

GEOTHERMAL INJECTION AND MONITORING PROGRAM HISTORY AT THE  
CAITHNESS POWER, INC. FLASH STEAM POWER PLANT  
STEAMBOAT SPRINGS, NEVADA

Colin Goranson  
Consultant  
Richmond, CA

Peter van de Kamp  
Cornelis Corp.  
Napa, CA

Ted DeLong  
Caithness Power, Inc.  
Reno, NV

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Abstract

The Caithness Power, Inc. 12 M<sub>w</sub>net single flash steam driven power plant began operations in February of 1988. Approximately 1,900,000 pph (4,500 gpm) of geothermal fluid from three production wells is required to generate 280,000 pph of steam for power plant operations at design conditions. Approximately 1,710,000 pph (3,700 gpm) of separated brine is reinjected into the reservoir through one injection well located 4,500 feet from the production area. To date approximately 3 billions gallons of geothermal fluid have been reinjected. The Nevada Department of Environmental Protection Class V Injection Permit requires monitoring of water levels and produced fluid chemistries of various shallow geothermal monitoring wells, hot springs and groundwater wells in the area. In addition, streams to which several Hot Spring areas discharge are also monitored. The monitoring program has shown that injection of geothermal fluid has had no effect on the nearby shallow groundwater system or hot spring areas.

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Introduction

The Steamboat Springs Known Geothermal Resource Area (KGRA) is located in northwestern Nevada approximately 9 miles south of the city of Reno, as shown in Figure 1. The Steamboat Hills geothermal area contains various geothermal manifestations including large areas of thermally altered rock, large sinter deposits, several active and extinct hot spring areas and brecciated areas caused by surface geothermal eruptions. Subsurface data indicate that several geothermal subsystems are present. High temperature (420°F - 460°F) geothermal fluid is found at 3,200 feet AMSL in the southern portion of the Steamboat Hills area. A shallow moderate temperature (320°F - 360°F) geothermal system exists

at 4,000 feet AMSL in the northern portion of Steamboat Hills. Several low temperature systems have also been identified in the area. Data obtained to date indicate that there is no pressure communication between the deep injection zone and the shallow geothermal system(s).

Caithness Power, Inc. (CPI) began operations of a single flash 12 Mw<sub>net</sub> power plant in February of 1988. Three production wells have supplied approximately 1,800,000 pounds per hour (pph) of geothermal fluid at an average temperature of 430°F from a fractured geothermal reservoir located at a depths between 2,300 to 2,600 feet (≈3,200 feet AMSL). Approximately 1,600,000 pph of separated brine at a temperature of 290°F is reinjected back into the fractured reservoir through one injection well. The injection well is located 4,500 feet from the production area.

The Nevada Department of Environmental Protection (NDEP) geothermal injection permit requires monitoring of the produced and injected fluid volumes and fluid chemistry, water levels and produced fluid monitoring of seven stratigraphic test (ST) wells, nine groundwater wells, three mixed fluid groundwater/geothermal wells, two Hot Springs, three water conveyance ditches and two stream monitoring points. The objective of the NDEP monitoring program is to determine whether injected fluid has influenced the shallow groundwater system in the vicinity of Steamboat Hills. In addition, data from several creek monitoring points are collected to determine whether geothermal hot spring discharge has increased from injection operations.

#### Well Locations and Geothermal Areas

Figure 2 shows the location of the CPI production and injection wells and several monitoring wells whose data are typical of the general behavior of the groundwater and shallow geothermal systems. Well completion methods and well depths vary in the area. Monitoring wells MW-3, MW-4, Pine Tree, TS-3, UFW, Boyd and Jeppson wells were completed as typical groundwater wells. Typical groundwater well completions in this area consist of drilling a certain diameter hole, running a combination blank and slotted casing string, gravel packing the annular area in the slotted section and back filling from the top of the slotted casing to surface with cement. The size of casing and slotted interval length varies from well to well. Geologic data for groundwater wells consists of lithology reported by the well driller and is essentially only descriptive of the material encountered. Stratigraphic test (ST) wells ST-2, ST-5 and ST-9 were drilled early on in the geothermal development project to investigate temperature and lithology before the drilling of large diameter production and injection wells commenced. Stratigraphic well completion consists of 7 inch

casing set to a certain depth and cemented to surface. The wells were then drilled deeper into the subsurface and completed open hole. Tubing with the bottom portion ( $\approx 20$  feet) slotted was then run from surface to the total depth of the well. The production and injection wells have 13 3/8 inch casing cemented from the bottom of the casing to surface. Production and injection interval completions are 12 1/4 inch open hole. Table 1 is a compilation of the available well completion data for the wells discussed in this report.

Table 1

Well Data for Selected Steamboat Hills Production,  
Injection and Monitor Wells

Well Name	Total Depth (feet)	Cased Depth (feet)	Cemented Depth (feet)	Well Temperature (°F)	Comments
83A-6	2681	2200	2200	430	Completed in metasediment
21-5	3050	1297	1297	420	Completed in granodiorite and metasediment
23-5	3022	1496	1496	460	Completed in metasediment
CoxI-1	3471	1767	1767	320	Completed in granodiorite
MW-3	800	NA	NA	NA	NA
MW-4	400	NA	50	NA	Top of volcanics 365 feet
UFW	NA	NA	NA	NA	NA
TS-3	110	50	NA	70	Completed in alluvium
Pine Tree	435	435	125	110	Alluvium to 86' "hot rock" 168' to 427'
ST-2	844	156	156	340	Completed in granodiorite
ST-5	1700	285	285	110	Alluvium to 370' granodiorite 370' to 1700'
ST-9	914	305	305	350	Completed in granodiorite
Boyd	56	NA	NA	64	Completed in alluvium
Jeppson	60	NA	NA	NA	Completed in alluvium

\*NA indicates not available

Many of the groundwater wells in the area have temperatures that are greater than that which would be expected in an area with a normal conductive thermal gradient. Figure 3 shows the thermal areas that have been identified to date. These areas have been identified by investigating the available well log data (approximately 600 wells) from the Nevada Department of Water Resources and from canvassing the local home owners in the Steamboat Hills area. The thermal areas shown in Figure 3 were delineated from shallow water wells with temperatures above 85°F. The data suggests that several isolated low temperature geothermal systems exist in the area. The relationship between these low temperature systems and the high and moderate temperature systems in the Steamboat Hills is unknown. However, thermal areas exist throughout the area from 60 miles southwest of Steamboat Hills at Walleys Hot Springs to the Moana geothermal area in Reno, north of Steamboat Hills. The data indicates that a large anomalous heat flow region exists in the Steamboat Hills area and locally along the eastern front of the Sierra Nevada Range.

#### Geology and Structure of the Steamboat Hills Area

Figure 4 shows the rock outcrops and the faulting and fracture patterns mapped in the Steamboat Hills area. The basic geology of the Steamboat Hills area consists of Triassic-Jurassic metavolcanic rocks of the Peavine Sequence which are located along the southern flank of the hills. The metavolcanics are intruded by granodiorite of Jurassic-Cretaceous age in the northern portion of the hills. Well lithologies and outcrops indicate that the contact is steeply dipping and striking in an easterly direction. Some wells penetrate alternating metamorphic rock and granodiorite indicating intrusive tonguing along an irregular contact. It is not known whether faulting has occurred along the contact.

A time hiatus representing the Laramide uplift yields an unconformity between the Miocene-Pliocene Alta and Kate Peak volcanics and the underlying metamorphic rocks and granodiorite intrusive. The Alta formation consists of soda trachyte lava flows with breccias and pyroclastics. The Kate Peak volcanics consist of andesitic lava flows and tuff-breccias up to several hundred feet thick.

An additional unconformity exists between the Kate Peak Formation and the Pliocene Lousetown volcanics. The Lousetown volcanics include basaltic andesite flows and a series of rhyolite "domes" that occur along a northeasterly trend. The mafic volcanics occur as local extrusives along northeasterly and northwesterly striking faults. The mode of occurrence of the lava flows suggests that they were extruded from apparently steeply dipping faults. The lava flows are

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characterized by flow banded rock grading upward into scoriaceous tops. The strike of flow banding is commonly oriented parallel to the faults from which the volcanics were extruded. Dips of the banded flows are normal to the strike. These volcanics serve as useful guides to locations of faults and fractures in the area. These volcanics have limited occurrence and do not blanket the northern Steamboat Hills as previously mapped.

The northeast trending Steamboat Hills are a part of the Carson section of the Walker Lane Structural Belt and are within the Basin and Range physiographic and geologic province. Gross structure of the Steamboat Hills is folded metavolcanics intruded to the north by Cretaceous granodiorite. The Alta and Kate Peak volcanics unconformably overly the granodiorite to the west and northeast. The whole block comprising Steamboat Hills is bounded to the north and south by N50-60E trending normal faults and to the east and west by north-northeast to north-south normal faults. This yields a parallelogram shaped block in map view which is 2,000 to 3,000 feet higher, structurally, than the adjacent areas to the east, west and north. A third prominent normal fault pattern occurs in a northwesterly direction.

