CASE HISTORIES OF VALE, OREGON AND SUSANVILLE, CALIFORNIA

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ABSTRACT

Injection in the very small Vale geothermal aquifer does not appear to be beneficial. Water levels and temperature in the upflow zone are dropping. Natural surface spring discharge has ceased. Temperatures in the outflow zone have decreased and well shut-in pressure occurred where before injection there was no pressure. New springs have surfaced near injection wells. The cause seems to be that injection is across a hydrogeologic boundary from production. Injection on the same side of the boundary does not appear possible.

The city of Susanville, California, overlies a fault controlled lateral leakage low-temperature geothermal resource. Current uses include space heating the LDS church, greenhouse heating at Tsuji Nurseries and by far the largest, the city district heating system. The city has made repeated unsuccessful attempts at injection. Injection under currently implied conditions of injecting only into zones containing equal or worse quality water set by the Regional Water Quality Control Board probably is not possible. The water quality improves as distance from the production zone increases and injection in the highly permeable zones near production wells almost certainly will result in unacceptable temperature breakthrough.

VALE, OREGON

Vale, Oregon is a city of approximately 1,700 people located about 15 miles west of the Oregon/Idaho border and on the Malheur River (Figure 1). Just east of the city, springs with temperatures reported at 194 to 198.5°F and flows estimated at 20 gpm have historically discharged for about 200 ft along the banks of the Malheur River. Russell (1903) reported a 140 ft well near the springs, and the hot water has probably been utilized as long as the area has been inhabited by white men and even earlier by local Indians. Significant spring discharge below river level is indicated by bubbling and upwelling in the river, areas where the river does not freeze and steam rising along the banks.

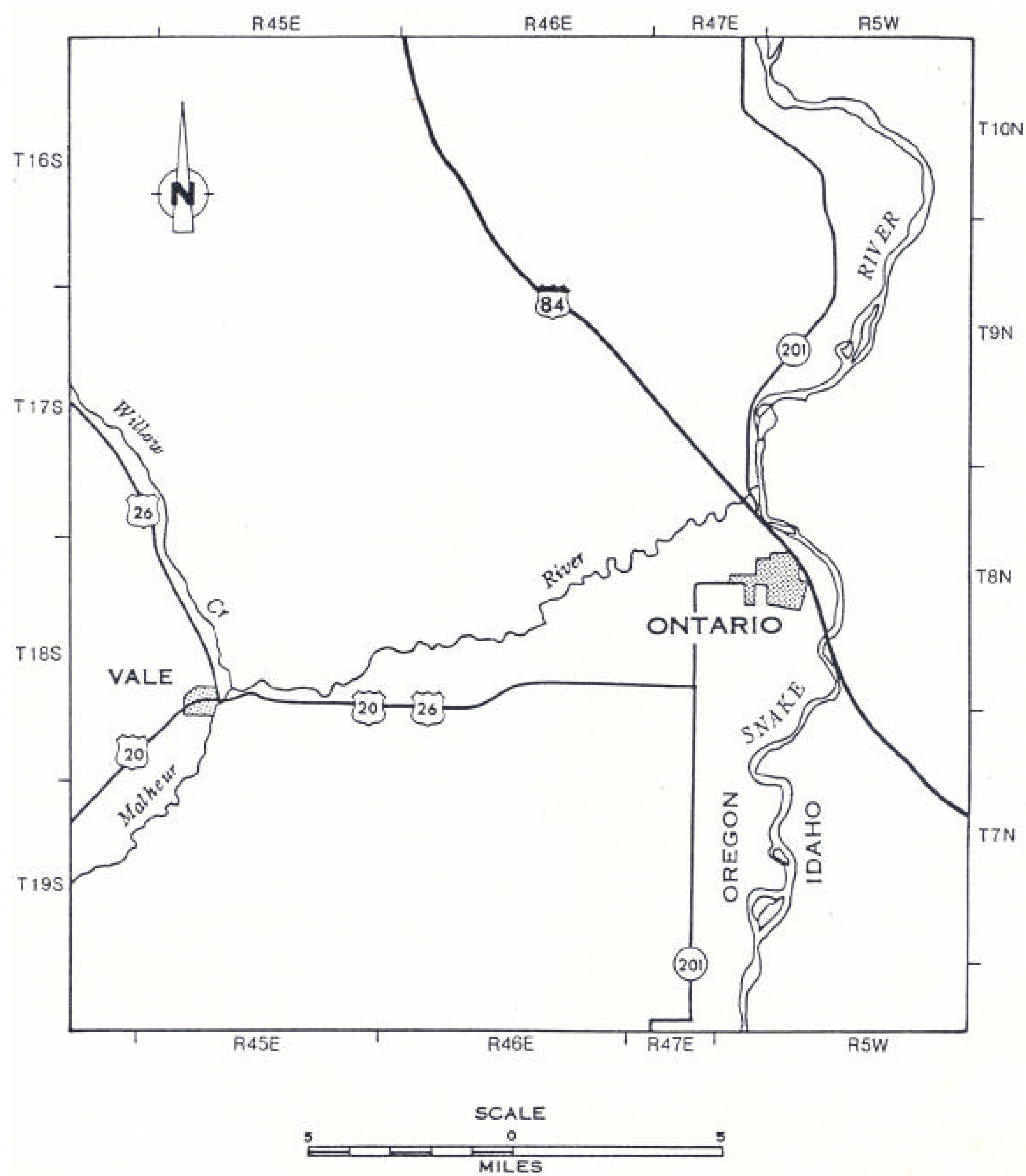

Figure 1. Location of the Vale Area.

The area of hot wells covers about 40 acres. There are no records of wells at or near boiling outside this area; although, there are wells with temperatures of 100ºF as much as one mile away. An area of anomalous heat flow about 10 miles long and 2 miles wide has been identified along Rhinehart Buttes just south of the area and along the Willow Creek fault zone. The Vale geothermal aquifer occurs at the northern terminus of the Rhinehart Buttes (Figure 2).

About 1910, a sanatorium and swimming pool were built. In the mid-1940s, a slaughter house was built which utilizes geothermal water. In the 1950s, a greenhouse was started and several homes were built which used the geothermal water for space and domestic water heating. In the 1950s, the sanatorium was closed and in the 1960s, the pool closed permanently. In the 1980s, development renewed with the construction of a grain dryer, new greenhouses and in 1984, a 180,000 ft^2 mushroom growing plant.

The Oregon Trail Mushroom plant is by far the largest user pumping approximately 225 gpm which is used for growing media processing and sterilization, growing rooms heating and cooling utilizing an absorption chiller, and plant space heating. Ag-Dryers pumps approximately 60 gpm for 30 - 90 days per year and the greenhouses about 40 gpm approximately one half the year. The other uses are small--their combined pumpage is about 2% of the large users.

The Vale geothermal aquifer appears to be the result of deep circulating water rising along a fault zone and spreading into shallow permeable zones--probably fractured silicified sedimentary rocks. As the water rises and spreads, it cools conductively and by mixing with non-thermal water and eventually discharges as hot springs.

The Vale aquifer can be divided into two distinct zones (Figure 3)--an upflow zone and an outflow zone--separated by at least one fault. The two zones have different hydrogeologic characteristics and based on aquifer tests and water levels appear to be somewhat isolated.

The hottest wells, with measured temperatures up to 230ºF, occur west of the fault in the upflow zone. Temperature gradients are very high and positive to about 45 feet below ground level where they remain positive but are lower (Figure 4). Water levels are generally higher in the upflow zone. Well tests indicate hydraulic characteristics are not uniform here with wells near the Buttes having reported yields of 80 - 640 gpm, and wells of similar depth nearer the river having yields of 20 - 30 gpm. As might be expected in fracture controlled aquifers, temperatures and especially yields differ dramatically over very short distances.

