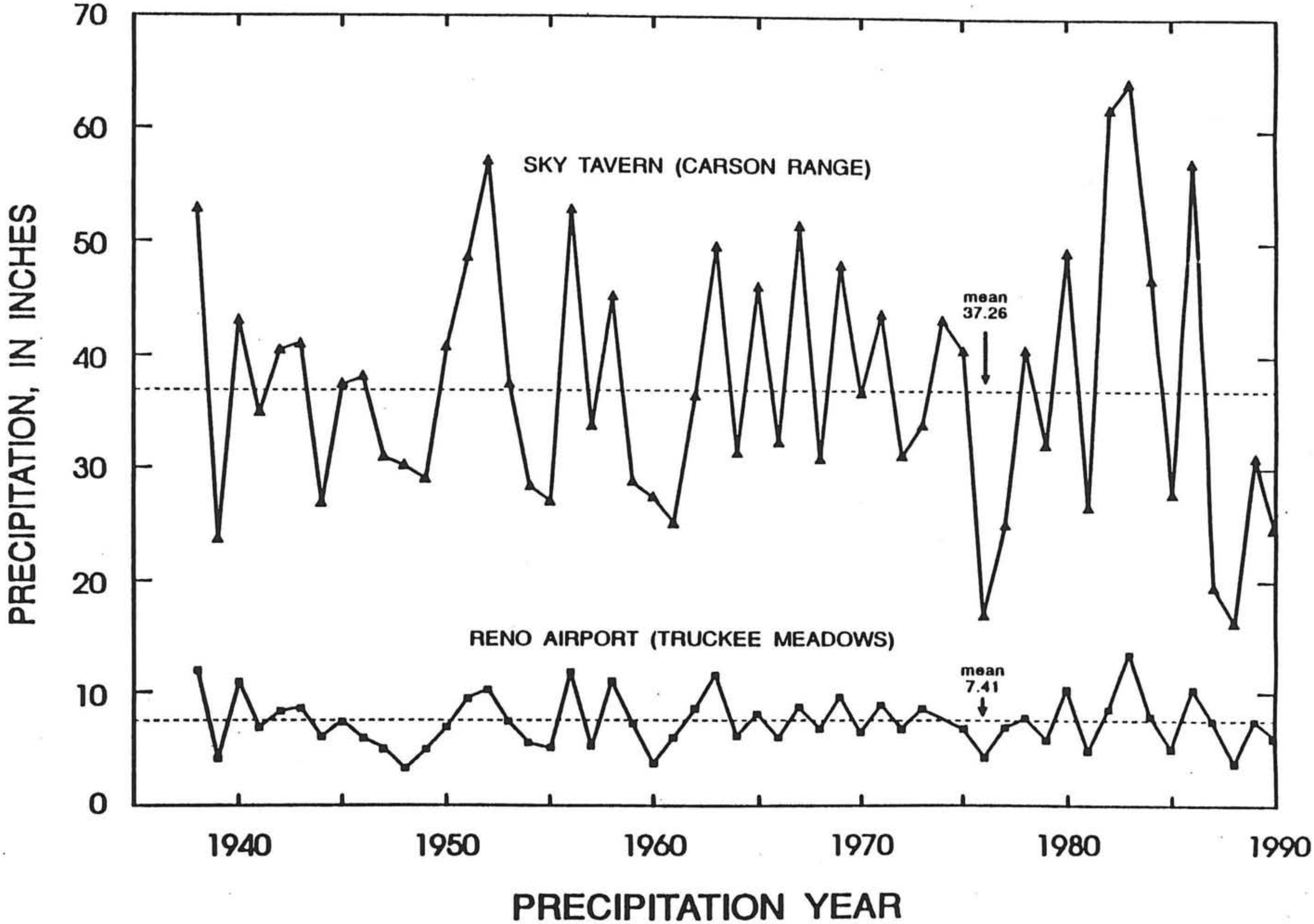


Figure 13. Annual precipitation for the Reno and Sky Tavern stations, 1938 to 1990. Each precipitation-year runs from July to June.

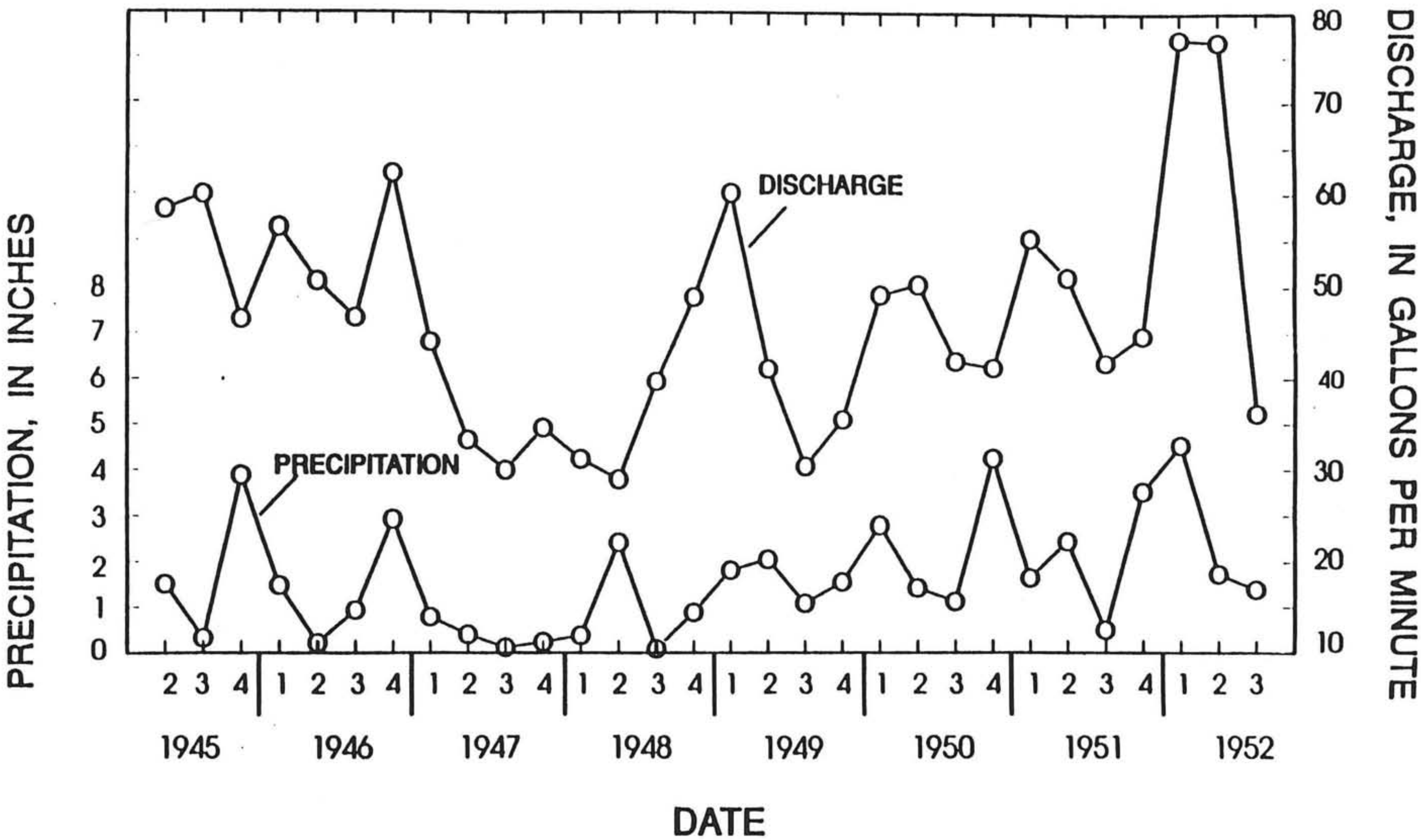


Figure 14. Total spring discharge from the main and low terraces and precipitation at the Reno Airport, averaged by quarters for the period 1945 to 1952 (data from White, 1968).

precipitation. In fact, in only two of the six years of record did the quarter of highest spring discharge coincide with the quarter of highest precipitation, and in only three quarters did lowest discharge coincide with lowest precipitation. This lack of correlation between seasonal variations in spring flow and precipitation probably indicates that interactions between the hot-springs and the ground-water system are complex, involving time delays on different scales at different times of the year superimposed on longer-term effects. Simple mixing of local nonthermal ground water with thermal water beneath the main terrace is unlikely to be significant, given the small range reported for the variation in spring chloride (9 mg/L out of 900 mg/L) and lack of a clear inverse relation between spring flow and chloride concentration.

Both the quarterly averaged discharge record (fig. 14) and the weekly measurement record (plate 4 in White, 1968) show a range in total spring flow at Steamboat from about 30 to 80 gal/min. Only about 5 gal/min of this total is from springs on the low terrace. Although the level of variability in spring discharge is comparable to the decline in discharge delineated since 1987, the recent decline involves a cessation of all spring flow from the main terrace which was never observed during White's study. Thus, the recent decline in hot-spring activity must be related to stresses that either were not present during the 1945-52 period or were present but of smaller magnitude in the past than at present. Significant variations in precipitation occurred during White's study, as did variations in water levels in the shallow ground-water system related to seasonal recharge from irrigation ditches (Cohen and Loetz, 1964). These two influences are the only ones likely to have accounted for the seasonal changes in spring flow measured during the earlier period. During the 1986-1989 period of hot-spring observation, these influences as well as those of ground-water pumpage for domestic use and geothermal fluid production for electric power generation could have affected hot-spring activity at the main terrace.

Annual and Long-Term Variations

Correlations exist between yearly-averaged spring discharge at Steamboat and precipitation at the Reno Airport and Sky Tavern sites over the 1945-52 period (fig. 15). Correlation coefficients for these data sets are 0.40 and 0.48 for the Sky Tavern and Reno Airport sites, respectively. Even higher degrees of correlation (with correlation coefficients approaching 0.9) exist for the 1945-49 and 1949-52 periods considered separately (White, 1968). In effect, there was a shift in the spring flow - precipitation relation during the 1949-50 water year. The reason for this apparent shift is unknown. These data, however, indicate that consecutive years of drought can result in decreased spring activity.

The precipitation records for the 1938-90 period show that drought conditions occurred during parts of White's period of observation and at other times in the past, most notably during the 1976-78 period. This is more clearly seen in plots of cumulative deviation from mean precipitation for the Sky Tavern site (fig. 16), in which periods of above-average precipitation are shown as positively sloping parts of the graph and periods of below-average precipitation correspond to negatively sloping parts. The change in cumulative deviation from 1986-1989 was -46 inches and represents the most severe drought for the period of record. However, the change in cumulative deviation from the mean was only about -30 inches by July 1987, when all but spring 8 on the main terrace had ceased flowing. Periods of comparable drought severity, as indicated by cumulative deviations from the mean precipitation, occurred during White's study and that of Nehring (1980) when spring flow on the main terrace was substantial. Thus, successive years of below normal precipitation cannot, by itself, account for the recent cessation of spring flow at the main terrace. It is likely, therefore, that differences in the distribution of precipitation within each year or other hydrologic factors are involved.

White (1968) noted that L.H. Taylor (unpublished report) estimated the total spring flow from the main terrace at about 180 gal/min in October 1916 and mapped numerous points of

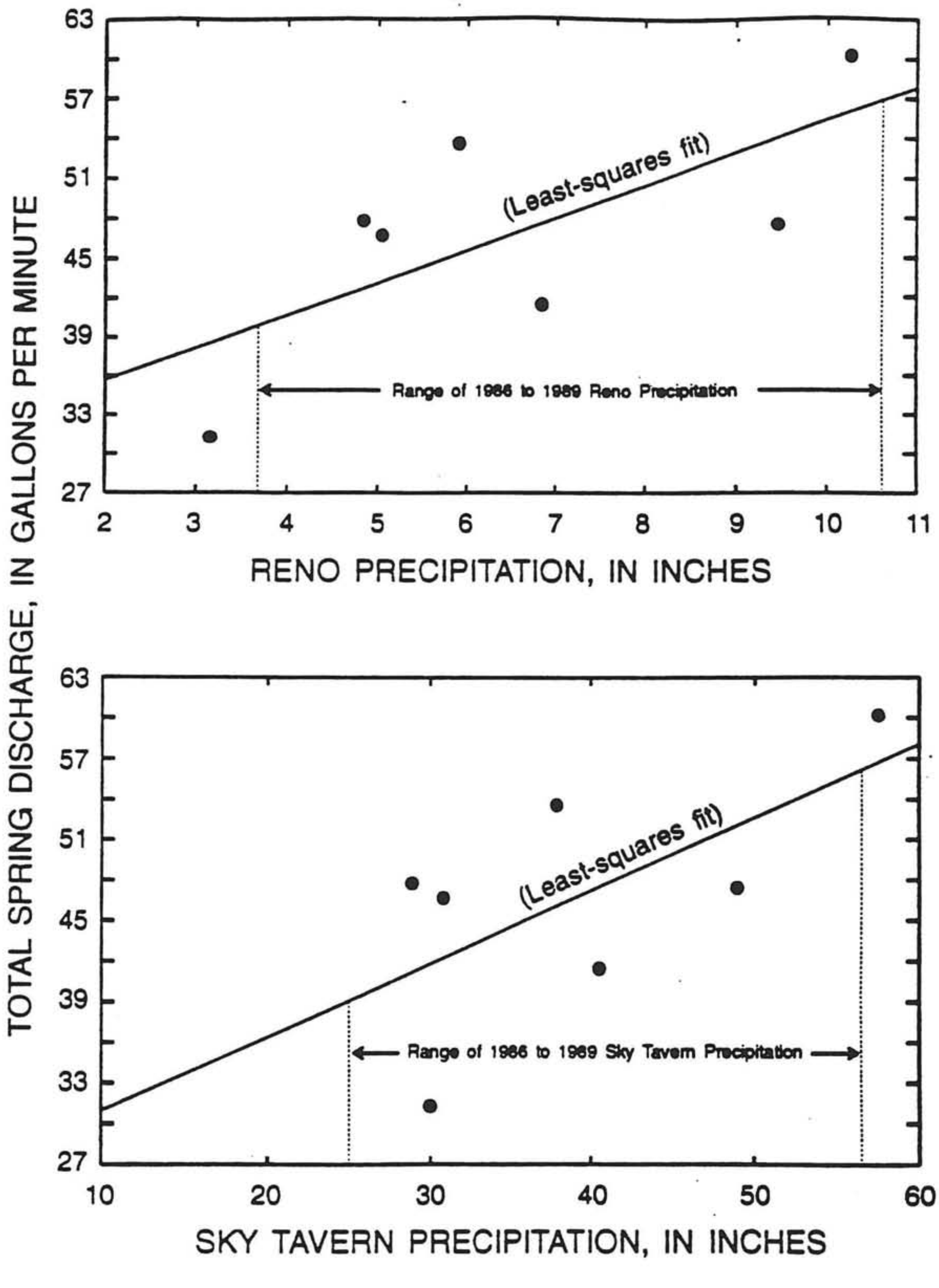


Figure 15. Total spring discharge from the main and low terraces and annual precipitation at the Reno Airport and Sky Tavern stations, 1946 to 1952 (from White, 1968). Annual precipitation is computed for the precipitation year, which runs from July to June.

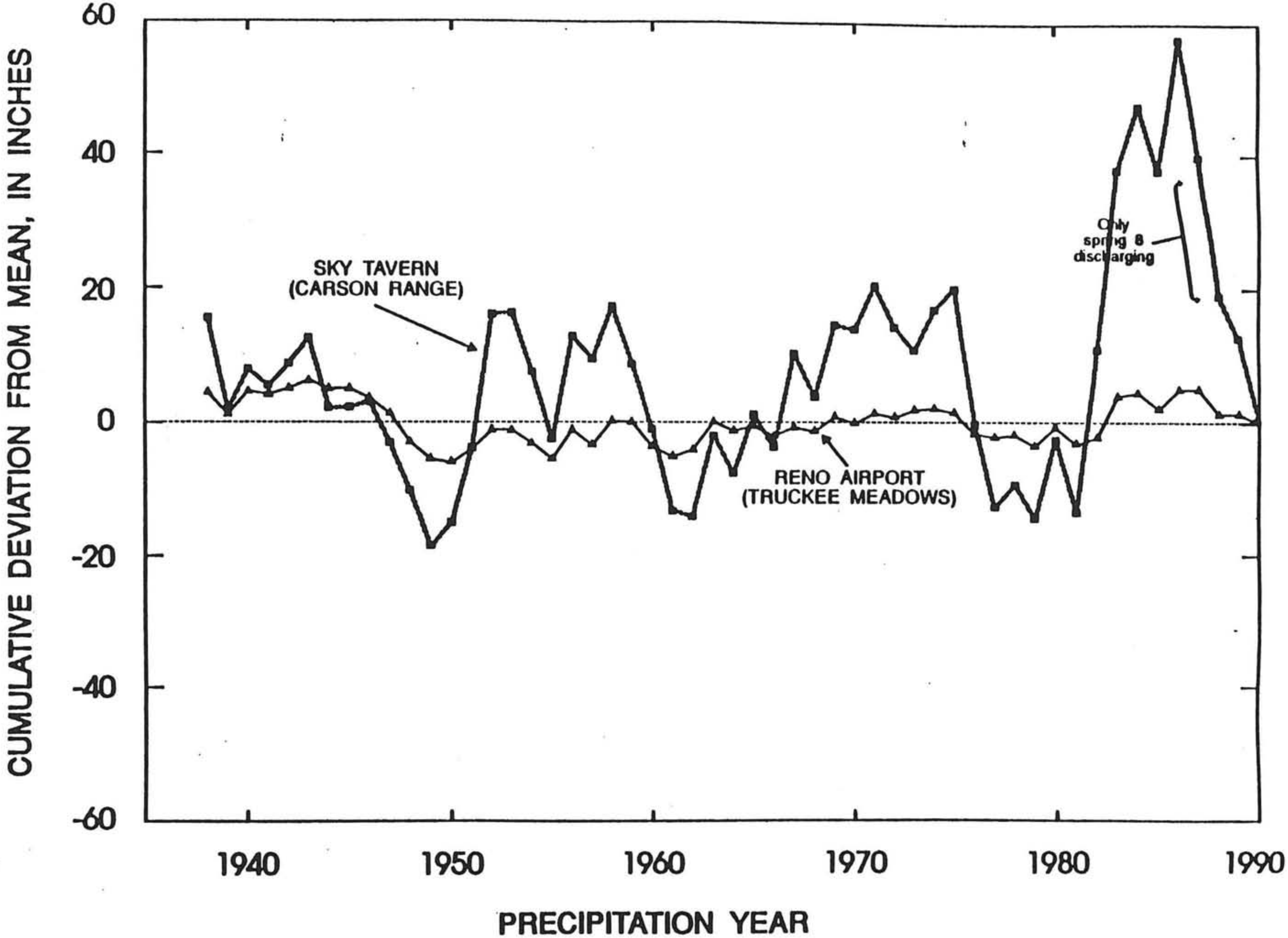


Figure 16. Cumulative deviation from mean annual precipitation for the Reno Airport and Sky Tavern stations, for the period 1938 to 1990. Each precipitation year runs from July to June.

discharge in the northern part of the main terrace that did not exist in the 1945-52 period. White (1968) considered that the difference between total spring discharge in October 1916 and the October average during the 1945-52 period (180 gal/min as compared with 45 gal/min) reflected the influence of two geothermal wells at the Reno Resort (plate 3 and fig. 5), rather than a long-term decline in spring discharge. This inference was based in part on observations of spring responses north of the ACEC (for example, spring 62) to discharge from the Reno wells. In contrast, no response from the Reno-well discharge was observed by White in springs further south within the ACEC.

Since 1952, spring flow from the main terrace has only been quantified during the period from June 1986 to April 1987 (Yeamans, 1987a). The total visually estimated flows from six main-terrace springs during this period ranged from 8-30 gal/min. Although these estimates suggest that total spring flow at this time was lower than during the 1945-1952 period, at least five springs with visible discharge were not included in the totals. Qualitative observations of spring flow and geyser activity during the 1979-1985 period (Appendix A) do not indicate any obvious decline in spring flow compared with the 1945-1952. Thus, systematic changes in spring flow and geyser activity that began in 1986 and have continued until the present, as discussed in a subsequent section, represent a relatively abrupt shift that cannot be accounted for by long-term trends that might accompany natural geologic processes such as self-sealing from mineral deposition.

Changes in Wells in the Shallow Ground-Water System Surrounding the Steamboat Hills

Water levels in the shallow ground-water system surrounding the Steamboat Hills have been monitored in numerous wells, as part of the monitoring programs carried out by the geothermal operators and by the South Truckee Meadows General Improvement District (STMGID). Water-level data from monitored wells are available from monthly measurements for all or part of the 1985-90 period. At some sites where the monitored wells or a nearby domestic wells is pumped periodically, geochemical data are also available. Such data were of interest in our study because head changes in the ground-water system, induced by various factors, could propagate to the geothermal system in the vicinity of the main terrace and Steamboat Creek and affect hot-spring discharge, water levels, and seepage into the creek. Monitoring of these wells by the geothermal operators has also been carried out to detect any movement of injected geothermal water into shallow aquifers.

Water levels in the shallow ground-water system may vary in response to recharge of nonthermal ground-water from precipitation and infiltration from creeks draining the Carson and Virginia Ranges and leakage from Steamboat Ditch and other irrigation ditches (fig. 2). Water-level variations also occur in response to ground-water pumpage for domestic use. Some wells in the South Truckee Meadows tap aquifers with a mixture of thermal and nonthermal ground water, as evidenced by higher-than normal temperatures and chloride concentrations.

STMGID currently operates four production wells to supply ground water to domestic users in the area. Well locations are shown in plate 4. STMGID production well SPW-4 is also shown in figure 17: the other three production wells are situated within distances of 0.3 to 0.8 miles north of STMGID monitor well MW-4 (fig. 17). The record of total pumpage

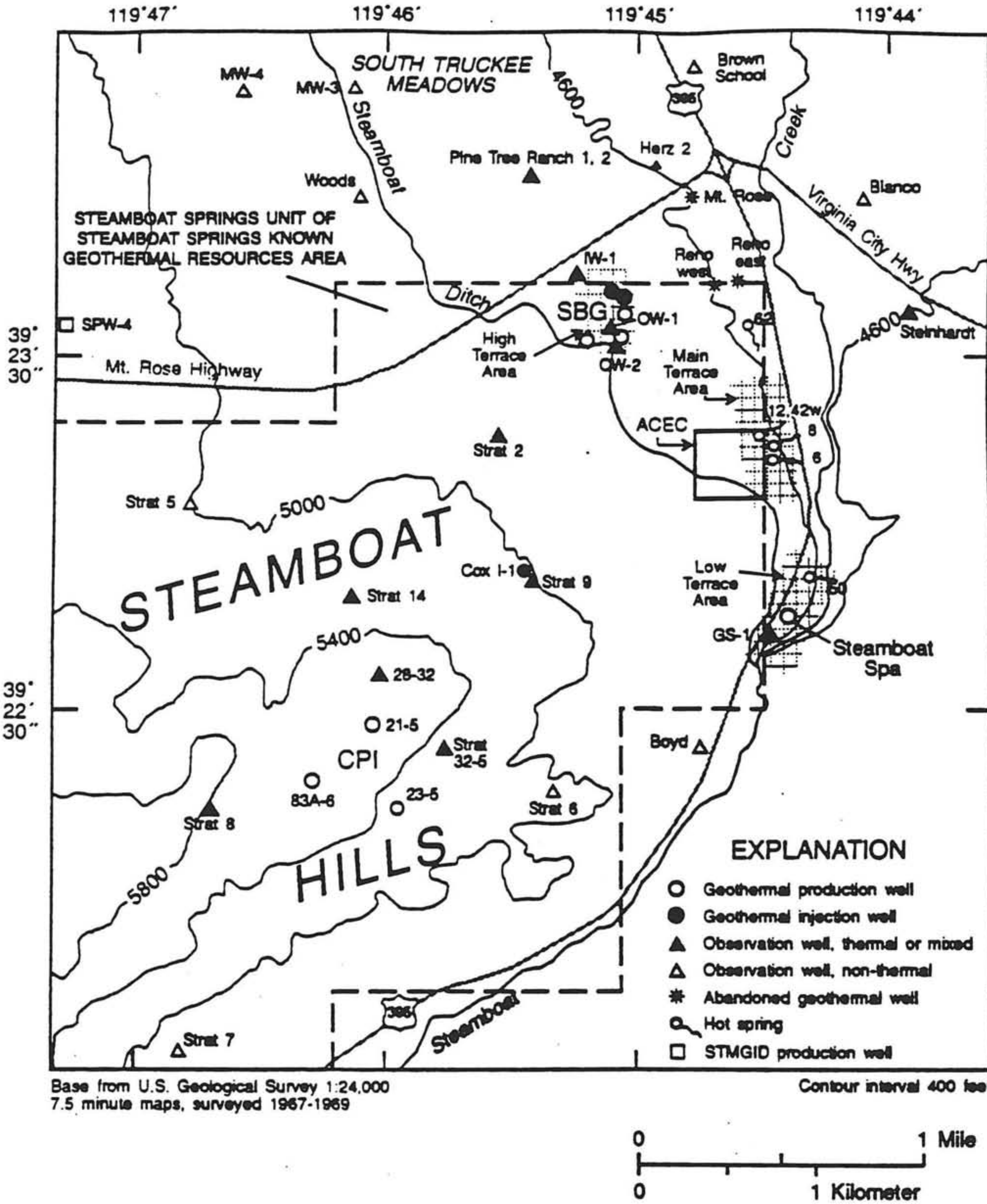


Figure 17. Location of observation wells in the Steamboat Hills and South Truckee Meadows being monitored by Caithness Power, Inc. (CPI) and SB GEO (SBG) geothermal developments. STMGID stands for South Truckee Meadows General Improvement District.

for the STMGID wells (fig. 18) shows summer maxima near 1,000 gal/min and winter minima near 200 gal/min over the period 1985-1988. Three of these wells were drilled in 1984 (SPW-1, SPW-2, SPW-3) to depths of 590-715 feet, with casings extending to depths of 240-260 feet. SPW-4 was drilled in 1981 to a depth of 831 feet and cased to 700 feet. A large increase in drilling of new water wells in the Steamboat area began in the late 1970's and has continued to the present time. Most of these wells were drilled for domestic water supply in areas of new housing west and north of the Steamboat Hills. No records of the amount of water produced from these wells is available; their individual capacities would be less than 1 gal/min. Although the total ground-water production from approximately 100 of these domestic wells would be small compared to that from the STMGID wells, the locations of such wells would have to be considered in evaluating potential effects on water level declines in the ground-water system adjacent to the Steamboat Hills.

The available water-level records for eight wells penetrating the shallow ground-water system surrounding the Steamboat Hills are shown in figures 19-24. Well locations are shown in figure 17, and well completion and temperature information is listed in table 3. Several of these wells produce mixtures of thermal and nonthermal water, as evidenced by temperatures of 43 -76°C and average chloride concentrations of 50-360 mg/L. Such wells show seasonal variations in water level and chloride concentration indicative of changes in the proportions of nonthermal and thermal water at those sites. This is best illustrated by the data for the Pine Tree Ranch wells PTR-1 and PTR-2, located northwest of the high terrace (fig. 17). Well PTR-1 is 110 feet deep and produces water at about 43°C; well PTR-2 is 435 feet deep (but cased only to 101 feet) with a bottom-hole temperature of 76°C. Water-level variations in PTR-1 and chloride changes in a nearby pumped well of unknown depth have been attributed to changes in rates of recharge of low-chloride irrigation water by infiltration from Steamboat Ditch and irrigated lands to the west (Yeamans and Broadhead, 1988). Similar, but damped, water-level changes occur in the deeper PTR-2 well. Both wells show a trend of long-term decline in water level; the decline in seasonally averaged water level in PTR-1 over the 1985-90 period amounts to about 18 feet.

STMGID monitor wells MW-3 (800-ft deep) and MW-4 (400-ft deep) are located northwest of the Pine Tree Ranch wells. Hydrographs for these wells (fig. 20) show damped seasonal fluctuations superimposed on long-term declines of 15-22 feet over the 1985-90 period. Although these wells are closer to Steamboat Ditch than PTR-1 and hence might be expected to show more seasonal fluctuation in water level, their greater depth apparently serves to dampen the seasonal response (as in the case of well PTR-2). Definition of seasonal changes in two of these wells is also limited by measurement intervals greater than 1 month in some years (for example 1985 and 1989).

Wells in the South Truckee Meadows show relatively high water levels in the fall and winter and low water levels in the spring and summer. This pattern is well correlated with seasonal variations in pumpage from the STMGID wells, and presumably other domestic ground-water wells in the area. Rising water levels in the fall and winter probably result from a combination of reduced ground-water pumpage and recharge from the creeks and irrigation ditches which flow from about April until September and peak in mid-summer. Seasonal fluctuations in water level were observed in wells in the South Truckee Meadows during the 1950's, prior to significant ground-water withdrawal from wells (Cohen and Loeltz,

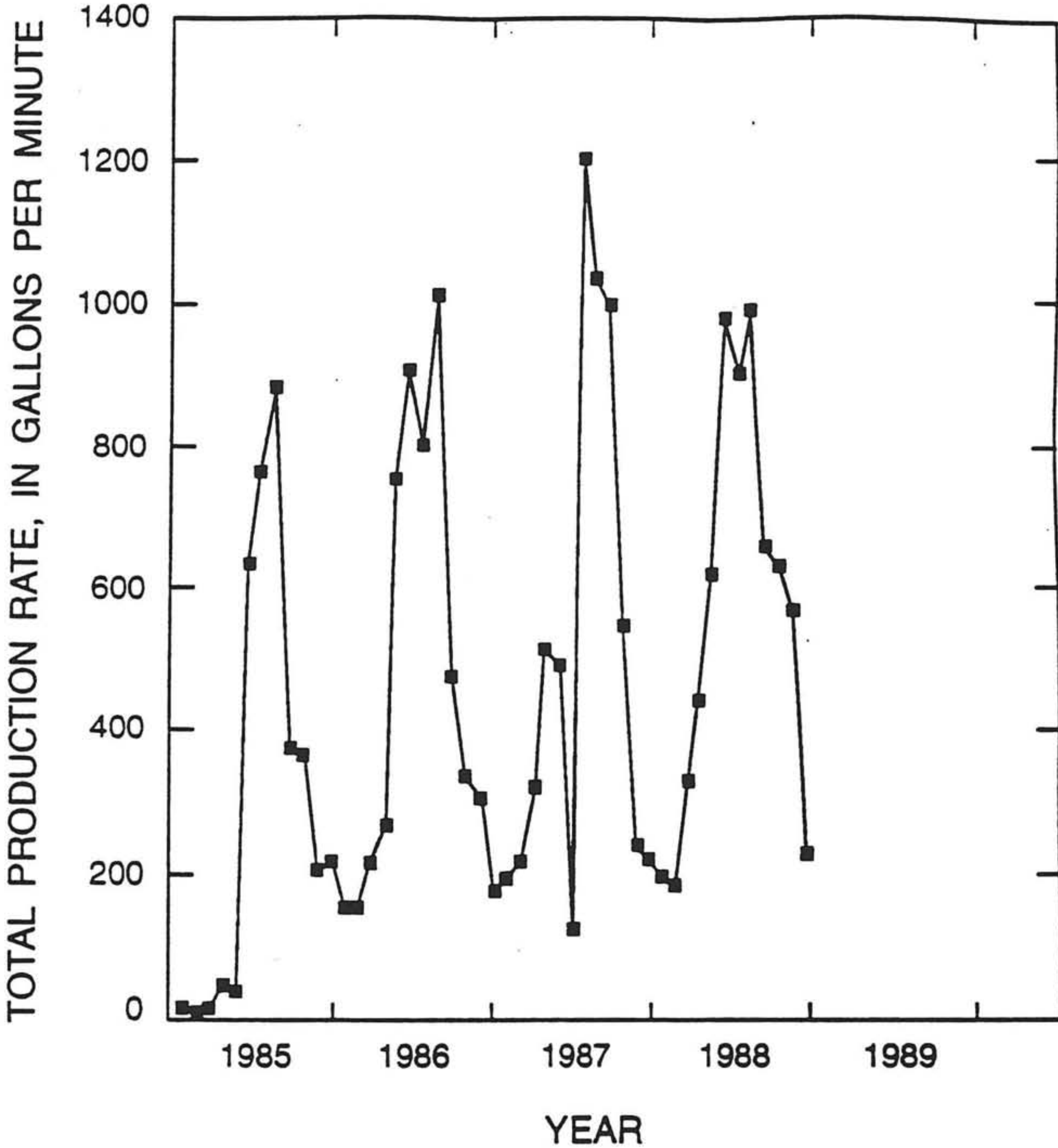


Figure 18. Total production rate from South Truckee Meadows General Improvement District (STMGID) wells.