In and adjacent to Steamboat Hills, the most recent tectonic movement occurred along northerly trending faults which extend through the hills 5+ miles south to Washoe Valley and 5+ miles north to Huffaker Hills. However, the northeast trend may have been active in the recent past as indicated by offsets in the Lousetown volcanic formation. The northeast and northwest trending faults were conduits for volcanic extrusions. In addition, Pleistocene rhyolite domes occur for 5 miles along the same northeast trend. This is strongly suggestive of a deep reaching fault zone through which lavas rose from their mantle source. The heat source for the geothermal system may be associated with these volcanics and deep seated faults.

Figure 5 is a cross section through Steamboat Hills and the surrounding alluvial areas. Wells have been projected onto this cross section and therefore lie above and below the cross section ground surface elevation. It can be noted on this figure that the CPI production and injection zones lie within the same elevation relative to sea level. The figure shows the relationship between the geologic formations described above. The contact between the metamorphic rocks and the intrusive granodiorite has not been mapped in detail.

#### Steamboat Hills Geothermal System

Figure 6 is a schematic representation of the geothermal system based on the data available to date. The southern portion of the geothermal system has production well

temperatures from 420 to 460°F. Chemical geothermometry analyses from production well fluids indicates a reservoir temperature of ≈500°F. Temperature profiles in the production wells have temperature reversals in the deeper portions of the wells indicating that the wells intercept an outflow zone from a deeper high temperature reservoir. The deep high temperature zone has not been encountered by wells drilled to date. The CoxI-1 injection well intercepts two geothermal zones. A shallow moderate temperature (350°F) geothermal zone was encountered at depths between 800 to 900 feet. A deeper zone at depths between 1,800 to 2,500 feet has a temperature of 320°F. The injection well is isothermal from 1,800 to 3,400 feet. Wells ST-2 and ST-9 also intercept the shallow geothermal zone with temperatures of 340°F and 350°F, respectively. Reservoir engineering pressure interference tests conducted between the production wells and injection well have shown that pressure communication exists between the deep production and deep injection areas. In the CPI production area a continuously cored stratigraphic test well drilled to 2,400 feet had numerous fractures that are tightly cemented with hydrothermally precipitated calcite and associated minerals. This core hole has a purely conductive temperature gradient with depth. The core hole indicates that a caprock is present in the CPI production area. There is no hydraulic communication between the deep CPI injection zone and the shallow moderate temperature geothermal reservoir. This pressure boundary is postulated due to the fact that injection of fluid into the CoxI-1 well has no effect on the water level in the ST-9 well, located approximately 200 feet to the southeast. Well ST-2 also shows no response to fluid injection. A moderate temperature fluid influx zone is inferred in the ST-9 area due to the noted temperature difference between the ST-9 well and the CPI high temperature production area. A steep lateral temperature gradient of 110°F/mile exists between production well 23-5 and monitor well ST-9. However, the lateral temperature gradient between wells ST-9 and ST-2 is only 10°F/mile. This information suggests that fluid must be convectively moving through the ST-9 and ST-2 area. It also indicates that fluid does not move directly between the CPI production area and the shallow moderate temperature geothermal zone. Another thermal influx zone is suggested in the Hot Spring area due to the fact that water level declines at the hot springs do not correlate with CPI production and injection operations.

#### Production and Injection Operations

Figure 7 is a plot of the production and injection data for the CPI operations. The large excursions in the production and injection rates during the first year of operations were due to wellbore scaling. Chemical inhibitors have successfully reduced well bore scaling problems. On the

average approximately 10% of the produced fluid is consumed in the power plant operations, and therefore, 90% of the produced fluid is reinjected at a temperature of 290°F.

Figure 8 is a plot of downhole flow data (spinner) as a function of depth shown along with the CoxI-1 well completion information. The spinner data were obtained while injecting approximately 3,500 gpm during power plant operations. Approximately 60% of the injected fluid leaves the wellbore between 1,800 and 1,820 feet. The spinner data indicate that several zones below this depth are also accepting injected fluid.

In order to more completely understand the fractured nature of the reservoir a Schlumberger Formation MicroScanner™ log (FMS) was run from 1,767 to 3,000 feet. The FMS log indicated that numerous fractures were present throughout the open hole section of the well with dips ranging between 5° to 90° and strikes scanning all azimuths. However, a detailed analysis of the spinner survey indicates that several discrete zones are accepting the injected fluid. The FMS log was examined in detail at these specific zones. The examination indicated that the only difference in the fractured nature of the reservoir was relatively distinct near vertical (85°-90° dip) fractures at the permeable zones. These near vertical fractures strike in a north-northeasterly direction. Additional near vertical fractures were noted orthogonally to the north-northeasterly fractures. Figure 8 shows the output from the FMS log analysis for one of the injection intervals.

The north-northeasterly trending permeable fractures zones identified in the injection well have also been noted in one other well that has been logged with the FMS tool. In addition, these north-northeasterly trending faults have been mapped on the surface and several of these fractures have associated geothermal manifestations. Additional wells will be logged in the future to yield a more complete description of the fractured nature of the reservoir.

#### Monitoring Well Data

The NDEP permit requires monitoring of wells and stream flows in the vicinity of Steamboat Hills. In addition, other entities including the South Truckee Meadows Improvement District (STMGID) and Far West Electric Energy (FWEE), operator of a 7 Mw binary power plant located to the north of Steamboat Hills, monitor various groundwater wells. Figure 2 shows the location of several of the wells for which data are available.

Figure 10 is a graphic representation of water level elevations for STMGID monitor wells MW-3 and MW-4, located approximately 2 miles north of Steamboat Hills. Monitoring began in 1985, 3 years before CPI production and injection operations began. It can be noted in the figure that groundwater levels have been declining over time and that the declines began prior to geothermal operations in the area. The reason for the water level decline is not completely understood but is most likely due to a reduction of recharge to the alluvial aquifers in the area during the recent drought years and increased groundwater use in the area by individual homeowners and STMGID (STMGID operates several groundwater production wells in the area that have produced greater than 1 billion gallons of groundwater to date).

Figure 11 shows the water level data for STMGID monitor wells TS-3 and UFW. The data show large seasonal cyclic variations in water levels and a general declining water level trend. The cyclic water level variations have not been analyzed in detail but are also most likely related to seasonal recharge to the aquifer system in this area.

Figure 12 shows the water level changes in the Boyd and Jeppson domestic water wells located east and south, respectively, from the CPI production and injection areas. These wells also show seasonal cyclic water level variations. However, the cyclic variations for the Boyd and Jeppson wells are offset in time when compared to the TS-3 and UFW wells. The Boyd and Jeppson wells do not exhibit the water level decline that is noted in groundwater wells located north and northeast of Steamboat Hills. It should also be noted that the water level elevations in the Boyd and Jeppson wells correspond to the elevation of Steamboat Creek, which runs parallel to Highway 395 in this area. This suggests that water level elevations in this area are controlled by Steamboat Creek.

Figure 13 shows the water level and produced fluid total dissolved solids (TDS) content for the Pine Tree Ranch well. Figure 14 shows the TDS and produced fluid temperature as a function of time for the same well. This well is completed in both a shallow groundwater aquifer and a deeper low temperature geothermal system. The water level, temperature and TDS data show seasonal cyclic variations. In addition there is an overall decline in the water level and a corresponding increase in produced fluid TDS and temperature over time. The increase in TDS and temperature began several years prior to long term geothermal operations in the area. This data, along with the data from other monitor wells in the area that illustrate declining water levels in the groundwater aquifers, indicates that the increasing TDS and fluid temperature at the Pine Tree Ranch well is due to a decrease in the pressure head, and therefore a decrease in



produced groundwater, in the shallow aquifer (ie; the well produces a relatively smaller fraction of groundwater over time).

Figure 15 is a plot of the water level data for the Pine Tree Ranch well and monitor well ST-5. The data indicates that the groundwater level decline is wide spread in the area.

Figure 16 is a plot of the water level changes at the Pine Tree Ranch well and at Hot Spring No. 6, located in the Main Terrace Hot Spring area (see Figure 2). The hot springs in the Main Terrace area ceased flowing in May 1988. The water level data shown in Figure 16 indicates that the water levels at the hot spring area behave similarly to the water levels in the groundwater system. This suggests that the groundwater system may be hydraulically connected to the geothermal system(s). It should also be noted that the water level elevation of the hot spring area is the same as that at the ST-5 monitor well located approximately 11,000 feet west of the Main Terrace hot spring area.

Figure 17 is a plot of the water level elevation data for monitor wells ST-2 and ST-9. These wells are completed in the shallow moderate temperature geothermal system. These wells also show water level declines similar to those noted in the groundwater system. These data also suggest that the groundwater system may be in natural hydraulic communication with the shallow moderate temperature geothermal system and hot spring areas.

Together, the data also show that injection into the deep CPI geothermal production and injection zone has had no effect on the shallow geothermal system (water levels would be expected to rise in wells ST-2 and ST-9 if pressure communication existed between the deep CPI injection zone and the shallow moderate temperature geothermal system(s)).

