GROUND WATER

OPEN-FILE REPORT

HYDROGEOLOGIC ASSESSMENT OF THE DEVELOPED GEOTHERMAL AQUIFER NEAR VALE, OREGON

OPEN-FILE REPORT NO. 88-04

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Abstract

Intense geothermal development has occurred near Vale, Oregon in a shallow hot aquifer underlying an area of about 40 acres. This aquifer appears to be the discharge area for hot, deep circulating regional ground water ascending from depth along a major fault zone.

The known hot aquifer discharges to the Malheur River primarily through hot springs with probable additional discharge through the stream bed below river level.

Current production has resulted in water level declines in part of the developed area. These declines have been accompanied by temperature drops in parts of the area. Some current users have been adversely affected by reduced temperatures.

Additional development of the known and developed hot aquifer will likely result in additional water level declines and temperature reductions. This could be detrimental to existing users.

Any additional development in the known and developed area must be accompanied by more efficient use of the resource and increased cooperation between the users. The area is small enough that some users could easily use discharge water from other users (cascading water use).

Current geothermal effluent injection practices do not appear to be benefiting the resource. If effluent is hot enough, it should be injected back into the same part of the system from which it was produced.

The area near Vale recognized by geologists as possibly having geothermal potential is at least ten miles long. However, there are no records of producing hot wells outside of the developed area. Although the potential for hot water production may exist outside the developed area, the location, depth, temperature, and production capabilities of the resource are unknown.

Introduction

There are a number of areas throughout Oregon, particularly in the eastern part of the state, where warm or hot ground water occurs in the shallow sub-surface. Such areas are usually typified by warm or hot springs. The majority of these areas are small and not developed. Some have been crudely excavated or otherwise slightly modified for bathing, while others have been developed by land owners for a variety of uses. Some of the larger thermal aquifers which are close to or within population centers have undergone private and commercial development. Such areas include Klamath Falls, Lakeview and Vale.

Regulation and management of geothermal water in Oregon comes under the jurisdiction of one of two agencies depending on the water temperature. Water above 250°F is classified as "Geothermal Resources" and is considered to be part of the surface estate of the property which it underlies and is managed by the Department of Geology and Mineral Industries in a manner similar to oil and gas. Water below 250°F is classified as "Low-Temperature Geothermal Resources" and is considered, like nonthermal ground water, to belong to the people of the State of Oregon. Low-temperature geothermal resources are managed by the Water Resources Department in a manner similar to nonthermal ground water, using the same statutes.

The Water Resources Department identifies and characterizes ground water resources in the state to aid in their protection and management. The Vale geothermal area was chosen for study in late 1984 because of it's small size and impending development.

Most of the information currently available on the Vale geothermal system consists of studies of the large area around Vale identified by geologists as having higher than normal heat flow. Higher than normal heat flow suggests the presence of a geothermal system at depth. Many reports and papers focus on evaluation of the deep system, which is still largely unknown and untested. Prior to this report, little has been published on the known and developed part of the geothermal system. Broad-scope studies are of limited value in resource management because they do not describe the nature of the known and developed hot aquifer, estimate how much water can be produced from it, or predict how will it respond to development.

Purpose and Scope

The purpose of this study is to evaluate the developed hot aquifer near Vale. The intent was to obtain sufficient understanding of the geology and hydrology of the area to provide an estimate of the maximum sustainable production and to aid in development of a management strategy.

This study included detailed water level measurements four times a year starting in 1894, continuous water level recording in one well, and temperature/depth logging of wells. The study also included evaluation of local geology, geothermal water chemistry, and several aquifer tests conducted by private consultants.

Acknowledgments

The author would like to express gratitude to the people whose cooperation and generosity aided this study. The geothermal users in Vale, particularly Paul Rutten and Jim Hammond of Oregon Trail Mushroom Company, Hugh Humphrey, Robert Butler and John Taburna all greatly helped this effort by allowing access to their wells and providing information on water use. Dr. David D. Blackwell of Southern Methodist University loaned us portable high-temperature logging equipment.

Geographic Description of the Vale Geothermal Area

The Vale geothermal area occurs east of the city of Vale, Oregon. Vale is a city of 1700 people about fifteen miles from the Oregon-Idaho Border and is the county seat of Malheur County (Figure 1). The shallow geothermal aquifer manifests itself as a group of hot springs which discharge into the Malheur River. Discharge temperatures as high as 194 to 198.5 degrees Fahrenheit have been reported (Russell, 1903; Bliss, 1983). Russell (1903) estimated a flow rate of 20 gallons per minute. No other flow rate estimates appear in the literature. Hot spring discharge rates observed during the coarse of this investigation varied from a few liters per minute to none. However, significant discharge below river level is indicated by bubbling and upwelling in the river, areas where the river does not normally freeze in the winter, and areas where steam rises from the bank.