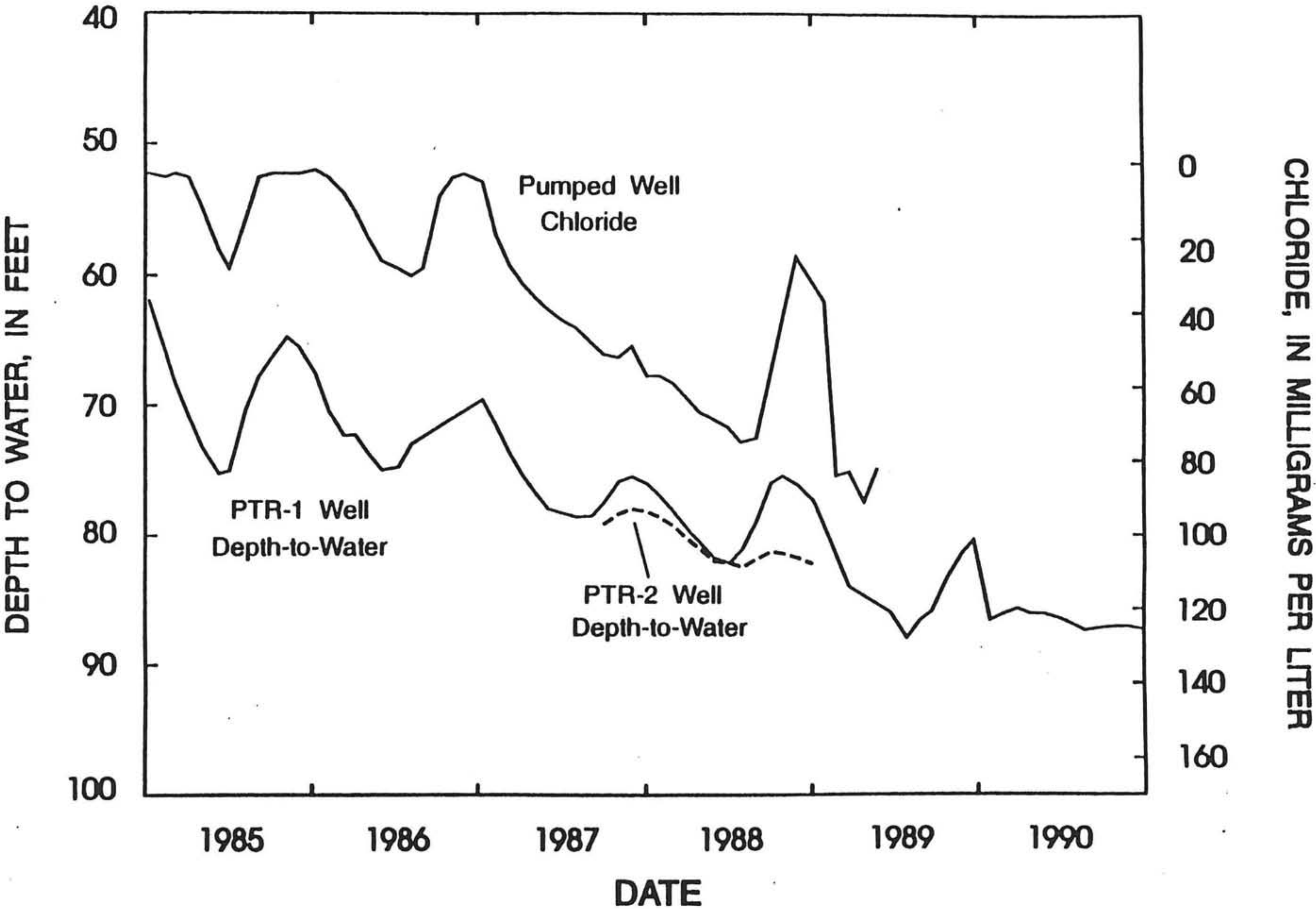


Figure 19. Water levels in Pine Tree Ranch wells PTR-1 and PTR-2 and chloride concentrations in a nearby pumped well of unknown depth, 1984 to 1991.

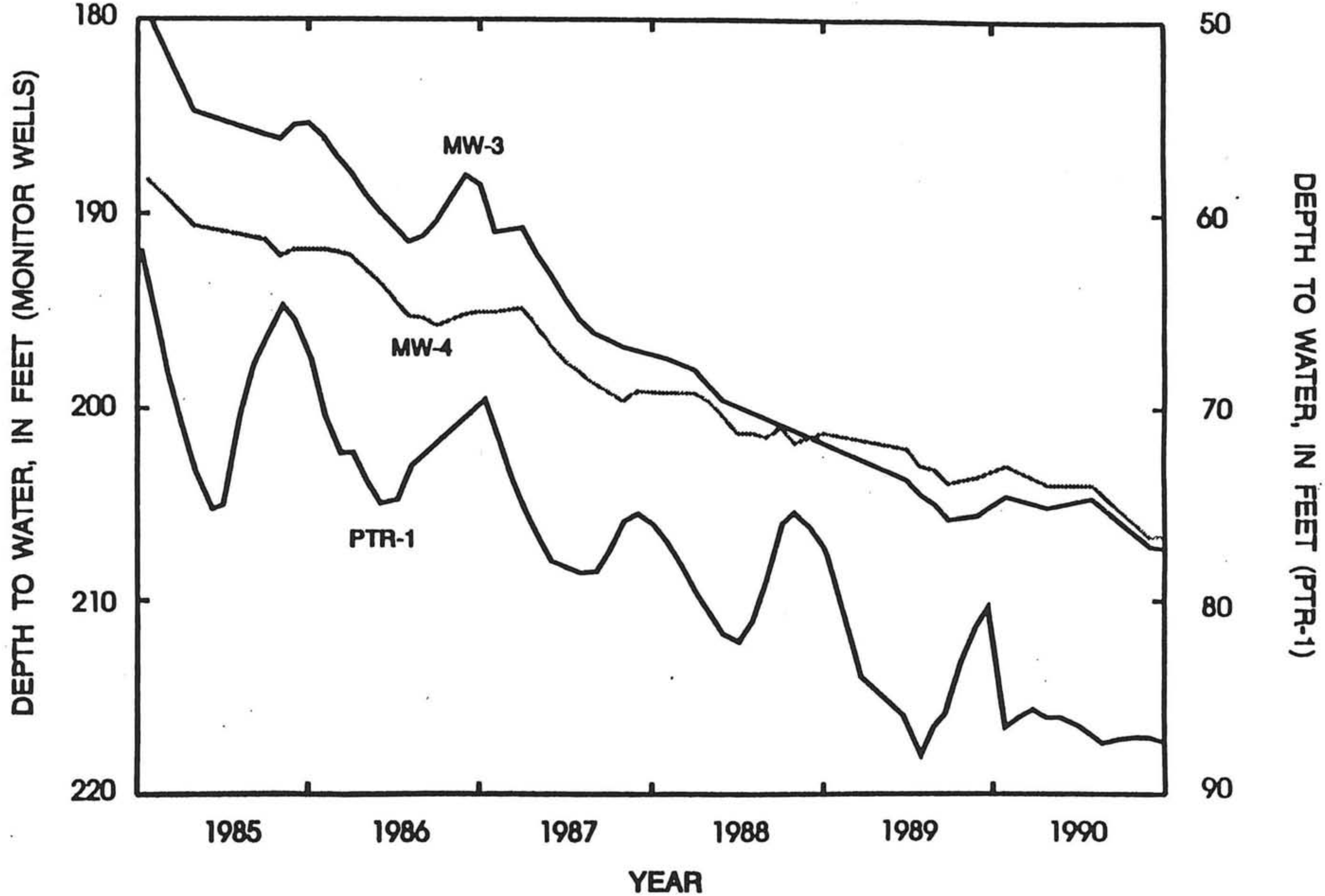


Figure 20. Water levels in the Pine Tree Ranch-1 (PTR-1) well and South Truckee Meadows General Improvement District (STMGID) monitor wells MW-3 and MW-4, 1985-1990.

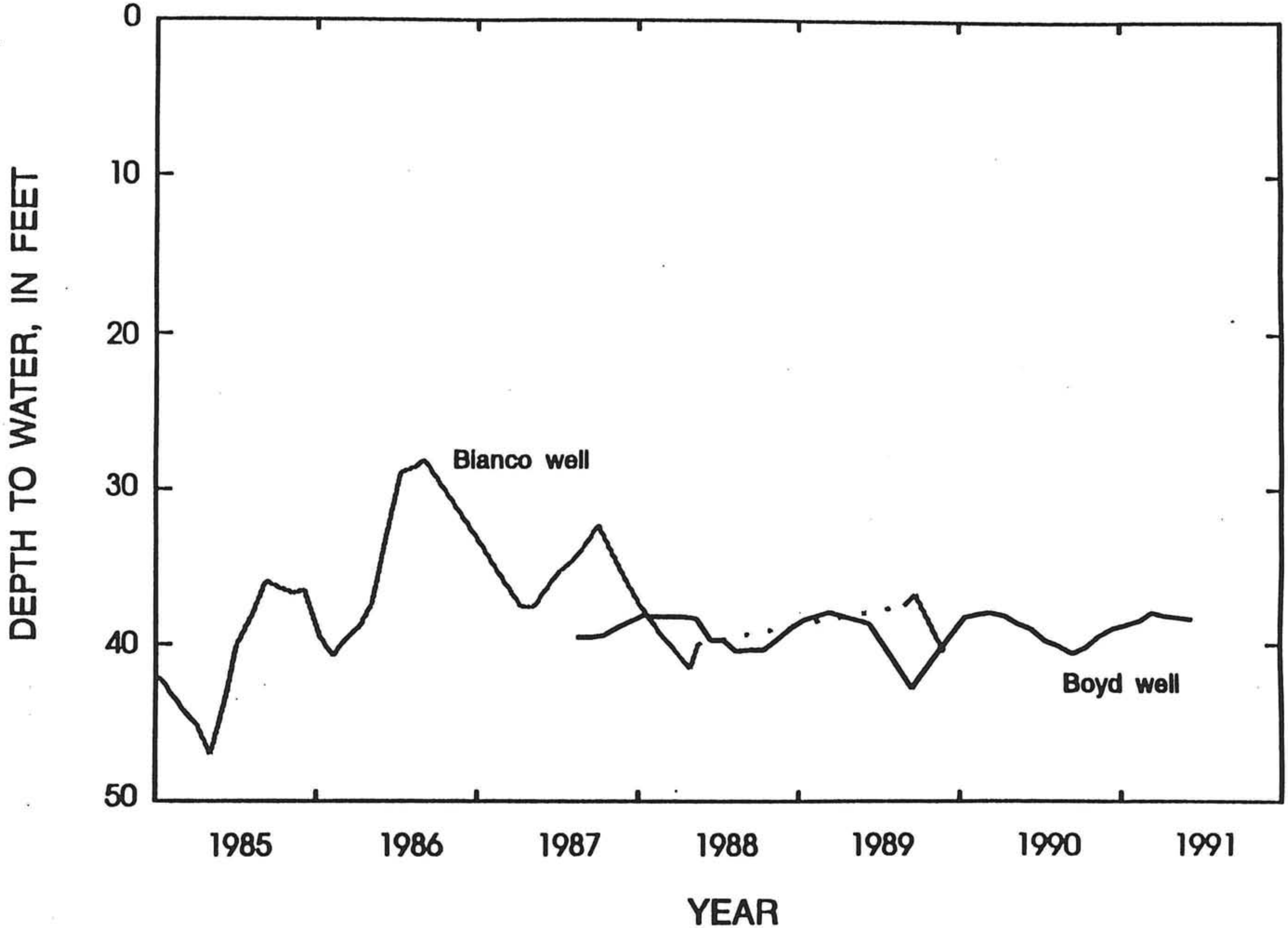


Figure 21. Water levels in the Bianco and Boyd wells, 1985-1991.

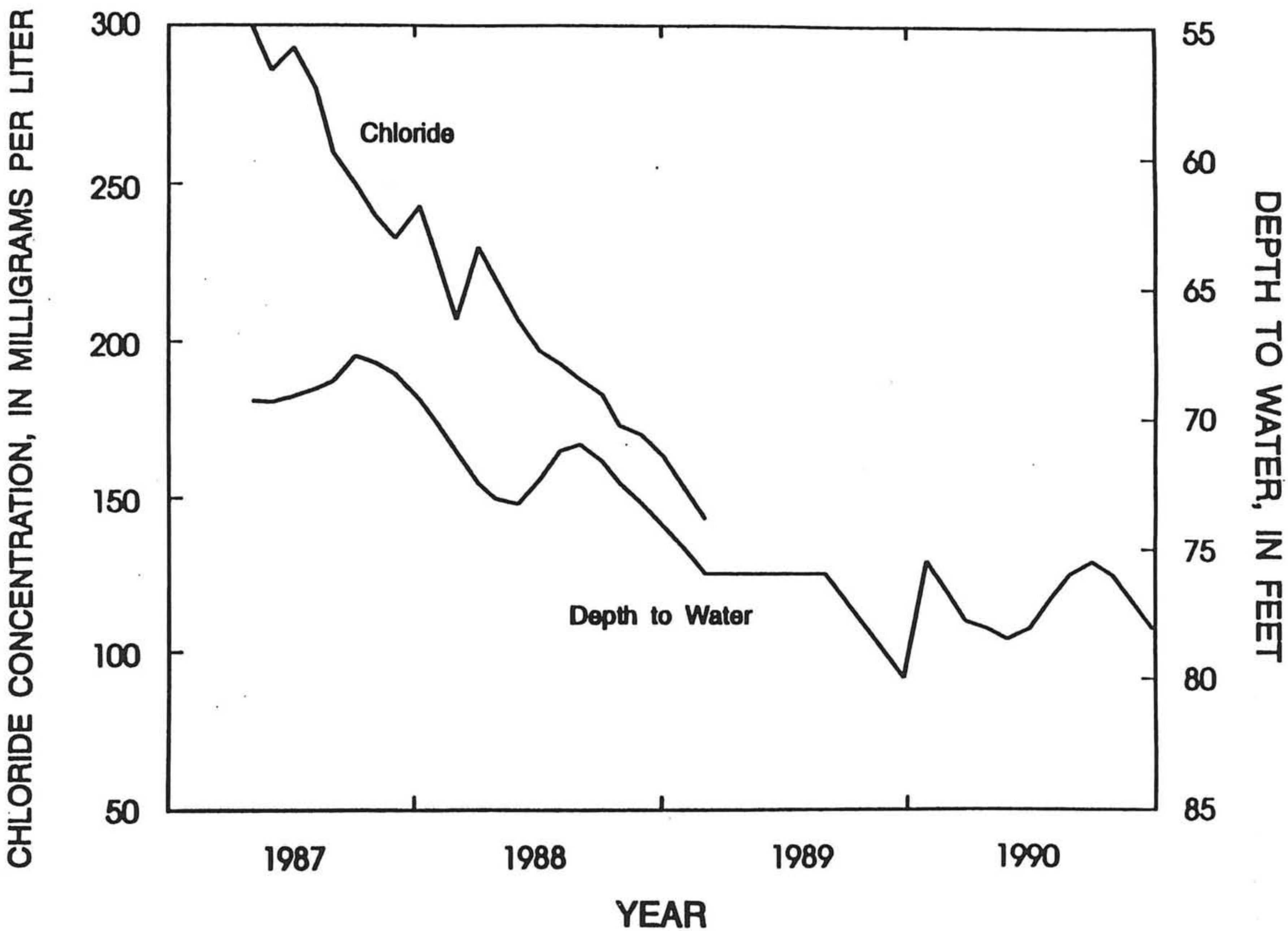


Figure 22. Water level in the Steinhardt well and chloride concentrations in water pumped from this well, 1987-1990.

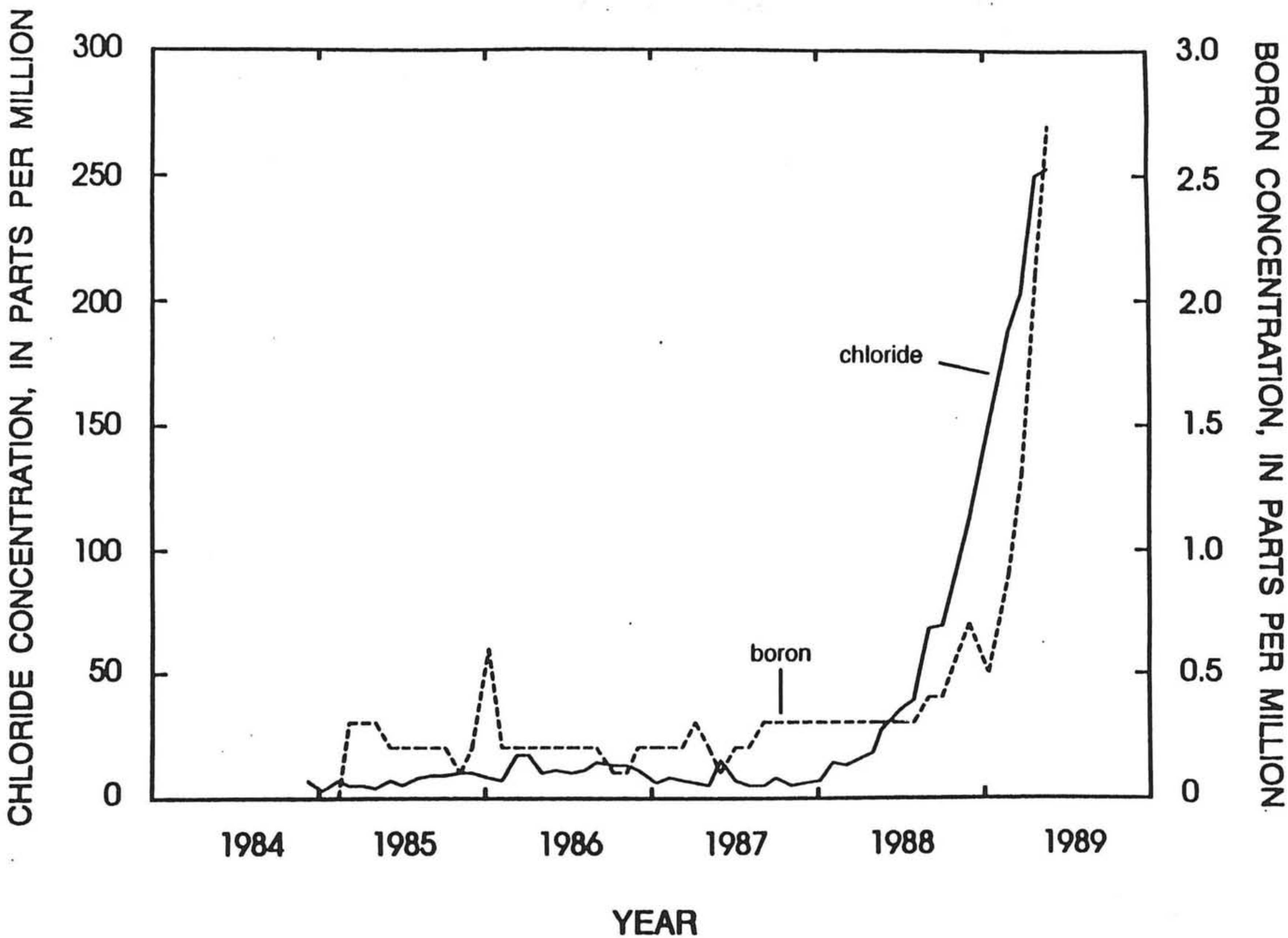


Figure 23. Concentrations of chloride and boron in water pumped from the Brown School well, December 1984 to May 1989.

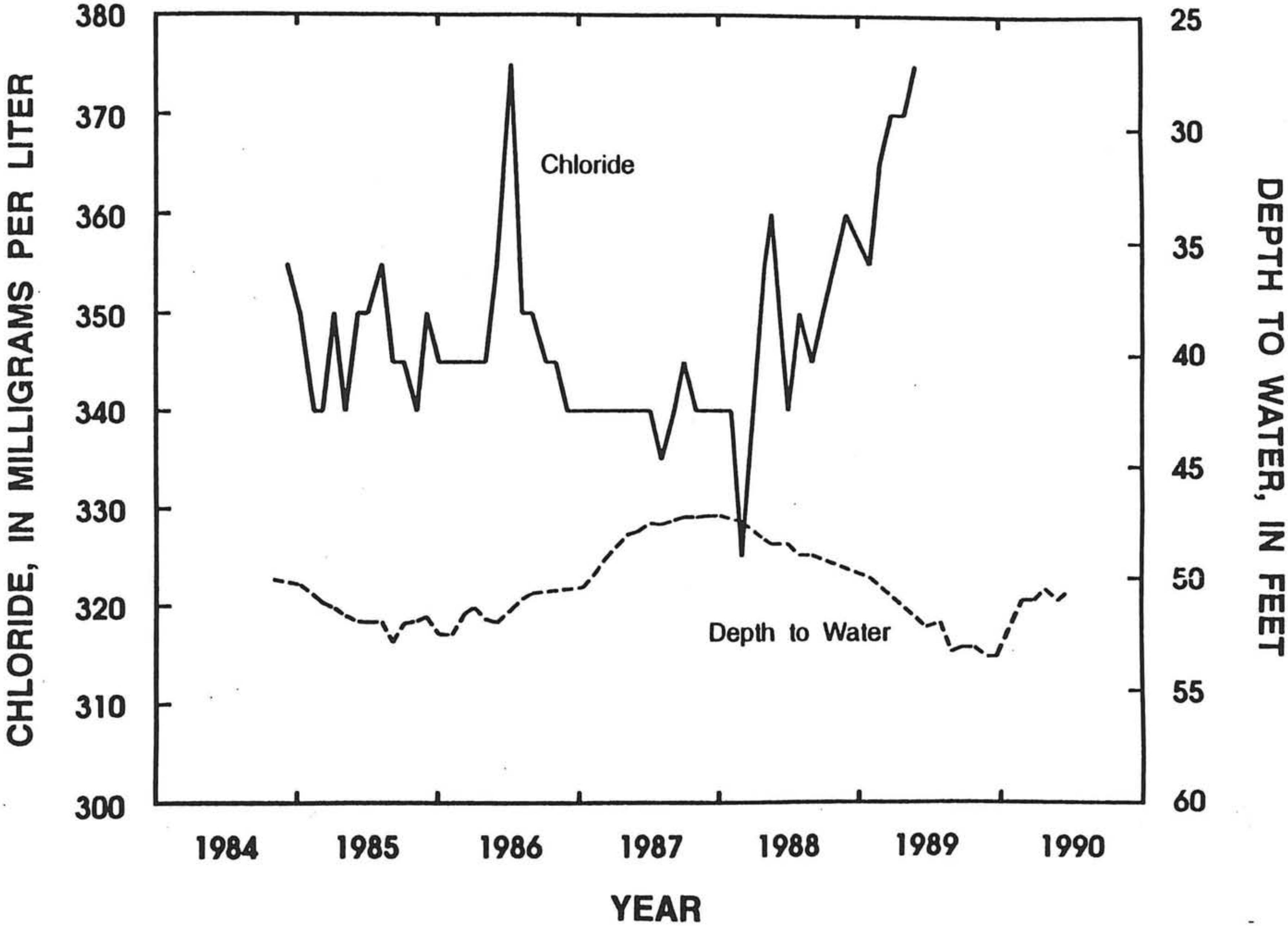


Figure 24. Water levels and concentrations of chloride in the Herz-2 (geothermal) well, 1984-1990.

Table 3. *Data for selected wells completed in the ground-water system of South Truckee Meadows and Pleasant Valley*

[nm, not measured; unk, unknown]

Well Name	Depth[1] (feet)	Temperature[2] (°C)	Chloride[3] (mg/L)	Water-level[4] Decline 1985-89 (feet)
PTR-1	110	43	10-80	25
PTR-2	435	76	nm	nm
MW-3	800	nm	nm	25
MW-4	400	nm	nm	16
Bianco	110	21	nm	~0
Boyd	56	18	16-22	~0
Steinhardt	135	nm	140-300	10
Brown School	unk	16	10-250	unk
Herz-2	155	57	340-370	~0

[1]From Van de Kamp and Goranson (1990).
[2]From Van de Kamp and Goranson (1990).
[3]From data shown in figs. 17-22.
[4]From data shown in figs. 17-22.

1964). Hydrographs from that period show water-level rises beginning sooner (June-July) than in the current situation. Thus, the effects of ground-water pumpage may be to delay the period of water-level recovery until the fall and to cause long-term declines in average water level in the ground-water system. In contrast, records of flow in Steamboat Ditch (van de Kamp and Goranson, 1990) show no clear evidence of changes in seasonal pattern or in rates of flow over the 1984-1989 period.

The available data for shallow nonthermal wells located closer to Steamboat Creek (locations shown in figure 17) show some evidence of seasonal fluctuations, but no long-term declines since 1985. Such wells include the Bianco well northeast of the ACEC and the Boyd well southwest of the ACEC (fig. 21). Water levels in these wells are probably controlled mainly by levels in Steamboat Creek. Data for the mixed-water Steinhardt well (fig. 22), located northeast of the ACEC, show an overall decline in water level since 1987 of about 10 feet and a corresponding decrease in chloride concentration (from 300 mg/L to 140 mg/L). This suggests a decrease in the thermal-water component tapped by this well.

The Brown School well and the Herz geothermal well (Herz-2), located north of the ACEC and on the west side of Steamboat Creek and Highway 395, have both shown increases in chloride concentration beginning in the fall of 1988 (figs. 23 and 24). In the Herz-2 well, this period of increasing chloride was accompanied by a decline in water level. These changes are suggestive of thermal-fluid movement into this region from geothermal fluid injection to the south. However, produced fluid from the SB GEO wells is low in calcium (12 mg/L) and calcium concentrations in the Brown School well have also increased significantly with time (17-194 mg/L, from Goranson and others, 1991). In addition, there has been a decline in water level in the shallower Herz domestic well of about 15 feet between 1986 and late 1988. Thus, other explanations for the chloride increase, such as a decrease in the nonthermal ground-water component in shallow aquifers in this area and inflow of thermal water from sources other than the SB GEO well field, must also be considered.

Changes in Hot Springs and Wells on the Main and Low Terraces

Aside from observations of hot-spring activity described by White (1968) for the 1945-52 period, records of spring discharge and water level at the main and low terrace are available only for parts of the 1977-1990 period, as indicated in Appendix A and figures in this report. This recent record includes measurements and observations made by NDEP, BLM, GOSA, and SDSU personnel, supplemented with observations by Nehring (1980) and Donald Hudson (independent consultant), and measurements and observations reported by Yeamans (1987a). The latter data consists of estimates of the flow rates of six main-terrace springs during part of the 1986-1987 period and short-term measurements of depths to water in several spring vents associated with well tests conducted by Caithness between 1979 and 1987.

Water-level measurements by BLM and NDEP were made in 1986-1988 while water was still visible in the main-terrace spring vents. SDSU personnel measured depths to water in several springs and wells at the terraces using either an electric sounder or a graduated rule in 1988 and 1989. Locations of all spring vents discussed here and elsewhere in this report are shown on plate 1. In the case of spring 6 on the main terrace, the 1988-89 water-level measurements were facilitated by removing sinter rubble from the vent to expose the water surface. On the low terrace, the discharge of the only active spring (spring 50) was also measured by SDSU. No water-level data were collected for this study after August 1989, except for a few measurements on spring 6 made by BLM in late 1989. Significant gaps in the data exist for time periods between SDSU and BLM measurements and during much of the 1988-1989 period.

The hydrograph for spring 6 is plotted in figure 25 for the period 1986-1989. More limited records for other springs on the main terrace (for example springs 12 and 42w, fig. 4) indicate that the general pattern of change in the spring 6 record is representative of water-level variations on the main terrace. Periods when spring 6 was flowing are indicated by zero depth-to-water. More detailed plots of the hot-spring data collected and compiled during this study are included in Appendix A. Also shown in figure 25 is the hydrograph for well PTR-1 and intervals of discharge from the SB GEO and CPI well fields, for which more information is given in tables 4 and 5.

Onset of the Decline in Hot-Spring Activity

Spring 6 and numerous other main-terrace springs that formerly discharged continuously or on a regular basis ceased flowing during CPI discharge interval 1 in March-May 1986. These changes appear anomalous compared with earlier years, as discussed below. Weekly observations between September 1983 and August 1984 reported by Lyles (1985), coupled with more recent observations listed in Appendix A suggest that spring 24 discharged continuously, or on a regular basis, for about two and a half years prior to the time it stopped flowing in April 1986. Shortly after the end of CPI discharge interval 1, most of the main-terrace springs experienced rising water levels or renewed discharge for several months. Springs 23n and 40 began to geyser in the summer of 1986 after a period of quiescence (Appendix A, Yeamans, 1986b). The record of estimated spring flow from the main terrace between June 1986 and April 1987 from Yeamans (1987a), as shown in figure 26, indicates that the combined discharge from the six monitored springs reached a peak in November 1986 of about 30 gal/min and subsequently declined to about 8 gal/min by April 1987. The overall pattern of variation in spring flow matches that observed by White (1968) of highest flow in the fall and winter, and thus appears to follow the usual seasonal trend. There is little evidence of correlation with the precipitation records for the Reno Airport or the Sky Tavern sites (fig. 26), but such short-term correlations were also not observed during the 1945-52 period.

The data from Yeamans (1987a) represents the combined discharge of springs 4, 6, 8, 10, 42, and 16se. As noted previously, however, other main-terrace springs were also flowing during this period. Yeamans (1987a) notes incidental observations of flows of 40-60 gal/min from spring 24 between October 1986 and February 1987 and eruptions from spring 40 and small flows from spring 2 during the fall of 1986. If the estimates of flow from spring 24 are accurate, the indicated total spring flow during the winter period is within the range of values reported for the 1945-52 period. This would suggest that only the estimated spring flows during the spring of 1986 and the spring of 1987 and thereafter are anomalously low. However, the inference that the long-term decline in hot-spring activity did not start until the spring of 1987 must be qualified because the accuracy of the spring discharge estimates of

(Expanded version included with Plates)

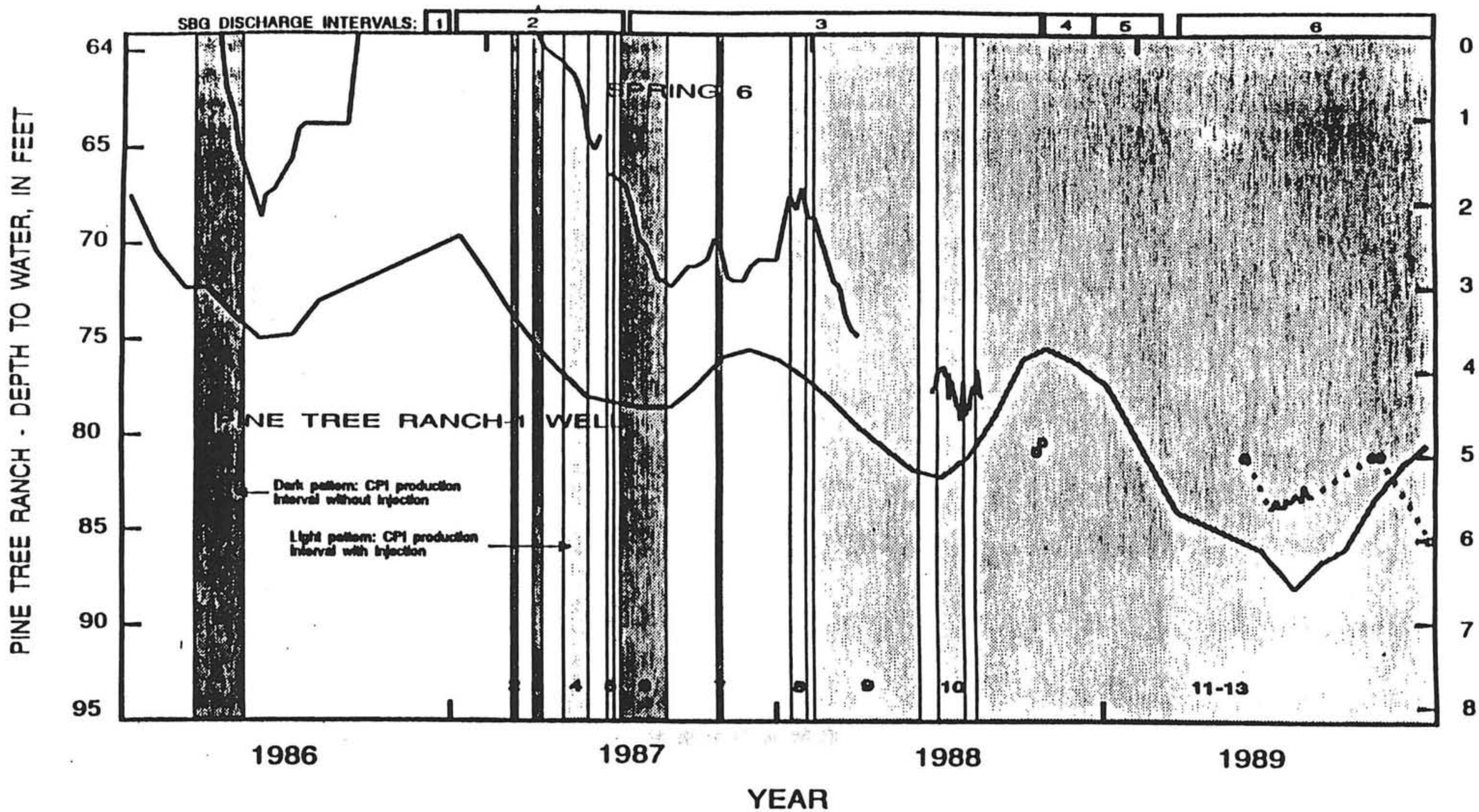


Figure 25. Water levels in spring 6 on the main terrace and the Pine Tree Ranch-1 (PTR-1) well, 1986-1989. Circles represent isolated measured water levels. Dots represent assumed trends of water levels between measurement intervals in 1989. See tables 4 and 5 for descriptions of Caithness Power Incorporated (CPI) and SB GEO (SBG) intervals.