## Conclusions

Caithness Power, Inc. has reinjected over 3 billion gallons of geothermal fluid to date. The monitoring program has been extremely successful in delineating the behavior of the geothermal and groundwater systems. Several domestic water wells in the area that are completed in both the shallow groundwater aquifers and deeper low temperature geothermal systems have shown increases in fluid temperature and produced TDS that are associated with water level declines in the shallow groundwater aquifers. Reservoir testing between the CPI production and injection areas indicates that the production and injection wells are in pressure communication. Production well chemistry and temperature data indicate that the injected fluid has not

migrated to the production wells. The injection monitoring program data indicate that there has been no effect on the groundwater system from injection operations in the Steamboat Hills area.

The data obtained during operations at Steamboat Hills suggests that the moderate and low temperature geothermal systems are in communication with the local shallow groundwater aquifers. However, this hydraulic communication does not necessarily indicate fluid migration would take place between the shallow moderate temperature geothermal system(s) and the groundwater aquifers during injection operations in the shallow geothermal system.

The data obtained from monitor wells prior to geothermal operations has been instrumental in illustrating that deleterious changes noted in groundwater wells in the area are due to a reduction in groundwater recharge and increased groundwater use. It is also important to note that the detrimental changes noted in the groundwater wells could have been erroneously assigned to geothermal injection operations if data had not illustrated the development of these problems prior to geothermal operations.

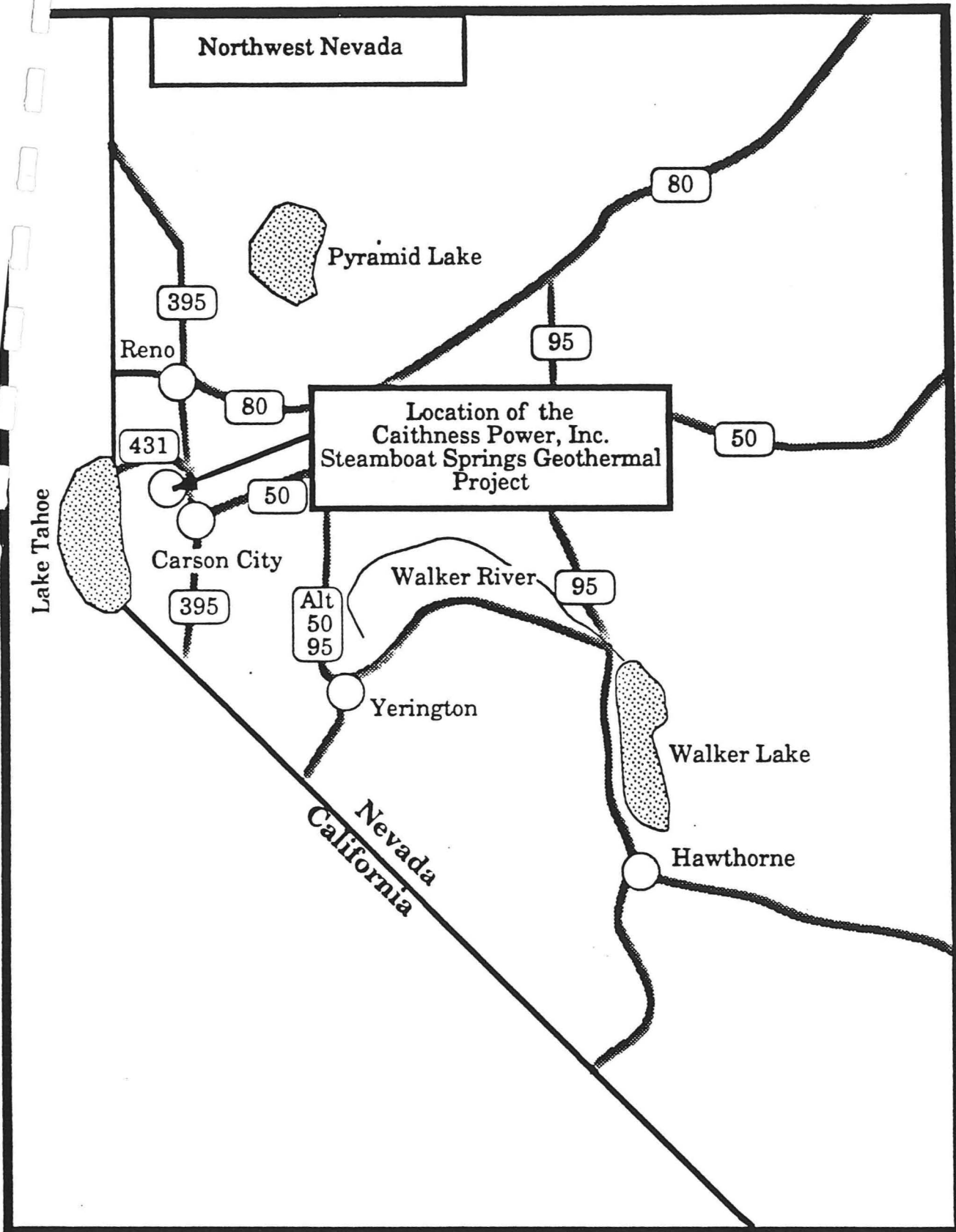


Figure 1) Location of the Caithness Power, Inc. Steamboat Springs Geothermal Project

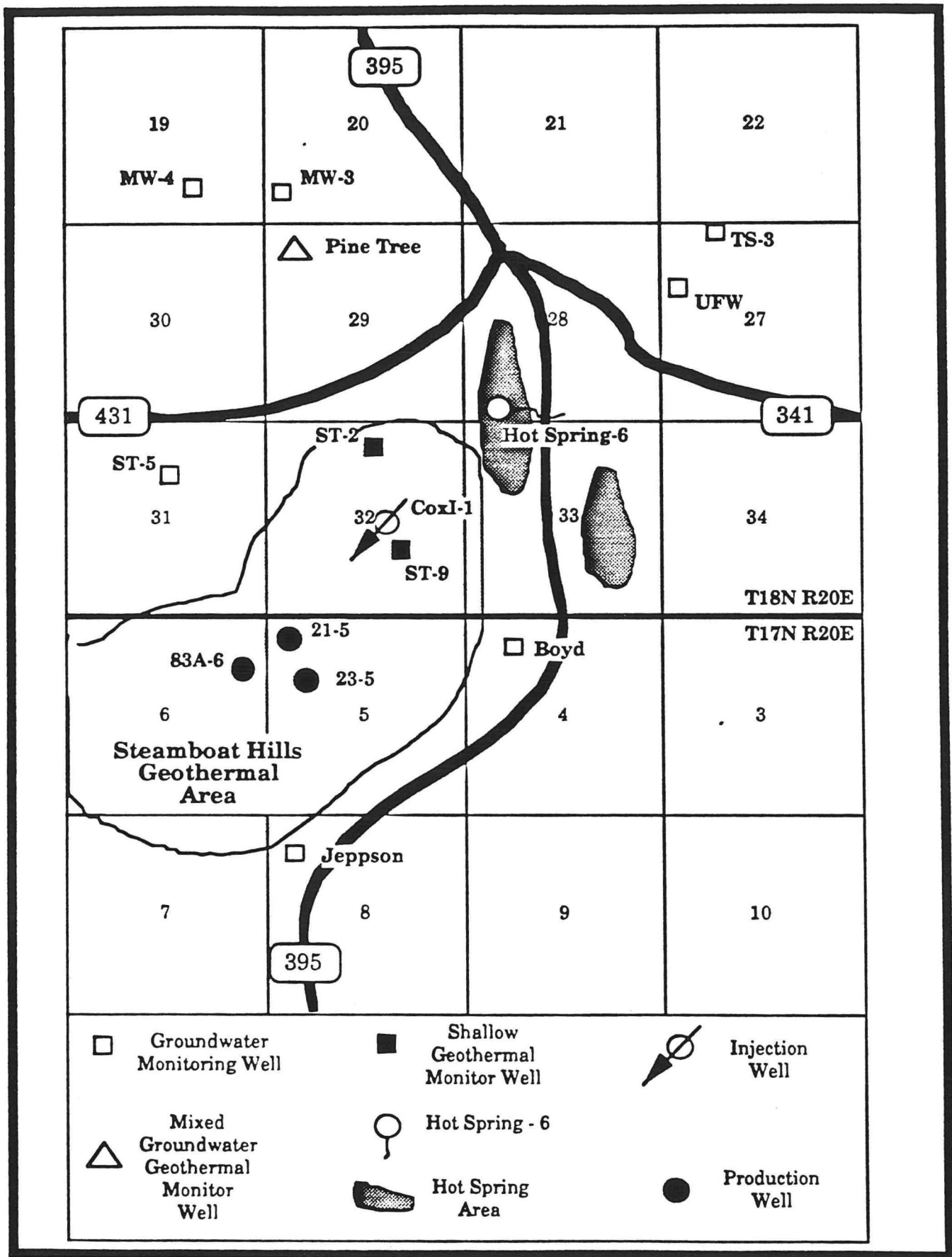
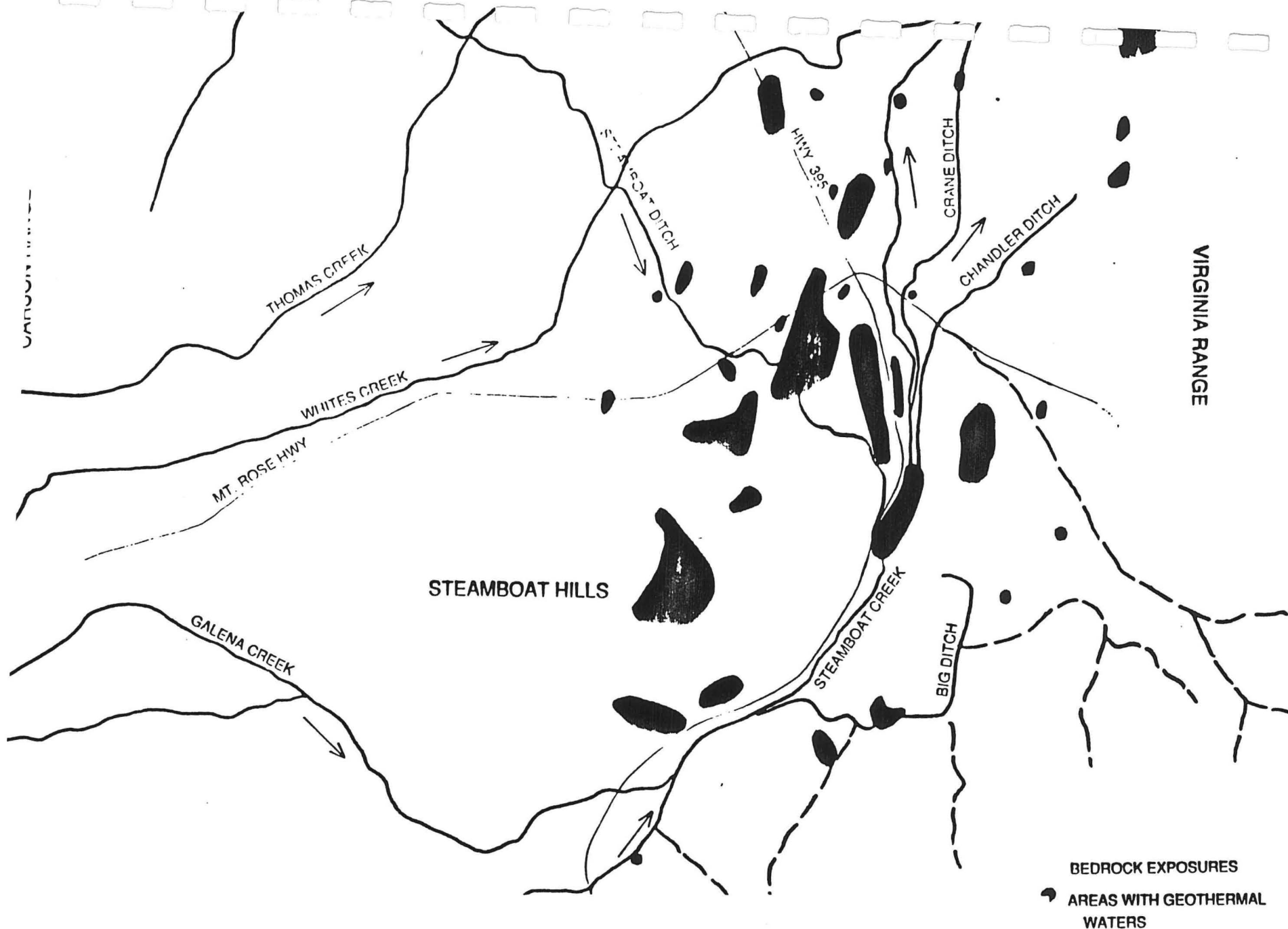