Although the hot springs occur only in a very small area, the area of hot wells includes at least 40 acres between Rhinehart Buttes and the Malheur River (Figure 2). There are no records of producing hot wells with temperatures at or near boiling in the Vale vicinity outside this 40 acre area; however, there are wells as warm as 100°F as far as one mile away. The area of warm and hot wells seems to be restricted to the northern part of Rhinehart Buttes. However, geophysical data suggest geothermal activity may be occurring at depth over a much larger area.

History of Development

The thermal water at vale has probably been utilized by man for as long as the area has been inhabited. Russell (1903) refers to a 140 foot well drilled near the hot springs. Around 1910 a sanatorium and swimming pool (a natatorium referred to locally as "The Nat") were constructed. In the mid 1940s a slaughterhouse was built which utilizes the geothermal water. In the mid 1950s, a geothermal greenhouse operation known as Vale Floral was started. In the 1950s a number of homes were built in the geothermal area which use geothermal water for domestic hot water and space heating. In the late

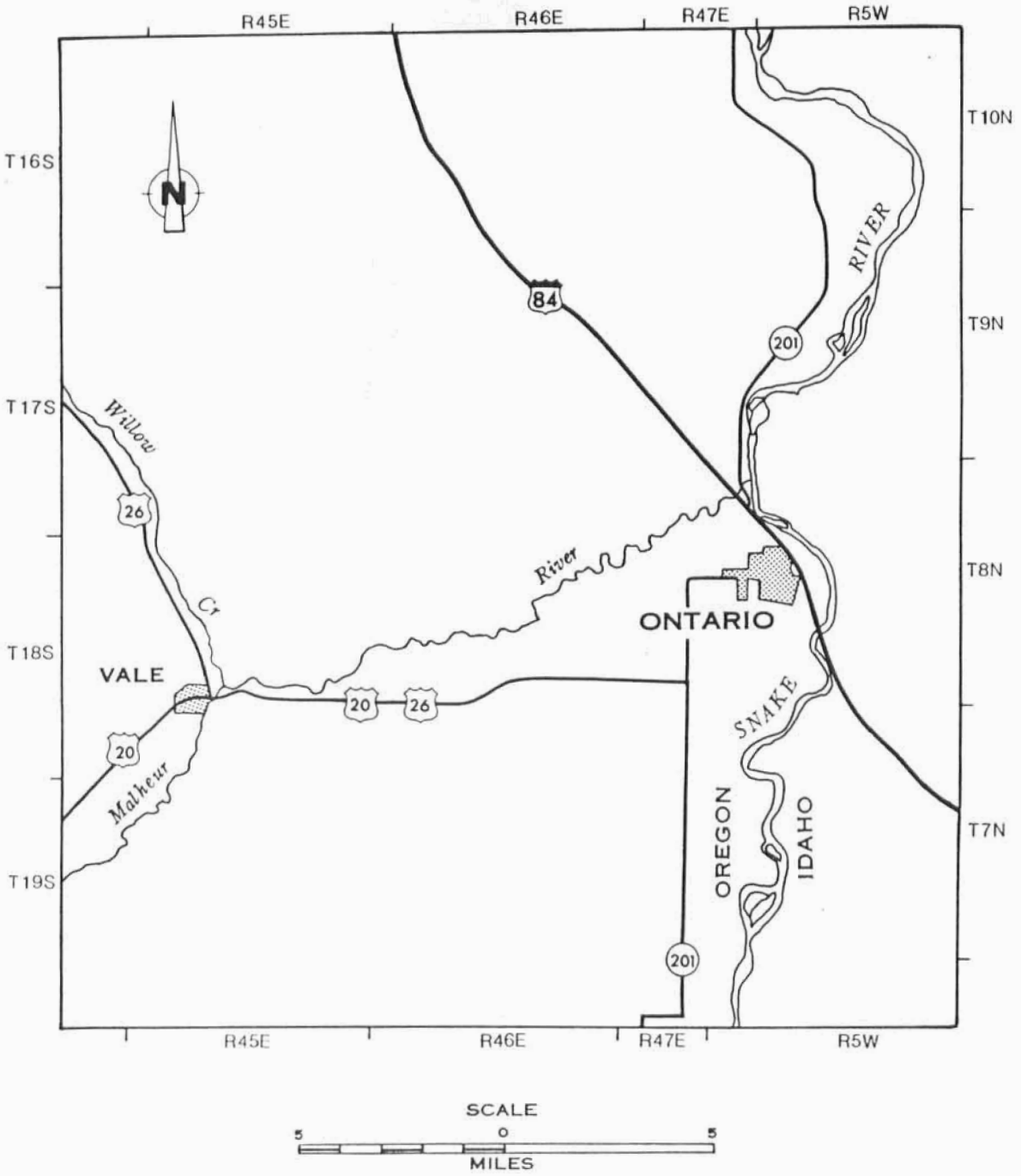


Figure 1. LOCATION OF THE VALE AREA

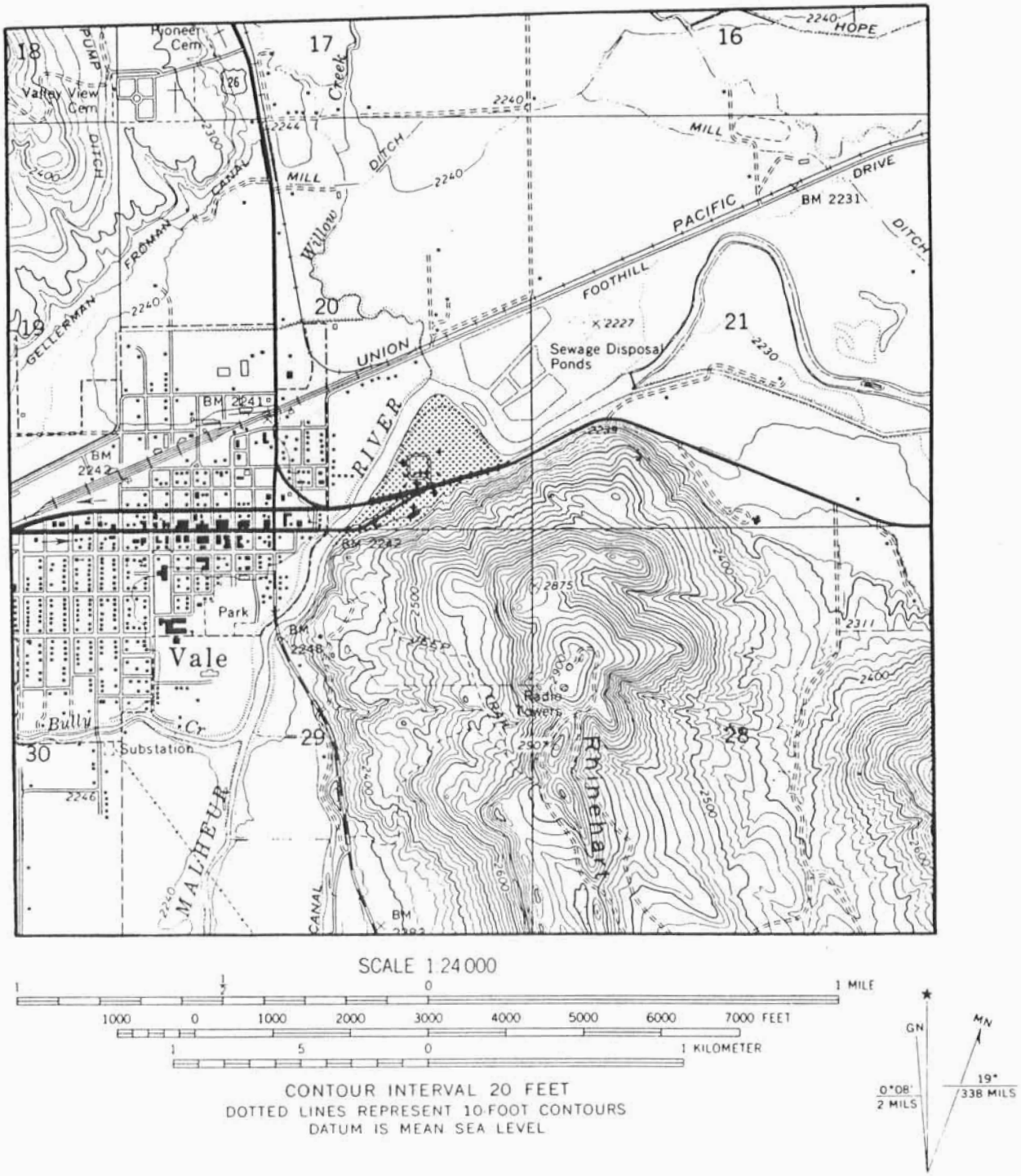


Figure 2. LOCATION OF THE DEVELOPED GEOTHERMAL AREA (Shaded)

1950s the sanatorium ceased operation and in the early 1960s The Nat closed permanently. The sanatorium was destroyed by fire in 1973. In the early 1980s, there was renewed development in the geothermal area including construction of a geothermal grain dryer, and new geothermal green houses. In 1984 a 180,000 square foot mushroom growing plant which uses geothermal water for heating and cooling started operation on the site where the Vale Floral greenhouses once stood.