Table 4. *Intervals of discharge from Caithness Power Incorporated production wells since 1986*

Interval	Production[1] wells	Injection well	Begin date	End date	Comments[2]
1	SB-1	None	3/21/86	5/15/86	NP=815 gal/min
2	SB-1	None	3/9/87	3/16/87	NP=620-810 gal/min
3	SB-1	None	4/2/87	4/13/87	
4	23-5	Cox I-1	5/6/87	6/3/87	No injection 5/17-19 NP=310 gal/min
5	23-5	Cox I-1	6/24/87	7/3/87	NP=310 gal/min
6	SB-1	None	7/9/87	8/29/87	NP=500 gal/min
7	83A-6	None	10/24/87	10/30/87	NP=970-2460 gal/min
8	23-5 83A-6	Cox I-1 Cox I-1	1/14/88 1/28/88	1/28/88 1/31/88	NP=340 gal/min
9	83A-6 23-5 21-5	Cox I-1	2/11/88	6/6/88	23-5, 83a-6 off 3/4-7 21-5 off 3/4-5
10	as above	Cox I-1	6/27/88	7/26/88	
11	as above	Cox I-1	8/8/88	11/25/88	23-5 off 9/15-10/17 83A-6 off 10/18-24 21-5 off 10/24-11/1
12	as above	Cox I-1	12/2/88	4/18/89	23/5 off 12/27-30 21-5 off 12/27-30
13	as above	Cox I-1	4/21/89	--[3]	

[1]Well SB-1 (Steamboat No. 1) redrilled 12/87 and renamed 21-5.
[2]Dates of production intervals and values of net production (NP) from Yeamans (1987a, 1987e), Berkeley Group (1987), Bureau of Land Management (unpub. data), Thermasource (1987), B. Metcalf (Collar, 1990), and Caithness Power Incorporated monthly production reports.
[3]All wells on-line as of 8/89.

Table 5. *Intervals of discharge from SB GEQ production wells since 1986*

Interval	Production wells	Injection wells	Begin date	End date	Injection rate (gal/min)[1]
1	PW-1, PW-2, PW-3	IW-3	12/2/86	12/29/86	unknown[2]
2	as above	IW-3	1/5/87	7/6/87	3321[3]
3	as above	IW-3	7/12/87	10/20/88	3158[4]
4	as above	IW-3	10/23/88	12/19/88	3218[5]
5	as above	IW-3 IW-2	12/19/88	3/4/89	756[6] 2142[6]
6	as above	IW-2	3/24/89	--[7]	

[1]Average calculated from daily average values reported by SB GEO (formerly Ormat Energy Systems, Inc.).
[2]Only two wells operating concurrently; test dates from GeothermEx, 1987.
[3]Power plant on-line; excludes July 1987 data.
[4]Power plant on-line; excludes July 1987 and October 1988 data.
[5]Power plant on-line; injection rates estimated from Nevada Division of Environmental Protection (unpub. cor.).
[6]Injection rates estimated.
[7]Wells still on-line as of 8/89.

(Expanded version included with Plates)

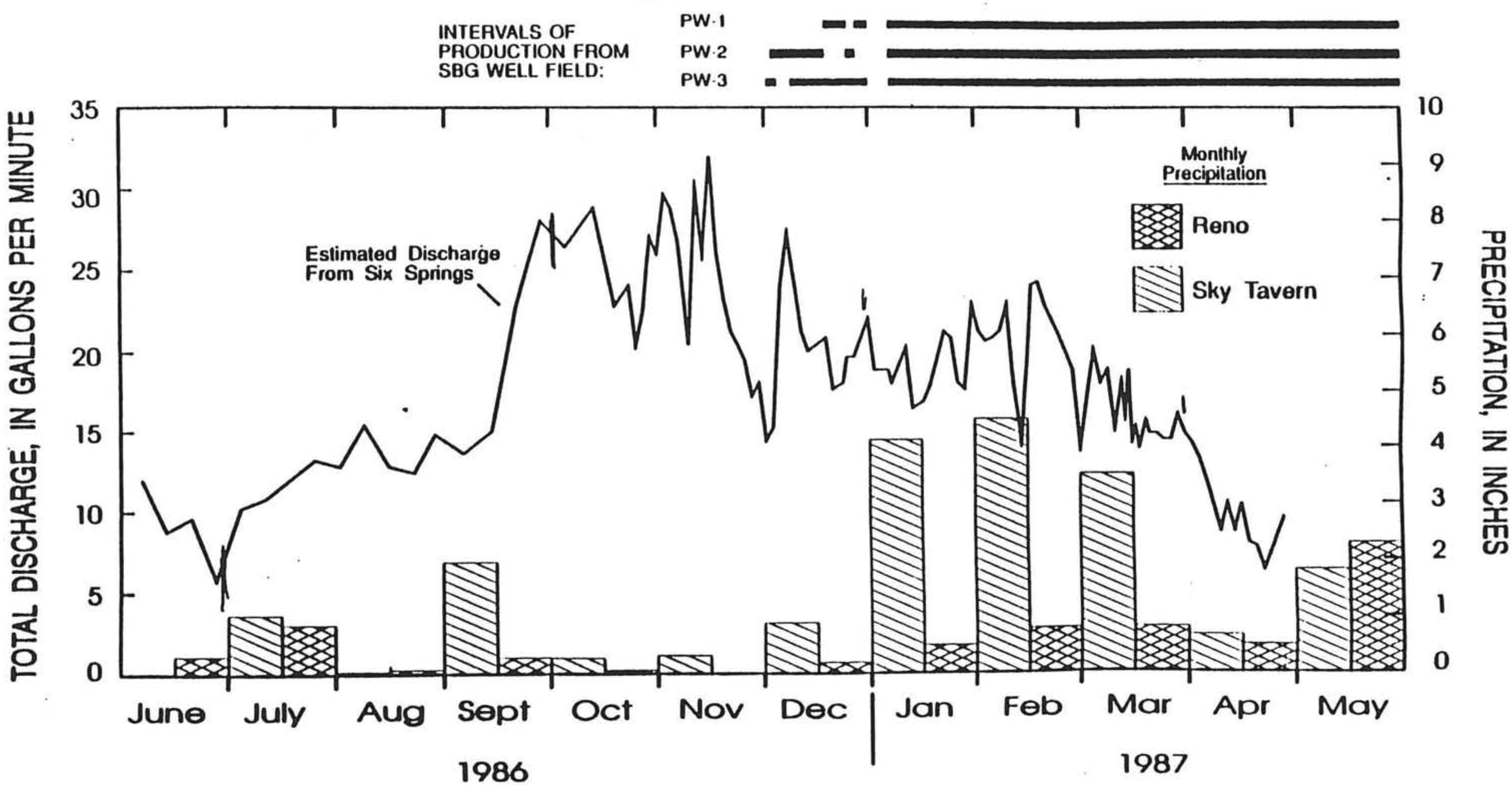


Figure 26. Visually estimated discharge from six springs on the main terrace and intervals of production from wells in the SB GEO (SBG) well field from June 1986 to April 1987 (from Yeamans, 1987a). Also shown is the monthly precipitation at the Reno Airport and Sky Tavern sites.

Yeamans (1987a) is indeterminate.

Collar (1990) describes decreases in discharge and water level in several springs during the mid-November 1986 to late February 1987 period. Although the most significant decrease in spring flow occurred in November and the information in Yeamans (1987a) indicates that well-testing and start-up operations did not begin until December, it is possible that some of the SB GEO wells were discharged in November. Detailed records of production during this period apparently do not exist. Between December 1986 and February 1987, water-levels declined in many main-terrace springs (for example, springs 4, 16, 16se, and 8nw), but other springs continued to flow.

A second period of noticeable decline in spring flow beginning in March 1987 was accompanied by full-scale production from the SB GEO field and the resumption of well testing at the CPI field. Over the 6-month period from March to August 1987, most or all of the main-terrace springs experienced generally declining water levels and subsequently became dry. Water levels in spring 8, the only spring on the main terrace to flow continuously during the 1945-52 period, remained relatively high until February 1988, when the spring was reported dry at a depth of about 1 foot (fig. 27). This designation refers to the fact that the measuring device was lowered to 1 foot below the spring orifice but failed to detect any water.

Seasonal and Long-Term Trends

Evidence of the influence of several factors can be seen in the records of seasonal and long-term change in water levels in springs such as 6 and 8. The general pattern of change observed in spring 6 over the 1986-1989 period is one of relatively high water levels in the winter and low water levels in the summer, superimposed on a overall decline of six feet. As such, there is a general correlation between the spring 6 hydrograph and the hydrograph for the PTR-1 well (fig. 25). This apparent seasonal pattern of water-level change in spring 6 is similar to the seasonal variation in spring flow noted by White (1968) for the 1945-1952 period (fig. 14). After 1988, the data for water-level spring 6 are too sparse to delineate a seasonal pattern, if one exists, except for the period of water-level rise in the second part of 1989. On the other hand, the data for other springs in the ACEC such as 8, 12, and 42w (figs. 4 and 27, and Appendix A) do not show any obvious seasonal cycles except perhaps during the spring 1986-spring 1987 period. The available data for these springs after mid-1987 make such determinations speculative.

Correlations can be seen between changes in water level in many springs and intervals of discharge at the geothermal well fields, as discussed in more detail below. The two periods of adequately documented water-level rise (in the fall of 1986 and 1987) are associated both with the expected seasonal recovery of the shallow ground-water system and with the cessation of well testing operations at the CPI field. However, the recovery of about 1 foot recorded in spring 6 in the fall of 1989 is noteworthy because it occurs during a period of relatively constant production at both geothermal well fields and there are corresponding recoveries in strat wells tapping the geothermal system in the Steamboat Hills (as discussed subsequently).

(Expanded version included with Plates)

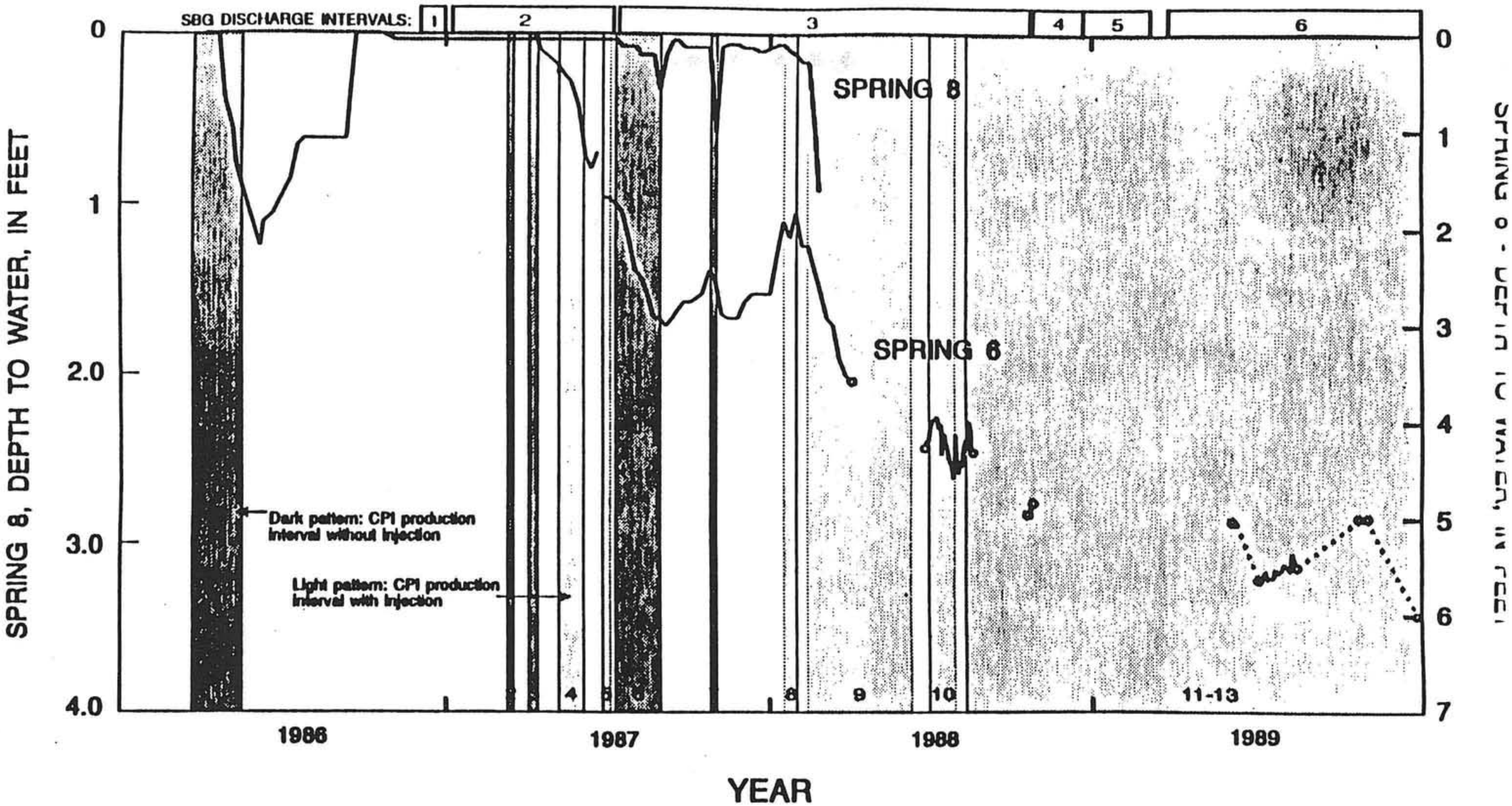


Figure 27. Water levels in spring 6 and spring 8 on the main terrace, 1986-1989. Circles represent individual measured water levels. Dots represent assumed trends of the spring 6 water levels between measurements in 1989. See tables 4 and 5 for descriptions of Caithness Power Incorporated (CPI) and SB GEO (SBG) discharge intervals.

The long-term trend for spring 6 shows a decline in water level of about 6 feet by the end of 1989. The overall decline for other springs on the main terrace is variable, including 13 feet for spring 42w and 17 feet for spring 12 (fig. 4). There is as yet no satisfactory explanation for these differences in overall decline. Factors which may be involved include differences in water temperature and density in different spring conduits and differences in vertical permeability in the conduits and horizontal permeability in the adjacent formations. The permeability factors should affect the head loss as fluid flows upward in each conduit and laterally into the wall rock. There may also be fracture connections between different conduits at depth which allow flow from one to another. Differences in altitude between springs on the main terrace may be indicative of differences in permeability in and adjacent to each conduit. For example, the spring 6 vent is about 20 feet lower in altitude than the spring 12 vent. In general, the altitude of the piezometric surface, as delineated by spring altitudes and water levels in wells on the main terrace prior to geothermal development in the Steamboat area, sloped eastward towards Steamboat Creek with an overall drop in altitude of about 100 feet.

During this study, water-level measurements were made in well GS-8 at the base of the main terrace, and in well GS-1 and an unnamed well on the low terrace (locations on plate 1). Other wells in these areas are either sealed shut or filled with debris. Comparison of water levels reported by White (1968) with recent measurements indicates overall declines of 4-7 feet in these wells through 1989, but only 1-3 feet between 1988 and 1989. The Byers well on the west side of the main terrace was been monitored in 1990 and 1991 by the USGS and Caithness; comparisons of depth-to-water measurements during this recent monitoring period with a measurement made in 1985 indicate a decline of about 40 feet (Colin Goranson, written commun., 1991; Donald H. Schaefer, written commun., 1991). The well is approximately 100 feet deep and reaches a maximum temperature of about 120°C. Data from White (1968) on well GS-3, drilled next to the Byers well to a depth of 686 feet, indicate that neither well penetrates the main fracture system through which high-chloride thermal water flows upward to the main-terrace hot springs.

Short-Term Fluctuations

A consistent pattern of correlation between intervals of CPI well discharge and short-term water-level fluctuations in spring 6 exists for the 1986-1988 period (fig. 25). The clearest response is that for interval 1, which involved a two month test of Steamboat No. 1 (later recompleted and renamed 21-5). The average well discharge during this period was about 815 gal/min and no fluid was reinjected (table 4). The decline in water level in spring 6 during and following CPI interval 1 was approximately 2 feet, although some additional decrease in head within the spring conduit must also have accompanied the change from flowing to non-flowing conditions. The net rate of production (production minus injection) during subsequent CPI discharge intervals was 300-500 gal/min, except for a few relatively short discharge intervals with higher net production. The production/injection rate histories for each well field are discussed further in the next section of the report. Other examples of water-level declines and recoveries associated with CPI discharge intervals include intervals 6, 7, 8, and 9. For interval 4 in May-June 1987, water levels in springs 6, 12, and 42w were declining before the test started, but the rate of decline accelerated during the test period, and water levels rose following shut-in.

Water-level data were collected daily over a two-month period in mid-1988 from springs 6, 12, and 42w (figs. 4 and 28). This period includes CPI discharge interval 10 and part of interval 11. All three springs show consistent responses of water-level decline during production and rise following shut-in, although the spring 6 response is more noisy because some measurements were made under boiling conditions. Water-level declines during interval 10 range from 0.6 feet in spring 6 to 1.84 feet in spring 42w. The relative amount of change in each spring during and following discharge interval 11 is in general correspondence with the differences in long-term water-level decline in these springs. That is, changes in springs 12 and 42w are two to three times larger than changes in spring 6. Semilog plots of these data (water-level change as a function of log time) show linear relations for both rising and falling periods, indicative of aquifer response to geothermal production (Collar, 1990).

Water levels in some of ACEC springs are affected by thermal cycling or intermittent boiling of the fluid column in the spring conduit. This condition can cause significant changes in the depth to water, as evidenced by the water-level record for spring 6 shown in figure 28. For springs with water levels shallow enough to be visible from the land surface, such a spring 8, measurements were avoided under boiling conditions. For other springs, the available water-level records may include measurements made under boiling conditions and some apparent short-term changes may reflect this anomalous condition.

Correspondence between changes in water level in spring 8 and CPI discharge intervals 6-9 are apparent in figure 27. Prior to discharge interval 6, water levels in spring 8 remained near the rim and discharge occurred through a crack below the rim.

Limited thermal-water production occurs on an intermittent basis from the Steamboat Spa well on the low terrace (fig. 17). This well is 260 feet deep and most likely draws thermal water from the older alluvium overlying granodiorite bedrock in this area (Appendix D). The history of discharge from this well is only approximately known; its maximum flow is about 60 gal/min, but mineral deposition limits its ability to sustain flow. The well is reported to have discharged continuously, without pumping, throughout 1987 and up to May 1988, when the discharge declined and ceased (Collar, 1990). From May 1988 to the last week in March 1989 the well remained inactive. From June to August 1989, the well was induced to flow each weekday from morning until evening. The shapes of the hydrographs for well GS-1 and the unnamed monitor well at the low terrace (Appendix E) are similar and most likely reflect the effects of discharge from the Steamboat Spa well.

Changes in wells in the Steamboat Hills and on the High Terrace

Five production wells and one injection well have been drilled by Caithness Power, Inc. in the Steamboat Hills (fig. 17); currently only wells 23-5, 83A-6, 21-5, and Cox I-1 are in use. The unused CPI production wells are 28-32 and 32-5, which are shown as observation wells in figure 17 (strat 32-5 is located adjacent to unused production well 32-5). Three production wells and two injection wells were drilled for the SB GEO power plant on the high terrace: wells PW-1, PW-2, PW-3, and IW-2 are currently being utilized. Water-level or downhole-pressure data have been collected on a semi-continuous basis from numerous

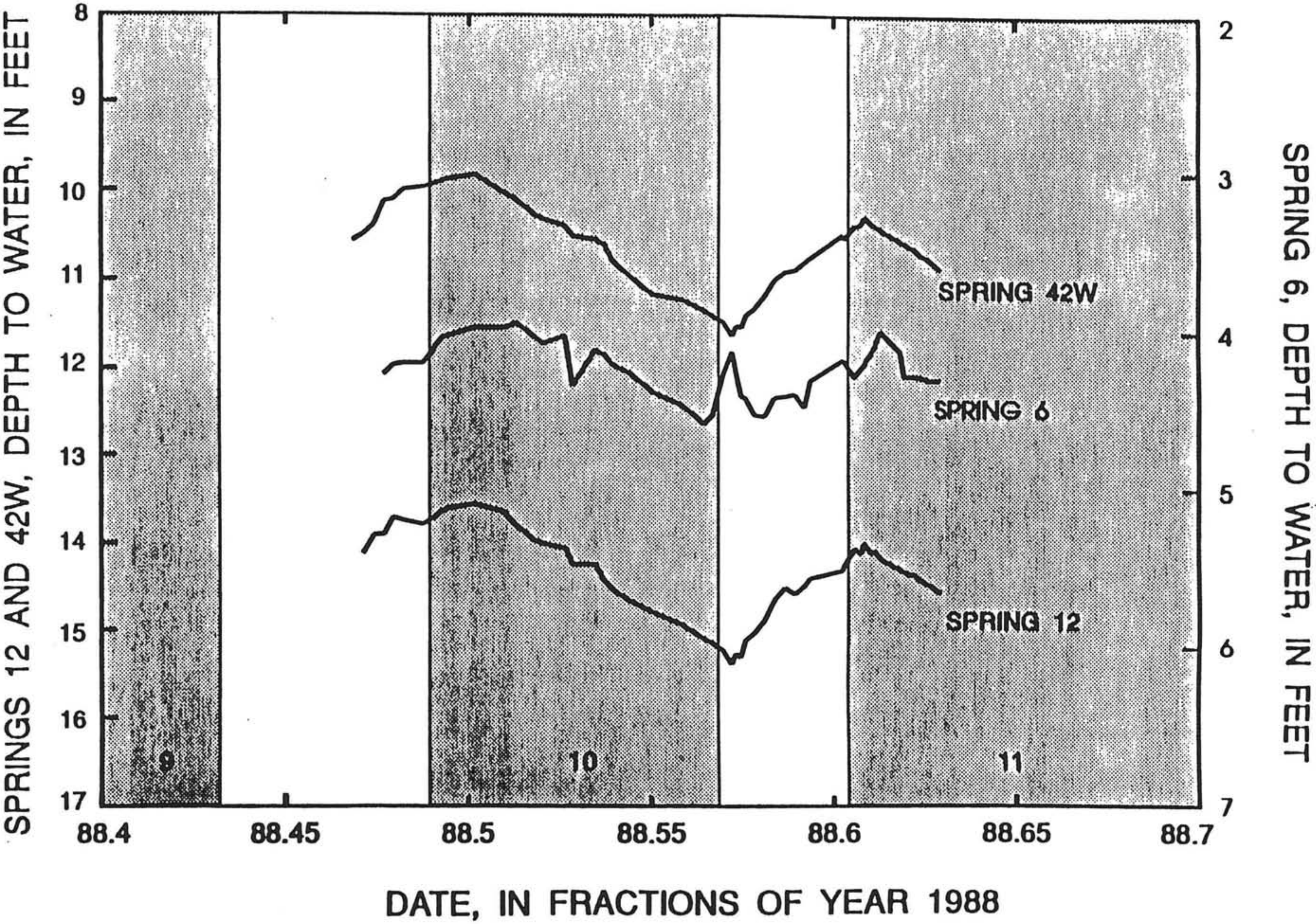


Figure 28. Water levels in springs 6, 12, and 42w on the main terrace during the summer of 1988 and periods of discharge from the CPI well field, as numbered in table 4.

monitor wells in the Steamboat Hills and on the high terrace, including hydrologic observation wells (OW) completed in the SB GEO well field and stratigraphic test (strat) wells drilled for temperature gradient information in the Steamboat Hills. These strat wells were later perforated or recompleted with tubing slotted near the bottom for water-level monitoring. Well-completion information for all these wells is listed in tables 6-8; each is shown in the geologic section in figure 6. Additional information, including temperature profiles and lithologic logs for some of these wells is given in Appendix B and C.

Observation Wells

Water-level data for the wells monitored in these areas is obtained from depth-to-water measurements made from the land surface or from gas-pressure measurements made in capillary tubing. The gas-pressure measurements are made with absolute-reading or gage-reading pressure transducers, and converted to depths-to-water using the known depth of the capillary tube pressure chamber. For the strat wells with capillary tubing, we have converted the gas-pressure measurements to depths-to-water using either measured absolute pressure or gage pressure converted to absolute pressure. This yields a water level record with less variation from barometric pressure changes than would the gage-pressure measurements alone because of the relatively high barometric efficiency of these wells. As a result, however, the actual depth to water in such wells is approximately 30 feet greater than our calculations would indicate. The influence of barometric pressure on water-level changes in the strat wells is discussed in a subsequent section of this report and by Collar (1990).

For monitor wells IW-1, OW-1, and OW-2 in the SB GEO well field, both downhole pressure and wellhead pressure are measured because gas columns exist in these wells. Reported depths to water for these wells (Ormat 1987a-d, 1988a-d, and 1989a-c), based on differences between downhole and wellhead pressure, give a misleading view of reservoir drawdown because the calculated depth to the water surface in the well changes as the gas-column pressure changes. Gas pressures have changed in part because of the addition of nitrogen to the wellbore from the capillary tubing. We have instead calculated effective depths-to-water from the downhole pressure and the reported depth of the pressure transducers in wells OW-2 and IW-1. By this method, changes in the effective depth-to-water represent actual changes in reservoir pressure. The reported depth-to-water data for OW-1 are highly variable and not readily interpretable, possibly because of instrument problems (Collar, 1990; Ormat Energy Systems, Inc., written commun., 1989). They are not reported here.

Detailed hydrographs for each monitor well are included in Appendix E. In these plots a distinction is made between depth-to-water calculations based on hand-held measurements and those based on transducer measurements. In the main part of the report, less detailed hydrographs are presented for some wells considered to be representative of changes observed in the geothermal system during the 1987-1990 period. These include strats 2, 5, 9 and 13, and observation wells IW-1 and OW-2. Except for strat 13, these wells have shown long-term declines in water level of 15-26 feet over the 1987-1990 period, but with significant short-term variations that are discussed below. Water-level and well completion data for other strat wells are summarized in table 8. These wells show either steady long-term declines of 11-22 feet (strats 6 and 7), or water-level rises of 1-2 feet over the 1987-1989 period. On the basis of an additional 15 foot decline in water level in strat 7 between 1980

Table 6. *Caithness Power Incorporated well-completion information*

Well	Distance to spring (feet)	Approximate elevation (feet)	Depth (feet)	Casing depth (feet)	Open-hole interval Elev. (feet) (thickness)	Open-hole rock types
Production						
23-5	9480	5348	2422	1475	3873-2926 (947 feet)	metamorphic
83A-6	10390	5732	2540	2137	3595-3192 (403 feet)	metamorphic, granodiorite
21-5	8875	5732	2767	1292	4440-2965 (1475 feet)	metamorphic, granodiorite
Injection						
Cox I-1	5100	5057	3449	1764	3293-1608 (1685 feet)	granodiorite

Table 7. *SB GEO well completion information*

Well	Distance to Spring (feet)	Approximate Elevation (feet)	Depth (feet)	Casing Depth (feet)	Open Hole Interval Elev. (feet) (thickness)	Open Hole Rock Types
Production						
PW-1	3990	4719	626	600	4119-4093 (26 feet)	granodiorite
PW-2	4090	4734	530	495	4239-4204 (35 feet)	granodiorite
PW-3	3720	4725	566	545	4180-4159 (21 feet)	granodiorite
Injection						
IW-2	4220	4698	1403	730	3968-3295 (673 feet)	granodiorite
IW-3	4370	4695	517	400	4295-4178 (117 feet)	tuff breccia (89 feet) granodiorite (28 feet)

Table 8. *Selected data for stratigraphic test wells in the Steamboat Hills area*

Well	Depth feet	Formation[1] perforated	Temperature[2] °C	Change in Water Level[3] 1987-1989 in feet
strat 2	844	Kgd	171	-26
5	1680	Kgd	44	-16
6	1936	Pkm	87	-22
7	1503	Tk	84	-11
8	1940	Pkm	96	(+1)[4]
9	915	Kgd	179	-14[5]
13	1767	Pkm	177	+9
14	1630	Kgd	177	+2

[1]Pkm = Pre-Cretaceous metasedimentary rocks; Kgd = Cretaceous granodiorite; Tk = Tertiary volcanics (Kate Peak Formation).
[2]Measured temperature in perforated interval or at bottom of well.
[3]Water level decline indicated by minus, rise by plus, measured from mid 1987 to mid 1989.
[4]No data for 1987 or 1989.
[5]No data before December 1987.

and 1985 (Yeamans, 1985), it appears that the declines in strats 6 and 7 are part of longer-term head declines in bedrock aquifers in and near Pleasant Valley (Collar, 1990). The small rises in strats 8 and 14 have no clear explanation.

Strat 13 is located next to CPI production well 23-5 and was completed with a slotted liner in metamorphic basement at 1,767 feet, where the measured temperature is 177°C. An overall rise in water level in strat 13 of about 9 feet was observed from 1987-1989, but there are several periods of water-level fall associated with CPI discharge intervals involving production from 23-5 and corresponding water-level rises following shut-in (fig. 29). During discharge interval 11 in 1988, well 23-5 did not discharge for a month between September and October, during which time the water level in strat 13 rose about 3 feet. This correlation indicates that a hydraulic connection exists between strat 13 and well 23-5. Other factors, however, must be responsible for the long-term rise in water level in strat 13.

Strats 2, 5, and 9 are located near the northern end of the Steamboat Hills, in the general vicinity of the Cox I-1 injection well. Strats 2 and 9, with bottom-hole temperatures of 171° - 179°C, are completed with liners slotted at depths of 830-930 feet in the same thermal flow zone penetrated by, but cased off in, the Cox I-1 well. Strat 5 shows a linear temperature profile, but a maximum temperature of only 44°C in granitic bedrock at a depth of 1,700 feet. Fluid sampled from strat 5 was relatively dilute (C. Stewart, Caithness Power Inc., written commun. 1991); its temperature and chemistry indicate that it is completed within the non-thermal ground-water system. No fluid samples have been obtained from strats 2 and 9. In spite of differences in bottom-hole temperature and presumably fluid chemistry between strats 2 and 9 and strat 5, similar water level changes have occurred in these wells since 1987. Between the spring of 1987 and summer of 1989, water levels declined approximately 16 feet in strat 5 and 26 feet in strat 2 (fig. 30). The rate of decline in strat 9 was comparable to that in strat 2.

A period of significant water-level rise and fall was observed in strats 2, 5, and 9 during the fall of 1989 and winter of 1990 (fig. 30). Both power plants were in nearly continuous operation during this period. Water-level rises also occurred during this period in the Pine Tree Ranch-1 well and STMGID monitor wells MW-3 and MW-4 (fig. 20) and in spring 6 (fig. 31). The magnitude of the rise in each well was comparable (5-7 feet), except for wells MW-3 and MW-4 and spring 6 for which the rise was on the order of 1 foot. Precipitation during the July 1988-June 1989 period was twice that in the two previous precipitation year (fig. 13). These comparisons suggest that similar processes, such as increased recharge to the shallow ground-water system or decreased rates of ground-water pumpage may influence changes in hydraulic head at each location. This inference must be qualified, however, in view of unexplained differences in the onset and duration of the water-level rise at these locations and relatively sparse data.