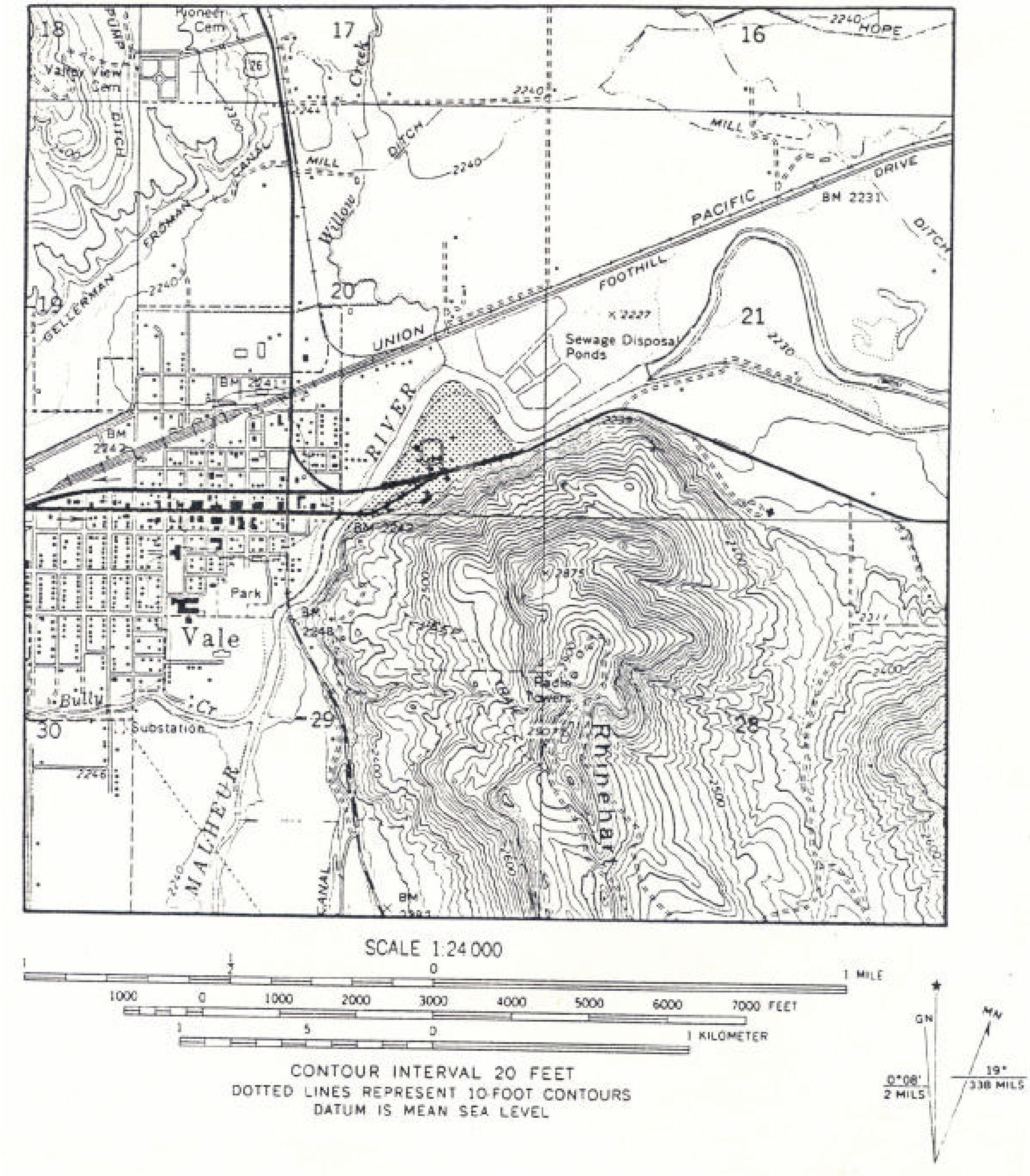

Figure 2. Location of the developed geothermal area.

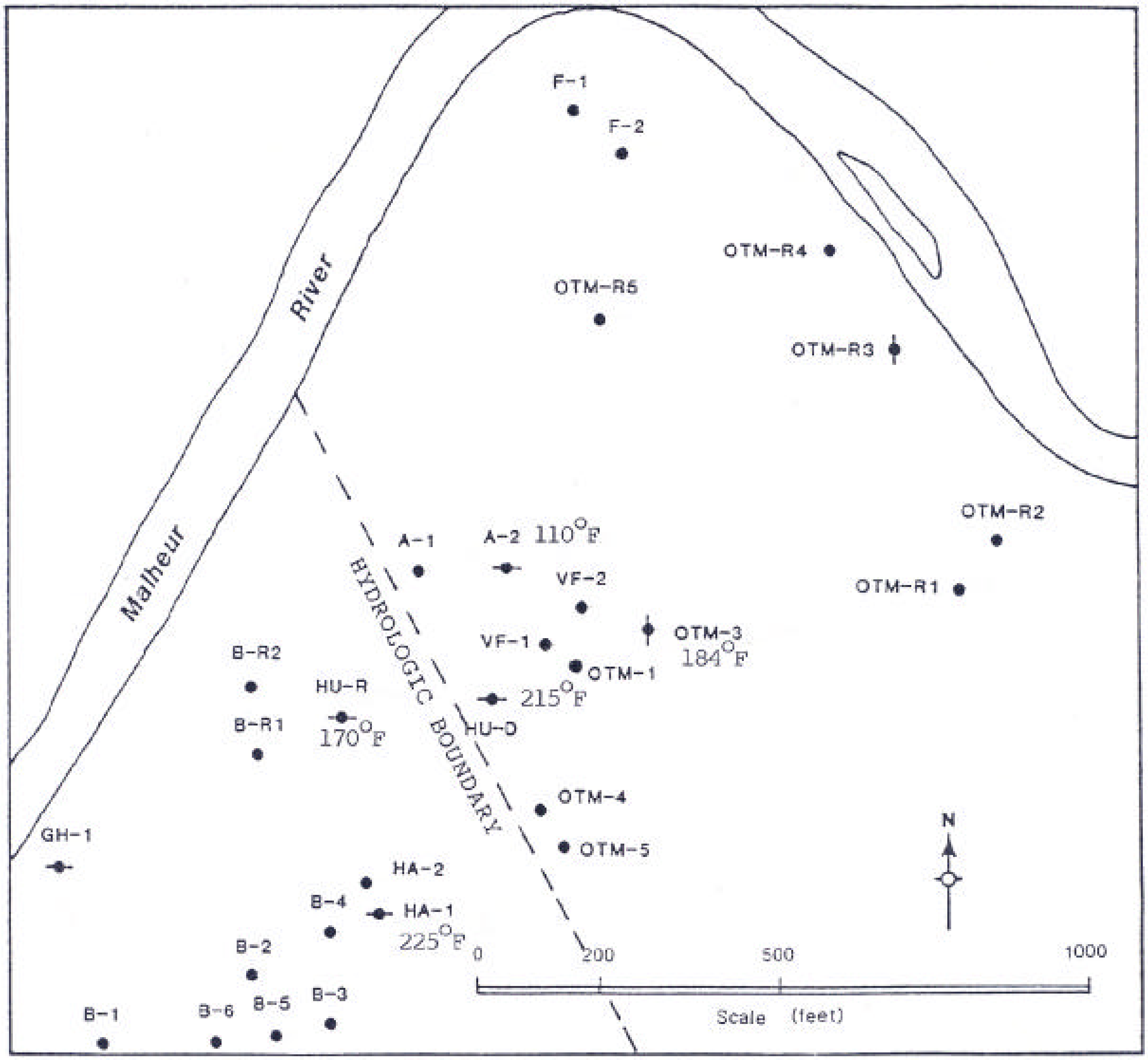

Figure 3. Location and numbers of the wells used in this study. Wells with horizontal lines are active production wells; wells with vertical lines are active injection wells.

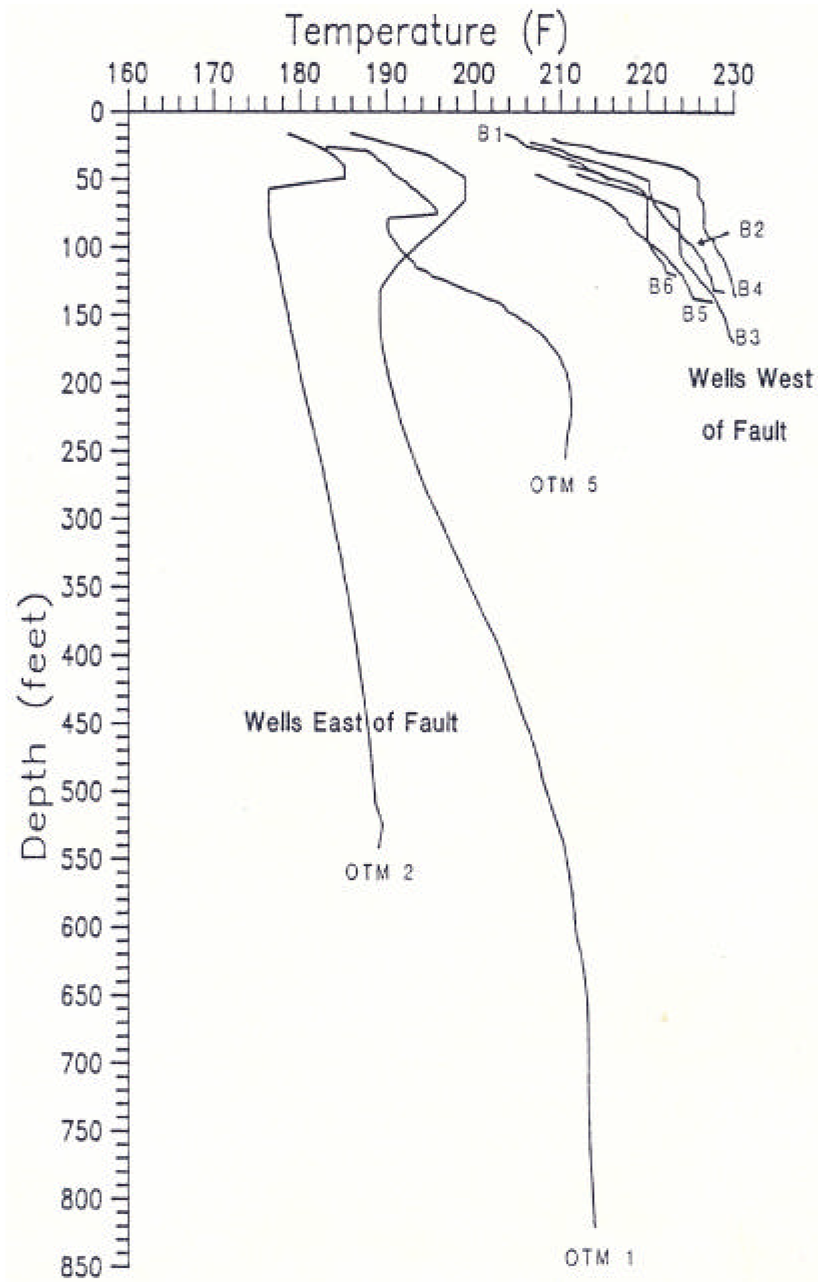

Figure 4. Temperature/depth profiles of representative wells east and west of the hydrologic boundary.

The wells east of the fault in the outflow zone are cooler. Shallow temperature gradients are high, but there is a dramatic reversal at 40 - 80 ft. The temperature profile of OTM-5 indicates a layer of hotter water at about 210 ft--perhaps underlain by another cool layer. In general, the gradients east of the fault suggest one or perhaps two relatively thin zones of lateral flow. Most of the hot water east of the fault appears in the 40 - 80 ft zone and wells as deep as 800 ft have no appreciable permeability below this zone.

Most of the wells and springs in both the upflow and outflow areas have similar water chemistry. Figure 5 shows the chloride content of the thermal and non-thermal water in the area. The one anomalous hot spring analysis is considered questionable and the Humphrey well is shallow (25 ft) and cooler, and considered to be a mixture of thermal and non-thermal water.