The current geothermal users in the area include the Oregon Trail Mushroom Company, Ag-Dryers (the grain drying facility), Hawley Meat Packing (slaughterhouse), a greenhouse operation, and several homes.

Well Numbering System

Because of the small size of the study area, the traditional well numbering system based on forty acre tracts was not used in this study. Instead, the wells were identified by a combination of letters and numbers reflecting the well owner or operator's initials and their numbers for the wells. Although an attempt was made to conform to the well owners numbering system, there is not 100 percent agreement. Figure 3 is a map showing the locations of wells used in this study and their assigned numbers. Table 1 is a list of information related to these wells.

Regional Geology

Early geologic observations and interpretations of the region are provided by Russell (1902, 1903), and Washburn (1909). Bryan (1929) in work related to the Owyhee Irrigation Project, provided the earliest detailed mapping of the main geologic units in the region. Kirkham (1931) presented a thorough summary of earlier work, and proposed definitions of the Payette and Idaho Formations based on stratigraphic and paleontological evidence primarily from western Idaho. Corcoran and others (1962) mapped the Mitchell Butte 30 minute quadrangle. They identified a number of additional formations within Kirkham's Payette and Idaho Formations. Kittleman and others (1965, 1967) further clarified the stratigraphy and greatly expanded the area of mapping. Brown and others (1980) present a compilation of earlier works in a report on the geothermal resource potential of the western Snake River Plain in Oregon. Brown (1982) authored a geologic map of the Vale East 1:24,000 quadrangle which presents the first published detailed geologic mapping in the Vale area.

The Vale geothermal area lies in the geologic province known as the Owyhee Uplands (Baldwin, 1981). The region is characterized by several thousand feet of volcanic and volcanic sedimentary material ranging in age from late Miocene to Pleistocene.