An anomalous rise in water level was also detected in strat 5 beginning in July 1991 and accumulating to about 34 feet by September 1991. Although no corresponding water-level rises had been detected in strats 2 and 9 and PTR-1 as of October 1991, a 15-foot rise was recorded in the Woods well 0.25 miles southwest of PTR-1 between July and October. These changes may in part reflect the effects of the abnormally high precipitation in the entire region in March 1991, and possibly an as yet undetermined reduction in pumpage from

(Expanded version included with Plates)

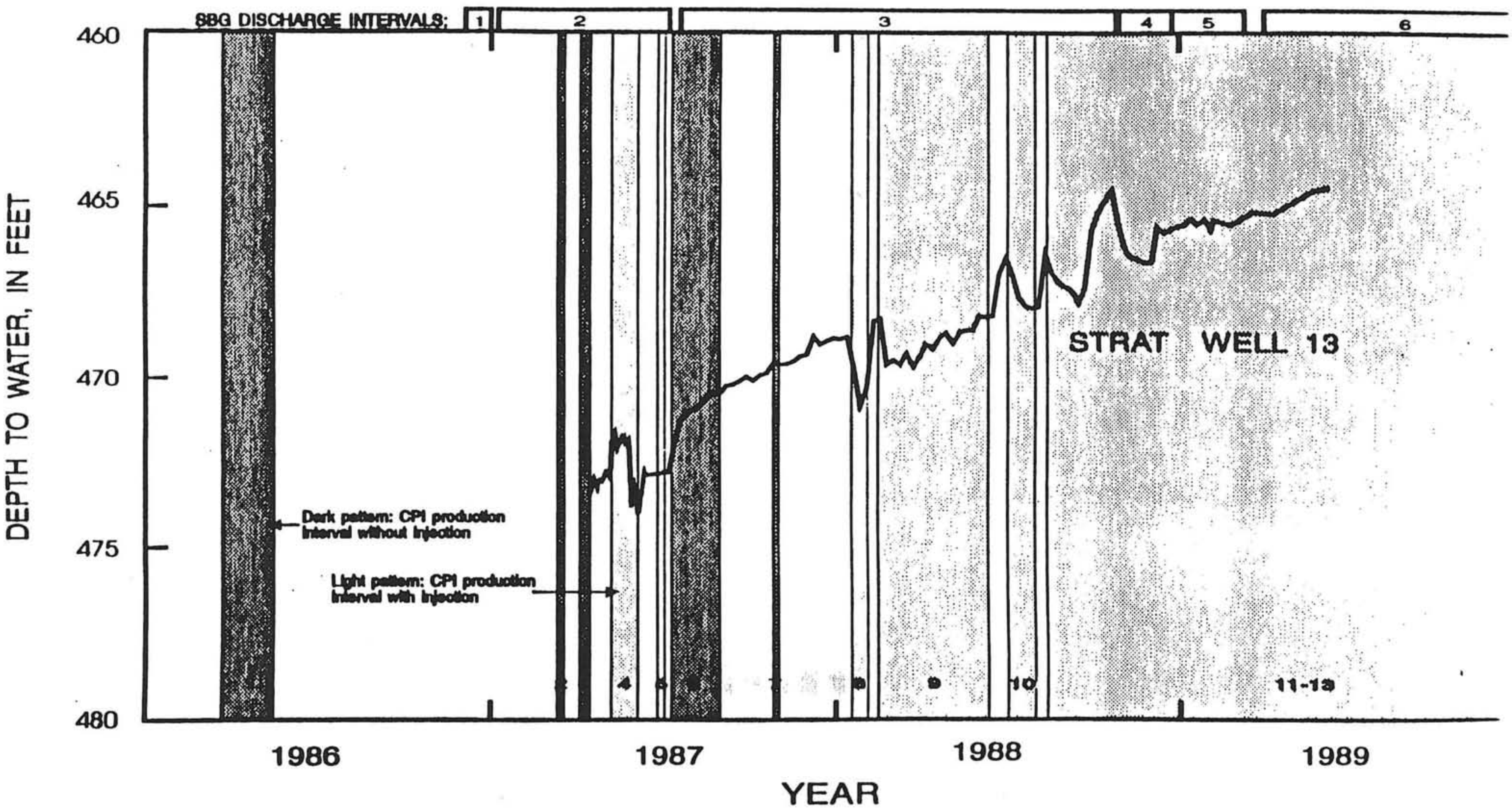


Figure 29. Water levels in strat well 13, 1986-1989. Also shown are intervals of production from the Caithness Power Incorporated (CPI) and SB GEO (SBG) well fields as numbered in tables 4 and 5.

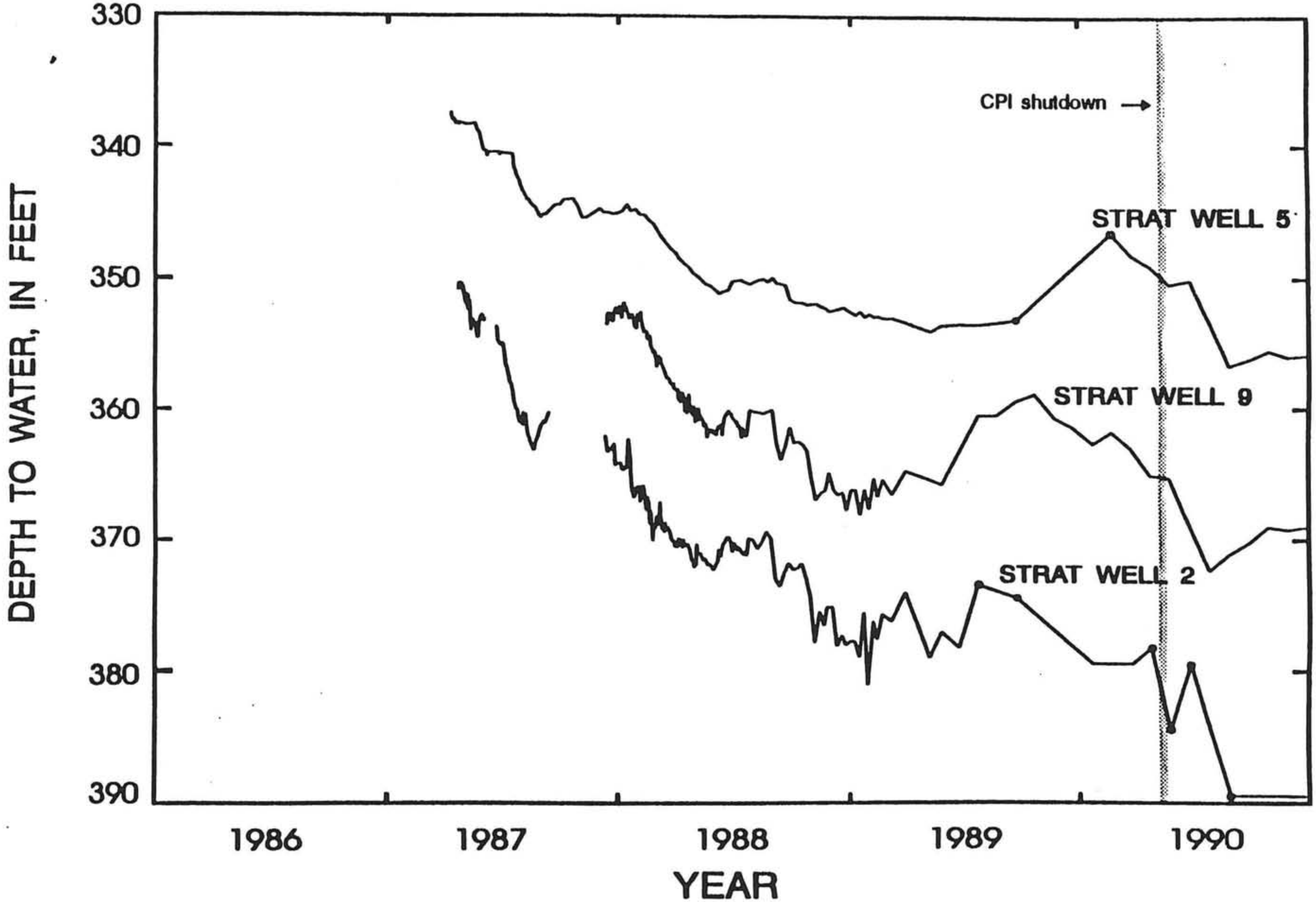


Figure 30. Water levels in strat wells 2, 5, and 9, 1986-1990. Dots represent monthly measurements made after June 1989. Water levels for strats 2 and 5 were adjusted by adding a constant to adjust to common scale (5 feet added for strat 5; 22 feet added for strat 2).

(Expanded version included with Plates)

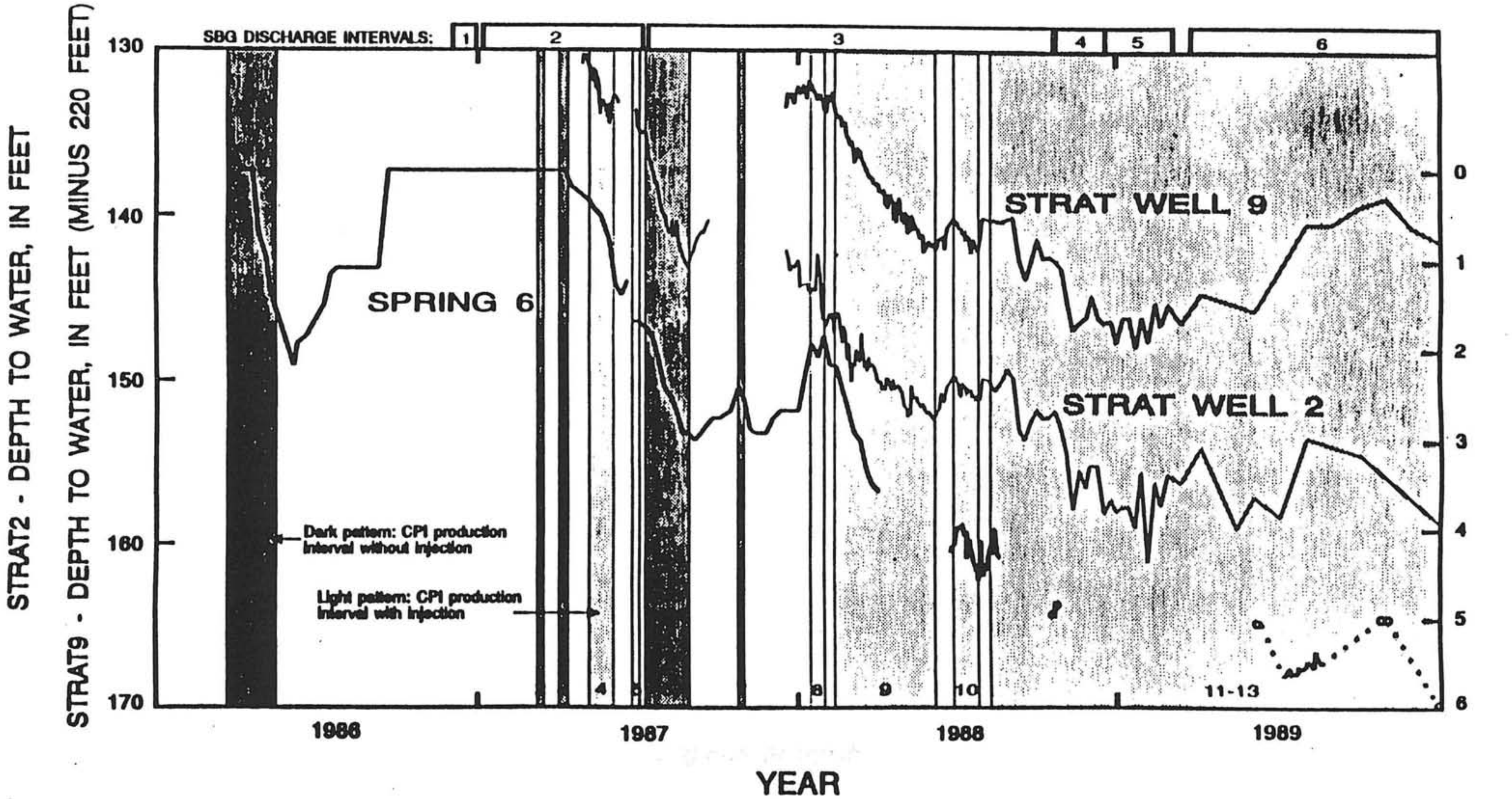


Figure 31. Water levels in spring 6 and strat wells 2 and 9, 1986-1989. For spring 6, circles represent isolated measured water levels. Dots show assumed water-level trends in 1989. CPI stands for Caithness Power Incorporated; SBG stands for SB GEO.

ground-water wells. However, the magnitude of the rise in strat 5 is difficult to account for by this means alone. Because the tubing in strat 5 (and in strat 2) is not cemented against the surface casing or the open-hole section, it is possible that the water level in this well responds to more than one aquifer. Nevertheless, the general correspondence between periods of water-level rises in the ground-water system in the South Truckee Meadows and in thermal and nonthermal aquifers in the Steamboat Hills argues for a corresponding relation during periods of water level decline.

Results of numerous interference tests on CPI wells, conducted since 1979, provide some evidence of pressure communication between the CPI well field and strat wells 2, 5, and 9. The evidence is sometimes hard to interpret unambiguously because of (1) noise in the water-level records from barometric pressure and earth-tide influences, boiling conditions at the water surface (strat 9), and instrument malfunctions; (2) inadequate measurement frequency and/or insufficient pre-test measurements; and (3) ongoing seasonal trends. Pressure monitoring data collected during a 2-week shut-down of the CPI well field in May 1990 has also proven useful in delineating and quantifying hydraulic connections between wells, as discussed below.

Pressure data collected during a 28-day test on Steamboat No.-1 in 1980 showed drawdowns and corresponding buildups of 4 feet and 6 feet in strats 2 and 9, respectively (Yeamans, 1984). No fluid was reinjected during this test. Faulder (1987) calculated a water-level decline of 1.9 feet in strat 2 during the first half of a 27-day flow test on well 23-5 (discharge interval 4 in table 4, for which all fluid was injected into Cox I-1). A total decline of about 4 feet was observed over the entire flow test. However, measurements were discontinued shortly after the end of the discharge interval so it is not known whether a corresponding pressure buildup occurred. In addition, very little pressure record was obtained prior to the start of the test, so that it is difficult to separate the seasonal trend in water level from that caused by production. No clear response in strat 9 was found during the 1987 test, although such interpretations are limited by a relatively large diurnal variation (1 psi, or 2.5 feet) that appears to reflect barometric pressure variations. Although Faulder (1987) concludes that strat 9 did not respond to injection into Cox I-1, it seems possible that the difference in response in strat 9 to this test compared with the 1980 test may reflect the effects of both drawdown from production and reservoir pressure support from reinjection. Data from subsequent discharge intervals indicate a difference in strat-well response to production with and without reinjection, as discussed below.

The data for strat 5 during the 1979, 1980, and 1987 interference tests yield conflicting indications of hydraulic communication with CPI production wells. A drawdown and recovery of approximately 1 foot was indicated from hand-held measurements during the 1979 test (Yeamans, 1984; Chevron, 1987). During the 1980 test, pressure transducer measurements indicated a decline in downhole pressure of 0.9 psi during production, but a continued decline in pressure following shut-in. Yeamans speculates that there may have been a malfunction related to a leak in the pressure line. During the 1987 test, no change in depth-to-water was observed during the first week of the 28-day test, leading Faulder (1987) to conclude that no pressure response to production was seen. However, a capillary tube and pressure chamber were installed in strat 5 about 1 week after the test began and following a short period of widely varying pressure data, the calculated depth-to-water shows a decline of about 2 feet during the remainder of the test. This is consistent with a more delayed and attenuated pressure response in strat 5 than in strats 2 and 9 that would be expected because strat 5 is not completed in the geothermal system.

Data reported at monthly intervals during 1990 from strats 2, 5, and 9 do not adequately delineate the effects of the shut-down of the CPI well field May 14-26, 1990 (fig. 29). Although a slight flattening of the downward trends in water level in strats 5 and 9 are indicated following the shut-down, the data for strat 2 may be affected by equipment problems, such as water in the gas chamber or a bad pressure gage. Fortunately, downhole pressure data collected at two-hour intervals are available during May and June 1990 for strat 9 and well 28-32. Well 28-32 is a production-diameter well north of CPI well 21-5. Although it is drilled to depth similar to the other CPI production wells, its static temperature profile (Appendix C) indicates that it reaches its maximum temperature of 209°C at a depth of 1,800 feet - some 600 feet shallower than the other production wells. The data for strat 9, contained in an unpublished report by Susan Petty Consulting (1992), show a water-level recovery following shut-in of about 2 feet but a drawdown following restart of full production of about 10 feet. After about 14 days of full production and 50 days since partial resumption of production and injection, water levels in strat 9 begin to rise in a logarithmic fashion typical of well response to injection. Well 28-32 showed a similar response to shut-in and restart, except that pressure support from injection appears to begin about 20 days after partial production and injection resumed. The results from this test, then, establish that there is pressure communication between the CPI production **and** injection zones and the shallow thermal reservoir penetrated by strat 9 and presumably strat 2.

The water-level records for strats 2 and 9 show some similarities with that for spring 6 (fig. 31). The overall pattern of decline from 1986 through the summer of 1989 is the same for each feature, as is the pattern of rising water level in the second-half of 1989. These similarities indicate that the same stresses may be involved. Correlations between changes in water level in these wells and periods of production from the CPI wells, discussed previously for the spring 6 water-level record, are also seen in the strat-well records. In particular, water-level declines of 5-8 feet are observed during intervals 6 and 9, with indications of subsequent partial recovery. A greater rate of water-level decline during interval 6, without injection, than during interval 9, with injection, is consistent with pressure support from injection. A similar effect is seen in the strat 5 record.

These data indicate that water levels in strats 2, 5, and 9 and in hot springs at the main terrace have responded both to changes in the shallow ground-water system in and around the Steamboat Hills and to production and injection at the CPI well field. The effects of production from the SB GEO well field on these features are more difficult to delineate. A hydraulic connection between the shallow thermal zone penetrated by strats 2 and 9 and the SB GEO production reservoir is suggested (but not proven) by the presence of a low resistivity trough between these areas and by observation of water-level declines in the Towne geothermal well at the high terrace during well tests in 1979 and 1980 (Yeamans, 1984). Of possible significance in this regard is the fact that overall declines in water level in strats 2 and 9 between 1987 and mid-1989 were significantly greater than the corresponding decline in strat 5. We would expect from the differences in hydrogeologic conditions at these sites (strat 5 penetrates a non-thermal ground-water aquifer; strats 2 and 9 penetrate a shallow thermal flow zone) that strat 5 should be more responsive to changes in the shallow ground-water system than strats 2 and 9. Hence the greater water-level declines in strats 2 and 9 may be indicative of the additional effect of geothermal well production.

The records of calculated depths to water, based on measured downhole pressures in observation wells IW-1 and OW-2 in the SB GEO well field (figs. 32 and 33) show declines of 15-20 feet over the 1987-89 period. There is considerable scatter in the data for these wells, most likely reflecting equipment problems and operator measurement errors. On the basis of the records for these observation wells, there appears to be reservoir head decline both on the production side of the field (20 feet in OW-2) and on the injection side of the field (15 feet in IW-1). This may indicate limited pressure support from injection, although other factors such as declines in water levels in the surrounding ground-water system may also affect these results. Head declines measured in the SB GEO observation wells are comparable to differences in heads between the high terrace and the main terrace before development, indicating that the present drawdown of the SB GEO reservoir might not induce significant inflow of thermal water from the main terrace, even if permeable fractures existed between these two areas.

Production Wells

The SB GEO production wells are relatively shallow (500-600 feet deep) and produce water at temperatures near 170°C. The currently used injection well (IW-3) is of comparable depth, but injection well IW-2, used until March 1989, is open from 730-1,414 feet (table 7). A summary of intervals of production and injection from the SB GEO field is given in table 5; plots of average monthly production rates are shown in figure 34. Considerable variability in production and injection rates occurred in 1987, but rates in subsequent years have been relatively constant. Although there is no net loss of mass from the fluid stream, there is a difference of about 200 gal/min between the volumetric production and injection rates because of the difference between production and injection temperatures. A more detailed plot of daily average injection rates for 1987-88 (fig. 35) shows that periods of significant change in well-field operation during 1987 were of relatively short duration. The hydrograph for spring 6 (fig. 35) shows little evidence of correlation with changes in injection rate, except for an apparent rise of about 1 foot in January 1988, following a week-long period of decreased production and injection.

Downhole pressure data for the SB GEO production wells are proprietary, and were not examined in detail during this study. Head changes of 20-40 feet (equivalent to pressure changes of about 8-15 psi) have been observed in these wells (Colin Goranson, written communication, 1991). Reservoir transmissivity values obtained from interference tests and from computer simulations of the production-well pressure data range from 10,000 to 20,000 ft^2/day (kh = 1,000 to 2,000 darcy-ft), depending on assumptions regarding injection pressure support and reservoir head decline caused by declines in water level in the shallow ground-water system (Goranson and others, 1991; C. Goranson, written commun., 1991). Reservoir pressure recovery of only about 5 psi (12 feet) was measured in the production wells during a recent shut-down of the field (C. Goranson, written commun., 1991). This indicates that the additional head decline measured in the production wells prior the shut-down may be caused by other factors, such as water-level declines in the shallow ground-water system and

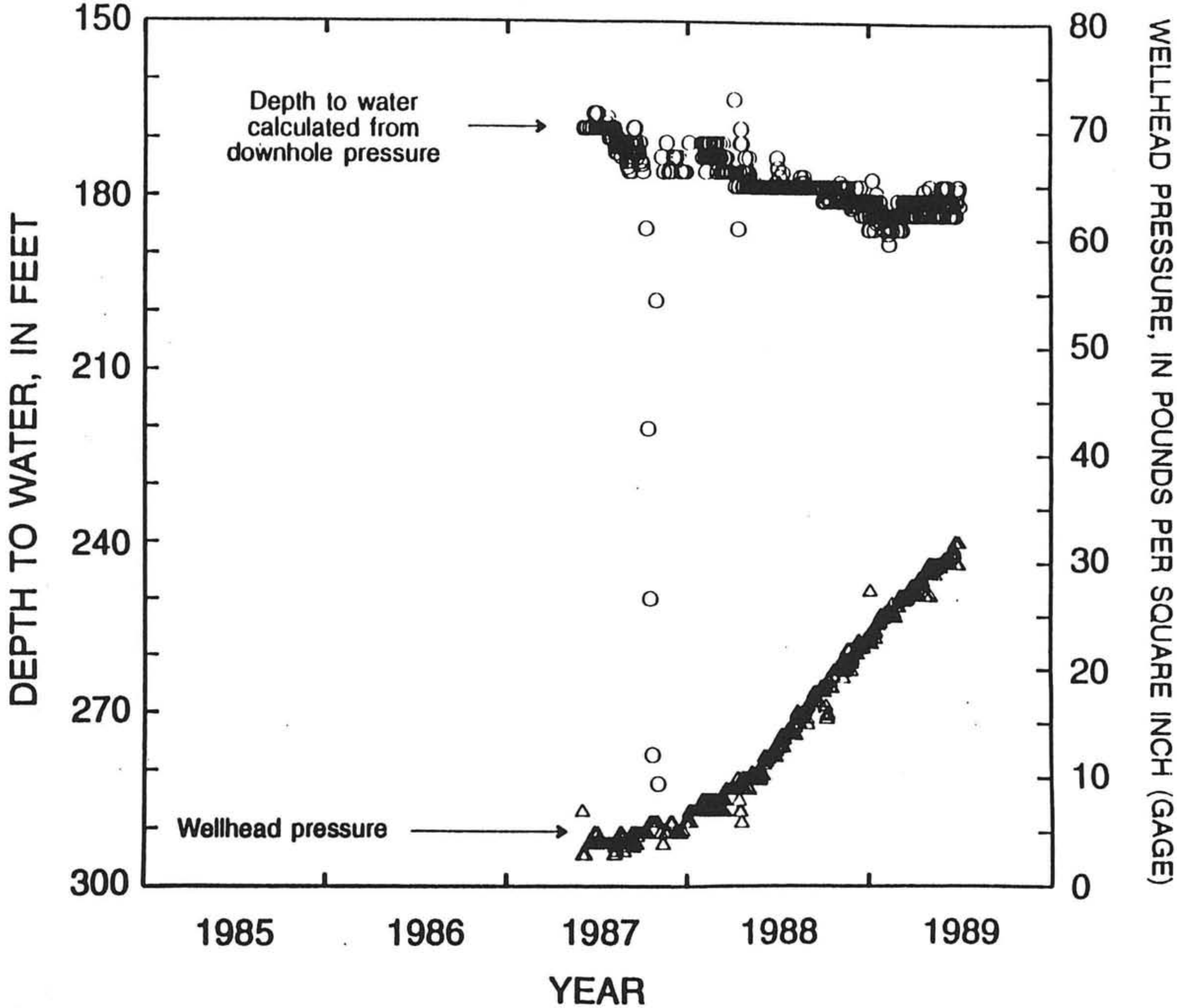


Figure 32. Depth-to-water in well IW-1, calculated from downhole-pressure and wellhead-pressure measurements, 1987-1989.

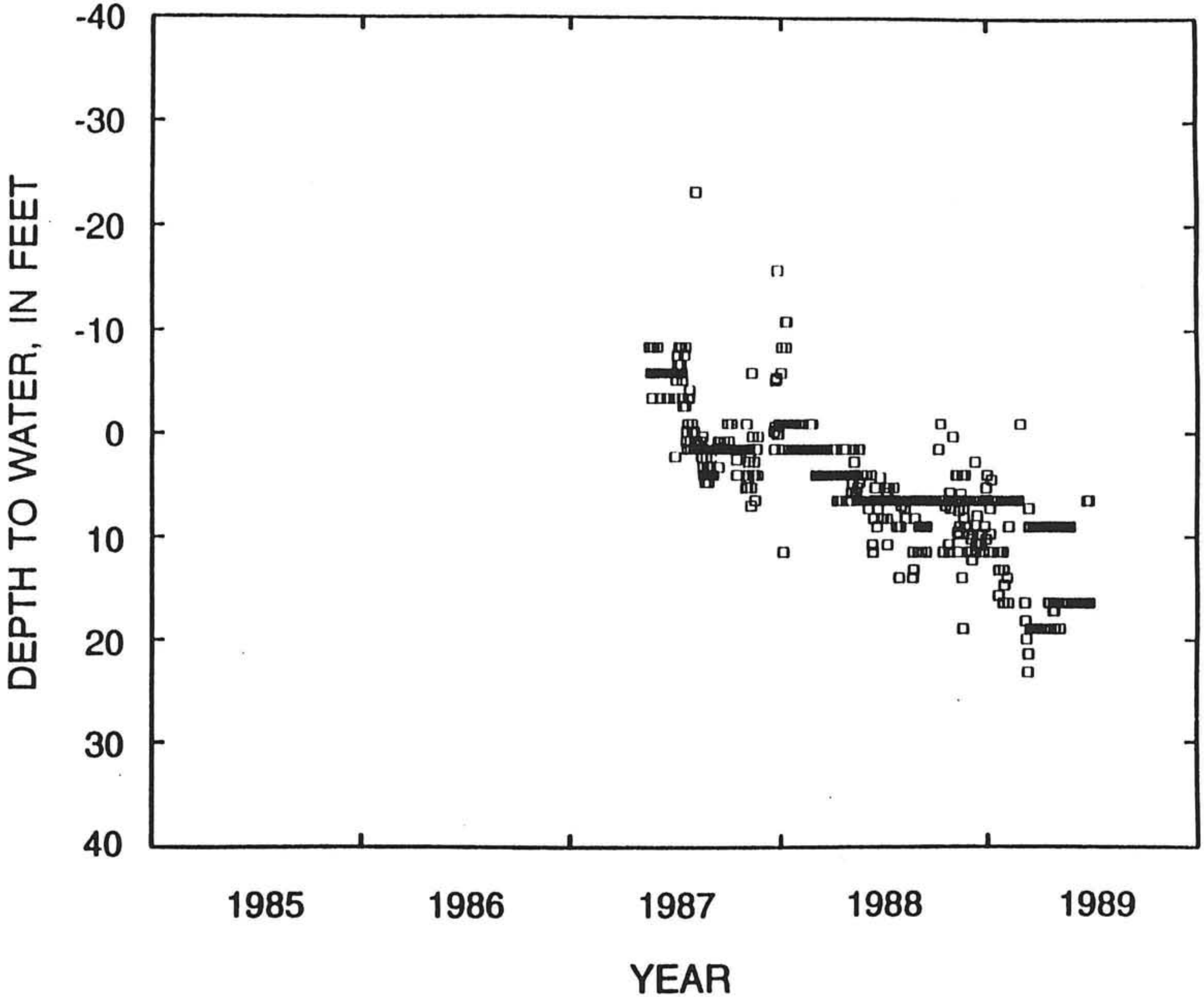


Figure 33. Depth-to-water in well OW-2, calculated from downhole-pressure measurements, 1987-1989.

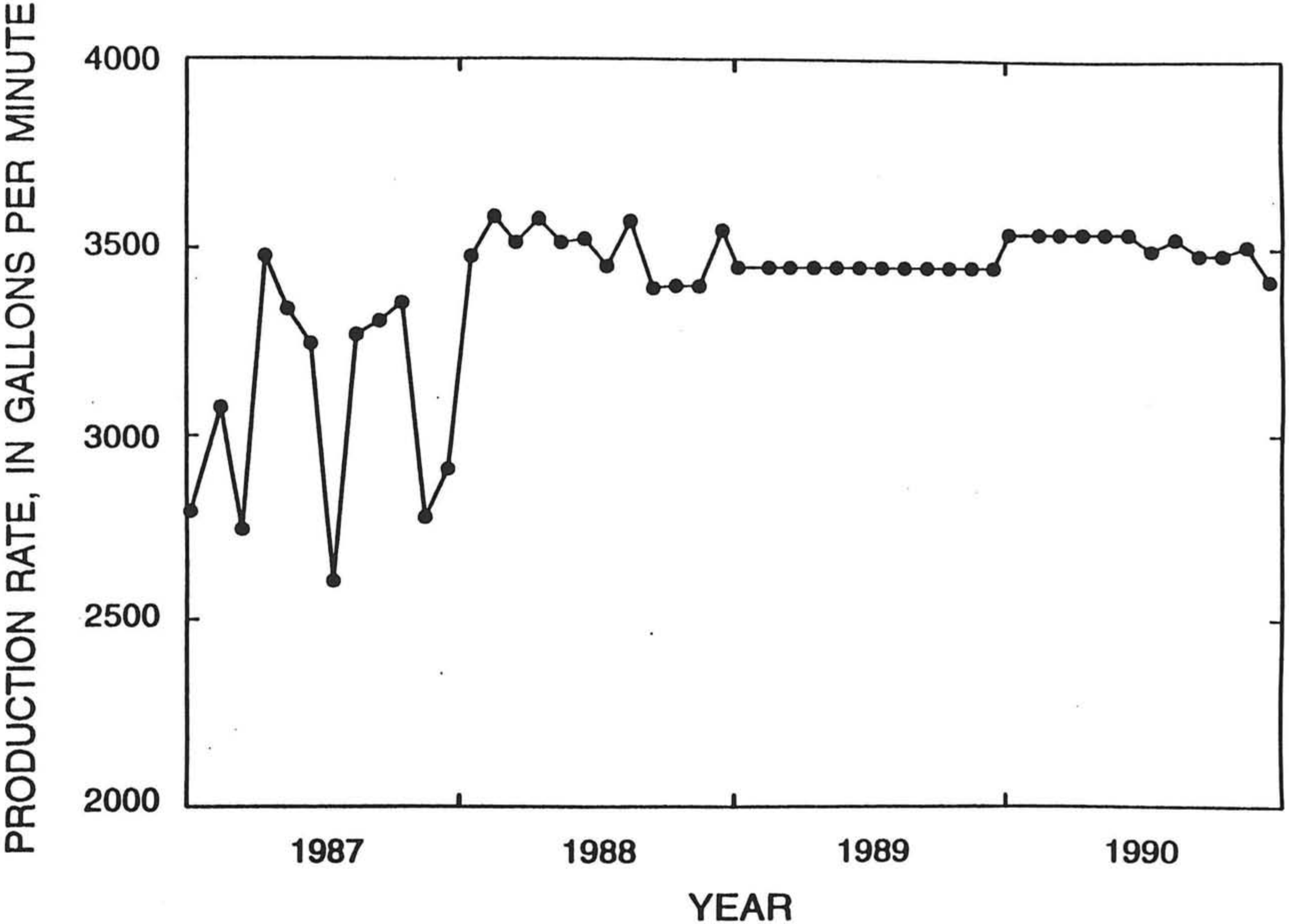


Figure 34. Monthly averaged total production rate for the SB GEO well field, 1987-1990 (from C. Goranson, written commun., 1991).