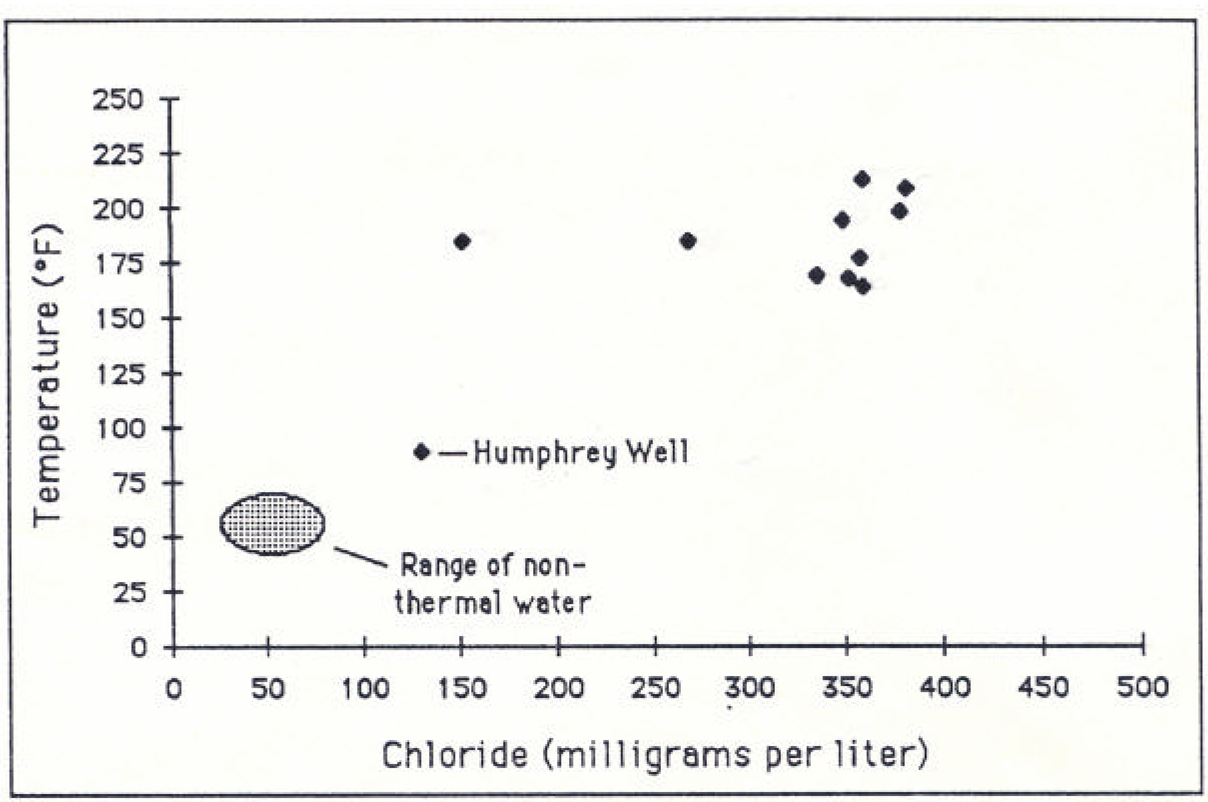

Figure 5. Chloride content versus discharge temperature of geothermal wells and springs.

Both alkali and silica geothermometry were used to estimate maximum subsurface temperatures. The alkali results suggest approximately 320°F, while the silica suggest about 265°F. Alkali geothermometers are based on the ratios of Na, K and Ca. Mixing small amounts of non-thermal water will reduce the concentration of these elements, but not appreciably change their ratios-

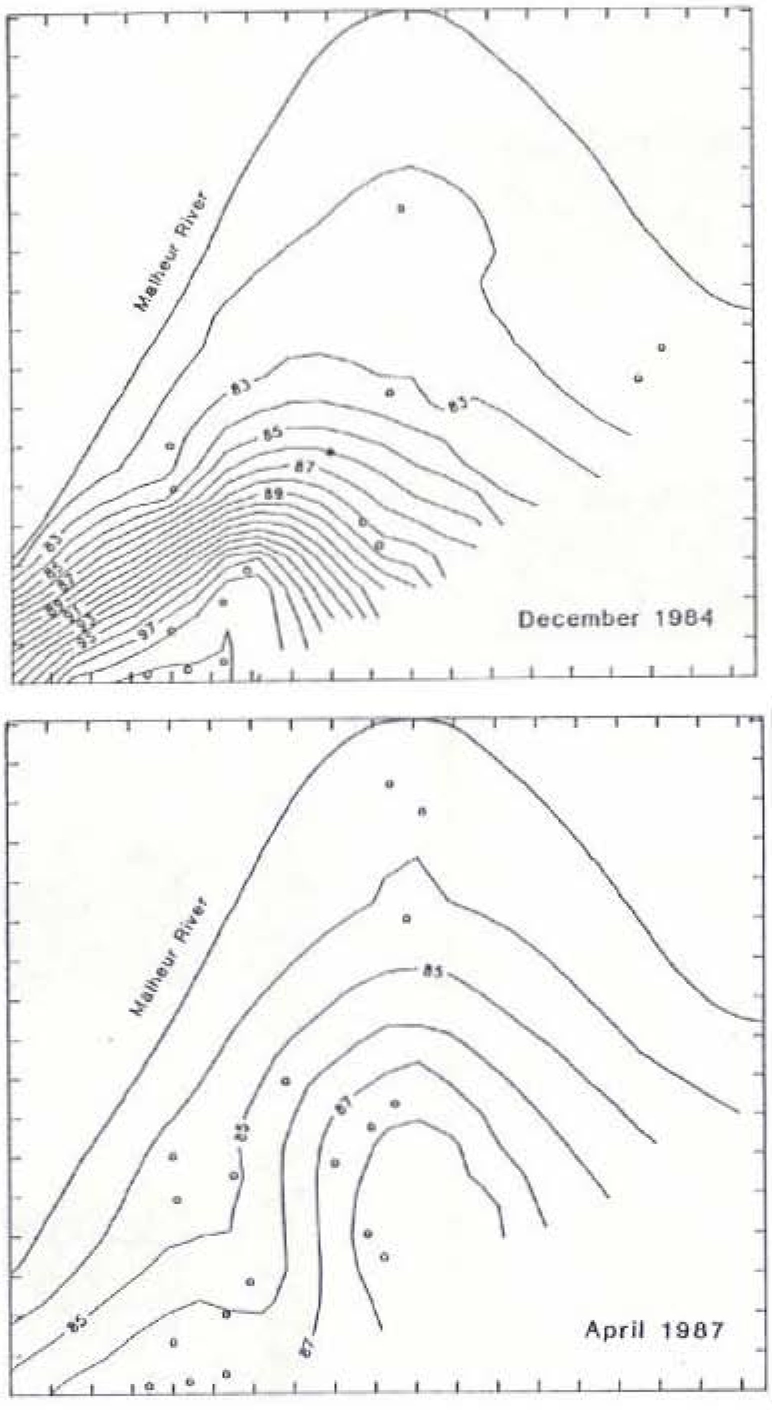

Figure 6. APPROXIMATE PIEZOMETRIC SURFACE OF THE GEOTHERMAL AQUIFER IN DECEMBER 1984 AND APRIL 1987. Elevations are relative to the benchmark on the west end of the north highway bridge which is arbitrarily set at 100 feet. Note difference in river stage.

-thus, the calculated temperatures are not affected. Silica geothermometers, on the other hand, are based on the actual amount of silica and dilution tends to reduce the estimated temperature. The results indicate the Vale hot water may be diluted with as much as one third non-thermal water.

The Oregon Water Resources Department has measured water levels in about 20 wells in the developed area quarterly since August of 1984. Figure 6 shows water levels in December 1984 and April 1987. In 1984, water levels were highest in the western upflow area and to the south near Rhinehart Buttes, and levels decreased to the northwest toward the river which acts as a constant head boundary and toward the eastern outflow zone. Contours indicate much of the water is flowing northwest to the springs area. Comparison of levels measured in December of 1984 and those indicated on well logs from the 1970s and early 1980s, indicate levels were relatively stable prior to 1985.

The April 1987 water level map shows some striking differences. There is a relatively large loss in water levels in the western upflow area and the highest levels occur in the area of injection.

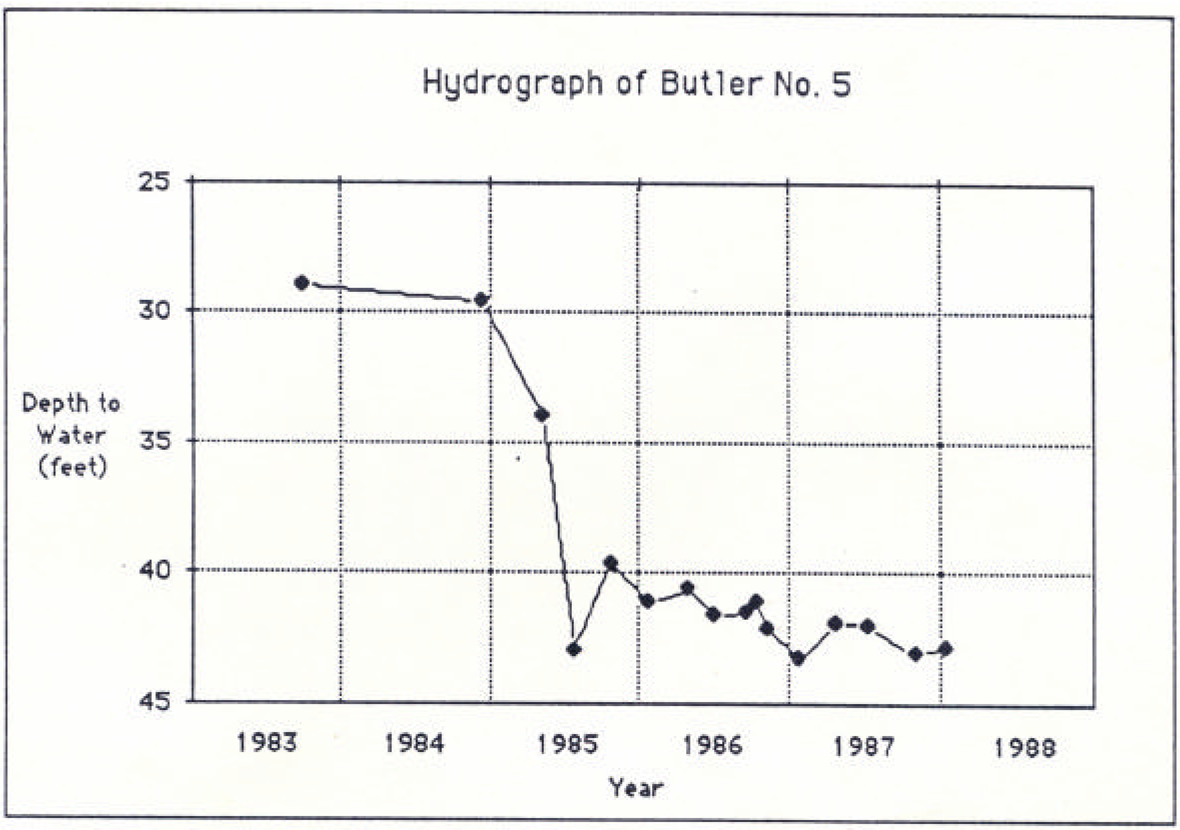

Figure 7. Typical water level trend in the area of water level declines.