Figure 2) Location of CPI Production and Injection Wells and Several of the Wells and Springs Monitored at Steamboat Springs



**Figure 3) Map of the Steamboat Springs Vicinity Showing Main Stream and and Drainage Ditchesw Along With Thermal Areas**



GEOLOGICAL MAP OF STEAMBOAT HILLS AREA  
WASHOE COUNTY, NEVADA

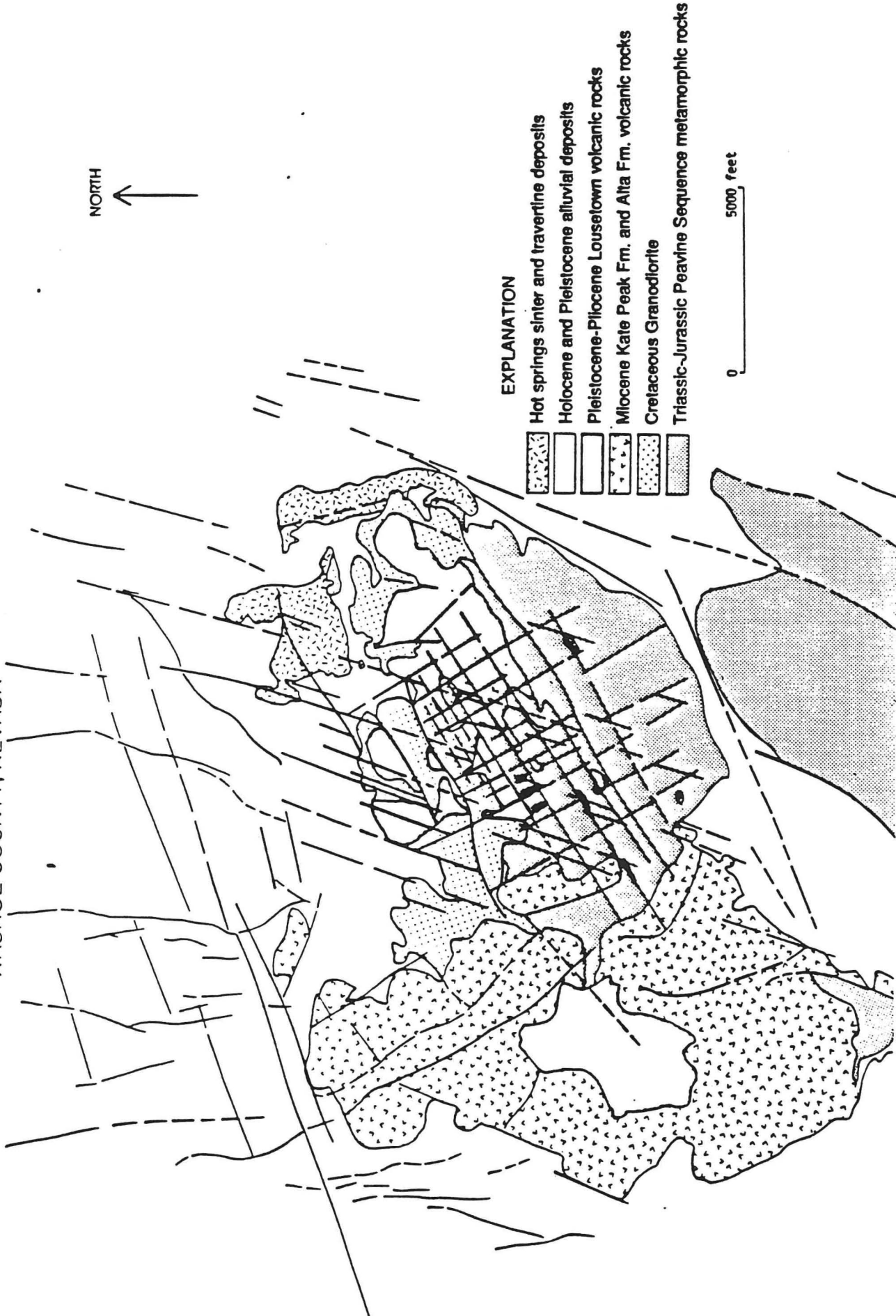
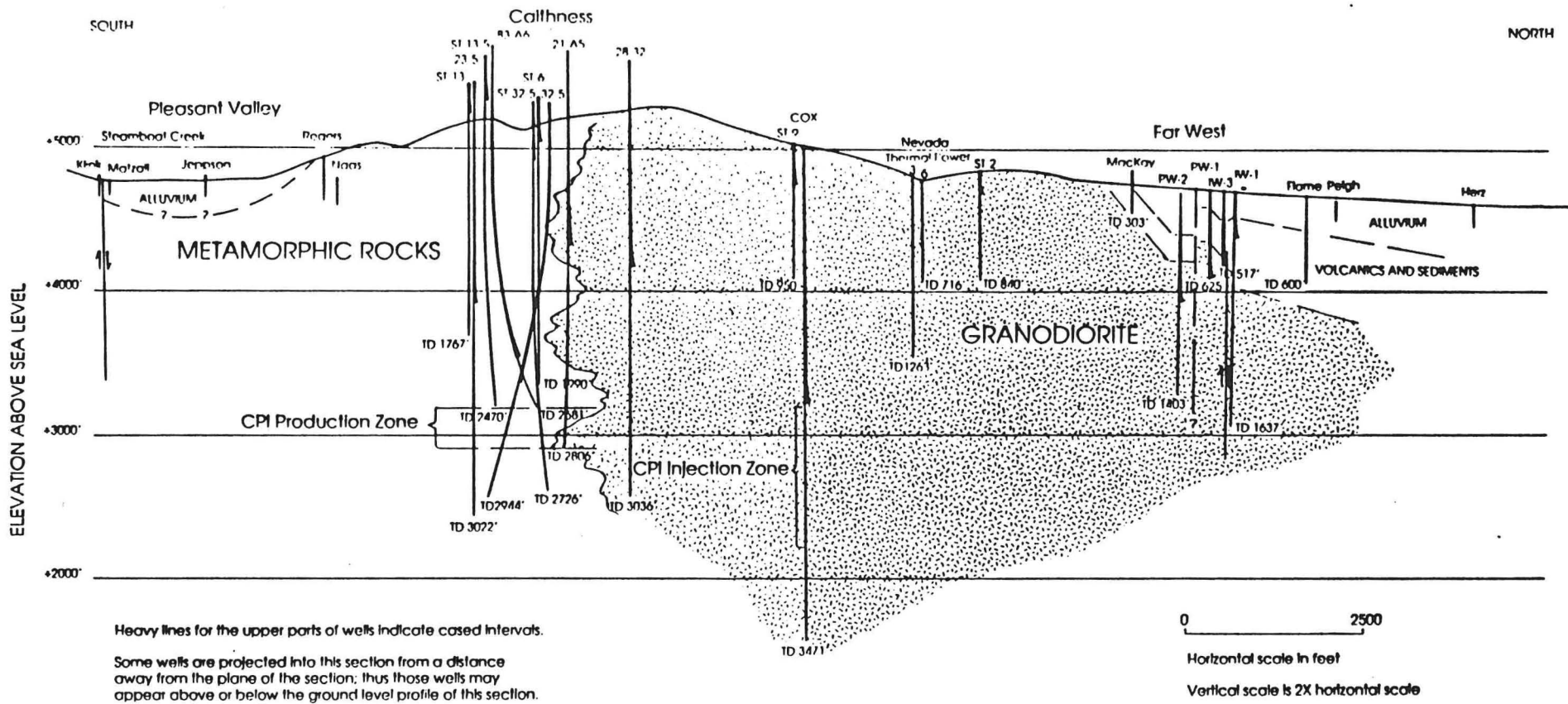