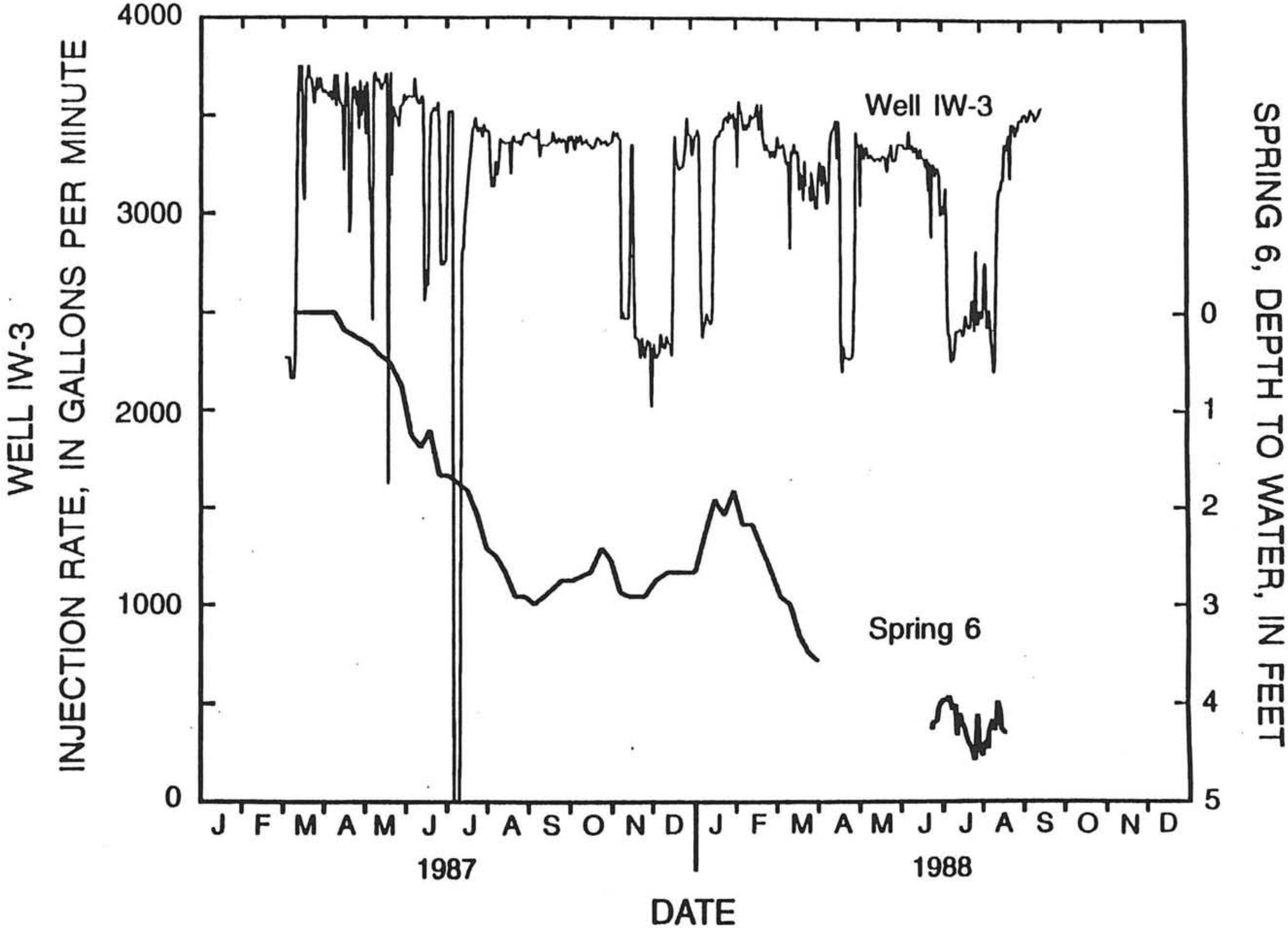


Figure 35. Daily averaged injection rate in SB GEO well IW-3 and depth to water in spring 6, 1987 - 1988 (modified from Collar, 1990).

drawdown in the CPI reservoir.

There is no indication of any decline in production reservoir temperature, as would be expected after almost 5 years of injection at distances of about 500 feet from the production wells. Goranson and others (1991) suggest that injected fluid moves downward along steeply dipping fractures which provide pressure communication with similar structures intersected by the production wells but effectively prevent injected fluid from flowing laterally to the production wells. A similar explanation for the apparent pressure support from injection without temperature declines in production wells may apply to the CPI well field.

Construction has begun for a significant addition of geothermal production adjacent to the SB GEO well field, involving new production wells sited east and southeast of the existing well field on private lands that border the northern boundary of the ACEC (JBR Consultants, 1991). Interference testing will be needed to delineate the degree of hydraulic connection between the existing SB GEO wells, additional production and injection wells to be drilled for this expansion, and hot springs on the main terrace.

CPI production is obtained from three wells drilled into a zone of open fractures in metamorphic and granitic bedrock at depths of 2,400-2,800 feet. Temperature profiles in these wells show high gradients down to zones of temperature reversal which mark the production reservoir in the CPI well field. Measured reservoir temperatures range from 221°C in wells 21-5 and 83A-6 to 238°C in well 23-5. Other wells drilled for production, including 28-32 and 32-5 (fig. 5) remain unused because of lower permeability or formation damage. Intervals of relatively constant production from the CPI well field are listed in table 4; plots of monthly average production and injection rates following initiation of full-scale operations in 1988 are shown in figure 36. As noted previously, the difference between the total production and injection rates has remained relatively constant since 1988, reflecting the consumptive loss of about 500 gal/min of steam condensate for power-plant cooling. Periods of very low monthly average production and injection correspond with plant shut-downs for maintenance.

Direct measurements of pressure changes in production wells are in number and reliability. Such measurements include nitrogen-line pressure readings in wells 21-5 and 83A-6 made for several hours before and after these wells were shut-in May 1990, capillary-tube pressure measurements in well 23-5 during a production test in May-June 1987, and pressure surveys run in 23-5 and 83A-6 under static (shut-in) conditions in 1987, 1988, and 1990. The gas-line pressure measurements suggest that drawdowns on the order of 4-7 psi (10-15 feet) occur within hours of initiation of production, but such interpretations are limited by large variability in these pressure measurements made under less-than ideal conditions. More reliable reservoir pressure measurements could have been made in observation wells completed and instrumented for that purpose. However, of the strat wells drilled in and near the CPI well field, only strat 32-5 (fig. 17), and possibly well 28-32, are deep enough to penetrate the production zone. Strat 32-5 has not been monitored, but could be cleaned out and used to record reservoir pressure changes (P. van de Kamp, oral commun., 1991).

Differences between downhole pressure surveys in wells 23-5 and 83A-6 suggest drawdowns on the order of 20-50 feet, whereas essentially no difference is seen between

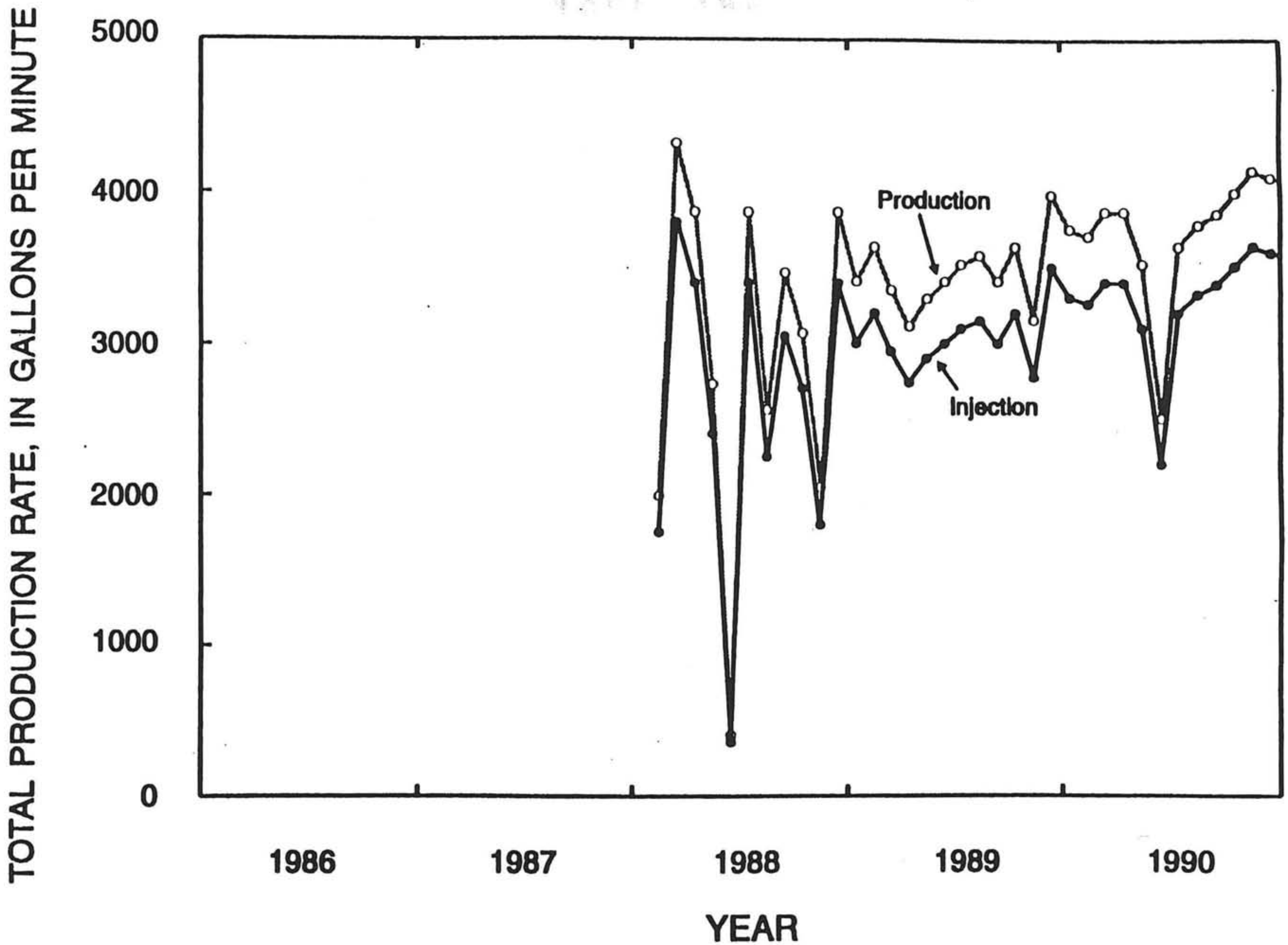


Figure 36. Monthly averaged production and injection rates for the Caithness Power Incorporated well field, 1988-1990.

pressure profiles run in 83A-6 under static conditions in May 1990 and flowing conditions in September 1990 (S. Petty, written commun., 1991). The use of repeat pressure surveys to estimate reservoir drawdown in limited by the accuracy of the downhole pressure tool and by differences in fluid-column temperatures and densities between surveys.

More reliable indications of reservoir drawdown are provided by pressure measurements made in with high-quality pressure gauges in unused production wells during interference tests conducted before full-scale operations began at the CPI field. In particular, tests conducted in March-May 1986, March-May 1987, and May-June 1987 involved production from one well and pressure monitoring in other unused production wells. Dates and production rates for these tests, only the latter of which involved injection in Cox I-1, are listed in table 4. Each test yielded calculated reservoir transmissivity and storage coefficients near 9,000 ft /day and 10^{-3}, respectively (table 9). Full pressure support from reinjection (net production = 310 gal/min) was assumed in calculating reservoir parameters for the May-June 1987 test. The drawdown trends in wells 21-5 and strat 2 can reasonably be extrapolated to conditions of higher flow rates and longer production times. From these test results, reservoir drawdown estimates of 10-15 feet can be calculated for full-scale production and injection (net production = 500 gal/min) over 2.5 years operation. Although considerably larger drawdown (190 feet) was measured in production well 23-5 during the first two weeks of the May-June 1987 test, this is most likely attributable to the effects of boiling and two-phase flow in the vicinity of the well during production. This well is normally operated at wellhead pressures high enough to prevent reservoir boiling (C. Goranson, oral commun., 1991).

The estimate of reservoir drawdown noted above is based on assumptions of uniformly high transmissivity over a large reservoir area (radial flow in an infinite, homogeneous porous media), and full pressure support from injection. The latter assumption allows the use of the difference between volumetric production and injection rates in calculating the stress on the reservoir. If injection pressure support is only partial, the calculated reservoir transmissivity from the interference test in 1987 would need to be larger to match the drawdown observed during this test. The same estimate of 10-15 feet of drawdown during full-scale production would apply in either case. Faulder (1987) concluded that pressure support (in well SB-1) is provided by injection in Cox I-1 because similar transmissivity values are indicated for the May-June 1987 interference test with injection as for previous tests that did not involve injection.

For the high transmissivities indicated from such tests, breakthrough of cooler injection fluid in the production wells should have been observed after 2.5 years of operation, if there were good communication between Cox I-1 and the producing wells through a permeable zone of limited vertical extent between these areas. The fact that significant cooling has not yet been observed from wellhead measurements may indicate that pressure communication is provided through steeply dipping fractures that allow cooler injection fluid to move downward rather than laterally toward the production wells. Under pre-development conditions, fluid chemistry in the injection zone was similar to that in the production zone, but temperatures were significantly different (160°C versus 225°C). Higher temperatures (~175°C) in the shallow thermal zone penetrated by strat wells 2 and 9 above the injection reservoir and pressure data collected during and after the May 1990 shut-down which show a delayed response in strat 9 to injection indicate that hydraulic connections between the injection zone,

Table 9. *Reservoir parameters determined for the geothermal system in the Steamboat Hills area from well test analyses and spring hydrographs*

Well(s) and Year of Test	Injection[1]	Transmissivity[2] ($feet^2$/day)	Storage Coefficient[3]	Observation Well	Source(s)
Steamboat No. 1, 1980	no	3270	$9.0x10^{-4}$	strat 2	Collar (1990)[4]
Steamboat No. 1, March-May, 1986	no	8500	($1.2x10^{-3}$)	23-5?	Berkeley Group (1987)
Steamboat No. 1, March-May, 1987	no	6800	($1.2x10^{-3}$)	--[5]	Berkeley Group (1987)
23-5/Cox I-1 May-June, 1987	yes	7930 9500, 8800	nd $7.8x10^{-4}$	strat 2 21-5	Faulder (1987) Goranson (1989) Faulder (1987)
Steamboat No. 1, 1987	no	1250-2140	$9.0x10^{-4}$	strat 2	Collar (1990)
21-5, 23-5[6] 83A-6, 1988	yes	1340-2400	$2.5x10^{-3}$	strat 9	Collar (1990)
21-5, 23-5[7] 83A-6, 1988	yes	3050	$2.8x10^{-3}$	spring 12, spring 42w	Collar (1990)

[1]Full pressure support from injection into Cox I-1 assumed where indicated.
[2]Based on values of net production and fluid properties at 200°C.
[3]Values in parentheses were calculated from reported values of cH, using $S=\rho g \phi cH$ with density at 200°C.
[4]Determined from Theis curve match of data from Yeamans (1984).
[5]Strats 2, 6, 7, 8, 9, and Caithness Power Incorporated (CPI) wells SB-1, 28-32, and 23-5 (T and S values are averages for area between SB-1 and Cox I-1).
[6]Strat 9 analysis for data from CPI production interval 9.
[7]For spring water-level data during CPI production intervals 10 and 11.

the shallow thermal zone, and perhaps the CPI production reservoir are somewhat indirect.

The calculated drawdown estimates noted above also assume that the reservoir acts as an open system, either because it is very large in extent or because it is recharged. Results from short-term tests indicate full recovery of water levels when production wells are shut in, as expected in an open system. But these results do not preclude the effects of low-permeability boundaries causing greater water-level declines during extended periods of production. We have only the gas-pressure measurements from the production wells and the pressure measurements on strat 9 and 28-32 during the 1990 shut down to suggest that reservoir pressures would fully recover following shut down, and hence that boundaries have effectively not yet been reached.

From the information discussed above, it is clear that the amount of drawdown in the production reservoir and the degree of pressure support from injection are as yet only approximately known. The best estimates we can make are that there is pressure support from injection and that drawdown in the production well field is still relatively small (10-15 feet). This level of reservoir drawdown has most likely caused water level declines of a few feet in the shallow thermal zone tapped by strat wells 2 and 9. Additional drawdown is expected to occur if more fluid is produced according to current plans for expansion of CPI generating capacity. A 30-percent increase in reservoir fluid production is anticipated, along with installation of two binary power plants to be supplied by injection water (R. Hoops, Bureau of Land Management, oral commun., 1991).

Changes in Thermal-Water Discharge

Measurements of chloride flux in Steamboat Creek during the 1988-89 period yield estimates of the total rate of discharge of thermal water from the Steamboat geothermal system that can be compared with previous estimates to indicate recent changes. Thermal-water discharge into Steamboat Creek is calculated from the increase in chloride flux between Rhodes Road south of the low terrace and Huffaker Hills, assuming a chloride concentration of 820 mg/L for thermal water from the Steamboat system. Our results are presented in table 2, along with those of White (1968). More detailed results of our measurements are included in Appendix G.

We obtained chloride and streamflow data at three different times, under differing conditions of streamflow diversion for irrigation. The most reliable results are for the March 1989 measurements when no such diversions were taking place; the calculated thermal-water discharge at that time was 663 gal/min. White (1968) calculated a discharge of 810 gal/min from springs and seepage into the creek in the spring of 1955. This suggests that the rate of thermal-water discharge to Steamboat Creek has declined, although the difference between these estimates (18 percent) may result in large part from measurement error. The total thermal-water discharge from the Steamboat geothermal system in 1955 was estimated as 1,110 gal/min, by adding in the average discharge of hot springs on the main and low terrace (65 gal/min) and wells on or near the terraces (300 gal/min). If it is assumed that the flow from these wells represents thermal water that would have flowed from hot springs or seeped directly into Steamboat Creek had the wells not been in operation, then the present-day thermal-water discharge would only be about 60 percent of what it was in 1955.

Most (~70 percent) of the well discharge in 1955 occurred from the Reno Resort wells, located approximately 0.25 miles north of the main terrace (fig. 17). White (1968) speculates that these wells were capturing thermal water that formerly flowed from springs close to these wells and springs in the northern part of the main terrace. He based this speculation on his observations of effects of well production on springs close to these wells and comparisons with unpublished descriptions of spring activity in 1916 by L.H. Taylor of the U.S. Geological Survey. Taylor estimated the total spring flow from the main terrace at 180 gal/min in October 1916, part of which occurred from springs in the northern part of the main terrace. White's measurements of total spring flow in the month of October during the 1945-1952 period averaged 45 gal/min.

Water-level elevations reported for the Reno wells and the Mt. Rose Resort well during White's study were near the elevation of Steamboat Creek and hence significantly lower than the elevations of the principal hot springs at the main terrace to south. Hence, it is reasonable to assume that under undisturbed conditions thermal water flowed eastward **and** northward in the subsurface from the main terrace toward Steamboat Creek, and that the Reno and Mt. Rose Resort wells captured thermal water that would have flowed to the creek. The calculated total thermal water discharge into Steamboat Creek in 1981-82, 1,300 gal/min (Shump, 1985), when there was no substantial discharge from geothermal wells, lends further support to the contention that the natural discharge from the Steamboat system was formerly 1,110 gal/min or larger. Observations of spring activity during the 1970's and early 1980's, while showing no evidence of flow from vents in the northern part of the main terrace and in the vicinity of the abandoned Reno wells, are too limited to conclude that the cessation of discharge from the Reno wells did not result in reactivation of some hot springs.

These considerations indicate that the total thermal-water discharge from the Steamboat geothermal system declined significantly in recent years. Collar (1990) suggests that the decline is caused by the net production of fluid from the CPI well field, because if this production (380 gal/min under 90°C conditions - table 2) is added to the calculated seepage into the creek, the indicated total discharge (1,050 gal/min) would be remarkably close to the estimate of White (1968). Production from the SB GEO well field is ignored in this argument because all the produced fluid is reinjected. The complication here is that at neither well field is there a net loss of chloride from the geothermal system, and chloride inputs to Steamboat Creek are what is actually being measured. Thus, for well field operations to be causing the apparent decrease in discharge of thermal water, there would need to be changes in the rates and directions of thermal-water flow through the well field areas. Drawdowns induced in each field by development could result in such changes, by effectively capturing some or all of the natural thermal-water throughflow. Furthermore, any chloride injected in the Cox I-1 well that does not flow toward the production wells would not yet be expected to reach Steamboat Creek because of poor pressure communication with the hot springs and slow rates of ground-water movement.

An alternative explanation for the apparent decline in discharge from the geothermal system is that thermal water from the main terrace is being diverted northward into the shallow ground-water system. This might be expected to accompany the declines in water levels in the South Truckee Meadows resulting from the drought and increased pumpage of ground-water. Increases in chloride in wells tapping aquifers with mixtures of thermal and non-thermal ground water (for example, PTR-1) may reflect both an increase in the thermal component and a decrease in the non-thermal component. However, because patterns and rates of flow of thermal and non-thermal ground water in the South Truckee Meadows are not adequately known, it is impossible to assess the degree to which thermal water that formerly flowed into Steamboat Creek is now being diverted into, and retained in, the ground-water system in the South Truckee Meadows.

FACTORS AFFECTING HOT-SPRING ACTIVITY

The systematic decline in hot-spring activity at the main terrace since 1986 appears to be unprecedented in this century. Spring flow ceased in 1987 and since that time measured water levels in spring vents declined 1 to 17 feet. During the 1945-52 period, variations in spring flow from the main terrace were observed, with total flow covering a range from about 30 gal/min to 90 gal/min but never dropping below 30 gal/min. Numerous factors were identified by White (1968) as contributing to the changes in spring activity during his period of study, including variations in barometric pressure, earth tides, and precipitation, and earthquakes. He considered that the first three were minor factors, causing relatively short-term, small amplitude changes in spring activity, and that the longer-term, larger magnitude changes were due to variations in precipitation and consequent ground-water recharge. These same factors, along with fluid production from geothermal and domestic ground-water wells, should have affected spring activity during our study.

Three scales of variation in spring flow and water level were considered to be of significance in our 1986-1989 period of observation: (1) short-term changes over periods of hours to weeks, (2) seasonal changes, and (3) long-term changes. The long-term changes involve cessation of flow and declines in water level that as yet show no signs of significant reversal. Seasonal changes, anticipated from the results of the 1945-52 observations, are poorly documented during the 1986-90 period because of the difficulties in making measurements in the spring vents and the complicating effects of other influences. Short-term variations in spring activity were the most useful in this study for delineating cause-and-effect relations with periods of geothermal well discharge.

Short-Term Variations

For this discussion, short-term variations in spring activity (flow and water level) are those occurring over time periods of hours to weeks. Factors that could influence these changes include barometric pressure, earth tides, earthquakes, local storms, and geothermal well discharge. Of these, earth tides and earthquakes are considered relatively minor, causing variations in water level on the order of 0.1 feet. Their effects are discussed by White (1968) and Collar (1990).

Barometric Pressure

Barometric pressure effects on spring flow and water level were considered by White (1968) to account for most of the day-to-day changes he observed. Barometric efficiency (BE) of an aquifer (BE) refers to the ratio of water-level change in a well or spring tapping the aquifer to the corresponding change in barometric pressure causing the water-level change. Equations relating BE to the compressibility and porosity of the aquifer and the compressibility of the fluid are presented by Collar (1990). White (1968) calculated barometric efficiencies of 0.2 to 1.18 for different vents on the main terrace. A BE greater than 1.0 is possible where water in the spring vent is at or near the boiling point. Spring vents highest in altitude on the main terrace were more strongly affected by barometric pressure changes than were vents at lower altitude. White (1968) considered this relation to reflect the effects of restrictive (lower permeability) fissures connecting the lower altitude vents with the higher altitude vents. A similar relation between barometric efficiency and altitude of vents on the low terrace was considered by White (1968) to indicate that the main and low terraces act as distinct subsystems that are interconnected at relatively great depth (several hundred feet). Differences in rock compressibility and porosity, as related to mineral deposition, may be partly responsible for the differences in BE between different vents. It is interesting to note, however, that a general correspondence between vent altitude on the main terrace and magnitude of water-level decline over the 1986-1989 period has been observed in this study, especially if one includes the data for well GS-8. Possible explanations for this relation are discussed below.

Water-level measurements in spring vents on the main terrace collected by SDSU personnel during this study also show influences of barometric pressure changes. During October 19-25, 1988, measurements were made in springs 6, 12, 42w, and 62 three to four times per day using an electric sounder or a graduated rule (spring 6). The data for springs 6 and 12 (figs. 37 and 38) show that most of the daily fluctuation in water level in these springs is due to barometric pressure changes (as measured at the Reno Airport). Barometric efficiencies, calculated by linear regression, are 0.42 for spring 6 and 0.45 for spring 12. The correlation coefficient for the spring 12 data set (0.44) was significantly lower that for the spring 6 data set (0.79), indicating that random errors and/or other influences (for example earth tides) affected the data for spring 12. From these results, and those of White (1968), it appears that water-level changes in the main-terrace springs induced by barometric pressure fluctuations have historically been no greater that about 0.5 feet and are commonly smaller (for example, 0.1 ft in spring 6). The larger changes result from barometric pressure changes accompanying storm fronts. Although such changes can occur over time scales of hours to weeks, they are unlikely to have been of significance in terms of either the long-term declines in water level at the main terrace or the short-term variations of 0.5-2.0 feet observed during intervals of geothermal well discharge.

Barometric pressure changes have a somewhat larger affect on the water-level records for strat wells 2 and 9. During the May 1987 interference test on CPI well 23-5, diurnal pressure changes as large as 0.2 psi and 1.0 psi were measured in the capillary tubing in strat 2 and strat 9, respectively (Faulder, 1987). These pressure measurements were apparently made with absolute-pressure-reading gages. The long-term water-level records for these wells also show significant variability related to barometric pressure changes, particularly after July 1988 when gage-pressure transducer readings were initiated. Barometric efficiencies estimated for each well are greater than 1.0; this must be related to the fact that the upper part of the fluid column in these wells is boiling. The appearance of the detailed hydrographs for these wells suggests that water-level variations of 0.25-0.5 feet may be caused by changes in barometric pressure.

Precipitation

White (1968) observed that precipitation of as much as 0.5 inches per storm had no detectable effects on the hot-spring system, whereas storms of 1 inch or more generally had clearly observable effects within periods of 1-2 days. No attempt was made in our study to correlate spring hydrographs with daily precipitation records because our interest was in

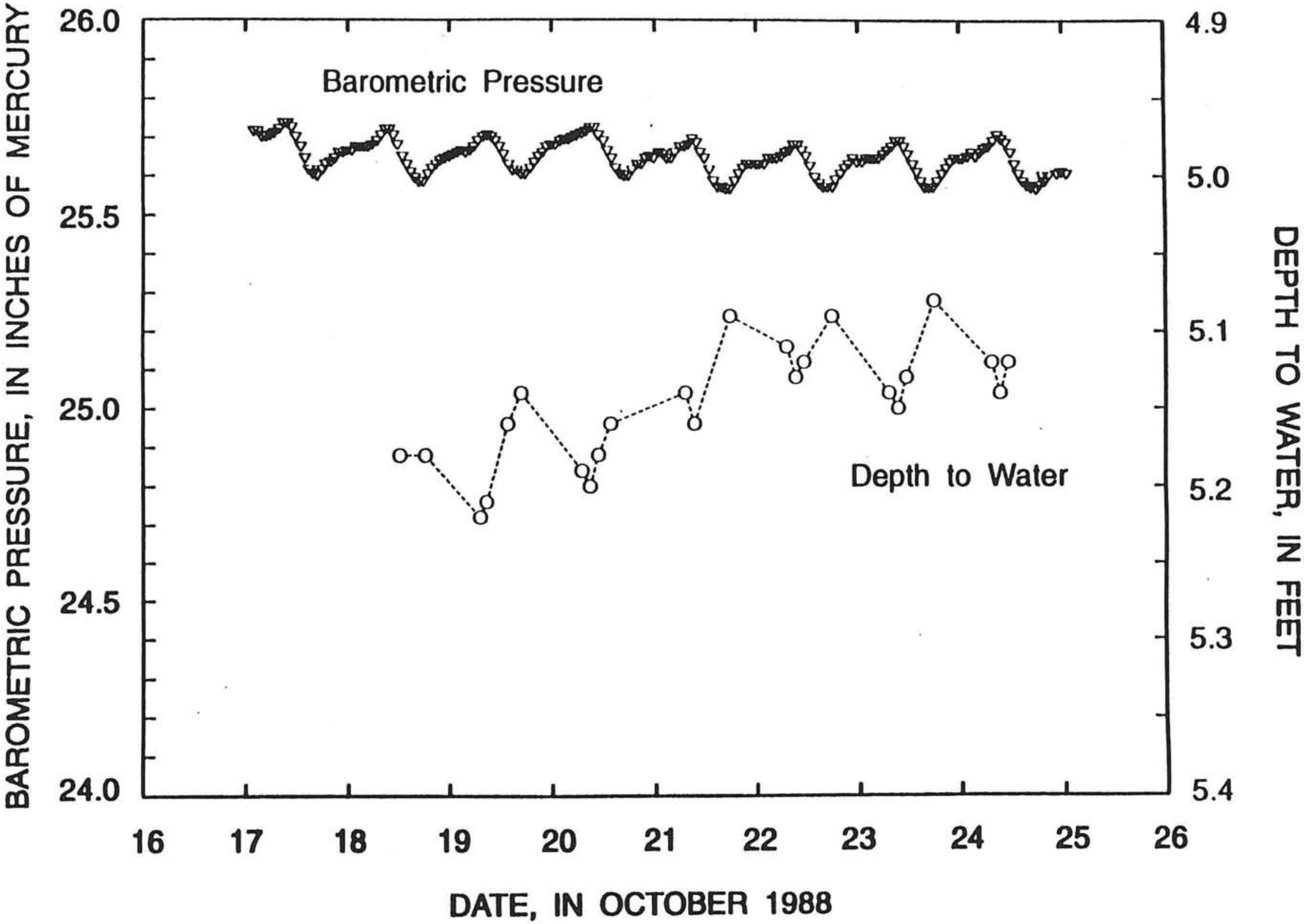


Figure 37. Depth to water in spring 6 and barometric pressure measured at the Reno Airport, in October 1988.

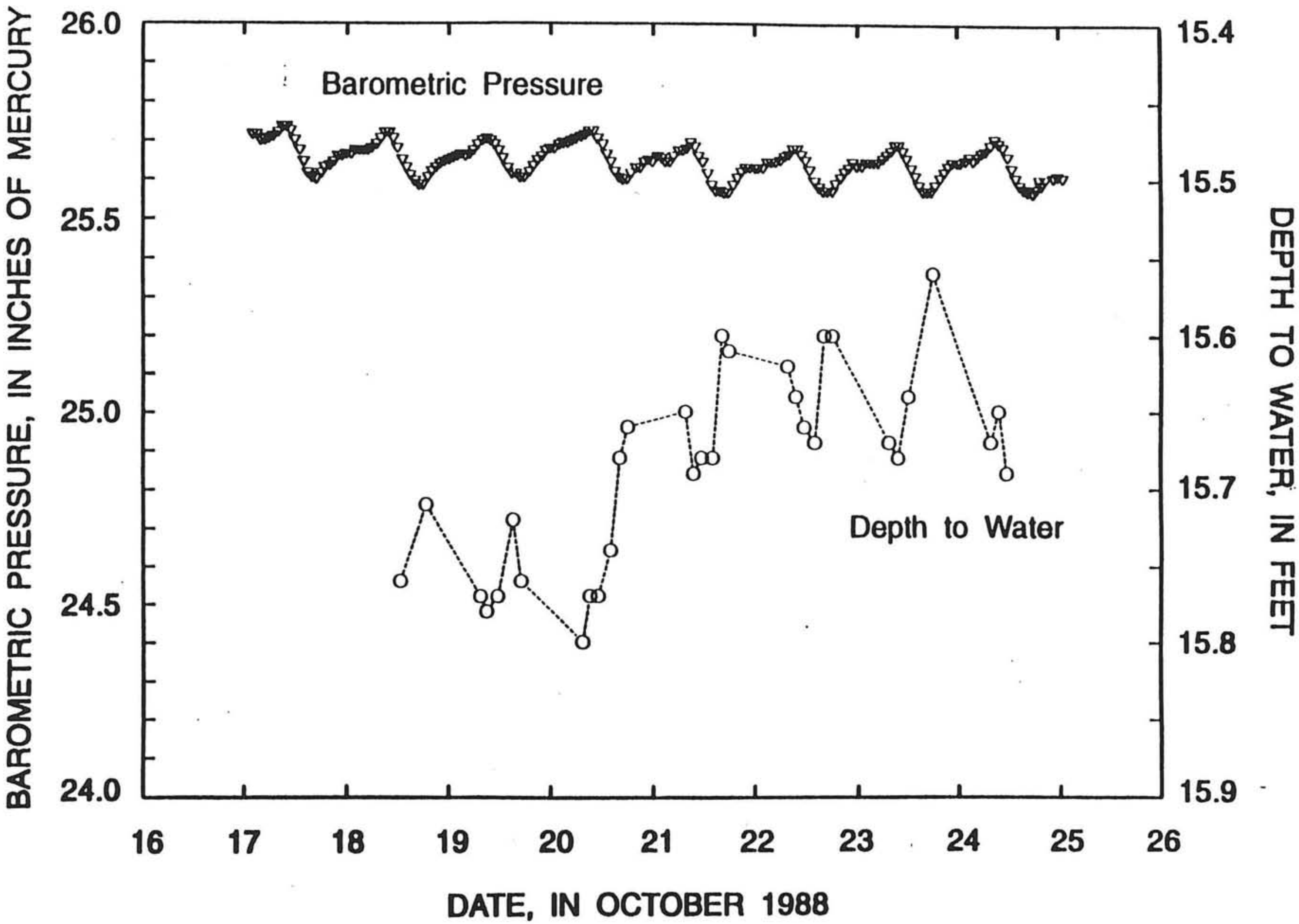


Figure 38. Depth to water in spring 12 and barometric pressure measured at the Reno Airport, in October 1988.

stresses that caused longer-term changes in the hot springs. In addition, we noted in previous sections of the report that correlations are not commonly observed between spring activity and monthly or even seasonally averaged precipitation (figs. 14 and 26).