Figure 7 is a hydrograph of the Butler No. 5 well located in the western area and approximately 350 ft from the major production well for Oregon Trail Mushrooms. The decline in water level is thought to be a direct result of pumpage and not depletion due to drought since water levels east of the fault have not changed.

Injection of low-temperature geothermal fluid is not required by Oregon law. There are two types of effluent disposal systems: standard and nonstandard. Standard effluent disposal systems are those in which the effluent is put to a secondary consumptive use or the effluent is injected to the same or compatible groundwater reservoir. Nonstandard effluent disposal systems are those in which the effluent is disposed of in a "wasteful" manner (such as drained into a storm sewer, drainage hole, or discharge to the land surface or water surface body), effluents contain added contaminants, injected into a non-compatible (differing chemical quality, temperature, hydraulic properties) groundwater reservoir. A standard system insures the highest water right protection and makes the most efficient use of the resource.

Oregon Trail Mushrooms is currently the only user in Vale that injects. The water is pumped from the upflow zone and injected into two wells in the outflow zone.

Spent geothermal water leaves the plant at about 200°F. An average of about 70 gpm is injected into OTM-3 located about 300 ft east of the hydrogeologic boundary, and the remainder, about 155 gpm, is injected into OTM-R3 about 650 ft northeast of OTM-3 and near the Malheur River. Injection pressure at OTM-R3 is 60 - 80 psi. Actual injection temperatures are not known.

There are several results that appear to be directly related to the pumping and injection at the Vale aquifer.

The lowering of the hydraulic gradient between the upflow zone and the river can be expected to lower flow velocities and reduce discharge from the springs. Reducing the gradient means longer travel time and more cooling by conduction. It also could change flow paths and move mixing zones closer to the upflow zone.

Hot springs discharge estimated during the course of the Oregon Water Resources Department (OWRD) study ranged from several liters per minute to none. Surface discharge temperatures in July 1987, were 120°F and probes inserted into sediment in the springs area recorded a maximum of 166.5°F. Published measured temperatures range from 198.5°F in 1903 to 207°F in 1980.

Local residents have reported temperature drops in three wells since 1985. The Humphrey rental house well drilled in 1985, had a discharge temperature of 170°F indicated on the well log. Maximum downhole temperature measured by OWRD range from 117°F in October 1986 to

94.3ºF in July 1987. This well is shallow and therefore subject to cool surface water intrusion. Ag-Dryers' well drilled in July 1981, had a discharge temperature of 215ºF indicated on the log. It produced 169ºF water in November 1987. Hawley Meat Packing reportedly drilled a new well because temperatures had dropped in their old well.

Temperatures appear to have dropped two to three degrees in the hot wells near the Oregon Trail Mushroom production wells. Figure 8 shows temperature profiles of Butler No. 4 taken in 1986, 1987 and 1988. Records from the mushroom plant indicate a similar drop may have occurred in their production well.

Temperature profiles of OTM-1 (Figure 9) in the outflow zone show the effects on the shallow lateral flow. Temperatures near this well have dropped 22 - 23ºF completely eliminating the "bump" in the earlier profiles.

Injection into OTM-R3 has also had effects. A well about 180 ft northeast and completed to essentially the same depth now has a wellhead pressure of 24 psi. There was no wellhead pressure prior to injection. During winter, steam can be observed rising from the river and river bank near OTM-R3 suggesting injected fluids may be migrating back toward the surface and entering the ground and/or surface water system.

Conclusions

Although most of the water pumped from the Vale Geothermal Aquifer is injected, there appears to be little benefit. The fluids are injected across a hydrogeologic boundary and appear to be adversely affecting the temperatures and water levels. To be effective in maintaining aquifer pressure, injection must be within hydrogeologic boundaries--but in this case, the area is so small and due to the fracture permeability nature of the resource with its high transmissivity, it may be difficult if not impossible to site an injection well which would not have excessive temperature breakthrough.

Since development of the area has occurred, natural discharge of the springs has decreased; but, discharge to the river through the stream bed has probably increased downstream due to injection wells. The net effect is a drop in discharge temperature, with the volume likely remaining relatively constant.

Increased pumping from either the upwelling or outflowing zone will likely result in lowering water levels. The maximum pumping the geothermal system could tolerate may be greater than current levels--however, if water levels are below river level, massive cold water intrusion may occur and if injection is across the boundary, flow may reverse across the boundary.

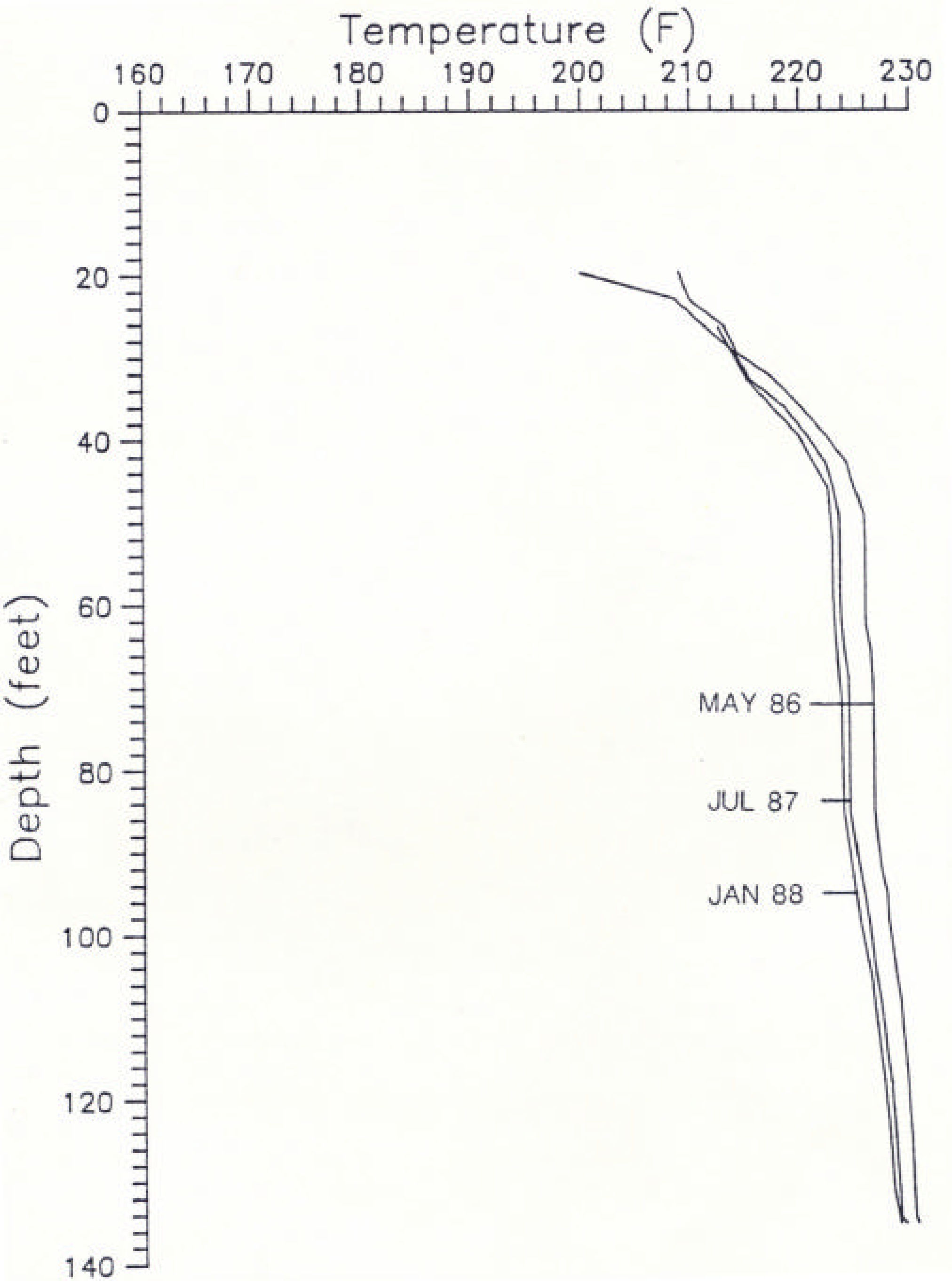

Figure 8. Temperature/depth profiles of Butler Well No. 4. This figure shows the apparent temperature drop in wells in the hot well area west of the fault.