Figure 4) Geological Map of the Steamboat Hills Area



**Figure 5) North-South Geological Cross Section Through Steamboat Hills**

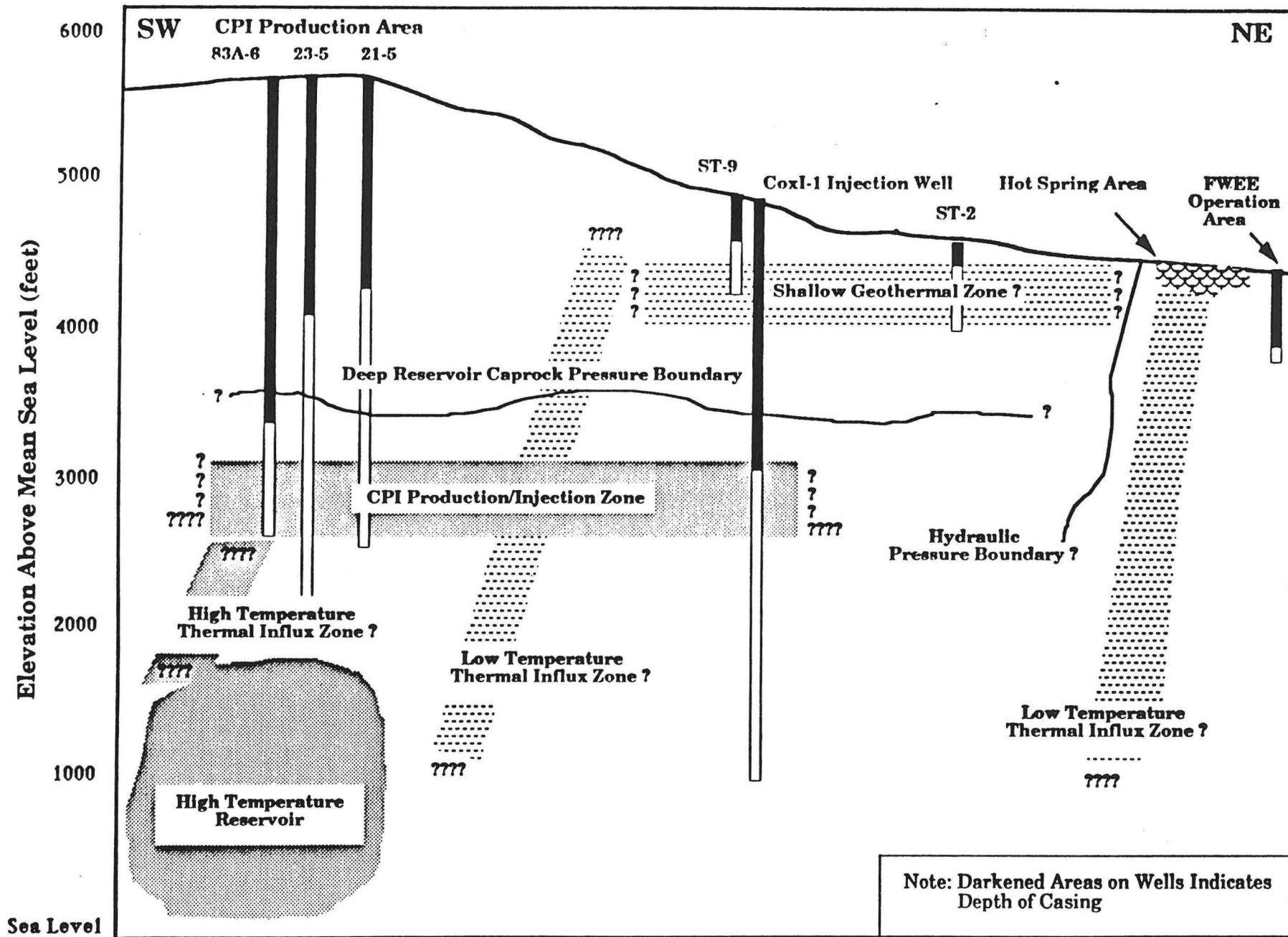


Figure 6) A Southwest-Northeast Schematic Cross Section of the Steamboat Springs Geothermal System