Geothermal Well Production

Short-term changes in hot-spring activity delineated during the 1986-1989 period include declines and rises in water level in several springs associated with CPI discharge interval 1 in 1986, declines and rises in springs 6, 12, and 42w associated with CPI intervals 9-11 in 1988, and similar changes in spring 6 during 1987. As noted previously, determinations of cause-and-effect relations for some of these changes is complicated by the influence of seasonal changes in the ground-water system, as indicated by the hydrograph for the Pine Tree Ranch-1 well (fig. 25). The 1986 data show a rapid rise in water level in spring 6 that occurs within three weeks of cessation of CPI discharge interval 1 and more than a month before water levels in PTR-1 begin their seasonal rise. The rate of ground-water production from the STMGID wells, which should have exerted a significant influence on heads in the shallow ground-water system, remained at relatively high levels until the fall of 1986. This suggests that production from the CPI well field had a significant effect on the temporary decline in spring activity in 1986.

Apparently no water-level data for strat wells 2, 5, and 9 were collected during 1986. Such data would have facilitated the interpretation of the cause(s) of the terrace-wide changes in the hot springs during that year. Water-level data for these wells during 1987-89 are well correlated with the spring 6 record, particularly over the period which includes CPI discharge intervals 4-9 (fig. 31). Data collected from the May 1990 CPI well field shut-down and from earlier periods of well testing before 1988 show convincing evidence of hydraulic connections between these strat wells and the CPI production and injection wells. Hence, the correspondence between short-term changes in water level in these strat wells and water levels in spring 6 during CPI discharge intervals argues for a similar hydraulic connection between the main-terrace springs and the CPI well field.

Monitoring data collected in springs 6, 12, and 42w and strats 2 and 9 during the summer of 1988 (figs. 28 and 31) are particularly useful in quantifying the effects of CPI well field operations on hot-spring activity. As noted previously, there is a consistent pattern of change in each spring (decline during production, and rise during shut-in) and a general correspondence between differences in short-term change and long-term water-level declines in these springs. Furthermore, corresponding changes in water level occurred in strats 2 and 9 during the summer of 1988. Taken together, these data indicate that CPI production can cause water-level declines of at least 1-2 feet at the main terrace and in the shallow thermal-water flow zone penetrated by strats 2 and 9.

Evidence that short-term changes in hot-spring activity have occurred in response to production from the SB GEO well field consists mainly of a decline in the total visually estimated flow of the main-terrace springs in November 1986; cessation in flow of two springs (4 and 16se) in December 1986; and declines in water level in several spring vents in January and February 1987, following the onset of well tests in December 1986 and full-scale operations in January 1987. Only for one period (January 1988) is there a clear correlation between a change in SB GEO production and water level in spring 6 (fig. 35).

Seasonal Variations

Seasonal variations in hot-spring activity similar to those observed during 1945-52 would be expected to occur during the 1986-89 period. A pattern of relatively high discharge and water level in the winter months and low discharge and water level in the summer months, superimposed on a long-term decline, is generally consistent with hydrographs for spring 6 and strat wells 2 and 9. Modest rises in water level in spring 6 and in strat wells 2, 5, and 9 in the fall of 1989 lend support to the contention that changes in water level in the shallow ground-water system in the Steamboat Hills and South Truckee Meadows have significantly influenced hot-spring activity. Yeamans' (1987a) record of estimated flow from six main-terrace springs between June 1986 and April 1987 shows an increase from 10 gal/min to 30 gal/min from summer to winter and a subsequent decline that reflects this seasonal pattern, but could also be influenced by CPI well testing. No clear pattern of seasonal change is seen in the hydrograph for springs 8, 12, and 42w, however, and water levels in the other main-terrace springs fell too deep to measure during the spring of 1987 so that patterns of seasonal change could not be evaluated.

Changes in precipitation and related changes in rates of recharge to the ground-water and geothermal systems must have been the primary influences on hot-spring flow during the 1945-52 period of detailed observation. Both seasonal variations and long-term changes in spring flow were observed. Although the correlation between quarterly averaged spring flow and precipitation is not strong, there was a consistent seasonal pattern to the spring-flow variations that must in some way be related to variations in water-level in the shallow ground-water system surrounding the main terrace. The general mechanism for such effects should involve a lowering of head in the thermal reservoir beneath the main terrace during periods of low ground-water level and a rise in head beneath the terrace during periods of high ground-water level. White (1968) diagrams a conceptual model for a hot-spring conduit placed above the level of discharge for the surrounding ground-water system that would allow for such effects from both changes in head in the thermal reservoir (causing changes in the rate of upflow) and changes in head in the ground-water system surrounding the conduit (causing changes in the rate of lateral leakage of thermal water from the upflow conduit). Because the main-terrace spring vents are at altitudes approximately 100 feet higher than the areas of seepage into Steamboat Creek, and because hot-spring discharge rates (~60 gal/min before 1987) are much less than thermal-water seepage rates into Steamboat Creek (~600 gal/min), hot-spring discharge should be relatively sensitive to head changes in the underlying thermal reservoir and to water-level changes in the surrounding ground-water system. During periods of relatively low streamflow or low water table, more thermal water would tend to leak laterally away from the spring conduits and flow in the subsurface eastward and northward toward eventual discharge in Steamboat Creek. During wetter periods, more thermal water should discharge at the springs.

Ground-water withdrawals for domestic consumption in the South Truckee Meadows have enhanced the seasonal variation in water levels in this area and therefore should have added to the effect that changes in the shallow ground-water system have on hot-spring activity at the main terrace. Declines in water level in the shallow ground-water system in the South Truckee Meadows in response to ground-water pumpage had begun by 1985. Although Yeamans' (1987a) estimates of spring flow in 1986-1987 suggest that hot-spring activity did not begin its systematic decline until the spring of 1987, the accuracy of these estimates is uncertain and therefore comparisons with measurements of total spring flow during the 1945-1952 period are questionable. This issue is of importance because the similarity in the hydrograph for the PTR-1 well and spring 6 indicates that the hot springs respond relatively rapidly to changes in water level in ground-water system. If, in fact, the hot-spring decline in hot-spring activity did not start until 1987, it would be difficult to explain the apparent lag between this decline and the long-term decline in the shallow ground-water system. Clearly, actual measurements of total spring flow in 1986 and in previous years would have been of great value in resolving this issue.

Long-Term Changes

Drought-related changes in recharge to both the geothermal system and the shallow ground-water system are unlikely to be solely responsible for the decline in hot-spring activity. As Collar (1990) points out, the almost complete cessation in hot-spring flow at the main terrace in 1987 occurred before the severity of the current drought had reached levels comparable to those during the 1945-1952 study period. Hence, lower precipitation and associated ground-water recharge alone could not be responsible for the loss of spring flow. Drought-related changes in recharge to the geothermal system over periods of several years are even less likely to have direct effects on hot-spring activity. Overall head differences driving water flow from recharge to discharge areas are on the order of 1,000-2,000 feet and overall flow paths probably approach 5-10 miles in length. Thus, changes in head within the recharge area (the Carson Range) should be damped out before reaching the discharge area, except in the unlikely event that rock permeabilities were uniformly high (similar to those estimated for the geothermal reservoirs). Similar conditions of relatively constant spring flow were described by Mifflin (1968) and Eakin (1966) for large-scale ground-water flow systems in Nevada.

Water-level measurements in observation wells show declines in the South Truckee Meadows ranging from 14-21 feet over the 1985-89 period in wells PTR-1, MW-3, and MW-4. These wells are located north and northeast of the main terrace; their water levels are affected by pumpage of ground water for domestic consumption and recharge from creeks draining the Carson Range and from leakage from irrigation ditches. Other wells located near Steamboat Creek and away from centers of pumpage have shown essentially no long-term declines. Wells in the northern part of the Steamboat Hills (strats 2, 5, and 9) have shown declines of 16-26 feet over the 1987-89 period. Such declines are equal to or larger than declines in water level in the hot spring vents (1-17 feet). With the existing data, however, there is no way to determine directly how much of the main-terrace water-level decline is due to declines in water level in the surrounding ground-water system.

Water levels in spring 6 and in various observation wells (including PTR-1, MW-3, MW-4, and strats 2, 5, and 9) rose in the fall of 1989, following a period of relatively high precipitation in the winter of 1989. Production from the geothermal well fields was relatively continuous but not constant during this period of rising water levels. It is likely that the water-level rise of 1 foot in spring 6 was related to rises in ground-water levels in the South Truckee Meadows and Steamboat Hills. Additional data collected from existing monitoring wells and from a monitoring well completed at the main terrace during periods of rising water level would help clarify these relations.

Evidence of the influence of geothermal well production on hot-spring activity consists of (1) correlations between short-term changes in water level in spring vents and periods of production from the CPI and SB GEO well fields, and (2) similar correlations between the spring 6, 12, and 42w hydrographs and the hydrographs for strat wells 2 and 9. The significance of (2) depends on the evidence discussed previously from CPI interference tests and 1990 CPI well-field shut-down that these strat wells are in hydraulic communication with the CPI production reservoir. The shallow thermal-water flow zone penetrated by strat wells 2 and 9 exhibits temperature and hydraulic head characteristics that are consistent with a hydraulic connection between this zone and the reservoir underlying the hot springs. Although it could be argued that a continuous zone of lateral flow between these strat wells and the main terrace may be an oversimplification, there is no known geologic or structural evidence to show that these wells and the CPI production wells are not in some way hydraulically connected with the hot springs.

The degree of correlation between intervals of CPI production and water-level changes at the main terrace is, in our view, too great to be explained away as due to the normal seasonal changes in spring activity. We infer from the magnitude of the water-level changes that specific intervals of CPI production have resulted in declines of 1-2 feet in the hot spring vents. Full-scale production for extended periods could presumably have a somewhat larger effect, depending on the delay that may be involved for injection pressure support to be manifested. There is less evidence from such correlations that production and injection from the SB GEO well field has had a discernable effect on hot-spring activity. This partly reflects the absence of interference tests at times when water levels were being measured at the main terrace.

Water-level declines of 1-2 feet at the main terrace from CPI production are reasonable, given the measurements of 2-10 feet of water-level change in strat 9 and well 28-32 associated with the May 1990 shut-in and subsequent start-up. The available information from the CPI well field indicates drawdowns of 10-15 feet after several years of full-scale production with injection support. Assuming that a hydraulic connection existed, the drawdown at the main terrace (2 miles away) would amount to a few feet under conditions of radial flow in a homogenous reservoir with transmissivity and storage coefficients equal to those determined for the CPI well field (9,000 ft^2/day and 0.001, respectively). An areally restricted connecting zone would tend to cause drawdowns of more than this amount at the main terrace for the same transmissivity, whereas a lower transmissivity applied to the radial flow case would yield less drawdown. Such calculations also indicate that the effects of geothermal production should begin to occur at the main terrace after times of 5-10 days, as actually observed. There is some indication from CPI well tests involving strat wells 2 and 9 and springs 12 and 42w as observation wells (table 9) that transmissivity may be lower outside the CPI well field. However, because the geometric and hydrologic characteristics of permeable regions between the CPI well field and the main terrace are largely unknown, these drawdown calculations are useful only to suggest that declines in hot-spring water levels of a few feet resulting from CPI production are hydrologically reasonable.

The SB GEO well field is much closer to the main terrace than is the CPI well field and has experienced 15-20 feet of drawdown. However, the current SB GEO well field may be less directly connected to the hot springs. This inference is based on the more limited evidence of correlations between SB GEO discharge intervals and changes in hot-spring water levels and the higher heads in the SB GEO reservoir than beneath the main terrace under pre-development conditions.

The available information indicates that 1-3 feet of water-level decline at the main terrace is likely to have been caused by long-term drawdown in the CPI reservoir. This estimate is based on the range of results obtained from actual measurements of changes in spring water levels associated with various CPI production intervals, pressure measurements in observation wells during and following the May 1990 shut-in, and calculations of reservoir drawdown after several years of full-scale production based on the results of various well tests. More accurate quantification of this influence would require completion of observation wells in the production reservoir and in the feed zone beneath the main terrace and some form of interference testing, most reasonably associated with a regularly scheduled field shut-down and restart. If the estimate of 1-3 feet of head decline from CPI production is correct, then the remainder of the declines observed at the main terrace should be attributable to water-level declines in the ground-water system, and to a much smaller extent to production from the SB GEO well field.

The effect of a given change in head beneath the main terrace on water levels in the hot-spring vents can only be speculated on at this time. Water-level declines in individual vents for which measurements have been made range from 1 to 17 feet between 1987 and 1989. As noted previously, the relative changes in water level in springs 6, 12, and 42w (~0.5-2.0 feet) were roughly the same during mid-1988 (CPI discharge intervals 9-11) as the overall declines since 1987 (6-17 feet). These differences are also generally consistent with the observation that spring vents at higher altitude on the main terrace exhibit larger changes in water level than do spring vents at lower altitude. This may be related to differences between the resistance of the spring conduits to upward flow and lateral leakage. Springs at higher altitudes should be those with less resistance to upward flow and perhaps more resistance to lateral leakage. Wells drilled on the main terrace, for example GS-4, GS-5, and the Rodeo well, had higher water-level altitudes than did the hot springs in the 1945-52 period, presumably because they provided relatively low vertical- and high lateral-resistance taps to deeper fractures.

Assuming that flow is taking place within and between different spring conduits, even though the hot springs no longer flow at the surface, the resistance to flow would still influence the water level in each vent. Under these conditions, the higher altitude (lower conduit resistance) springs should exhibit the greatest change in water level from a given change in head in the underlying source reservoir. Furthermore, the water-level changes in such vents should be closer to, or better representations of, the head changes in the source reservoir. This indicates that for the purposes of evaluating the effects of different stresses on hot- spring activity, the head change beneath the ACEC between 1987 and 1990 was close to 20 feet.

The only wells on the main terrace for which recent water-level measurements could be obtained are GS-8 on the far eastern (low altitude) side of the terrace and the Byers well on the far western (high altitude) side (plate 1). The measurements for GS-8 show a water-level decline of about 1 foot between 1988 and 1989 and 7 feet since the 1950's. Similar measurements for the Byers well show a decline of about 40 feet between 1985 and 1991, on the basis of a depth to water of 5 feet in 1985 (from C. Goranson, oral commun., 1991). The Byers well, which is about 100 feet deep with a bottom-hole temperature of 120°C, most likely does not penetrate the principal fracture system supplying thermal water to the main-terrace springs(based on thermal, chemical, and lithologic data for the adjacent GS-3 well described by White, 1968). Thus, the decline in water level in this well since 1985 may be indicative of the declines in water level in the shallow ground-water system surrounding the terrace. However, water-level measurements in Byers well are also affected at times by thermal cycling and boiling (D.H. Schaefer, written commun., 1991). Well GS-8 appears to tap thermal water flowing eastward in alluvium toward Steamboat Creek from the conduit system in bedrock beneath the main terrace. Changes in water level in GS-8 may be partly controlled by the water levels in Steamboat Creek.

The depth to water measured in TH-1, a core hole recently completed north of the ACEC hot springs for the proposed expansion near the SB GEO well field (referred to as the Steamboat #2 and #3 Geothermal Projects in JBR Consultants Group, 1991), was 33 feet (C. Goranson, oral commun., 1991). Although this well appears to tap vertical fractures that may be connected with the conduit system supplying the main-terrace springs, it would be questionable to use the depth to water in this well as a measure of the change in head beneath the main terrace because there was a significant pre-development gradient in head northward between the ACEC and the Reno and Mt. Rose Resort wells.

High-chloride thermal water began discharging at the main terrace adjacent to well GS-5 in the summer of 1991. This discharge appears to originate from a shallow casing break in GS-5. It is most likely that such flow does not indicate a recovery of hot-spring water levels, but rather the effects of relatively light two-phase fluid flowing up the well casing and leaking out near the surface. A similar situation was apparently responsible for high wellhead pressures measured in several of the GS series wells on the main terrace during drilling (White, 1968; D.White, oral commun., 1991).

MONITORING PROGRAM

Hydrologic monitoring in the Steamboat area is done by the geothermal operators to (1) observe, assess, and correct adverse effects on the springs and geysers in the Area of Critical Environmental Concern (ACEC) (Chevron Resources, 1987) and (2) to detect adverse impacts to ground-water quality in alluvial aquifers surrounding the Steamboat Hills. Both Caithness Power Incorporated (CPI) and SB GEO are required to furnish quarterly reports on monitoring results to the Nevada Division of Environmental Protection (NDEP) under permits NEV50018 (for SB GEO) and NEV70007 (CPI). Currently, CPI reports on all aspects of the monitoring activities, including water-level measurements in observation wells, chemical sampling of observation wells, and measurements of stage and chloride concentration in Steamboat Creek; SB GEO reports separately on pressure measurements in three observation wells in their well field and water level and fluid chemistry for seven wells in the South Truckee Meadows. Sites considered part of the monitoring program are listed in table 10, along with parameters recorded and measurement frequency at each site (site locations shown in plate 3). Not listed are production and injection wells at each facility, for which records of daily measurements of flow and wellhead temperature, and wellhead pressure and downhole pressure (SB GEO wells only) are furnished. Caithness is required to monitor springs 12 and 42w according to the NDEP permit and to make visual observations of other spring activity. However, such monitoring has been restricted by declines in water level in the spring vents and refusal of private land owners to give permission for access to many of the springs on the main terrace (outside the ACEC) and the low terrace. Data collected by CPI on hot-spring activity has been significantly augmented since mid-1986 by measurements and observations made by BLM, NDEP, and SDSU personnel, and other private individuals (Appendix A).

Stream-Water Quality and Stage

CPI monitored stream stage (using a staff gage) in Steamboat Creek at Rhodes Road and at Virginia City Highway (State Highway 341) and in Steamboat, Chandler, and Crane irrigation ditches near the Virginia City and Mt Rose Highways (plate 3) at monthly intervals during 1987-89. Water samples at these locations were collected and analyzed for chloride concentration. None of the staff-gage readings have been calibrated to stream discharge, so there is as yet no streamflow data corresponding to the chloride concentration data.

Review of CPI records for the time period May 1987 to September 1988 (Yeamans, 1987e-f, 1988a-c) reveals significant variations in chloride concentration. These variations probably reflect dilution of the thermal-water component derived from seepage by nonthermal water inputs from upstream sources. These data cannot be interpreted in terms of the locations and rates of thermal-water inputs to Steamboat Creek until rating curves are developed from actual discharge measurements at the staff-gage sites.

Water Levels and Fluid Measures in Wells

Pressure measurements in strat wells 2 and 9 are potentially most useful in delineating possible effects of geothermal well-field operations on shallow thermal aquifers beneath the Steamboat Hills. Indeed, the stated purpose of monitoring these wells is to observe changes

Table 10. *Current monitoring sites for Caithness Power Incorporated (CPI) and SB GEO (SBG) geothermal developments (excluding production and injection wells and points denied access by land owner)*

Type of feature: TW, Thermal Well; W, Nonthermal Well; DW, Domestic Well; S, Spring; SW, Surface Water.
Parameters: WL, Water Level; Q, Discharge Rate; T, Temperature; C, Chemistry.
Frequency: (w:m), weekly monitoring for the first year, monthly thereafter; (m:q), monthly monitoring for the first year, quarterly thereafter; (m:q&y), Monthly monitoring for the first year, quarterly and yearly thereafter; (m:q4:y), Monthly monitoring for the first year, quarterly for the following 4 years, yearly thereafter; (y), yearly.

Monitoring Site	Type of feature	Parameters (frequency)
Caithness Power Incorporated		
Strat. Well 2	TW	WL(w:m), T(y)
Strat. Well 5	W	as above
Strat. Well 6	W	as above
Strat. Well 7	W	as above
Strat. Well 9	TW	as above
Strat. Well 13	TW	as above
Strat. Well 14	TW	as above
STMGID Well[1]	DW	WL, T, C(m:q)
Woods Well	DW	as above
Tangen Well	DW	as above
MacKay Well[1]	TW	as above
Curti Barn Well	TW	as above
Curti Domestic Well	DW	as above
Pine Tree Ranch Well 2	TW	as above
1055 Lavender Well[1]	TW	as above
Steinhardt Well	TW	as above
Boyd Well[1]	DW	as above
Rogers Well[1]	DW	as above
Jeppson Well[1]	DW	as above
Seep	S	Q, T, C(m:q)
Spring 12[2]	S	Q[4], Wl, T, C(m:q)
Spring 42[2]	S	Q[4], Wl, T(m:q), C(m:q&y)
Other main terrace spring[3]	S	Visual observations
Steamboat Creek at Rhodes Road	SW	Q, T, C(m:q)
Steamboat Creek at Virginia City Hwy	SW	as above

Table 10. Current monitoring sites for Caithness Power Incorporated (CPI) and SB GEO (SBG) geothermal developments--continued

Monitoring Site	Type of feature	Parameters (frequency)
Steamboat Ditch	SW	as above
Chandler Ditch	SW	as above
Crane Ditch	SW	as above
Steamboat Spa[3]	SW	as above
SB GEO (formerly Ormat Energy Systems Inc.)		
Brown School Well	DW	WL[2], T, C(m:q4:y)
Herz Domestic Well	DW	as above
Herz Well #2	TW	as above
Bianco Well	DW	as above
Pine Tree Rch Well 1[1]	TW	as above
Flame Well	TW	as above
Peigh Well	DW	as above
OW-1	TW	WL (weekly average)
OW-2	TW	WL (weekly average)
IW-1	TW	WL (weekly average)

[1]Separate wells were used for water level measurement and water chemistry sample. STMGID stands for South Truckee Meadows General Improvement District.

[2]Only where possible to obtain sample or measurement.

[3]Access to springs 4, 6, 8, 10, and 16se was denied, as was access to low terrace springs and wells.

[4]Visually estimated.

in head in the Steamboat geothermal system due to CPI well discharge and injection before such changes are observed at the main terrace and to determine if CPI well-field operations are affecting the hydrology in the vicinity of the main-terrace springs (Chevron Resources, 1987). Pressure data collected from strats 2 and 9 before July 1988 were obtained from absolute-reading transducers; gage-pressure transducers were used after that time and are currently being used. Data from the gage-pressure transducers show relatively large fluctuations in response to barometric pressure changes that, along with a reduction in measurement frequency, make it more difficult to delineate and interpret short-term changes. Even when a correction is applied by adding the observed barometric pressure at the Reno Airport, the resultant hydrographs show more variability after July 1988 than before (see for example fig. 30). Better water-level information could be obtained from these wells if records of local barometric pressure were used to filter the fluid pressure data.

Strat 9 is completed with 2.88-inch liner perforated from 905-915 feet. Attempts were made to cement the liner from the top, but the outcome of the cementing operations, in terms of the thickness of cemented liner, is unknown. Strat 2 is completed with 2.88-inch liner slotted from 795-835 feet. There is apparently no cement in the water-filled annulus below the depth of the surface casing (156 feet). Sections of the formation outside the liner at 250 feet and 430 feet have been gun perforated. Thus, for strat 2, and to a lesser extent strat 9, measured pressures could respond to hydrologic changes in more than one zone. This is obviously not an ideal situation for interpretive purposes.

Strat 5 is completed with 2.88-inch tubing (open but unslotted), to 1,687 feet. Water-level data for strat well 5 are determined from depth-to-water measurements made from the land surface, except for brief periods in 1987 when downhole pressure transducers were used. A float-activated recording system is currently in place in strat 5 for continuous water-level monitoring. Because of its location and depth, water levels in this well could be expected to respond both to changes in the shallow ground-water system and to changes in bedrock aquifers. As noted previously, interpretations of data from different interference tests lead to varying interpretations of the influence of geothermal well production on water-levels in strat 5. We currently do not know the depth or depths at which the 1,700 ft-deep liner in strat 5 is perforated or slotted.

Both downhole- and wellhead-pressure data are collected on the SB GEO production, injection, and monitor wells. Only the data for monitor wells IW-1, OW-1, and OW-2 are reported to NDEP. Problems with the pressure data for these wells, and the corresponding calculated depth-to-water data were discussed previously. The existing data for these wells are useful mainly for providing a measure of the overall decline in downhole pressure in the existing SB GEO production zone. The proposed expansion for the Steamboat #2 and #3 Geothermal Projects can be expected to cause additional reservoir drawdown that may affect heads beneath the main terrace. Consideration should be given by BLM and NDEP for monitoring such effects in a well such at TH-1 near the northern boundary of the ACEC.

A clear need exists at present for means of monitoring fluid pressures in the CPI reservoir and beneath the ACEC part of the main terrace. The addition of monitoring wells at these locations would offer opportunities to conduct interference test(s) at the CPI well field that could better quantify the degree of hydraulic communication between these areas and to observe increases in head beneath the main terrace that may accompany a return to higher precipitation conditions in the Steamboat area. Such monitoring would also make it possible to assess the success of any mitigation measures that might be attempted to increase heads and water levels at the main terrace, such as injection into the shallow thermal zone penetrated by the Cox I-1 and strat 9 wells, as discussed below. Because of environmental problems associated with drilling a monitor well in the ACEC, attempts should first be made to gain access to or recomplete an existing well on the main terrace (for example the Rodeo well and wells GS-4 and GS-5) that currently is either sealed near the surface with mineral deposits or are filled in with rubble. A recent attempt to drive a well point into the spring 42w vent for access to make water-level measurements proved unsuccessful (Schaefer, 1991).

Water-level and temperature data were collected from the Byers well from October 1990 to July 1991, but have since been discontinued. These data show a decline in water level of about 2 feet over this period, with barometrically induced fluctuations of about ± 0.2 feet. Although water-level changes in this well may not adequately reflect pressure changes in the hot-spring conduits and underlying source reservoir, water-level data collected from the Byers well would provide useful control for interpreting similar data from a monitor well drilled into the principal fracture system beneath the main terrace. This well should be monitored with a pressure transducer rather than a float because thermal fluctuations may cause large changes in fluid level in this well.

There currently exists no adequate means for monitoring changes in reservoir pressure in the CPI well field. The production wells cannot easily be instrumented for this purpose and the currently monitored strat wells are not completed into the deep reservoir. Strat 32-5, however, is completed into the production reservoir in the vicinity of unused production well 32-5. Temperature and lithologic data for strat 32-5 indicate that, if it were cleaned out, it could serve as an adequate monitor of reservoir drawdown. There is, however, no previous pressure record for this well. Alternatively, well 28-32 could be monitored on a continuous basis. Well 28-32 has been shown to be connected with the other production wells and the Cox I-1 injector, but exhibits its maximum downhole pressure at a depth some 600 feet shallower than the CPI production wells.

CONCLUSIONS AND SUGGESTED ADDITIONAL DATA COLLECTION

Conclusions

The principal conclusions of this study are listed below.

1. A systematic decline in hot-spring activity became apparent in the Area of Critical Environmental Concern (ACEC), located on the main silica terrace at Steamboat Springs, in early 1987, but may have started earlier. By mid-1989, all springs had ceased flowing and measured water-level declines in spring vents in the ACEC ranged from 1 to 17 feet. The total decline in head in the reservoir supplying thermal water to the springs was probably close to 17 feet in 1989, when the spring water levels could no longer be measured.

2. These changes were accompanied by successive years of below-normal precipitation in the Steamboat region beginning with the July 1986-June 1987 precipitation year. Lower precipitation and associated decreases in recharge to the ground-water and geothermal systems are unlikely to be the only factors responsible for the decline in hot-spring activity because similar periods of drought in the past did not cause such drastic reductions in spring flow.

3. Drought conditions and increased pumpage of ground water for domestic consumption in parts of the South Truckee Meadows north and northwest of the main terrace have resulted in long-term declines in water level in alluvial aquifers. Most of this pumpage occurs from wells operated by the South Truckee Meadows General Improvement District (STMGID). Between 1985 and 1989, the decline in annually averaged water-level in two cold-water observation wells and a warm-water (43°C) observation well located in these areas ranged from 14 to 21 feet. These wells also show seasonal variations in water level that reflect cycles of recharge and pumpage of ground water.

4. Water-level declines of 14-26 feet were measured between 1987 and 1989 in strat wells 2, 5, and 9 in the northern part of the Steamboat Hills. Strat wells 2 and 9 are drilled into permeable zones containing thermal water at temperatures near 175°C, whereas strat well 5 is completed in the nonthermal ground-water system. Similarities between both long-term declines and seasonal changes in water level in these strat wells and changes observed in wells in the South Truckee Meadows indicate that water level changes in these strat wells are due in large part to variations in ground-water withdrawals and recharge to the ground-water system.

5. Data collected during numerous interference tests show that strat wells 2 and 9 and well 28-32 are hydraulically connected with the Caithness Power Incorporated (CPI) production and injection wells, but that only a few feet of the long-term water-level decline in these wells can be attributed to CPI well-field operations.

6. Most (about 80-95 percent) of the long-term decline in water level in the ACEC springs may be due to the effects of declines in water level in the shallow ground-water system. These percentages were calculated (and then rounded off) by subtracting the effects of CPI well-

field operations noted below (1-3 feet) from the estimated total head decline in the ACEC in 1989 (17 feet). The only direct indications of the effects of changes in water level in the ground-water system on hot-spring activity are the seasonal and annual variations in spring flow delineated during the 1945-1952 period, the general correspondence between the water level record for spring 6 and the Pine Tree Ranch-1 well during the 1986-1989 period, and the period of rising water level in spring 6, strat wells 2, 5, and 9, and the Pine Tree Ranch-1 well in late 1989.

7. Water-level declines in the ACEC springs of 1-3 feet due to production from the Caithness well field are indicated by correlations between short-term changes in spring water level and periods of production from the CPI well field, similarities between short-term responses observed in the hydrographs for several hot springs and strat wells 2 and 9, and theoretical calculations of reservoir drawdown after several years of production. This effect represents about 5-20 percent of the estimated total head decline beneath the ACEC in 1989.

8. Under full-scale production with pressure support from injection, drawdown in the CPI production reservoir is estimated to be about 10-15 feet. There are indications of greater drawdown in the immediate vicinity of the production wells. Both the long-term drawdown in the production reservoir and the resultant decrease in head beneath the ACEC need to be better quantified by reservoir testing involving pressure measurements in observation wells completed in the production reservoir and in the reservoir feeding the ACEC hot springs. Theoretical calculations suggest that if there were a high-transmissivity connection between the CPI well field and the main terrace, water-level declines of a few feet at the main terrace could result from well-field drawdown of 10-15 feet.

9. The location and characteristics of the apparent hydraulic connection between the CPI production reservoir and the ACEC hot springs are uncertain. Such a connection could be provided through a shallow thermal-water flow zone evidenced in several wells in the northern part of the Steamboat Hills at depths near 1,000 feet. Such a zone could be fed by upflow of thermal water from the deeper production reservoir along steeply dipping faults. The injection zone in Cox I-1 may not be in direct hydraulic connection with this shallow thermal aquifer, but may influence production-induced pressure changes in this zone by providing pressure support through the deeper reservoir to the CPI production wells.

10. Although head declines of 15-20 feet have been observed in the SB GEO well field, there is only limited evidence for an influence of SB GEO operations on the ACEC hot springs. This may reflect lower permeability or fault-related anisotropic conditions between these two areas and higher heads at the high terrace than at the main terrace under pre-development conditions. It is likely, however, that the proposed expansion of geothermal production to the southeast of the SB GEO well field will have a more significant effect on the ACEC springs.

Additional Data Collection

The findings of this study represent the best interpretation that can be made at this time as to the influence of various factors on the recent decline in hot-spring activity at Steamboat. The available data do not prove that a given stress has caused a certain amount of water-level decline in the hot springs. Indeed, because there is no monitoring point into the reservoir beneath the main terrace that feeds the hot springs, there is no accurate measure of the change in head or pressure beneath the main-terrace ACEC. The estimates given here of the effects of geothermal well production and water-level declines in the shallow ground-water system should best be considered as indicative of the relative effects of these factors. Such a delineation may suffice for decision-making purposes. We can, however, suggest several steps to provide better measures of these effects and of additional effects from future changes in climate, ground-water pumpage, and geothermal well production. These suggestions are listed below.