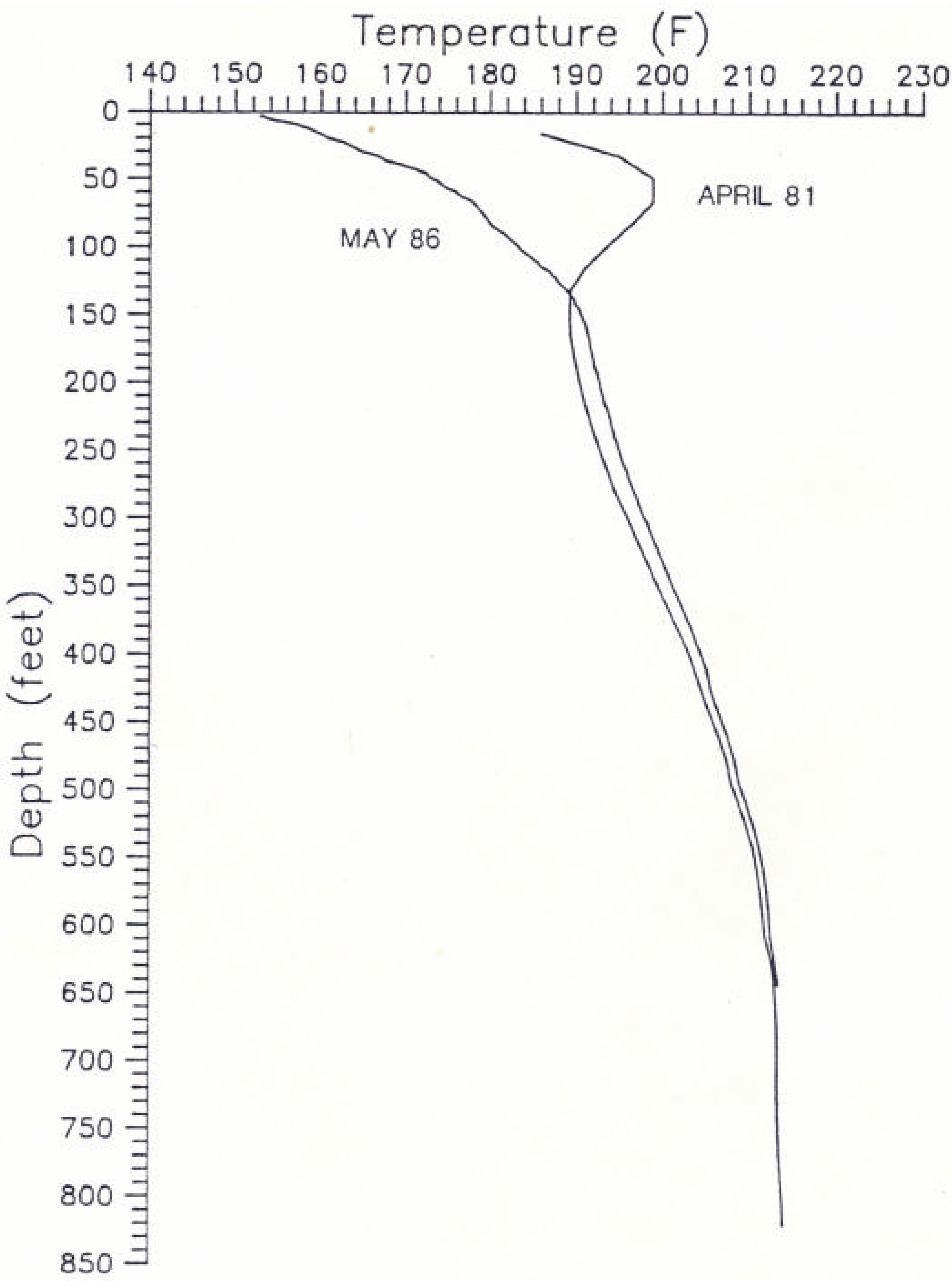

Figure 9. Temperature/depth profiles in Oregon Trail Mushroom Company Well Number 1. This figure shows the apparent drop in temperature of the shallow out-flow zone east of the fault.

Current disposal practice is not benefiting the resource. Withdrawal can be minimized by using the water more efficiently--cascading from one user to another. The proximity of users and nature of the uses should make this practical requiring only cooperation between users. This appears to be happening since the OWRD study was completed.

Careful planning, cooperation and monitoring of effects will probably permit increased utilization with minimal increased pumping. Careful location of injection wells and control of injection temperature and flows will help alleviate the situation.

Acknowledgement

Information for this paper was taken exclusively from "Hydrogeologic Assessment of the Developed Geothermal Aquifer Near Vale, Oregon, Open - File Report No. 88-04", State of Oregon Water Resources Department, by Marshall W. Gannett.

SUSANVILLE, CALIFORNIA

The city of Susanville is located in northeastern California near the intersection of three major physiographic provinces: the Modoc Plateau to the north, the Basin and Range to the east and southeast, and the Sierra Nevada to the south and west. The city is at the extreme west end of the Honey Lake Valley, a part of the Basin and Range, and is underlain by Warner Basalts. The Warner unit is a thick series of volcanic lava, mud and ash flows interbedded with lake sediments. The Susan River heads in the mountains to the west, flows through the city and into Honey Lake, a saline sink with no outlet. Salinity of the lake is 1200-1400 mg/l TDS. The Susan River varies from about 85 to 270 TDS (U.S. BuRec, 1982).

Although there were no known surface expressions of a geothermal resource, a few wells intersected warm water at 75 - 500 ft. Prior to 1976, there were six wells with temperatures of 120 -140^{o}F utilized for space heating, a swimming pool and greenhouses. In 1974, the Bureau of Reclamation initiated a study of the geothermal resource. Resource investigation continued and with assistance from various agencies including the Department of Interior, National Science Foundation, Energy Research and Development Administration, Department of Energy, Housing and Urban Development and California Energy Commission, ultimately a geothermal district heating system was constructed. The system currently provides a peak flow of about 500 gpm serving 77 facilities and has the potential to more than double in heat output utilizing the existing production wells.

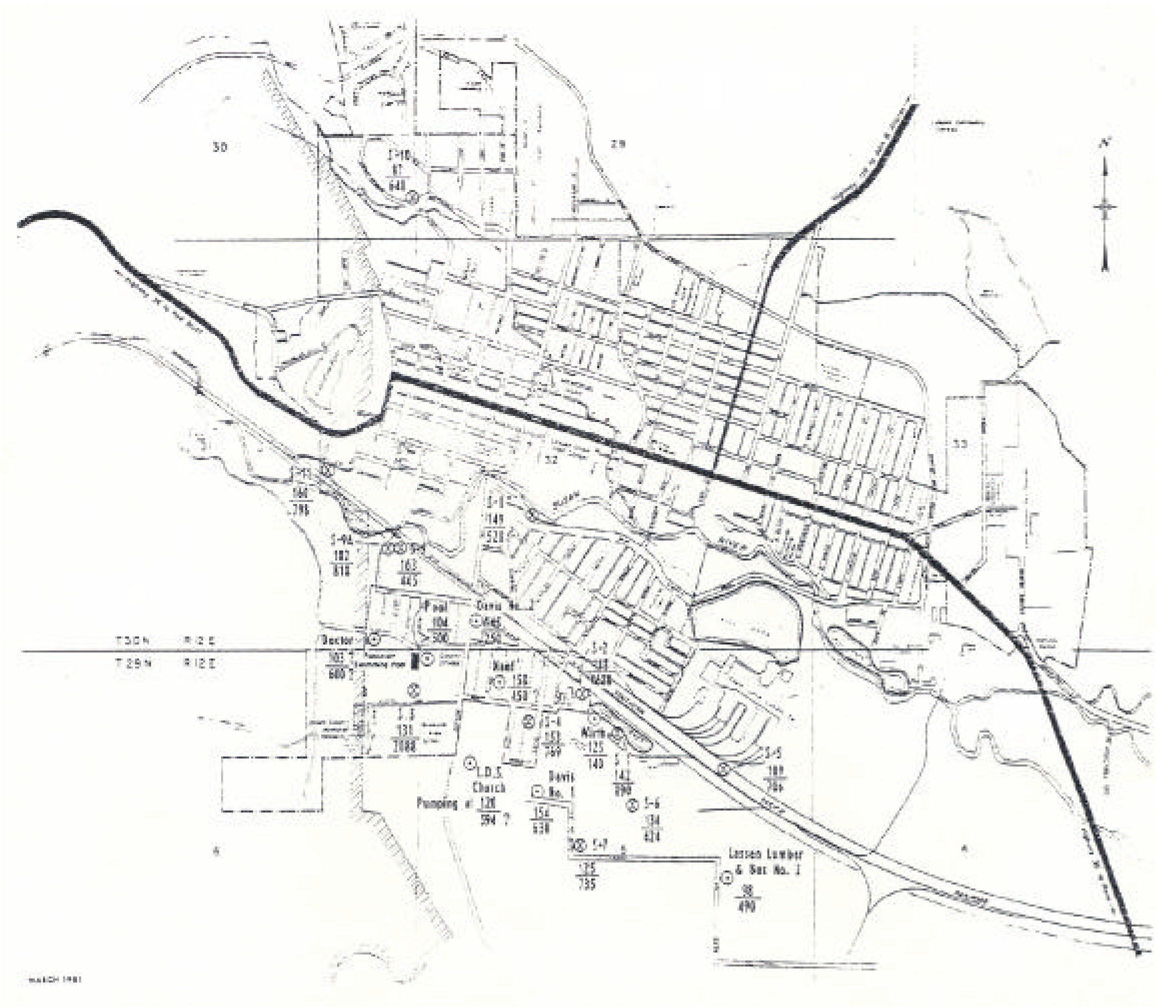

Figure 10. Location of warm wells and deep "Suzy" test holes - Susanville area.