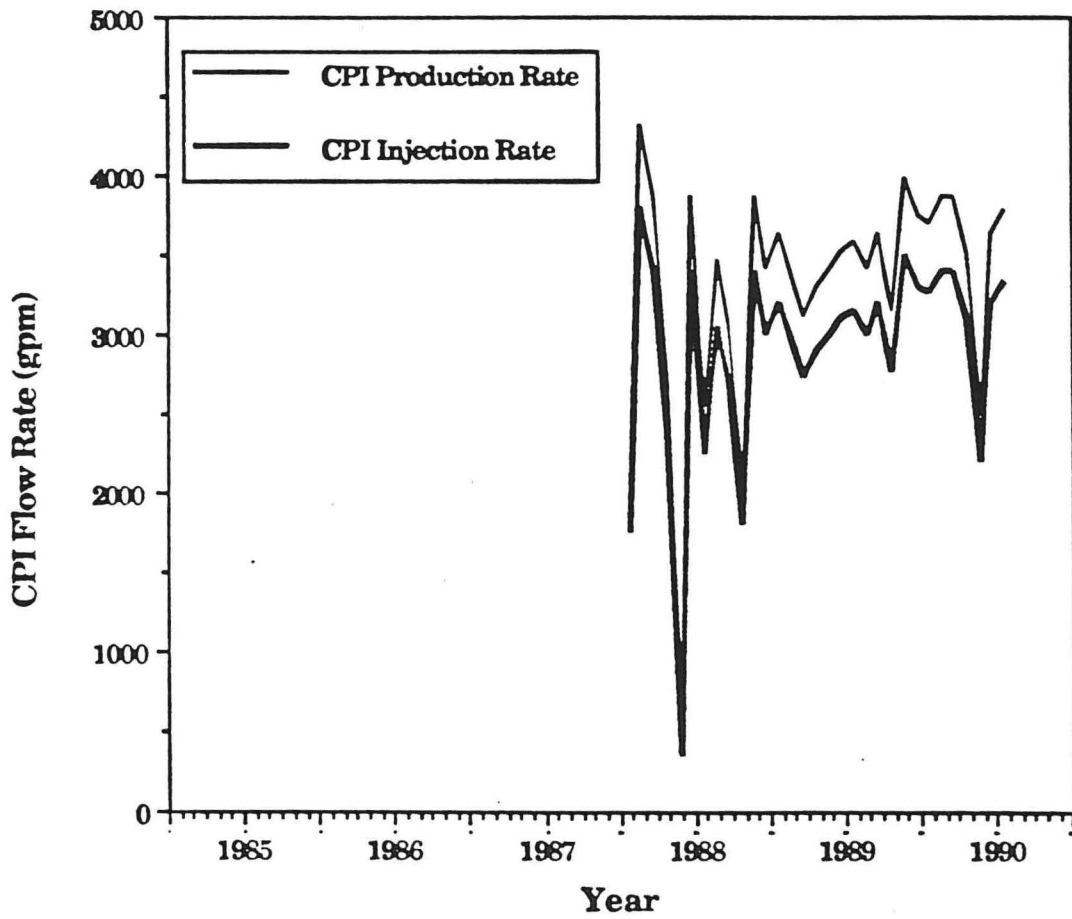


Figure 7) Caithness Power, Inc. Production and Injection Flow Rates

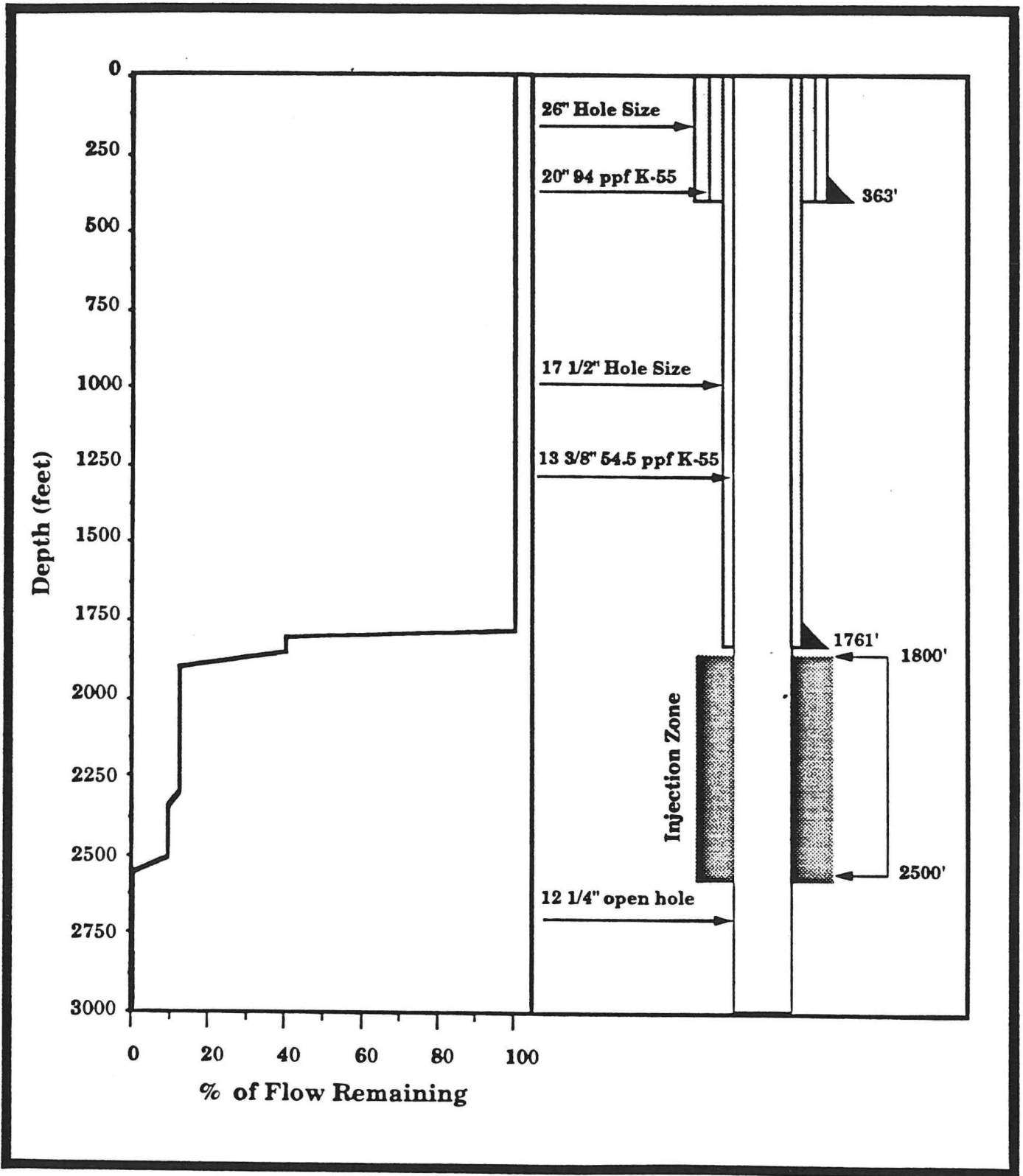


Figure 8) Downhole Flow Meter (Spinner) Data and Well Completion Information for Injection Well CoxI-1

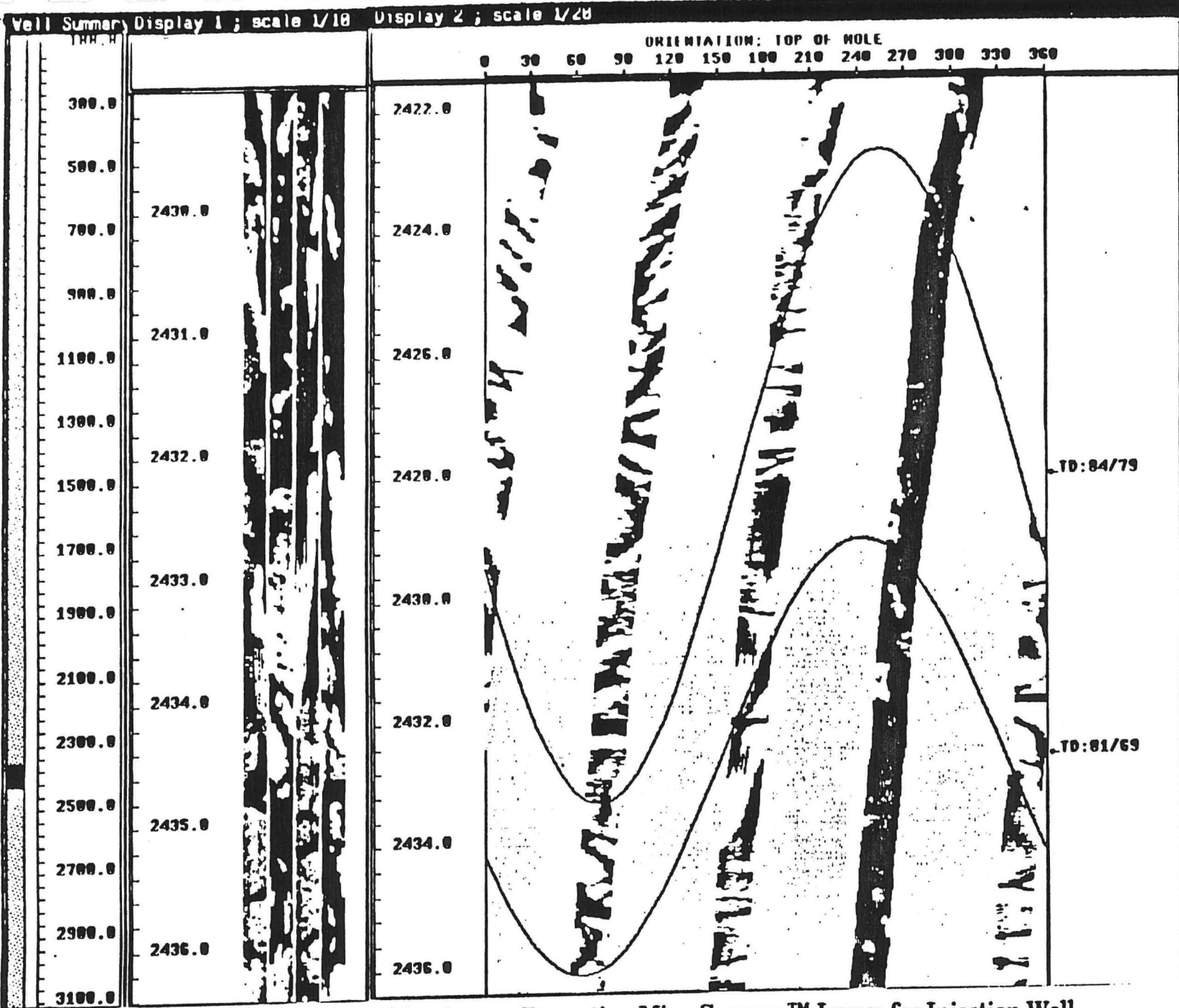


Figure 9) A Schlumberger Formation MicroScanner™ Image for Injection Well COXI-1 at Depths Between 2422-2436 Feet