1. An observation well is needed within the ACEC to monitor pressure changes in the reservoir feeding the hot springs. Initial attempts should be made to gain access to an existing well in the ACEC, possibly GS-4, GS-5, or the Rodeo well; if those efforts are unsuccessful, then a new well should be drilled. Such a well should then be instrumented for continuous pressure measurement using a transducer. Similar measurements should be obtained in the Byers well at the west side of main terrace.

2. Well TH-1, drilled north of the ACEC for the Steamboat #2 and #3 Geothermal Projects, should be instrumented for use as an observation well to delineate the effects of future geothermal production north of the ACEC.

3. Pressure monitoring should be done in a well completed in the CPI production reservoir. Unused production well 28-32 could be used for that purpose, as could well 32-5 if it could first be cleaned out.

4. An interference test should be conducted at the CPI well field to provide better information with which to quantify the effects of production and injection on pressures beneath the main terrace. Several types of test are possible, including (a) a field-wide shut-down for a period of at least two weeks during the spring or summer, when ground-water levels should be in decline; (b) flow tests on a new production well; and (c) temporary diversion of part of the injection stream into strat 9.

5. Testing involving injection into strat well 9 might permit better evaluation of possible hydraulic connections between strat wells 2 and 9, the main terrace, and the CPI production reservoir. However, before attempting to use strat well 9 for this purpose by diverting some of the injection stream from Cox I-1, the physical status of strat 9 would need to be thoroughly investigated. Also, there is no way to accurately predict beforehand what effects injection in strat well 9 would have on the ground-water system in the South Truckee Meadows or on the SB GEO well field. Consequently, these areas would have to be monitored to detect adverse effects.

6. Utilization of absolute-reading pressure gages on the gas lines in the strat wells should be

considered to eliminate some of the variability caused by barometric pressure variations. Alternatively, the pressure records could be filtered for barometric (and earth tide) effects utilizing barometric data obtained with a separate transducer on site. Increasing the measurement frequency in strat wells 2, 5, and 9 would also make it possible to better delineate seasonal variations.

7. More easily interpretable pressure records could be obtained from these wells if the annulus in strats 2 and 9 were cemented to isolate the shallow thermal aquifer near the bottom of the well. However, the cost and possibility of well failure associated with such efforts must be weighed against the anticipated benefits prior to a decision being reached about these wells.

8. Measurements of both chloride concentration and stream discharge (not only stage) in Steamboat Creek at Rhodes Road, Virginia City Highway, and Huffaker Hills should be made on an annual or biannual basis (spring and fall) to determine rates of inflow of thermal water. If a suitable monitor well in the ACEC can be established, regular chloride and temperature measurements should also be made in the well.

Should these suggestions be carried out, additional information useful in understanding various hydrologic aspects of the Steamboat area would be obtained. Such an increased understanding will assist in future management of the hydrologic and biologic resources of the ACEC. Until some or all of these measures are accomplished, it would be difficult to specify mitigation measures to correct adverse effects of geothermal production. Mitigation measures that would involve changes in reinjection locations or curtailment of production are unlikely to be effective in returning the hot springs to their former flowing conditions because other factors, such as continued ground-water pumpage and expansion of the geothermal production on private lands north of the ACEC, are likely to have significant negative effects on the ACEC springs.

REFERENCES CITED

American Public Health Association, 1985, Standard methods for the examination of water and wastewater, 16th ed.: Washington, D.C., 1268 p.

Bateman, R.L. and Scheibach, R. B., 1975, Evaluation of geothermal activity in the Truckee Meadows, Washoe county, Nevada: Nevada Bureau of Mines and Geology Report 25, 38 p.

Berkeley Group, Inc., 1987, Hydrogeologic description and estimated hydrologic impacts of long-term production and injection of geothermal fluids at the Steamboat Springs geothermal field, Steamboat Springs, Nevada: unpublished report, 16 p.

Bonham, H.F. and Rogers, D.K., 1983, Mt. Rose NE quadrangle geologic map: Nevada Bureaus of Mines and Geology, Reno area map 4Bg.

Brannock, W.W., Philip, F.F., Gianella, V.P. and White, D.E., 1948, Preliminary geochemical results at Steamboat Springs, Nevada: Transactions American Geophysical Union, vol. 29, p. 211-226.

Buchanan, T.J. and Somers, W.P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey, Techniques of Water Resources Investigations, Book 3, Chapter 8, 65 p.

California Division of Mines and Geology, 1938, Geologic map of California prepared by Olaf P. Jenkins, 6 sheets, scale 1:500,000.

Chevron Resources Co., 1987, Proposed Steamboat Hills geothermal project environmental assessment: report prepared for the Bureau of Land Management. Cohen, P. and Loeltz, O.J., 1964, Evaluation of hydrogeology and hydrogeochemistry of Truckee Meadows area, Washoe County, Nevada: U.S. Geological Survey Water Supply Paper 1779-S, 63 p.

Christopherson, K., Long, C., and Hoover, D., 1980, Evaluation of airborne electromagnetic surveys for geothermal exploration: Abstract for Annual Meeting of the Society for Exploration Geophysicists, Houston, Texas.

Cohen, P.C. and Loeltz, O.J., 1964, Evaluation of hydrogeology and hydrogeochemistry of Truckee Meadows area, Washoe County, Nevada: U.S. Geological Survey Water Supply Paper 1779-S, 63 p.

Collar, R.J., 1990, Causes for the decline of hot spring and geyser activity, Steamboat Springs, Nevada: M.S. Thesis, San Diego State University, California, 327 p.

Collar, R.J., and Huntley, D., 1990, Effects of geothermal production and injection on hot spring and geyser activity, Steamboat Springs, Nevada: Proceedings of the 12th New Zealand Geothermal Workshop, p. 183-188.

Cooley, R.L., Fordham, J.W. and Westphal, J.A., 1971, Hydrology of Truckee Meadows, Nevada: Center for Water Resources Research, Desert Research Institute, University of

Nevada System, Project Report no. 15, 49 p.

Corbett, D.M. et al, 1943, Stream-gauging procedure: U.S. Geological Survey Water Supply Paper 888, 245 p.

Corwin, R.F., and Hoover, D.B., 1979, The self-potential method in geothermal exploration: Geophysics, vol. 44, no. 2, p. 226-245.

Craig, H. 1963, The isotopic geochemistry of water and carbon in geothermal areas, in E. Tongiorgi, ed., Nuclear geology on geothermal areas: Consiglio Naxeonale delle Richerche, Lab. de Geol. Nucl., Pisa, p. 17-53.

Desormier, W.L., 1984, Geologic report on the proposed Steamboat Springs unit, Washoe county, Nevada: unpublished report, 31 p.

Eakin, T.E. 1966, A regional interbasin ground water system in the White River area, southeastern Nevada: Water Resources Research, vol. 2, no. 2, p. 251-271.

Faulder, D.D., 1987, Steamboat Hills SB 23-5 production and Cox I-1 injection tests, May 6-19, 1987, Steamboat Hills, Nevada, in Chevron Resources Co., Proposed Steamboat Hills geothermal project environmental assessment: report prepared for the Bureau of Land Management.

Flynn, T. and Ghusn, G.Jr, 1984, Geologic and hydrologic research on the moana geothermal system Washoe County, Nevada: Final report by the Division of Earth Sciences, Environmental Research Center, University of Nevada, La Vegas for the U.S. Department of Energy under DOE Contract No. AC03-82RA50075, 148 p.

GeothermEx, Inc., 1986, Geothermal Energy Potential of GDA leasehold at Steamboat Springs, Nevada, based on field operations completed by December 1985: Report prepared by GeothermEx, Inc., Richmond, California for ORMAT Systems, Inc., Sparks, Nevada, 50p.

GeothermEx, Inc., 1987, Results of the long-term well test program at the GDA leasehold at Steamboat Springs geothermal field, Nevada: unpublished report prepared for Bonneville Pacific Corporation.

Goranson, C., 1989, Reservoir engineering study of the Steamboat Springs geothermal system Washoe county, Nevada including an analysis of the effects of long term geothermal production on the existing hot spring system located at the main terrace area: unpublished report prepared for Caithness Power, Inc., 20 p.

Goranson, C., 1991, Summary and interpretation of six years of ground water monitoring data and four years of geothermal production and injection well operating at the SB GEO, Inc. Geothermal Binary Power Plant, Steamboat Springs, Nevada: unpublished report (2 volumes) prepared for SB GEO, Inc., 45 p. (vol I), 95 p. (vol II).

Goranson, C., and van de Kamp, P. 1989, An interpretation of the relationship between the local ground water system and the shallow isolated moderate temperature geothermal areas in the Steamboat Springs geothermal and South Truckee Meadows area: unpublished report of work performed for Caithness Power, Inc., 12 p.

Goranson, C., van de Kamp, P., and DeLong, T., 1990, Geothermal injection and monitoring program history at the Caithness Power, Inc., flash steam power plant Steamboat Springs, Nevada: Proceedings of the Symposium on Subsurface Injection of Geothermal Fluids, October 29-30, 1990, Santa Rosa, California, Sponsored by the Underground Injection Practices Council Research Foundation, p. 101-121.

Goranson, C., van de Kamp, P., and Call, E., 1991, Summary and interpretation of six years of ground water monitoring data at the SB GEO, Inc., Geothermal Power Plant, Steamboat Springs, Nevada: Paper presented at the Underground Injection Practices Council meeting in Reno, Nevada, July 28-31, 1991, 17 p.

Hudson, D.M., 1987, Steamboat Springs geothermal area, Washoe county, Nevada, in Bulk mineable precious metal deposits of the western United States, Guidebook for Field Trips: Geological Society of Nevada, p. 408-412.

JBR Consultants Group, 1991, Steamboat #2 and #3 Geothermal Project; Steamboat Development Corp., Environmental Report: unpublished report, 52 p.

Jenkins, O.P., 1938, Geologic map of California: California Division of Mines and Geology, 6 sheets, scale 1:500,000.

Katzer, T., Durbin, T.J., and Maurer, D.K., 1984, Water-resources appraisal of the Galena Creek basin, Washoe county, Nevada: U.S. Geological Survey Open-File Report 84-433, 59 p.

Lyles, B.F., 1985, Time-variant hydrogeologic and geochemical study of selected thermal springs in western Nevada: M.S. Thesis, University of Nevada-Reno, 203 p.

Long, C.L., and Brigham, R.H., 1975, Audio-magnetic data log for Steamboat Hills, Nevada: U.S. Geological Survey Open-file Report 75-447, 7 p.

Mifflin, M.D., 1968, Delineation of ground-water flow systems in Nevada: Technical Report Series H-W, Hydrology and Water-Resources Publication No. 4, Center for Water Resources Research, Desert Research Institute, University of Nevada, Reno, 100 p.

Nehring, N.L., 1980, Geochemistry of Steamboat Springs, Nevada: M.S. thesis, San Jose State University, 61 p.

Ormat, Inc., 1987a, Steamboat geothermal power plant, first quarterly report: January 1, 1987-March 31, 1987: submitted to Nevada Division of Environmental Protection.

Ormat, Inc., 1987b, Steamboat geothermal power plant, second quarterly report; April 1, 1987-June 30, 1987: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1987c, Steamboat geothermal power plant, third quarterly report: July 1, 1987-September 30, 1987: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1987d, Steamboat geothermal power plant, fourth quarterly report: October 1, 1987-December 31, 1987; submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1988a, Steamboat geothermal power plant, first quarterly report: January 1, 1988-March 31, 1988: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1988b, Steamboat geothermal power plant, second quarterly report; April 1, 1988-June 30, 1988: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1988c, Steamboat geothermal power plant, third quarterly report: July 1, 1988-September 30, 1988: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1988d, Steamboat geothermal power plant, fourth quarterly report: October 1, 1988-December 31, 1988: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1989a, Steamboat geothermal power plant, first quarter report; January 1, 1989-March 30, 1989: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1989b, Steamboat geothermal power plant, second quarter report: April 1, 1989-June 30, 1989: submitted to the Nevada Division of Environmental Protection.

Ormat, Inc., 1989c, Steamboat geothermal power plant, third quarter report: July 1-September 30, 1989: submitted to the Nevada Division of Environmental Protection.

Schaefer, D.H., 1991, Report to Bureau of Land Management, Carson City, Nevada, for Interagency Agreement No. NV950-IAO-003, 12 p.

Shump, K.N., 1985, Streamflow and water quality effects of ground water discharge to Steamboat Creek, Nevada: M.S. Thesis, University Nevada-Reno, 101 p.

Silberman, M.L., White, D.E., Keith, T.E.C. and Dockter, R.D., 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from ages of spatially associated volcanic rocks: U.S. Geological Survey Professional Paper 458-D, 14 p.

Stewart, J.H., and Carlson, J.E., 1978, Geologic map of Nevada: U.S. Geological Survey, 2 sheets, scale 1:500,000.

Tabor, R.W. and Ellen, S., 1975, Washoe City folio geologic map: Nevada Bureau of Mines and Geology, Environmental Series, Washoe Lake area.

Thermasource, Inc., 1987, Proposed participating area Steamboat Springs geothermal unit, Washoe county, Nevada: unpublished report prepared for Yankee Caithness joint venture.

Thompson, G.A. and Sandberg, C.H., 1958, Structural significance of gravity surveys in the Virginia City-Mount Rose area, Nevada and California: Bulletin of the Geological Society of America, vol. 69, p. 1269-1282.

Thompson, G.A. and White, D.E., 1964, Regional geology of the Steamboat Springs area Washoe county, Nevada: U.S. Geological Survey Professional Paper 458-A, 52 p.

van de Kamp, P.C., and Goranson, C.B., 1990, Summary of the hydrological characteristics of the Steamboat Hills area, Nevada: unpublished report for Caithness Power, Inc., 60 p.

White, D.E., 1955, Violent mud-volcano eruption of Lake City hot springs, northeastern California: Geological Society of America Bulletin, vol. 66, no. 9, p. 1109-1130.

White, D.E., Thompson, G.A. and Sandberg, C.H., 1964, Rocks, structure, and geologic history of Steamboat Springs thermal area, Washoe county, Nevada: U.S. Geological Survey Professional Paper 458-B, 63 p.

White, D.E., 1968, Hydrology, activity and heatflow of the Steamboat Springs thermal system, Washoe county, Nevada: U.S. Geological Survey Professional Paper 458-C, 109 p.

Yeamans, F., 1984, Hydrology of Steamboat Springs geothermal system: unpublished report prepared for Phillips Petroleum Company.

Yeamans, F., 1985, Results of ground water monitoring during drilling of Phillips Petroleum Company's #23-5, July-August 1985 Steamboat Springs, Nevada: unpublished report prepared for Phillips Petroleum Company.

Yeamans, F., 1986a, Monitoring results and hot spring hydrology, June 7 - September 21, 1986, main terrace, Steamboat Springs, Nevada: unpublished report prepared for Chevron Resources Company, 42 p.

Yeamans, F., 1986b, Monitoring results and hot spring hydrology, September 21 - November 29, 1986, main terrace, Steamboat Springs, Nevada: unpublished report prepared for Chevron Resources Company, 16 p.

Yeamans, F., 1987a, Analysis of hot spring monitoring data, Steamboat Springs, June 7, 1986 to April 28, 1987: unpublished report prepared for Chevron-Yankee/Caithness, 23 p.

Yeamans, F., 1987b, Monitoring results and hot spring hydrology, December 1, 1986 - April 28, 1987: unpublished report prepared for Chevron Resources Company, 16 p.

Yeamans, F., 1987c, Steamboat Hills project, SB 23-5 production and Cox I-1 injection test, Steamboat Springs main terrace (ACEC) and Steamboat Creek monitoring results, May 6-20, 1987, in Chevron Resources Co., Proposed Steamboat Hills geothermal project environmental assessment: report prepared for the Bureau of Land Management.

Yeamans, F., 1987d, Results of the hot spring, ground and surface water monitoring program.

Cox I-1 injection test, May-July 1987: unpublished report prepared for Chevron-Yankee/Caithness joint venture geothermal project, Steamboat, Nevada, 21 p.

Yeamans, F., 1987e, Yankee/Caithness joint venture, Steamboat geothermal project, third quarter report; July 1, 1987 to September 30, 1987: submitted to the Nevada Division of Environmental Protection.

Yeamans, F., 1987f, Yankee/Caithness joint venture, Steamboat geothermal project, fourth quarter report; October 1, 1987 to December 31, 1987: submitted to the Nevada Division of Environmental Protection.

Yeamans, F., 1988a, Yankee/Caithness joint venture, Steamboat geothermal project, first quarter report; January 1, 1988-March 31, 1988: submitted to the Nevada Division of Environmental Protection.

Yeamans, F., 1988b, Yankee/Caithness joint venture, Steamboat geothermal project, second quarter report; April 1, 1988-June 30, 1988: submitted to the Nevada Division of Environmental Protection.

Yeamans, F., 1988c, Yankee/Caithness joint venture, Steamboat geothermal project, third quarter report; July 1, 1988-September 30, 1988: submitted to the Nevada Division of Environmental Protection.

Yeamans, F., 1988d, Caithness Power, Inc., Steamboat geothermal project, fourth quarter report: October 1, 1988-December 31, 1888: submitted to the Nevada Division of Environmental Protection.

Yeamans, F. and R. Broadhead, 1988, Hydrogeology and water chemistry in the vicinity of Brown school, Steamboat, Nevada: report prepared for the Nevada Division of Environmental Protection, 23 p.

FACTORS AFFECTING THE DECLINE IN HOT-SPRING ACTIVITY
IN THE STEAMBOAT SPRINGS AREA OF CRITICAL ENVIRONMENTAL CONCERN,
WASHOE COUNTY, NEVADA

By Michael L. Sorey and Elizabeth M. Colvard
U.S. Geological Survey

U.S. GEOLOGICAL SURVEY

Administrative Report for the Bureau of Land Management

APPENDICES A-G

(Note: Appendices not included herein -
Copy on file with Bureau of Land Management, Nevada State Office)

APPENDIX E

Correspondence with the Nevada Natural Heritage Program

Nevada Natural Heritage Program

Capitol Complex • 201 South Fall Street • Carson City, Nevada 89710
(702) 885-4370

15 November 1989

Jill Pitts
Environmental Management Assoc.
3100 Mill St., Suite 209
Reno, NV 89502

Dear Ms. Pitts:

We were happy to comply with your request for information on sensitive plant and animal species in the Steamboat Hills area. We searched our maps for the following sections:

T17N R19E Sections 1, 12, 13
T17N R20E Sections 3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, 18
T18N R19E Sections 24, 25, 36
T18N R20E Sections 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, 34

Although we don't have specific animal occurrences mapped in the study area, we want to mention that the wetlands throughout the Washoe Valley are important for several listed and sensitive birds. The bald eagle, white pelican, and numerous raptors and shore birds feed and/or nest in the region.

Please note that our data are dependent on the research and observations of many individuals and organizations, and in most cases not the result of comprehensive or site-specific field surveys.

Enclosed is an invoice and our new data request forms. Please call if we can be of further assistance.

Sincerely,

Kristin Kolar

Kristin Kolar
Data Manager/Research Asst.

SENSITIVE SPECIES IN THE STEAMBOAT HILLS AREA

Compiled for Environmental Management Assoc.
by The Nevada Natural Heritage Program, 15 November 1989

Scientific Name	Common Name	Federal Status	State Status	NNNPS Status	Township/ Range	Centrum Section	Additional Sections	Last Observed
ERIOGONUM LOBBII VAR ROBUSTIUS	LOBB'S BUCKWHEAT	C2	NONE	W	018N020E	35	AND SECTION 26	1986-06-24
ERIOGONUM LOBBII VAR ROBUSTIUS	LOBB'S BUCKWHEAT	C2	NONE	W	018N020E	35		1946-06-18
ERIOGONUM OVALIFOLIUM VAR WILLIAMSIAE	STEAMBOAT BUCKWHEAT	LE	CE	E	018N020E	28	& SECTIONS 29,33	1989-11-03
POLYCTENIUM WILLIAMSIAE	WILLIAM'S COMB-LEAF	C2	CE	T	017N020E	16		1983-
POLYCTENIUM WILLIAMSIAE	WILLIAM'S COMB-LEAF	C2	CE	T	017N020E	16	CENTER OF SECTION	1987-07-06

Section: U = Unsurveyed

NNNPS Status: E = Recommended endangered
T = Recommended threatened
W = Watch
D = Delete
PE = Possibly extinct

State Status: CE = Critically endangered (NRS 527.260-.300)
CY = Cactus - Yucca Law (NRS 527.060-.120)
# = Recommended for critically endangered, pending formal listing

Federal Status Key

The standard abbreviations for federal endangerment status as published in the Federal Register by the USFWS, Office of Endangered Species. The status for candidates and their meanings are discussed in each Federal Register notice. The following is a list of the standard USFWS abbreviations used in this field.

LE = Listed endangered
LT = Listed threatened
LELT = Listed endangered in part of range, threatened in a different part
PE = Proposed endangered
PT = Proposed threatened
PEPT = Proposed endangered, threatened
C1 = Candidate, category 1
C1* = C1, but lacking known occurrences
C1** = C1, but lacking known occurrences, except in captivity/cultivation
C2 = Candidate, category 2
C2* = C2, but lacking known occurrences
C2** = C2, but lacking known occurrences, except in captivity/cultivation
3A = Former candidate, rejected because presumed extinct
3B = " " , rejected because a synonym or hybrid
3C = " " , rejected because more common or adequately protected
E = Endangered
T = Threatened
S/A = Similarity of appearance species
XN = Nonessential experimental population
XE = Essential experimental population

APPENDIX F

Section 7 Consultation Correspondence

N-12085
(NV-920.4)

FEB 1 9 1993

Memorandum

To: Field Supervisor, Reno Field Station, U.S. Fish and Wildlife Service

From: State Director, Nevada

Subject: Request for Formal Section 7 Consultation Regarding the Steamboat Buckwheat at Steamboat Hot Springs

Caithness Power Inc. has submitted an application to increase the allowable flow rates of production and injection wells associated with a geothermal power plant located in the Steamboat Hot Springs area. The well field and power plant are located in the vicinity of the Steamboat buckwheat Eriogonum ovalifolium var. williamsiae and its habitat.

A description of the proposed action and biological information regarding the Steamboat buckwheat is provided in the Steamboat Hills Geothermal Project Draft Environmental Analysis, which was hand delivered to your office on February 9, 1993. A draft Record of Decision, which describes the preferred option and the mitigation measures which will be implemented into the permit approval, will be submitted to your office shortly.

Bureau of Land Management (BLM) analysis indicates that the proposed action is not likely to adversely affect the Steamboat buckwheat or its habitat. We are requesting Fish and Wildlife Service (FWS) concurrence with this opinion. However, should FWS not concur, please consider this letter a request to commence formal Section 7 consultation.

BLM has the responsibility to make management decisions regarding geothermal operations and their hydrological association with the Steamboat ACEC. Based on the results of the hydrological monitoring program of the Steamboat area and conclusions of the data prepared by GS in a major scientific report, BLM has determined that the proposed project will not cause a significant hydrological impact to the ACEC. We request that you form your opinion regarding the biological situation within the context of this determination.

Our analysis that the proposed project is not likely to adversely affect the Steamboat buckwheat or its habitat is based on the following:

1. No direct affect to the Steamboat buckwheat is likely to occur since no portion of the proposed action will occur within a mile and a half of any known buckwheat colony.

2. No indirect impact to the buckwheat is likely to occur. Analysis by both BLM and GS of all available hydrological information indicates that any change of the water table at the ACEC, and associated sinter deposition and soil development due to Caithness operations, is not significant.

3. The federal action will not physically disturb any surface. Our analysis indicates that Caithness will not contribute to any cumulative impacts to the Steamboat buckwheat resulting from activities occurring on nearby private lands. These impacts are beyond the control of Caithness and are equally likely to occur regardless of the level of Caithness activities.

4. FWS has provided biological opinions regarding direct, indirect and cumulative impacts in previous formal and informal consultations. FWS opinion has been that the proposals were not likely to jeopardize the continued existence of the Steamboat buckwheat. The ongoing hydrological monitoring of the Steamboat area has not presented any substantial information which would indicate that this conclusion should be amended.

As has been informally discussed, there may be opportunity for FWS and BLM to cooperatively develop and monitor Conditions of Approval directed towards improving our understanding of how the Steamboat buckwheat is responding to ongoing activities in the area.

Should you require additional information regarding this request for consultation, please contact Terry Woosley at 785-6466 or Richard Hoops at 785-6568.

/s/ BILLY R. TEMPLETON

cc: DM, Carson City (NV-030)
NV-930
RHoops:rd:2/17/93:FWSLTTR

United States Department of the Interior

FISH AND WILDLIFE SERVICE

NEVADA ECOLOGICAL SERVICES FIELD OFFICE
4600 Kietzke Lane, Building C-125
Reno, Nevada 89502-5093

March 26, 1993
File No. 1-5-93-F-122R

Memorandum

To: State Director, Bureau of Land Management, Reno, Nevada

From: Field Supervisor, Ecological Services, Reno, Nevada

Subject: Formal Consultation on Yankee/Caithness Joint Venture Steamboat Hills Geothermal Project Amendment

On February 22, 1993, we received your memorandum dated February 19, 1993, requesting initiation of formal consultation under section 7 of the Endangered Species Act of 1973, as amended (Act), concerning possible impacts to the Steamboat buckwheat (*Eriogonum ovalifolium* var. *williamsiae*) from the proposed amendment to the Yankee/Caithness Joint Venture Steamboat Hills Geothermal Project Amendment. Additional information regarding the project was subsequently transmitted by memorandum dated March 19, 1993, and received in this office on March 22, 1993.

On January 27, 1987, the Fish and Wildlife Service (Service) issued a Biological Opinion on the Steamboat Buckwheat for the Proposed Chevron Resources Company Geothermal Project (now Caithness Power, Inc.) (File No. 1-5-87-F-10). In June 1991, Caithness Power, Inc. submitted an Amended Plan of Operation/Plan of Utilization to the Bureau of Land Management (Bureau), seeking approval to increase the total geothermal fluid production and injection rates from the Steamboat Hills Project area from the currently approved 1.9×10^6 lb/hr up to a maximum of 3.8×10^6 lb/hr. The Service has determined that the proposed increased production will modify the agency action in a manner that causes an effect to the Steamboat buckwheat that was not considered in the 1987 Biological Opinion. Therefore, the Service reinitiated section 7 consultation on March 22, 1993, the date upon which we received the entire package of information from the Bureau.

Upon receipt of adequate information to initiate formal consultation, regulations require that the Service conclude formal consultation within 90 days of initiation and deliver a biological opinion to the Federal agency within 45 days of concluding formal consultation (50 CFR § 402.14(e)). This formal consultation has been assigned File Number 1-5-93-F-122R. Please refer to this File Number in future correspondence on this project. Should you have any questions, please contact Sherry Barrett at (702) 784-5227

David L. Harlow

cc:
District Manager, Carson City District, Bureau of Land Management, Carson City, Nevada
Assistant Regional Director, Ecological Services, Fish and Wildlife Service, Portland, Oregon (AFWE-EHC)
Attn: Richard Hill

APPENDIX G

U.S. Fish and Wildlife Service
Biological Opinion

United States Department of the Interior

FISH AND WILDLIFE SERVICE
NEVADA ECOLOGICAL SERVICES FIELD OFFICE
4600 Kietzke Lane, Building C-125
Reno, Nevada 89502-5093

TAKE PRIDE IN AMERICA

June 18, 1993
File No. 1-5-93-F-122R

Memorandum

To: State Director, Bureau of Land Management, Reno, Nevada

From: Field Supervisor, Ecological Services, Reno, Nevada

Subject: Biological Opinion for the Proposed Expansion of Steamboat Hills Geothermal Project: Amendment for Geothermal Fluid Rate Increase

This Biological Opinion responds to your request dated February 19, 1993, for formal consultation with the U.S. Fish and Wildlife Service (Service) pursuant to section 7 of the Endangered Species Act of 1973, as amended (Act). The consultation analyzes the application submitted by Yankee/Caithness Joint Venture, L.P. (Caithness) and Caithness Power Inc. (CPI) to the Bureau of Land Management (BLM), to increase allowable flow rates of production and injection wells associated with the Steamboat Hills Geothermal Project (Steamboat Hills Project). The well field and power plant are located in the vicinity of the habitat for Steamboat buckwheat (*Eriogonum ovalifolium* Nutt. var. *williamsiae* Reveal), a plant federally listed as Endangered under the Act. This formal consultation was conducted pursuant to the regulations governing interagency cooperation under the Act (50 CFR Part 402).

In January 1987, the Service issued a Biological Opinion (File 1-5-87-F-10) for facility construction and operation at production rates of 1.9×10^6 pounds per hour (lb/hr). The Biological Opinion determined that construction and operation of the proposed project was not likely to jeopardize the continued existence of the Steamboat buckwheat. That opinion was based on information available then suggesting that any decrease in spring discharge resulting from geothermal production could be corrected by relocation of injection wells to allow better hydraulic connection with the hot springs. The Biological Opinion was predicated on the implementation of a hydrologic monitoring program for monitoring the groundwater system in the Steamboat Hills area for changes which might be caused by geothermal development.

In September 1989 the Service requested that consultation on the Steamboat Geothermal operations be reinitiated, after reviewing a preliminary report describing hydrological monitoring during the period June 20 to August 18, 1988, (Huntley, Collar, and Sorey 1988). In this preliminary report, it was stated that "geothermal production at CPI does influence ground water levels in the ACEC, but, because the monitoring encompasses only one season, it is unclear as to whether the geothermal production is the principal source of water level decline, or only a contributing source." The Service's request for formal consultation was rescinded after additional information was supplied by BLM and Caithness indicating that continuing activities would not have adverse impacts on Steamboat buckwheat.

In October 1989, Caithness applied for a permit to reenter an existing geothermal well on public lands. Informal consultation was completed between the Service, the BLM, and the U.S. Forest Service (USFS) on that proposal. Apparently, this work was not carried out. Subsequently, in 1991, an amendment to the 1987 Caithness Plan of Operation/Plan of Utilization (POO/POU) was issued, proposing to increase production and injection rates of geothermal fluid for the project from 1.9×10^6 lb/hr to a maximum of 3.8×10^6 lb/hr. The need to increase production was a result of lower than expected temperatures encountered in the production wells, necessitating higher production rates to operate the electrical generator at design capacity. An Environmental Assessment (EA) was subsequently prepared to address possible impacts resulting from the proposed increase (BLM 1993).

This Biological Opinion was prepared using information contained in the Preliminary EA of the Yankee/Caithness Joint Venture, L.P. Steamboat Hills Geothermal POO/POU Amendment for Geothermal Fluid Rate Increase, (BLM 1993); various reports addressing hydrologic conditions in the Steamboat Hills area (Sorey and Colvard 1992; Nork 1992; Petty 1992; and others); reports providing information on the occurrence and habitat requirements of Steamboat buckwheat (CH2M Hill 1986; Nelson 1991); discussions and meetings with BLM and Caithness/CPI personnel; and information in the Nevada Field Office files.

Description of the Proposed Action

Caithness and CPI propose to increase electrical generation at the existing Steamboat Hills Project. The proposed action entails improvements to the existing Steamboat Hills Project facility to increase geothermal fluid production and injection rates from the currently approved rate of 1.9×10^6 lb/hr, to a maximum rate of 3.8×10^6 lb/hr. This increase in production will allow the facility to operate at its design capacity of 12.5 megawatt (MW). The proposed action addressed in this consultation is limited to the possible effects of increased geothermal production on Steamboat buckwheat. Construction of the existing facility and construction of new facilities required for increased production have been addressed previously and are not the subject of this consultation. A map of the project area (Figure 9-2 of the project EA; BLM 1993) is included as an attachment to this opinion.

The existing Steamboat Hills Project facility consists of a single-flash geothermal electrical generation facility, geothermal production and injection wells, associated pipelines, access roads, transmission lines, and other miscellaneous features. Geothermal fluids are pumped through production wells from depths of 2,500-3,000 feet and conveyed in surface pipelines to the single-flash geothermal electrical generation facility. Prior to utilization, geothermal fluids are separated into steam and liquid components. The liquids and cooling tower blowdown water are injected back into the geothermal reservoir at a depth of approximately 2,000 feet. Estimated average water loss through consumption of the geothermal steam in generation of electricity is approximately 10 percent of total geothermal production (BLM 1993). The Steamboat Hills Project has an economic life expectancy of 30 years (BLM 1993), or until the geothermal field is depleted.