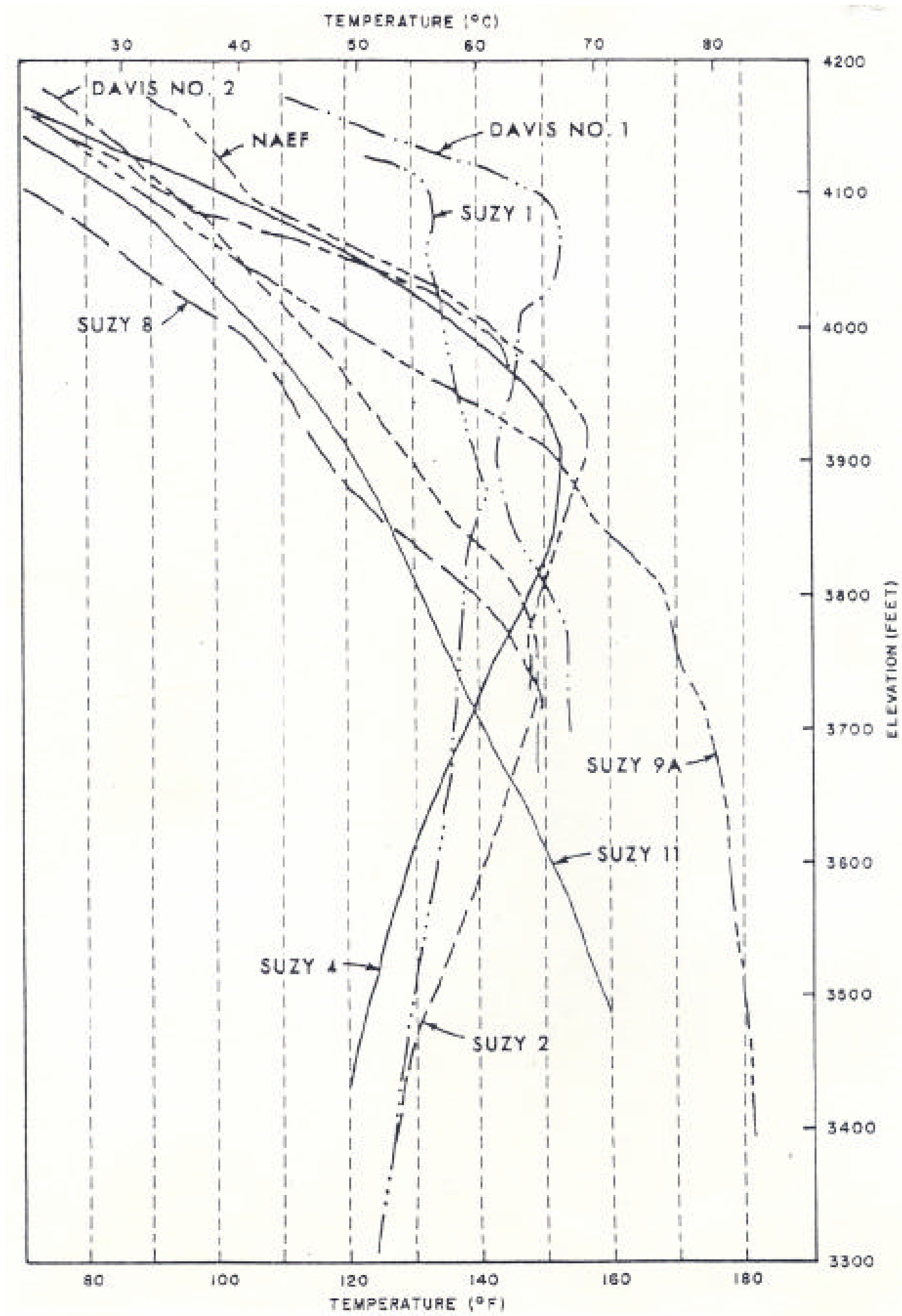

Figure 11. Temperature profiles of wells and test holes with temperatures over 130°F - Susanville Anomaly.

In 1977, the Bureau of Reclamation drilled 12 Suzy test holes ranging from about 400 to 2,088 ft deep (Figure 10). Based on well lithology and temperature profiles, it was determined that geothermal fluid at about 180ºF rises along a fault or faults at the west side of the city, encounters subsurface zones of fractured and scoriated volanics and less permeable sediments and flows south-east. As the geothermal fluid moves laterally, it cools by conduction and mixing, and probably ultimately becomes a part of the regional groundwater. The hottest well was Suzy 9A with 182ºF at 818 ft. Slickensides in cores from Suzy 9A and Suzy 11 give direct evidence of faults or shear zones at depth.

Temperature profile reversals (Figure 11) indicate the wells southeast of Suzy 9A completely penetrated the shallow geothermal aquifer. Temperature contours of various depths (Figures 12 through 15) indicate an elongate shallow resource area to the southeast with fairly rapid cooling to the far southeast and the southwest.

The temperature profile along line A-A' (Figure 16) also indicates upwelling near Suzy 9A, cooling to the northwest at Suzy 11 and rapid cooling to the southeast at Suzy 7. The higher temperature near the Davis No. 1 well implies upwelling along a fracture zone.

Aquifer tests by the Bureau of Reclamation and Lawrence Berkeley Laboratory show the producing aquifer is fracture dominated with high lateral permeability and low porosity. There is good communication between the hot wells, and poor communication between the hot wells and cooler wells. A recent pump test of a geothermal well drilled since the Bureau of Reclamation and LBL's work, Allen No. 2, indicated that injection there would result in upward leakage into an overlying alluvial aquifer providing domestic water supplies to residences (William E. Nork, Inc., 1989).

Table 1

	Chemical constituents (in mg/L)										
Well	Na	K	Mg	Ca	Cl	HCO_3	SO_4	SiO_2	B	TDS	T ºC
Roosevelt Pool	18	4	3	20	2	122	5	57	1	231	33
LDS Church	140	5	2	24	64	68	190	62	1.4	558	49
Davis #1	177	8	1	32	98	36	260	66	1.9	690	61
SUZY-9A	205	6	1	32	190	37	294	–	3.1	810	74

In general, water quality increases from Suzy 9A to the southeast (Table 1). Suzy 9A, the hottest well has a TDS of 810 mg/l, Roosevelt Pool near the western margin of the resource 231 mg/l and the LDS Church further southeast 558 mg/l. Somewhat anomalous is Davis No. 1 (now Tsuji No. 1) with 690 mg/l. This is another indication of upwelling along a fracture zone near that well. If a fracture exists there, it may be acting as a partial hydrogeologic boundary between the hotter area and Suzy 7 to the south in the cooler area. There is a direct correlation between pumped water temperatures and total dissolved solids.

Currently only limited injection is practiced in Susanville by the city district heating system; although, the city has made repeated attempts at injection. Tsuji Nurseries and the LDS Church's effluent is discharged into a drainage system that ultimately ends at the Susan River southeast of the city. The city has an injection well, Richardson 1, that accepts 150 gpm. The remainder, 50 - 300 gpm depending on heat load, is discharged into the same drainage system as the other two users. The city has a surface discharge permit issued by the Lahontan Regional Water Quality Control Board, which is up for renewal in November 1990. The permit requires expensive water chemistry monitoring of both effluent and receiving waters. So far as is known, the other two users have not been required to file for permits.

The city has made repeated attempts at injection (Figure 17). The original district piping design called for injection into an existing well known as the Park well in the north central part of the city. When injection was attempted, it was found the well annulus was improperly sealed permitting the effluent to reach land surface.

The second attempt resulted in siting and drilling a 1,200 ft well, Richardson 1, just north of the Susan River in 1982. This was only partially successful since the well will accept only 150 gpm at acceptable pressure.

The third attempt was to utilize one of the Suzy series wells, Suzy 6. Drilling records of Suzy 6 indicated lost circulation zones. The circulation loss and temperature of 134°F at 540 ft seemed to indicate the well had penetrated the geothermal aquifer. The well had been completed with 6-inch casing, gravel packed and perforated for use as an aquifer evaluation well. Test pumping of Suzy 6 in 1983, indicated the well would not accept the required amount of fluids. This was interpreted as being the result of packer failure during cementing resulting in plugging the aquifer with grout.

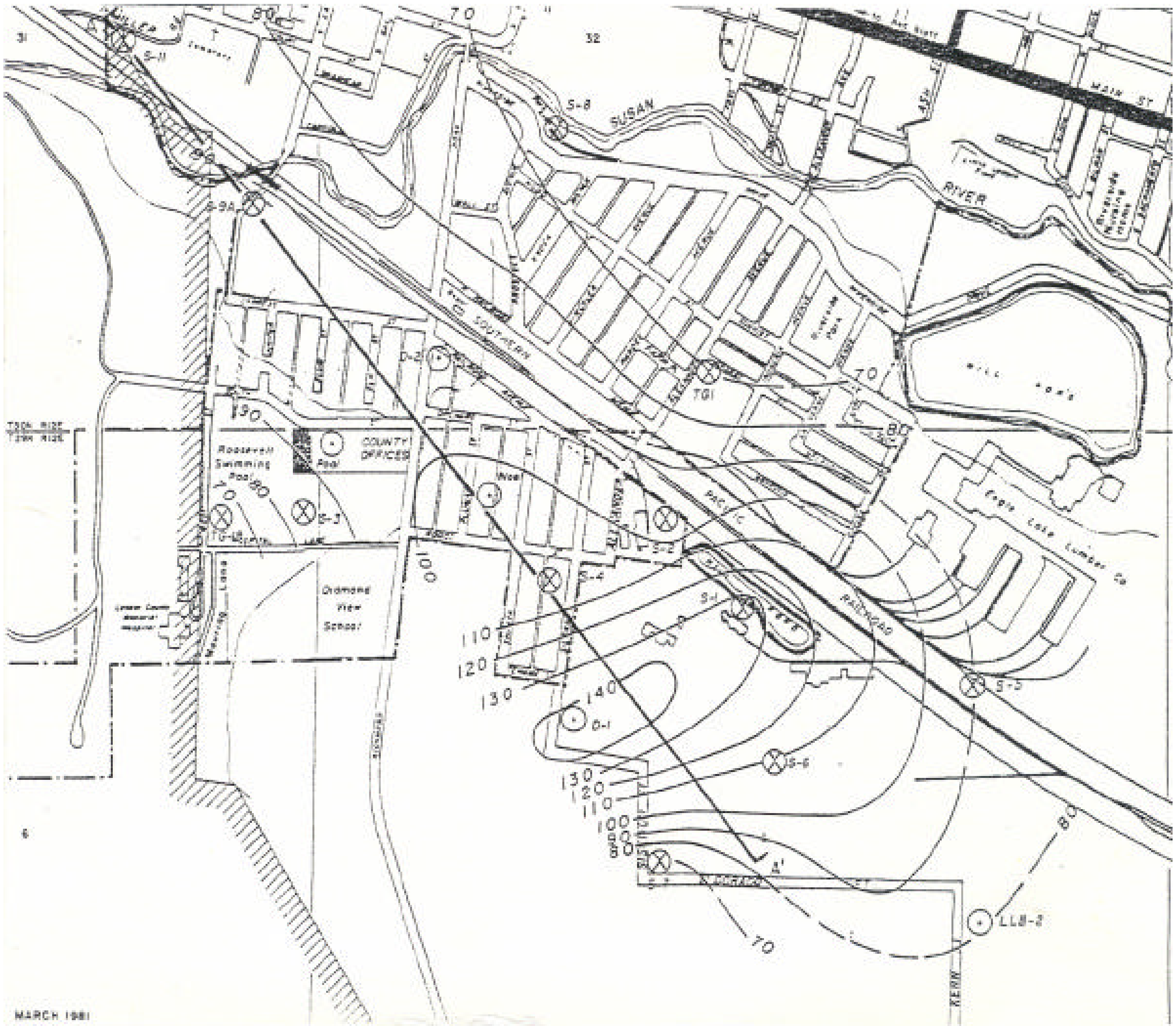

Figure 12. Temperature contours at 100 ft.