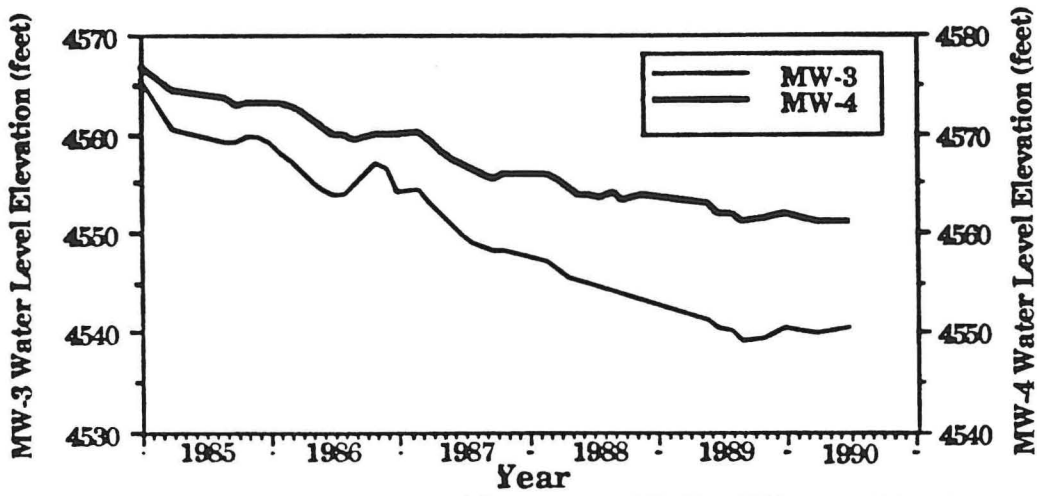


Figure 10) Water Level Changes at Wells MW-3 and MW-4

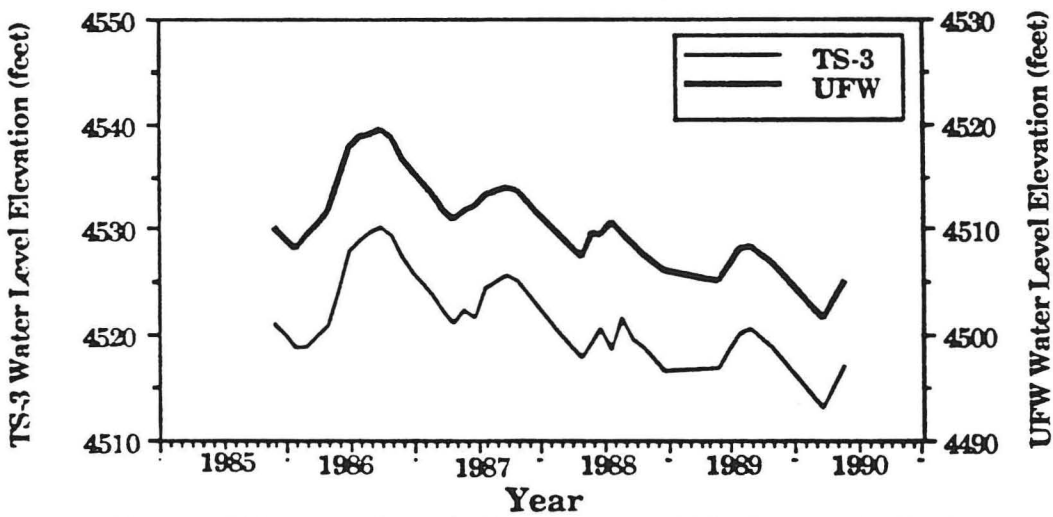


Figure 11) Water Level Changes at Wells TS-3 and UFW

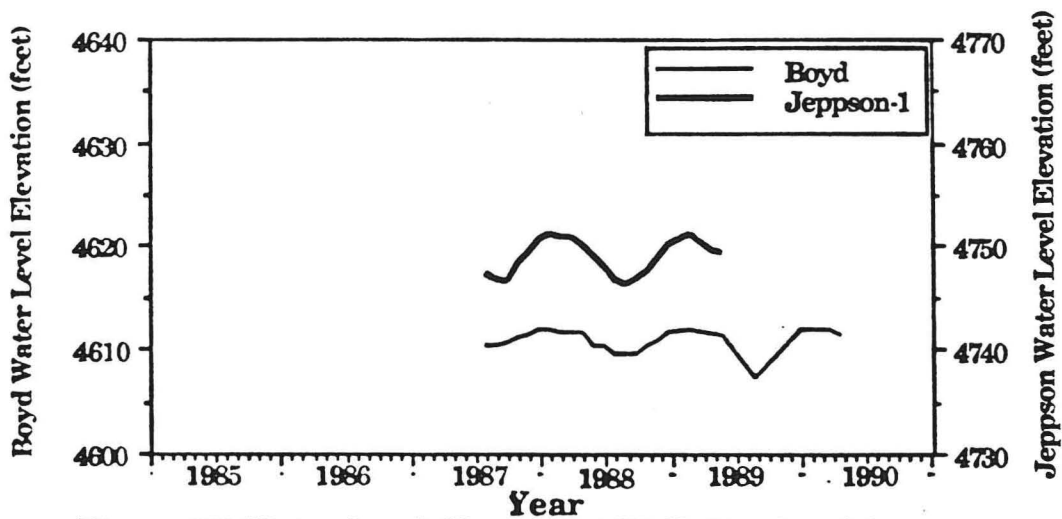


Figure 12) Water Level Changes at Wells Boyd and Jeppson

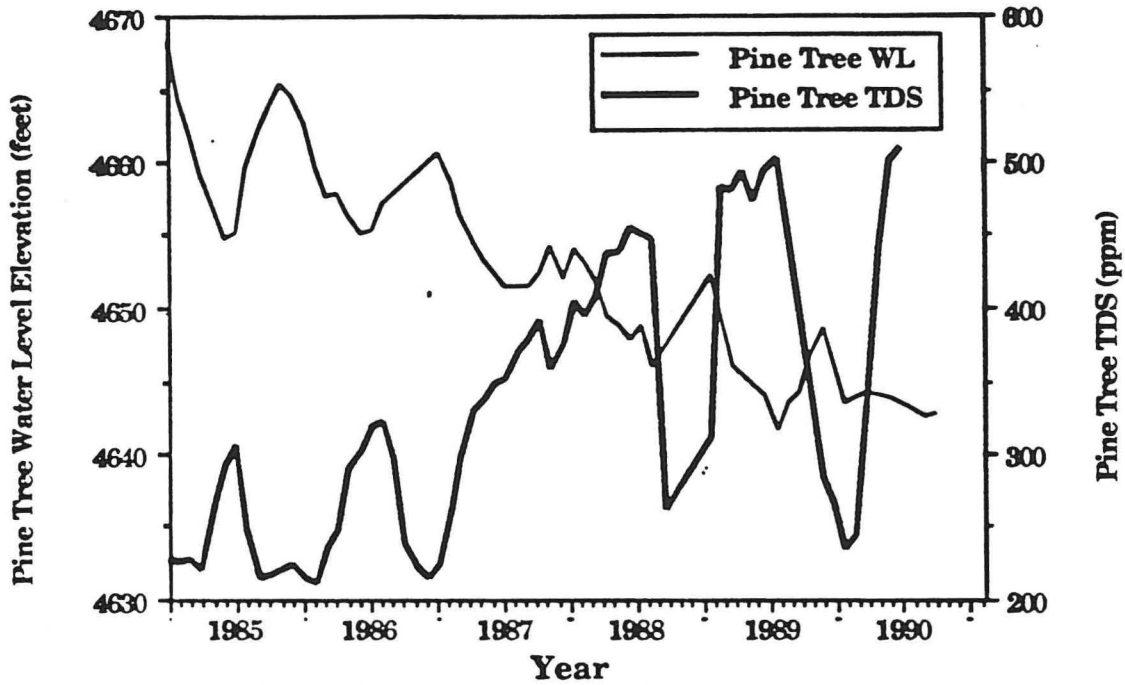


Figure 13) Water Level and Produced Fluid Chemistry Changes at the Pine Tree Ranch Well Versus Time

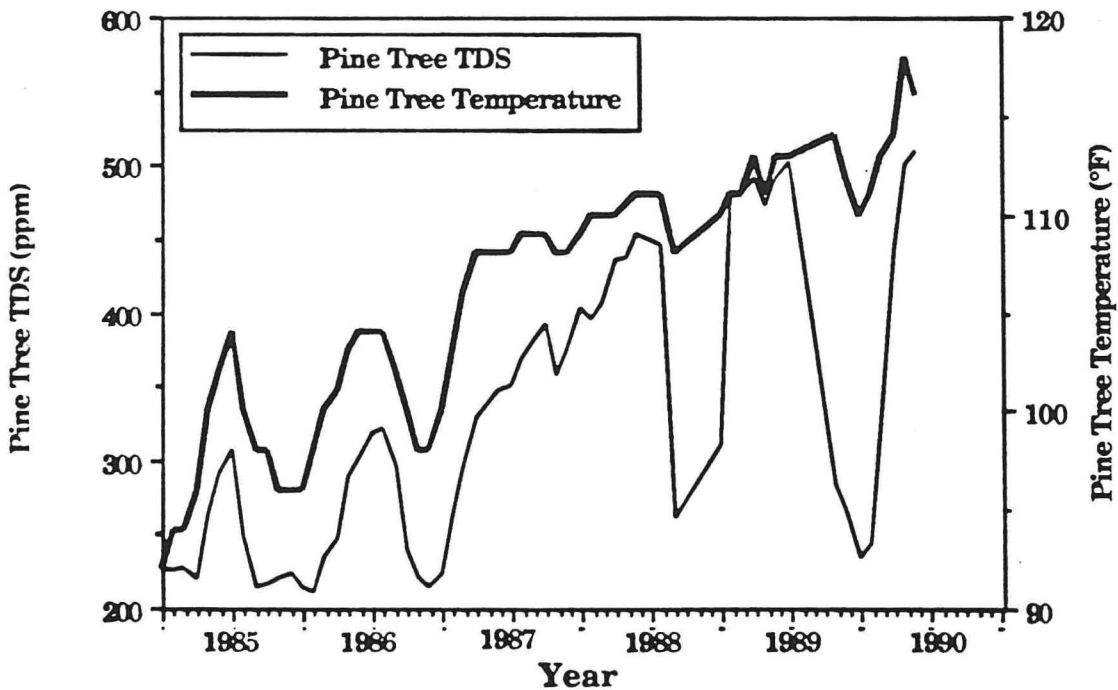


Figure 14) Produced Fluid Temperature and Total Dissolved Solids (TDS) at the Pine Tree Ranch Well Versus Time