The effects of increased production of geothermal fluids on shallow water table levels is uncertain. Estimates of thermal head decline beneath the Steamboat Hills hot springs by current operations ranges from 0.5 to 3 feet. Assuming that the effects of geothermal production increases are linear, a doubling of the production/consumption rate may double the decline in the thermal head, adding an additional 0.5 to 3 feet to the current thermal water table decline (BLM 1993), for a combined possible effect of 1 to 6 feet. The total decline in head beneath the hot springs was estimated to be 17 feet in 1989, and up to 20 feet in 1990 (BLM 1993). Possible effects of geothermal production on thermal water levels thus constitute only a portion of the total effect apparently resulting from multiple demands on groundwater resources in the Steamboat Springs area.

Under the Proposed Action, the existing Hydrologic Monitoring Program, originally approved and implemented under the 1987 POO/POU, would be expanded to: 1) Monitor Steamboat Hills Project geothermal reservoir performance in order to better predict future behavior and best manage the resource under use; 2) better understand groundwater responses to changes in recharge, precipitation, withdrawal, and production and injection operations at the Steamboat Hills Project geothermal field; and 3) obtain data on the hydrology of the area to understand the potential for impacts, and the mitigation of impacts, to the Steamboat hot springs from the operation of the Steamboat Hills Project. This monitoring program is intended to eliminate any potential hydrologic change to the geothermal reservoir which feeds the Steamboat hot springs area resulting from operations by the Steamboat Hills Project. The BLM reserves the right to require amendments to the monitoring program to alter monitoring locations, data collected, monitoring frequency or reporting requirements, as needed to ensure collection of data meeting the objectives of the program (BLM 1993).

Based on the outcome of analyses conducted in conjunction with the Hydrologic Monitoring Program, BLM proposes the following mitigation measures to offset impacts from the proposed action to the hydrological system:

1) If pressure, temperature, and/or chemical changes or trends are detected in the geothermal production or injection fields or in the monitoring wells, the operator will temporarily or permanently modify operations and monitor reservoir response;

2) if the monitoring information indicates that operations have produced an unacceptable level of impact to existing conditions or to the trend of activities of the hot springs, the operator will temporarily or permanently modify operations and monitor reservoir response. Such modifications could include reduction or elimination of the consumption of geothermal fluids if needed to reverse the effects of geothermal production; and

3) the operator will be required to develop, in coordination with the BLM, a mechanism to ensure that any mitigation measures taken will be implemented in a timely manner.

The full details of the mitigation program are provided in section 6.2.2 of the project EA (BLM 1993).

Status of the Species

Steamboat buckwheat is a low, densely matted, compact perennial herb known only from the Steamboat hot springs area. The plant was first collected in 1884 by K.C. Brandegee, but was not identified taxonomically until 1981, when it was determined to be a new variety of *Eriogonum ovalifolium* (Reveal 1981). The variety was determined by the Service to be an endangered species on July 8, 1985, because of its limited range and potential threats to its continued existence through present or threatened destruction, modification, or curtailment of its habitat or range (Federal Register 1986). Steamboat buckwheat is also State-listed as endangered under Nevada Revised Statute 524.260 - 524.300. Any commercial development on private lands potentially impacting the plant or its habitat requires a Conditional Permit from the Nevada Division of Forestry.

Steamboat buckwheat typically grows on open, slightly to steeply sloped areas composed of loose, gravelly, sandy-clay soil known as sinter, which is derived from siliceous hot springs deposits (Williams 1982; CH2M Hill 1986). Recent studies of Steamboat buckwheat and its habitat suggests the species is endemic to the Steamboat Hills area, and is the first plant to colonize decomposing siliceous sinter after sufficient leaching of soluble chemical constituents has occurred. As further leaching and soil formation proceed slowly over time, other plant species establish in these areas, apparently out-competing Steamboat buckwheat for nutrients, space, and moisture (CH2M Hill 1986). Steamboat buckwheat has not been found on deep or alluvial soils, nor has it been found in association with materials recently deposited by active geysers and vents. There is evidence to suggest that moisture available for plant uptake is derived from precipitation rather than from spring sources (CH2M Hill 1986).

When Steamboat buckwheat was listed in the mid 1980's, it was known only from one population consisting of seven colonies, located on 20 acres of BLM-managed public lands and 40 acres of privately-owned lands (Williams 1982; Federal Register 1986). More recent surveys have delineated its range to include approximately 50 acres of actual populations within an area of approximately 370 acres (Nelson 1991; CH2M Hill 1986; BLM 1993). Of the approximately 50 acres on which Steamboat buckwheat is present, an estimated 65 percent is located on Federal lands, or on private lands included within a conservation agreement for preservation of the species and its habitat. The remaining 35 percent of the populations are located on private lands. Nevada State laws regarding State-listed endangered plants, including Steamboat buckwheat, are the sole legal mechanism providing protection for the species and its habitats on private lands.

Various direct impacts have occurred to the habitat and populations of Steamboat buckwheat in past years, including off-road-vehicle use, establishment of roads through habitat areas, uncontrolled dumping, and development of land for private and commercial use. Direct disturbance of Steamboat buckwheat on private lands has also occurred in conjunction with development of geothermal power facilities by S.B. Geo., Inc. (SBG) on the Dorothy Towne Lease property (Towne). In October 1991 a Conditional Permit for Disturbance or Destruction of Critically Endangered Species was issued by the Nevada Division of Forestry for expansion of the facility. This permit required development of both a conservation agreement and management plan for the Steamboat buckwheat.

In 1991 Steamboat Development Corporation and The Nature Conservancy entered into a 30-year agreement to manage populations of Steamboat buckwheat on private lands currently being used by SBG for geothermal production and electric power generation. In conjunction with this agreement, approximately 17,000 plants were removed from 0.15 acre of habitat slated for destruction and transplanted into other areas. Approximately 75 percent survival was noted during the first full growing season following transplanting (personal communication, Dr. Teri Knight, Nevada Natural Heritage Program, May 24, 1993). Other conservation measures included in the agreement provide for population monitoring and avoidance of plants during routine maintenance activities.

It has been suggested that development of freshwater and geothermal groundwater resources may be having indirect impacts on steamboat buckwheat habitats, although there is no definitive evidence that this is the case. The potential for indirect impacts by groundwater pumpage is discussed in the following sections.

Environmental Baseline

Lands in the Steamboat Hills are under various land ownership and management status. As of 1988, Federal lands in the area are under jurisdiction of the USFS, with the exception of the Steamboat Area of Critical Environmental Concern (ACEC), which is managed by the BLM. The BLM, under the Steamboat Geothermal Steam Act of 1970, and, where necessary in concurrence with USFS, is also responsible for granting approval to geothermal-related development on federally-managed lands (BLM 1993).

Numerous hot springs were formerly present in the area of the Steamboat Hills known as the "Main Terrace." Historic activities at these hot springs resulted in the designation of the Steamboat ACEC, a 40-acre parcel currently managed and protected by the BLM for its unique combination of geothermal features, including hot springs, former geyser activity, fumaroles (steam vents), and Steamboat buckwheat habitat.

In the past, various land-disturbing activities have occurred in the Steamboat Hills area which have had direct impacts on Steamboat buckwheat populations through habitat disturbance. These activities include construction of the U.S. Post Office, U.S. Highway 395, Sierra Pacific Power Company substation, the private Towne residence, and the SBG facility. It is estimated that approximately 3.43 acres of Steamboat buckwheat habitat was destroyed as a combined result of these projects (BLM 1993).

The potential effects of geothermal production on hot spring activities has been of concern since about 1986 when declines in geyser and hot spring activities were observed by various individuals. Subsequently, a systematic decline in hot-spring activity was apparent in the ACEC and areas adjacent to the ACEC in 1987. By mid-1989 all of the springs had ceased flowing, measured water-level declines in the spring vents ranged from 1 to 17 feet, and total decline in head of the shallow thermal reservoir feeding the hot springs was probably close to 17 feet (Sorey and Colvard 1992). This decline was interpreted by some individuals as an indication that geothermal production had adversely affected hot spring production.

Numerous studies have been conducted since that time to determine the factors responsible for observed declines in hot spring activities. Hydrologic investigations conducted by San Diego State University over a 55-day period during the summer of 1988 (The Collar Report) concluded that the Steamboat Hills deep geothermal reservoir tapped by CPI was connected to the hot springs aquifer and that geothermal production was a major contributing factor in the decline of hot spring activities. Conclusions of this report were largely based on apparent correlations between drawdowns in hot springs with periods of geothermal fluid production and concurrent injection by CPI (Huntley, Collar, and Sorey 1988).

Various criticisms were subsequently expressed regarding the methods and conclusions of the Collar study including: 1) The data set was too short to determine if springs received pressure report from injection, which would cancel the alleged response to production; 2) use of an electrical-line water sensor was unreliable in hot springs due to the tortuous path the line must follow and the presence of steam which could affect the perceived water-level response; and 3) there was a possibility of thermal cycling, causing short-period water-level fluctuations which could lead to erroneous conclusions regarding long-term responses (Petty 1992).

Since then, other hydrologic analyses and reservoir modelling studies have been conducted in an effort to determine the factors responsible for declines in hot springs activity. Analyses of monitoring data in conjunction with analyses of reservoir properties concluded that, while the hydrologic and geologic systems beneath Steamboat Hills are extremely complex, there appears to be no direct connection of the deep geothermal aquifer with shallower zones; and water level changes at the hot springs, which began prior to the start of geothermal operations, are more likely related to other conditions such as regional drought (van de Kamp and Goranson 1990).

More recent studies by the U.S. Geological Survey (Sorey and Colvard 1992) under contract to the BLM; and by W.E. Nork, Inc. (Nork 1992), prepared for Environmental Management Associates in support of the EA, describe the complexity of the hydrogeologic system in the Steamboat Hills area. Two broad conclusions are suggested: 1) Despite substantial expenditure of time and resources by numerous investigators to date, dynamics and details of the system are not well understood; and 2) no single model unequivocally explains the nature of the geothermal system, although various models have been described.

Central to understanding if geothermal production affects hot springs activities is the question of whether or not the deep geothermal aquifer is connected to the shallow thermal aquifer. It is unclear whether the Steamboat Hills are actually underlain by a single geothermal reservoir or several isolated reservoirs.

It has been suggested that there are at least three isolated geothermal systems in the Steamboat region; including the high-temperature system tapped by the Caithness production wells at depths of 2,000-3,000 feet, a moderate-temperature system tapped by SBG at depths of 400 to 600 feet; and several low-temperature systems located within the alluvial aquifers that feed the hot springs at the main and low terraces (van de Kamp and Goranson 1990).

An alternate model suggests one geothermal system. According to this model, regions of localized high permeability associated with faults and fractures exist within otherwise impermeable rocks, providing some degree of communication between the different systems (Sorey and Colvard 1992). Neither model is completely explained with the information currently available and the actual conceptual model of the Steamboat Hills geothermal system may lie somewhere in between the two models (Nork 1992; BLM 1993).

It has also been proposed that the non-geothermal aquifer is somehow connected to the shallow geothermal aquifer. Fresh ground water from this aquifer is derived primarily from alluvial materials which are tapped by various users for domestic use. It is generally agreed that the geothermal system is hydraulically connected to the alluvial aquifers pumped for domestic use, although the extent of this connection is not completely understood (Sorey and Colvard 1992; Nork 1992; BLM 1993).

Recent water-level declines in both the geothermal and non-geothermal systems have been variously attributed to multiple factors; including geothermal production, reduction in groundwater recharge associated with regional declines in precipitation since 1985 (i.e. drought), increases in groundwater withdrawals from wells in the south Truckee Meadows to accommodate commercial and residential development; and conversion of land use from agricultural to suburban use, which has reduced secondary recharge (BLM 1993; Nork 1992; Sorey and Colvard 1992). Much of the decline in water levels (80-95 percent) in the hot springs may be attributable to groundwater withdrawal for domestic and quasi-municipal use (Sorey and Colvard 1992; BLM 1993). Similarities in the shapes of the hydrographs of the shallow geothermal and cold-water aquifers suggest that the same factors causing a long-term drop in regional groundwater (mainly groundwater withdrawals and lack of recharge due to drought) are also causing a long-term drop in the water levels beneath the hot springs (Sorey and Colvard 1992; Petty 1993).

However, the available information indicates that geothermal production from the deep aquifer does contribute to hot spring water-level declines. Decline estimates attributable to geothermal production are estimated variously at 1 to 3 feet (Sorey and Colvard 1992) and 0.5 to 1.0 feet (Nork 1992). Evidence for declines in shallow thermal aquifers include correlations between short-term changes in hot spring water level and periods of production from the CPI well field, similarities between short-term responses observed in the hydrographs for several hot springs and two monitoring wells, and theoretical calculations of reservoir drawdown after several years of production (Sorey and Colvard 1992).

Effects of the Proposed Action on the Listed Species

Any potential effect on Steamboat buckwheat by geothermal production would be indirect in nature because there is no ground disturbance associated with the proposed action. The overlying concern is if sinter production has been suspended or permanently stopped as a result of geothermal production. Several aspects of existing or perceived circumstances related to the hot springs environment are pertinent to the determination of this effect: 1) The existence of, and magnitude of effect of, geothermal production on hot springs activity; 2) the duration under which the existing sinter substrate will provide suitable habitat for the Steamboat buckwheat; and 3) the potential for resumption of hot spring flows (and subsequently, production of sinter) if Caithness/CPI geothermal production were to be discontinued.

Effects of Geothermal Production on Hot Springs Activity

Hydrologic data are not adequate to unequivocally relate geothermal production by Caithness/CPI to declines or cessation in hot springs activity (Sorey and Colvard 1992; Nork 1992; BLM 1993). The available information suggests that the proposed increase in geothermal production *may be contributing to* the current lack of activity at the hot springs, although the magnitude of the drawdown in the shallow geothermal aquifer is believed to be not more than 0.5 to 3 feet. The proposed increase in geothermal production may as much as double the present effects from the Caithness/CPI operations, resulting in 1 to 6 feet of drawdown. Predicted drawdown from other stresses on this hydrologic system are predicted to be substantially greater than those resulting from geothermal production (Sorey and Colvard 1992; Nork 1992; BLM 1993). Caithness and BLM believe that at the end of project life, any effects of project operations on geothermal resources would be reversed within a few years or tens of years (BLM 1993).

Availability of Sinter Substrates Through Time

Deposition of siliceous material by the hot springs has not occurred since cessation of surface flows in the hot springs area. As a result, the sinter substrates providing habitat for Steamboat buckwheat are not being formed. Eventually, the existing sinters will become weathered to the extent that other plant species can invade and out-compete Steamboat buckwheat. **Because the hot springs are not anticipated to flow in the near future, the most recently deposited siliceous materials (located in areas adjacent to hot spring vents) will weather and become available for colonization by Steamboat buckwheat. In the short term, this may provide more habitat for the plant than what would have been available if the hot springs continued to flow into these areas (BLM 1993).**

Eventually, all presently existing sinter substrates in the Steamboat Hills area will weather beyond conditions suitable for the Steamboat buckwheat. Estimates assessing the period of time involved for this to occur have not been verified. It has been speculated that such a process could entail hundreds or thousands of years (BLM 1993). Given a gradual rate of weathering, it is probable that sinter habitat will still be present after 30 years, the estimated operating period for Caithness/CPI geothermal production.

Resumption of Hot Springs Activity After Completion of Caithness/CPI Operations

Estimated duration of geothermal production by Caithness/CPI is 30 years. It has been suggested that the effects of geothermal production on the deep reservoir will be reversed over time (BLM 1993). This reversal of effect in the deep geothermal reservoir would conceivably also reverse any possible effects of geothermal production on the shallow geothermal reservoir. If this is the case, hot springs surface activity might resume at some point in time, if all aquifer pumping (both geothermal and non-geothermal) was abandoned. It is highly unlikely, however, that all such activities would be concluded in the foreseeable future.

Conclusion Regarding Effects

The greatest concern relates to longevity of the existing supply of sinter habitat, which is dependent on hot springs activities. The available information suggests that the present circumstances of shallow aquifer drawdown and associated declines in hot springs activity is a result of the effects of multiple entities. It is possible that geothermal production by Caithness/CPI has contributed to this effect, although it is uncertain as to the extent of effect by these operations. The evidence available to date suggests that even if Caithness/CPI were to stop geothermal production, the cessation of this activity alone would not result in renewed activity at the hot springs (BLM 1993).

The Service has determined that this level of impact will not appreciably reduce the likelihood of survival and recovery of the Steamboat buckwheat because: 1) The possible effects of Caithness/CPI operations on the thermal water reservoir beneath the hot springs, while not fully understood, appear to constitute only a portion of the overall effect resulting from multiple factors; 2) the available information suggests that, even if Caithness/CPI operations were stopped, hot spring activity would not resume due to adverse activities by other entities; and 3) if in the course of monitoring, geothermal production were determined to be a major causal factor in the decline of the hot springs, operations would be modified to ameliorate any effect as per the modified and expanded hydrologic monitoring program originally approved under the 1987 POO/POU (BLM 1993).

Cumulative Effects

Cumulative effects are those effects of future non-Federal (State, local government, or private) activities on endangered and threatened species or critical habitat that are reasonably certain to occur during the course of the Federal activity subject to consultation. Future Federal activities are subject to the consultation requirements established in section 7 of the Act, and therefore, are not considered cumulative to the proposed action. Future Federal activities include completion of Interstate 580 between Reno and Carson City, which could include disturbance of approximately 1.84 acres of Steamboat buckwheat populations.

Cumulative impacts of activities in the Steamboat Hills area on natural resources were identified during preparation of the project EA (BLM 1993). Potential cumulative direct effects could result from projects causing land disturbance. Future projects may include expansion of the Sierra Pacific Power Company substation, which would impact approximately 0.3 acre; and development of the Guisti Trust Lease, which could potentially disturb an estimated 1.0 acre of Steamboat buckwheat habitat. Commercial or private developments could also occur on other private lands providing habitat for the Steamboat buckwheat. Any disturbance on private lands would require the issuance of a Conditional Permit from Nevada Division of Forestry for disturbance or removal of Steamboat buckwheat.

Potential cumulative indirect effects from other geothermal projects include the expansion of SBG's production by an additional 8.63 x 10^6 lb/hr (of which 100 percent would be reinjected); and possible future geothermal production on the Guisti Trust Lease at a rate of 1.36 x 10^6 lb/hr (although to date, no project has been proposed for this site). In addition, future commercial and residential development in the south Truckee Meadows could triple in the next 15 years (BLM 1993), resulting in a significant demand on the non-geothermal aquifer.

Biological Opinion

It is our Biological Opinion that the proposed action by Caithness/CPI to increase geothermal production from the deep geothermal reservoir in the Steamboat Hills is not likely to jeopardize the continued existence of Steamboat buckwheat in the Steamboat Hills area in the foreseeable future. No critical habitat has been designated for the Steamboat buckwheat.

Incidental Take

Protection of listed plants is provided by the Act to the extent that a Federal permit is required for removal of endangered plants from areas under Federal jurisdiction, or for any act that would remove, cut, dig up, damage, or destroy any such species on any other area in knowing violation of any regulation of any State or in the course of any violation of a State criminal trespass law. The BLM and the USFS each have a continuing duty to regulate the activity that is covered by this incidental take statement on public lands in the Steamboat Hills area.

The Service does not anticipate that the proposed action will result in any direct impact to the Steamboat buckwheat which would require protective measures.

Conservation Recommendations

Section 7(a)(1) of the Act directs Federal agencies to use their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. The term "conservation recommendations" has been defined as Service suggestions regarding discretionary Federal agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, or regarding the development of information.

1. The BLM should modify and expand the monitoring program originally approved under the 1987 POO/POU, as described in the project EA (BLM 1993). This would provide the additional information needed for assessing the impacts of geothermal production on hot springs activities. The BLM should require that the applicant submit an analysis of monitoring data on a quarterly basis to provide regular and timely information for determining possible effects of Caithness/CPI operations on hot springs activity.

2. The BLM should require the applicant to add an observation well within or near the ACEC to monitor pressure changes in the shallow reservoir beneath the hot springs. Particular requirements and recommendations for this well have been specified by Sorey and Colvard (1992), Nork (1992), Petty (1992), and Petty and Adair (1993). The Service recommends that such recommendations be followed to the extent necessary to quantify the level of effect of geothermal production on hot springs activity.

3. BLM should require Caithness/CPI to immediately implement a study that will determine the rate of sinter weathering and associated soil development. This study should quantify the duration under which the existing sinter substrates will persist in the Steamboat Hills area, given the current cessation of hot springs surface activity. The information gained from this study would be useful in understanding the effects of shallow thermal reservoir drawdowns and associated loss of hot spring activity on Steamboat buckwheat habitat.

Reinitiation Requirement

This concludes formal consultation on the proposed action outlined in your February 19, 1993, request. As required by 50 § CFR 402.16, reinitiation of formal consultation is required if: 1) New information reveals effects of the Federal agency action that may affect listed species or critical habitat in a manner or to any extent not considered in this Biological Opinion; 2) the Federal agency action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in this Biological Opinion; and 3) a new species is listed or critical habitat designated that may be affected by the action.

We appreciate the assistance and cooperation of your staff throughout this consultation process. If we can be of any further assistance, please contact me or Janet Bair at (702) 784-5227.

David L. Harlow

Attachment

cc:
State Forester, Nevada Division of Forestry, Carson City, Nevada
Director, Nevada Natural Heritage Program, Carson City, Nevada
District Ranger, Carson Ranger District, Toiyabe National Forest, Carson City, Nevada
Chief, Division of Endangered Species, Fish and Wildlife Service, Arlington, Virginia
Assistant Regional Director, Ecological Services, Fish and Wildlife Service, Portland, Oregon.
(w/atch)

LITERATURE CITED

CH2M Hill. 1986. Factors affecting the distribution of *Eriogonum ovalifolium* var. *williamsiae* at Steamboat Springs. Report to Western States Geothermal Company, October, 1986.

Federal Register. 1986. Endangered and threatened wildlife and plants: determination of endangered status for *Eriogonum ovalifolium* var. *williamsiae* (steamboat buckwheat): Final Rule. U.S. Fish and Wildlife Service. Volume 51(130): 24669-24672.

Huntley, D., RJ Collar, and ML Sorey. 1988. Preliminary report on hydrologic monitoring at the Steamboat Springs, Nevada Geothermal Area.

Nork, WE. 1992. A summary of the hydrogeology of the Steamboat Hills and vicinity. Prepared for: Environmental Management Associates by William E. Nork, Inc., Brea, California.

Petty, S. 1992. Available data from Steamboat Hot Springs:Discussion of data quality and interpretation. Prepared for: Caithness Corporation by Susan Petty Consulting, Solana Beach, California.

Petty, S. and RG Adair. 1993. Assessment of the Byers Wellas a monitoring site for the Steamboat Hills Area of Critical Environmental Concern. Prepared for: Caithness Corporation by Susan Petty Consulting, Solana Beach, California.

Reveal, J. 1981. Notes on endangered buckwheats with three newly described forms from the western United States. Brittonia 33(3):446.

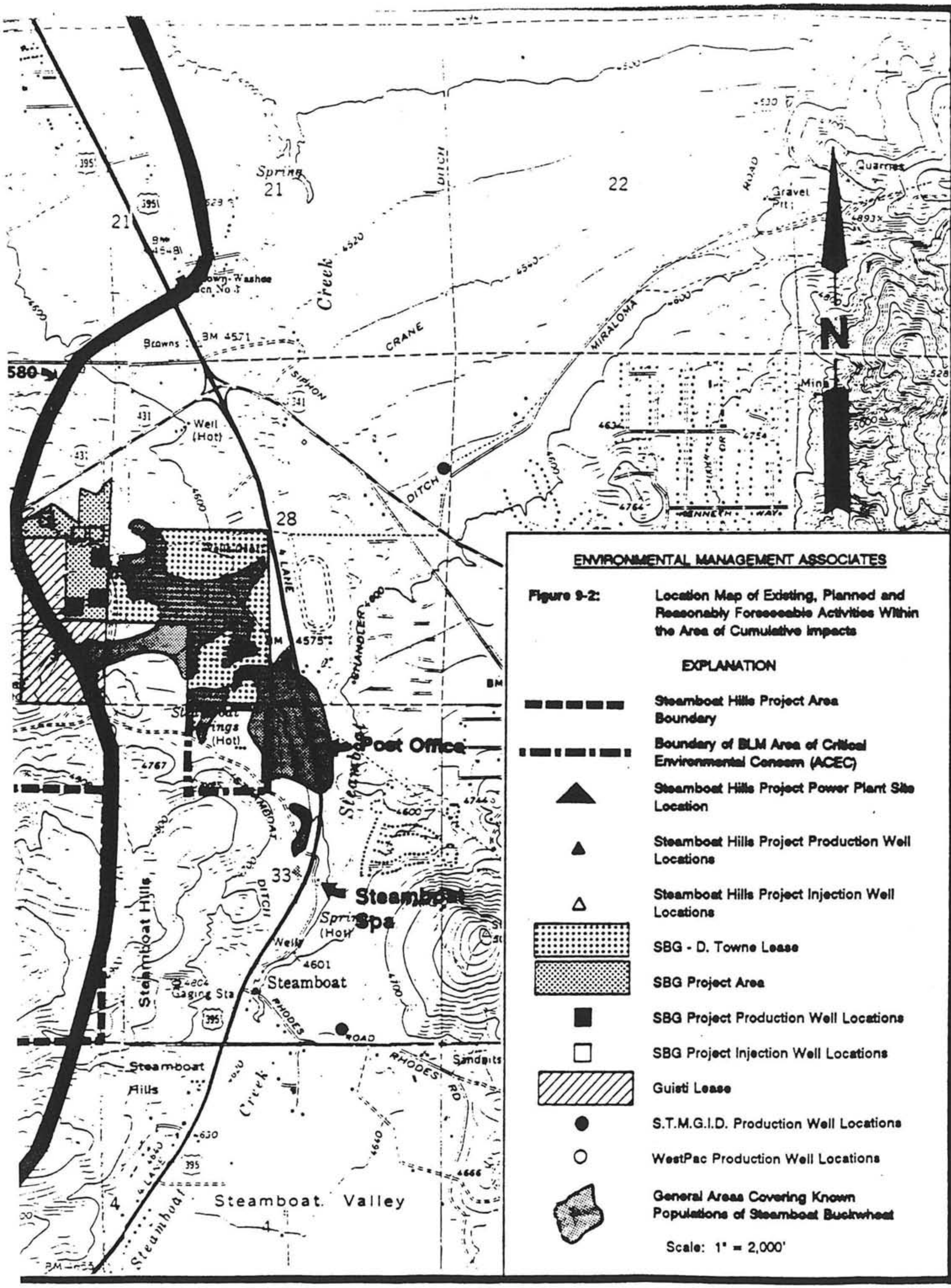
Sorey, ML and EM Colvard. 1992. Factors affecting the decline in hot-spring activity in the Steamboat Springs Area of Critical Environmental Concern, Washoe County, Nevada. U.S. Geological Survey Administrative Report for the Bureau of Land Management. Menlo Park, California.

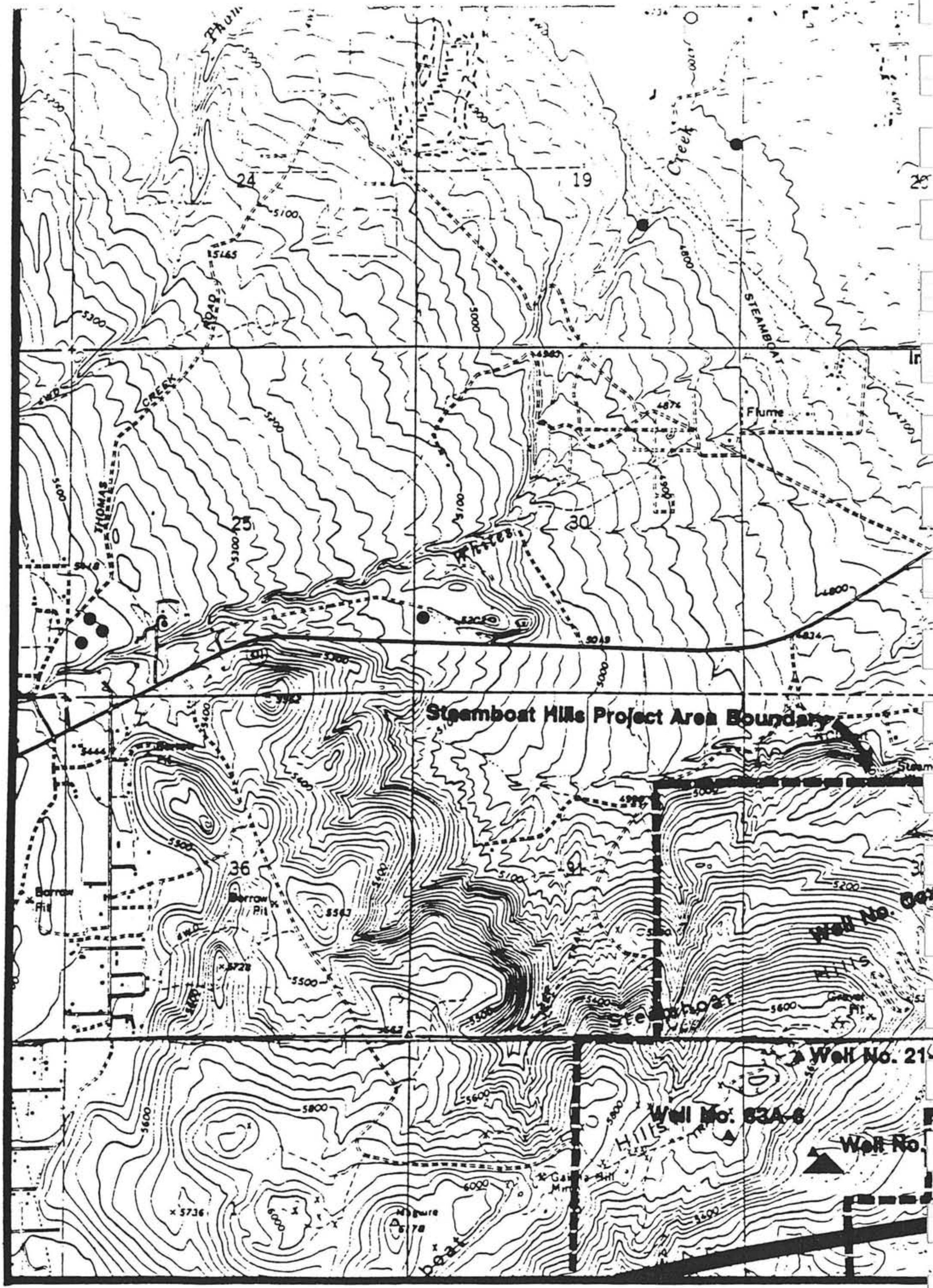
U.S. Bureau of Land Management. 1993. Yankee Caithness Joint Venture , L.P. (Caithness) and Caithness Power Inc. (CPI), Plan of Operation/Plan of Utilization Amendment for Geothermal Fluid Rate Increase. Preliminary Environmental Assessment NV920-9201.

U.S. Fish and Wildlife Service. 1987. Memorandum to the State Director, Bureau of Land Management, regarding Formal Section 7 Consultation on the Steamboat Buckwheat for the Proposed Chevron Resources Company Geothermal Project.

van de Kamp, PC and CB Goranson. 1990. Summary of the hydrological characteristics of the Steamboat Hills Area, Nevada. Unpublished Report, 13 p.

Williams, M. 1982. Status report on *Eriogonum ovalifolium* var. *williamsiae*. Unpublished report under contract with U.S. Fish and Wildlife Service. 30 pp.


ENVIRONMENTAL MANAGEMENT ASSOCIATES
Figure 9-2:
Location Map of Existing, Planned and Reasonably Foreseeable Activities Within the Area of Cumulative Impacts
EXPLANATION
Steamboat Hills Project Area Boundary
Boundary of BLM Area of Critical Environmental Concern (ACEC)
Steamboat Hills Project Power Plant Site Location
Steamboat Hills Project Production Well Locations
Steamboat Hills Project Injection Well Locations
SBG - D. Towne Lease
SBG Project Area
SBG Project Production Well Locations
SBG Project Injection Well Locations
Guisti Lease
S.T.M.G.I.D. Production Well Locations
WestPac Production Well Locations
General Areas Covering Known Populations of Steamboat Buckwheat
Scale: 1" = 2,000'
N
Spring
21
22
28
33
4
Creek
CRANE
SIPHON
DITCH
MIRALOMA
ROAD
Gravel Pit
Quarries
Browns
BM 4571
580
Well (Hot)
BM 4575
CHANDLER
Post Office
Steamboat
Steamboat Spa
Steamboat Hills
Gaging Sta
RHODES
RHODES RD
Sandpits
Steamboat Valley
Steamboat Hills
395


Steamboat Hills Project Area Boundary
Well No. 21
Well No. 83A-6
Well No.
Flume
THOMAS CREEK
ROAD
STEAMBOAT
Creek
Steamboat
Hills
Borrow Pit
Barrow Pit
Gravel Pit
24
19
25
30
36
31
5100
5300
5000
5500
5600
5800
6000