Figure 13. Temperature contours at 200 ft.

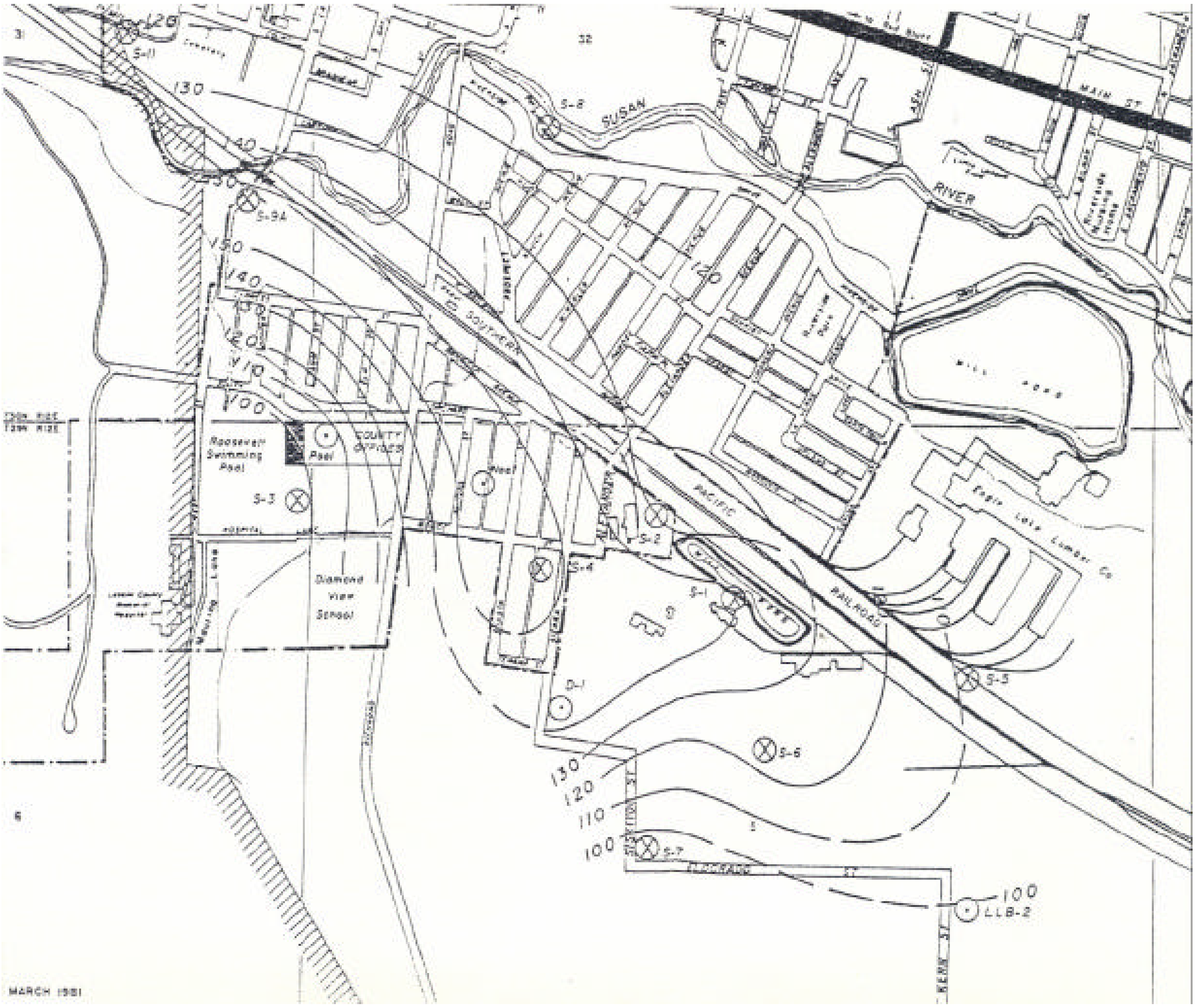

Figure 14. Temperature contours at 300 ft.

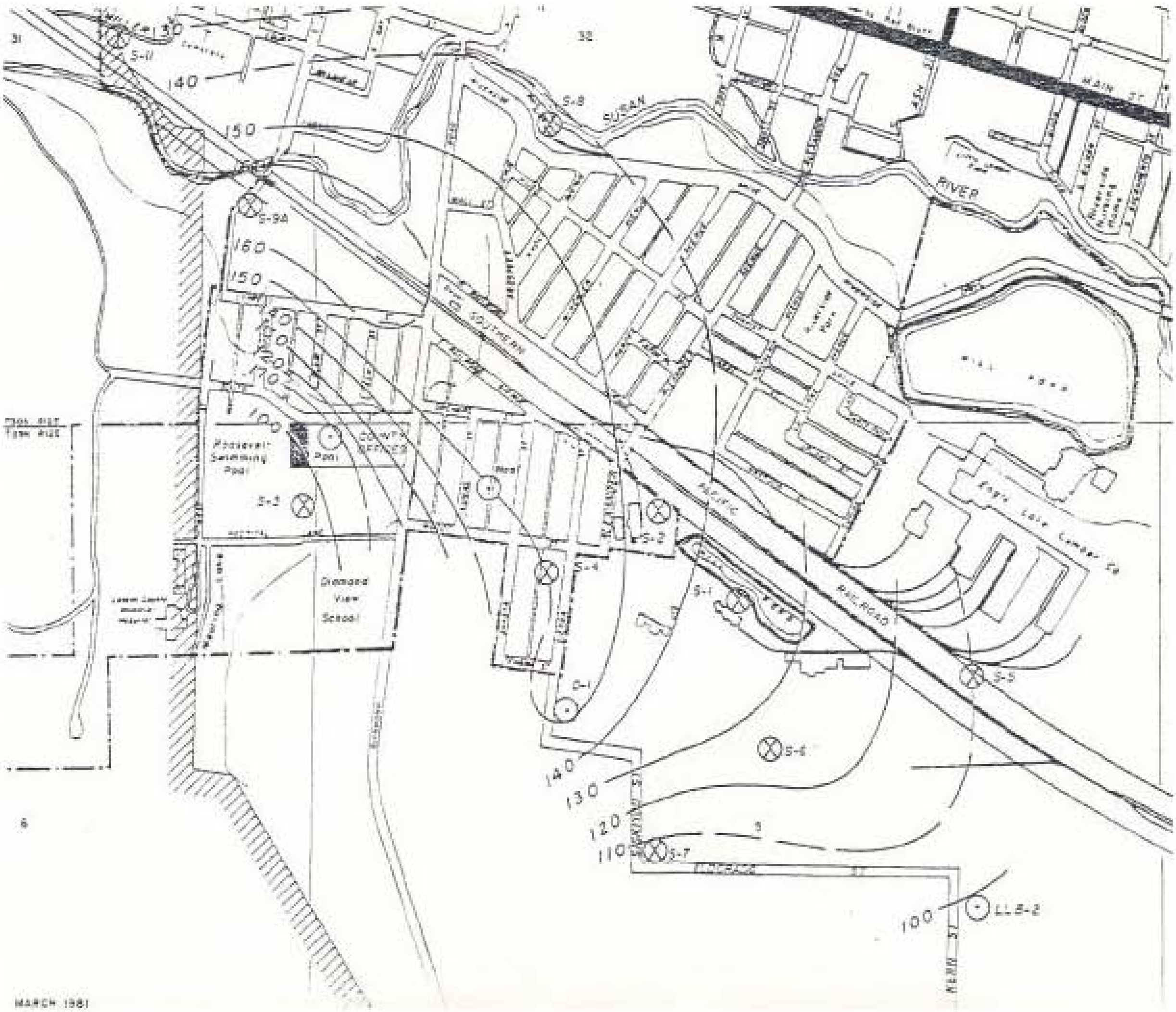

Figure 15. Temperature contours at 400 ft.