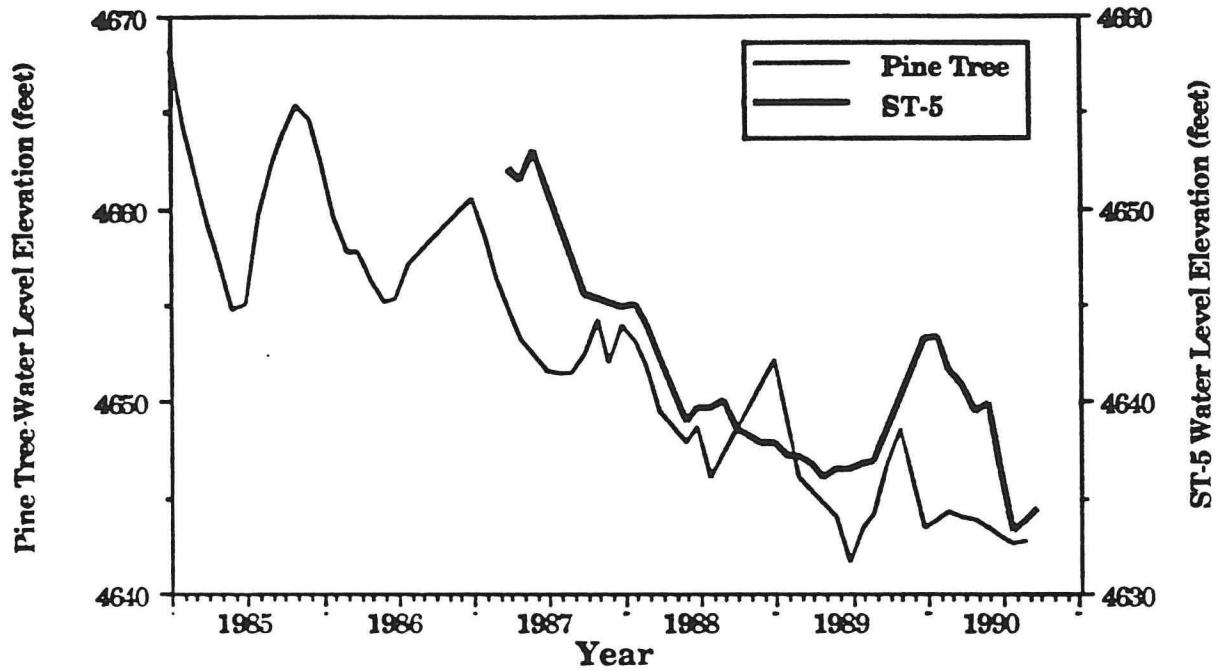


Figure 15) Water Level Changes at the Pine Tree Ranch Well and Well Strat Test No. 5 (ST-5)

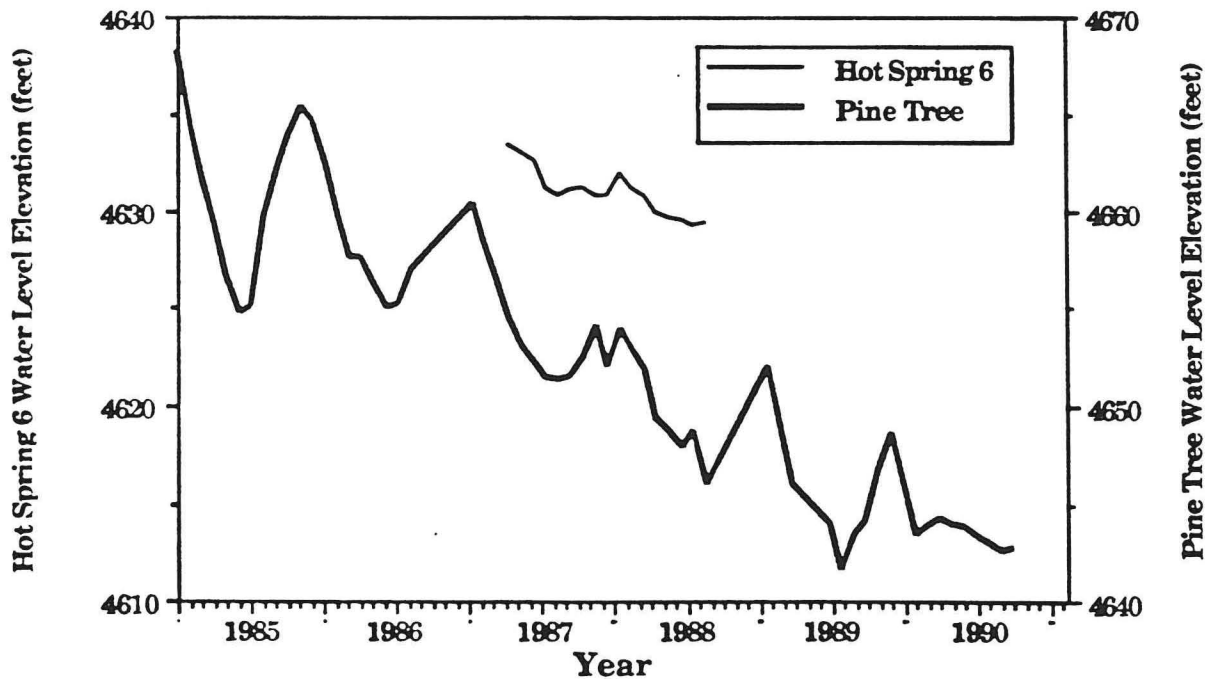


Figure 16) Water Level Changes at the Pine Tree Ranch Well and Hot Spring No. 6 on the Main Terrace

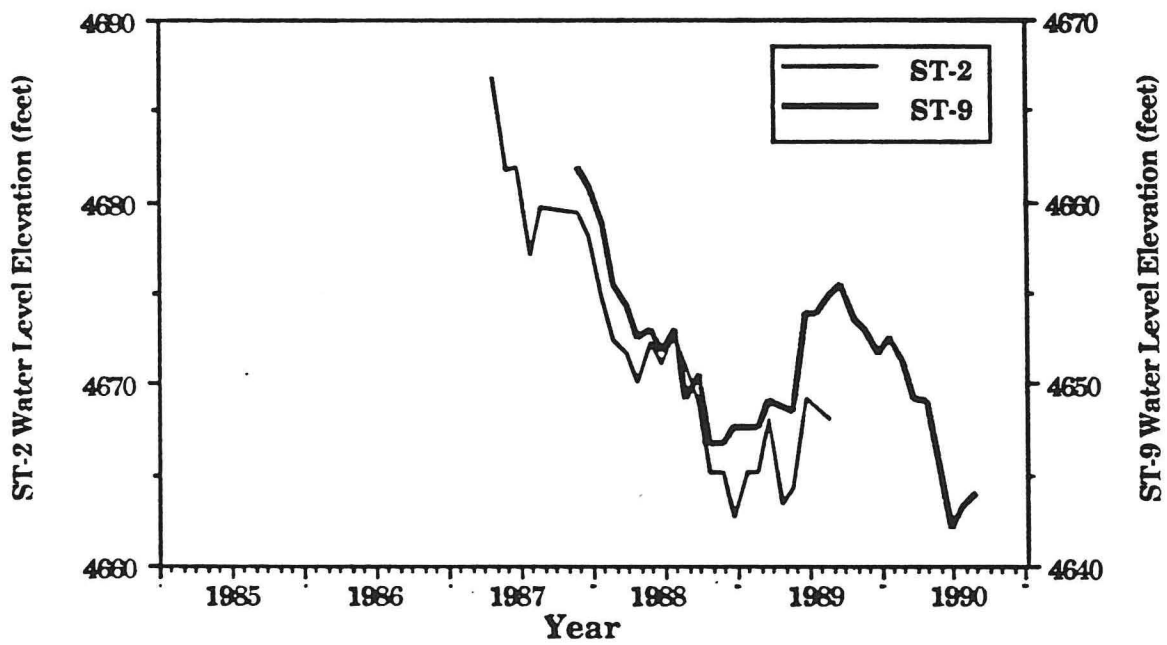


Figure 17) Water Level Changes at Well Strat Test No. 2 (ST-2) and Well Strat Test No. 9 (ST-9)