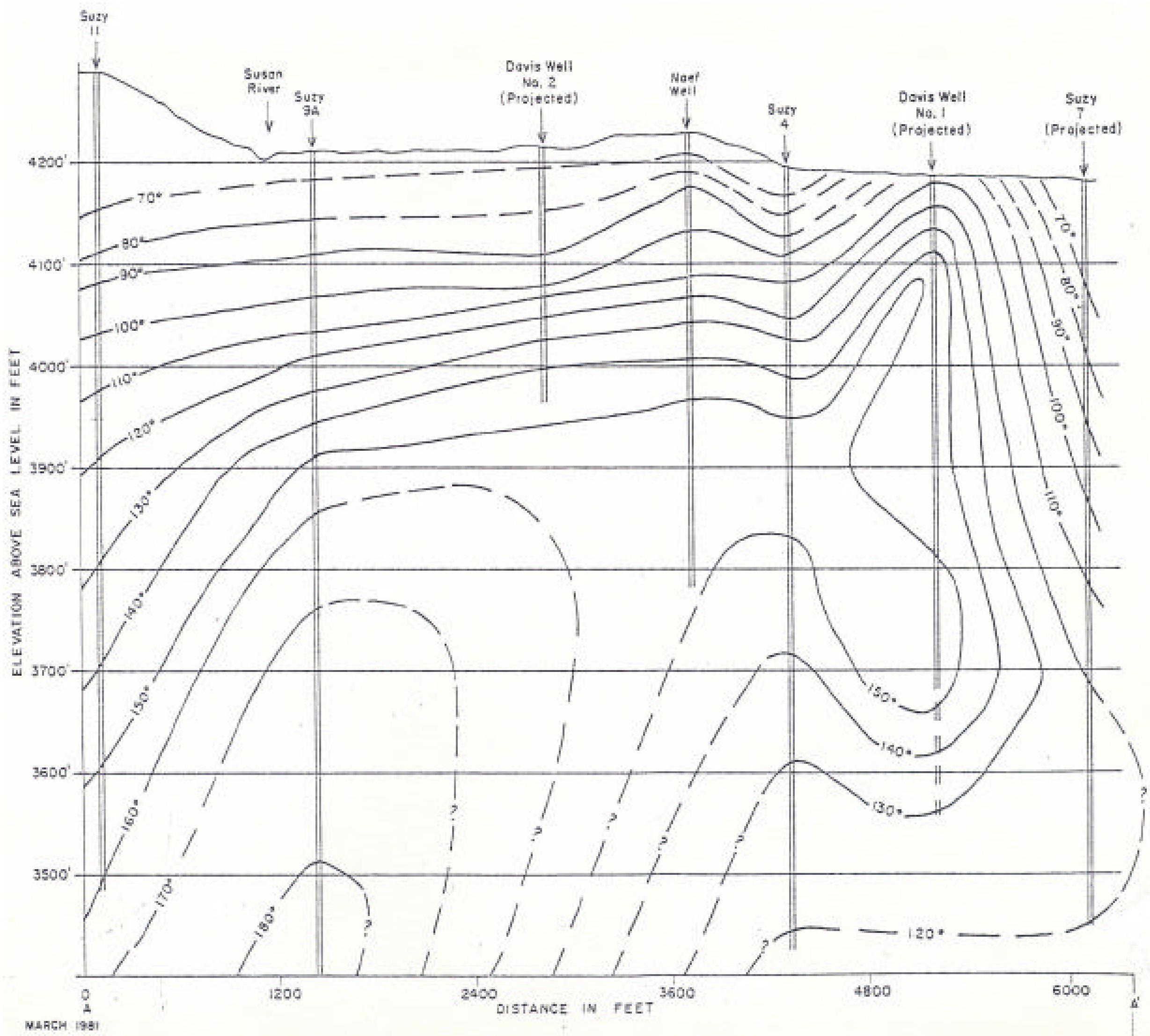

Figure 16. Subsurface temperature profile A-A'
Susanville Anomaly

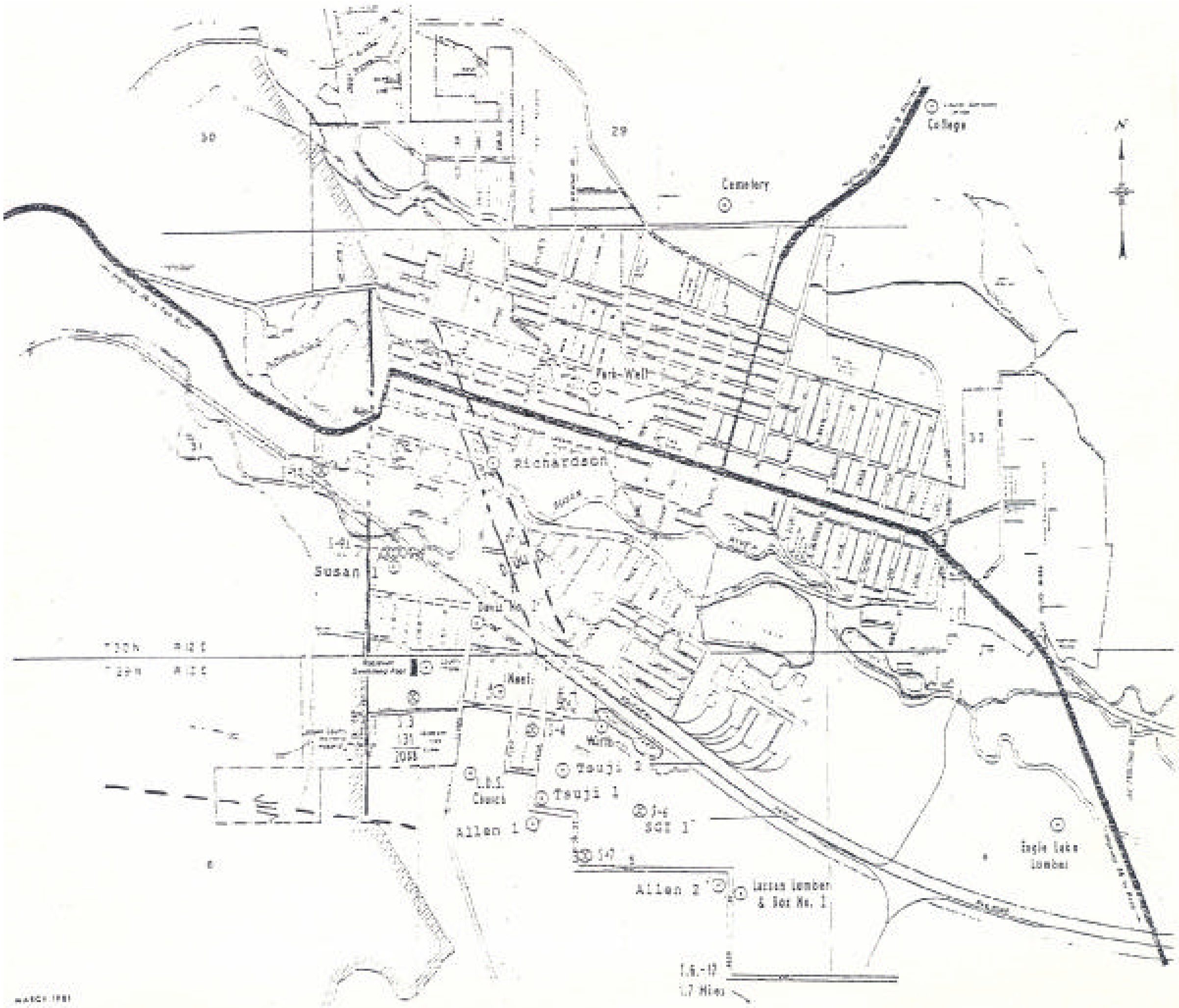

Figure 17. Location of wells and shallow test holes with temperature gradients - Susanville area.

In 1984, Richardson 1 was reevaluated by GeothermEx. This included running spinner tests to determine at what levels, and how much, fluid would be accepted. GeothermEx found Richardson 1 had a productivity and injectivity index of 0.85 gpm/ft--about 1/10 that of other thermal wells in the area (GeothermEx, 1984). One of the alternatives suggested was acid stimulation. This was initiated but abandoned before work started due to concerns over an accidental acid spill into the river.

Since the failure of Suzy 6 was thought to be due to plugging by grout, it was decided to drill another well nearby. The site was available and the district system outflow piping was nearby. The new well, SGI-1, was drilled to 650 ft in 1988; but, a bailer test produced only about 5 gpm. The lithology indicated the geologic formations here are not very permeable, somewhat discounting the grout plugging theory.

The latest effort was to investigate the possibility of injecting into a shallower and cooler portion of the reservoir thought to be at least partially confined by a series of lava flows. This was the test of the Allen No. 2 well reported above which indicated injectate may migrate to domestic water supplies.

Injection at Susanville is not required to maintain reservoir pressure--at least at current or foreseeable production rates. There has been no measurable decline in reservoir pressures or temperatures. The requirement is only to dispose of fluid that exceeds surface discharge standards for the Susan River. This has not made the problem easier to solve. Careful consideration of the data leads to the conclusion that it is probably impossible to solve--at least under existing conditions imposed by the Water Quality Control Board.

Conclusions

1. Geothermal fluids at about 180ºF and with 810 mg/l TDS rise along vertical or near vertical faults and/or fracture zones in a small highly transmissive area. These fluids are used to provide heat in surface geothermal district heating systems, and since flow through the systems is rapid, the fluids do not equilibrate to lower TDS at their system exit temperature.

2. Geothermal fluids which are not intercepted by wells and pumped enter subsurface permeable zones and flow laterally southeast cooling and mixing with meteoric water as they travel. Dilution and equilibration reduce the TDS during this journey and the fluids probably ultimately enter the regional groundwater reservoir.

3. Lahontan Regional Water Quality Control Board has stated (at least for other projects) that injection must be into a zone of equal or lesser quality groundwater.

4. Injection of geothermal fluids cooled by surface systems into or very near the upflow zones where their TDS equals the reservoir TDS is almost certain to cause drastic temperature reductions at the pumped wells rendering the district heating systems inoperable.

5. Injection at sites far enough from production wells to minimize thermal breakthrough is not allowable. By the time reservoir geothermal fluids have reached such sites, they have cooled, equilibrated and mixed, and TDS is reduced even though these fluids are derived from hotter higher TDS fluids.

The current requirements of the surface discharge permit to chemically analyze pumped and river water at semi-monthly and weekly periods respectively seems excessive. These analyses currently cost the city $8,000 per year. The natural geothermal system has been flowing probably for thousands of years with little or no change in temperature and chemistry. It is unlikely to change. Five years of data have been gathered on the river, above and below discharge. This should be sufficient for the project's future operation. The analyses requirement is perhaps counter productive since it diverts funds that could be used for further hydrogeologic work and, if a suitable site can be located, future injection well drilling.

Acknowledgement

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