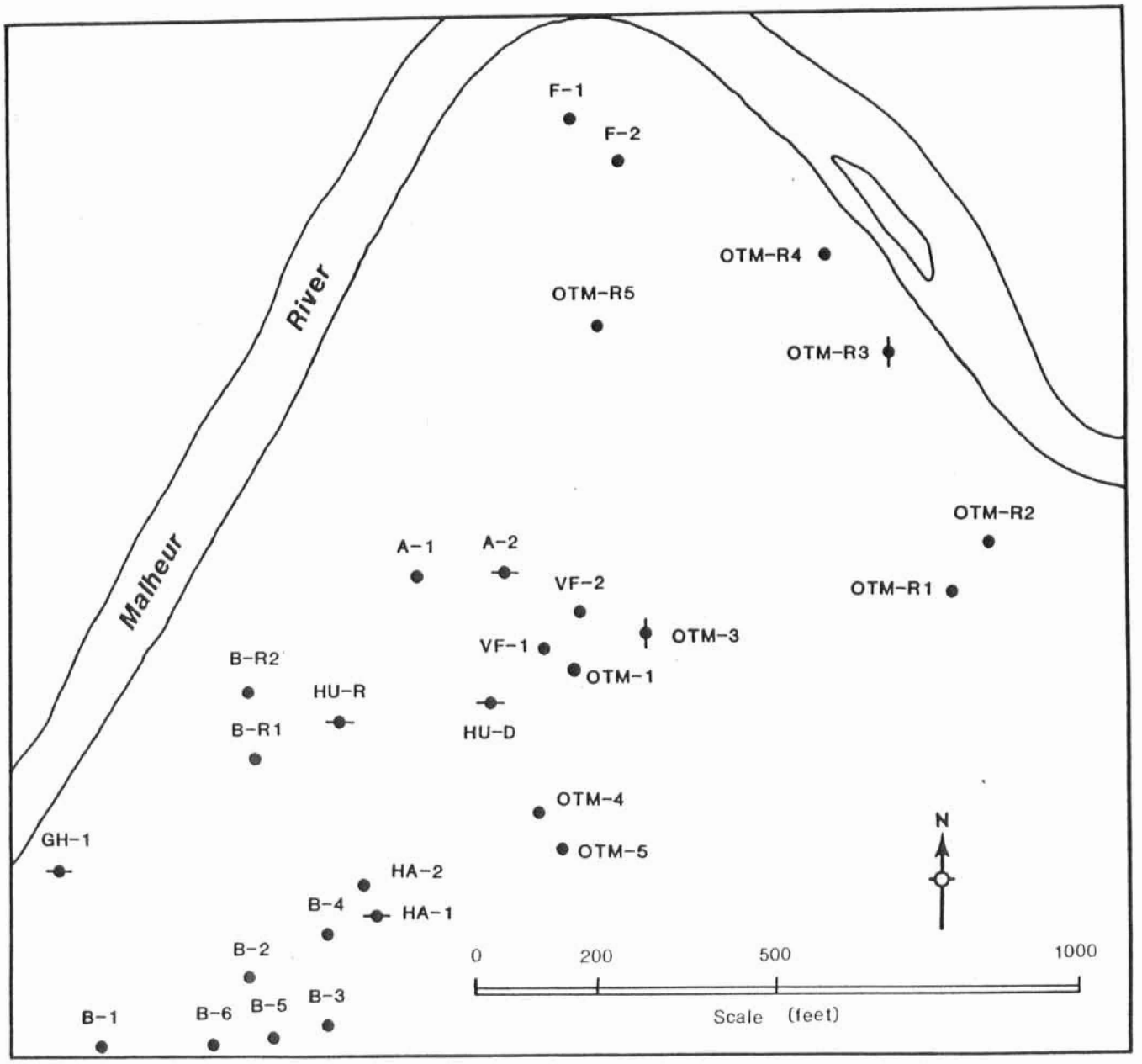


Figure 3. LOCATION AND NUMBERS OF THE WELLS USED IN THIS STUDY. Wells with horizontal lines are active production wells, wells with vertical lines are active injection wells.

Table 1. INFORMATION ON SELECTED WELLS IN THE VALE GEOTHERMAL AREA

Well Number	Owner	Depth	Production Temp. (°F)	Yield (gpm)	Max. Down Hole Temp °F*
A-1	Anthony	680	200	15	213
A-2	Anthony	30	110	24	-
B-1	Butler	?	220	200	215
B-2	Butler**	140	200-210	125-200	229
B-3	Butler	170	200	200	230
B-4	Butler**	140	200-210	125-200	229
B-5	Butler	140	?	80	227
B-6	Butler	?	?	?	223
B-R1	Butler	100	112	30	187
B-R2	Butler	100	120	20	148
F-1	Fuhriman	24	54	12	-
F-2	Fuhriman	106	67	24	-
GH-1	Butler (?)	?	?	?	-
HA-1	Hammond	125	225	550	-
HA-2	Hammond	120	220	640	-
HU-D	Ag-Dryers	140	215	100	183
HU-R	Humphrey	23	170	25	-
OTM-1	Oregon Trail	850	210	9	213
OTM-2	Oregon Trail	600	180	250(?)	189
OTM-3	Oregon Trail	50	184	250	-
OTM-4	DeLong	80	215	300	198
OTM-5	DeLong	250	220	250	211
OTM-R1	Oregon Trail	200	80	60	-
OTM-R2	Oregon Trail	200	78	45	-
OTM-R3	Oregon Trail	220	?	?	-
OTM-R4	Oregon Trail	355	?	?	-
OTM-R5	Oregon Trail	210	?	60	-
VF-1	Oregon Trail	50	192	80	170
VF-2	Oregon Trail	27	?	20	168

* Maximum down-hole temperatures measured by OWRD

** Unclear which log goes with which well

The geologic units in the region include great thicknesses of basalt, rhyolite, ash flow tuff, air-fall volcaniclastic deposits, and a wide variety of water-lain volcanic-derived sediments.

Bedrock in the vicinity around Vale is composed primarily of tuffaceous siltstone with lesser sandstone and conglomerate. A drill hole east of Rhinehart Buttes penetrated basalt at a depth of about 660 feet (Brown, 1982). Drillers logs in the developed area indicate basalt interbedded with sediments below about 540 feet. For a detailed discussion of the regional geology of the Vale area see Kittleman and others (1965), Corcoran and others (1962), and Brown (1982)

The area around Vale is transected by large scale north-northwest trending normal faults. This fault pattern is reflected in the surface geology and topography. Contour maps presented by Brown and others (1980) of gravity and aeromagnetic data from Couch and Baker (1977), Lillie (1977) and Couch (1978) also show a general north-northwest structural pattern. Bowen and Blackwell (1975) identify a major north-northwest trending fault which passes through the vicinity of Rhinehart Buttes and continues up the valley of Willow Creek. They named this the Willow Creek Fault. Detailed mapping (Brown 1982) reveals that the Willow Creek Fault in the vicinity of Vale actually comprises a number of parallel faults. It is therefore referred to as the Willow Creek Fault Zone in this report.

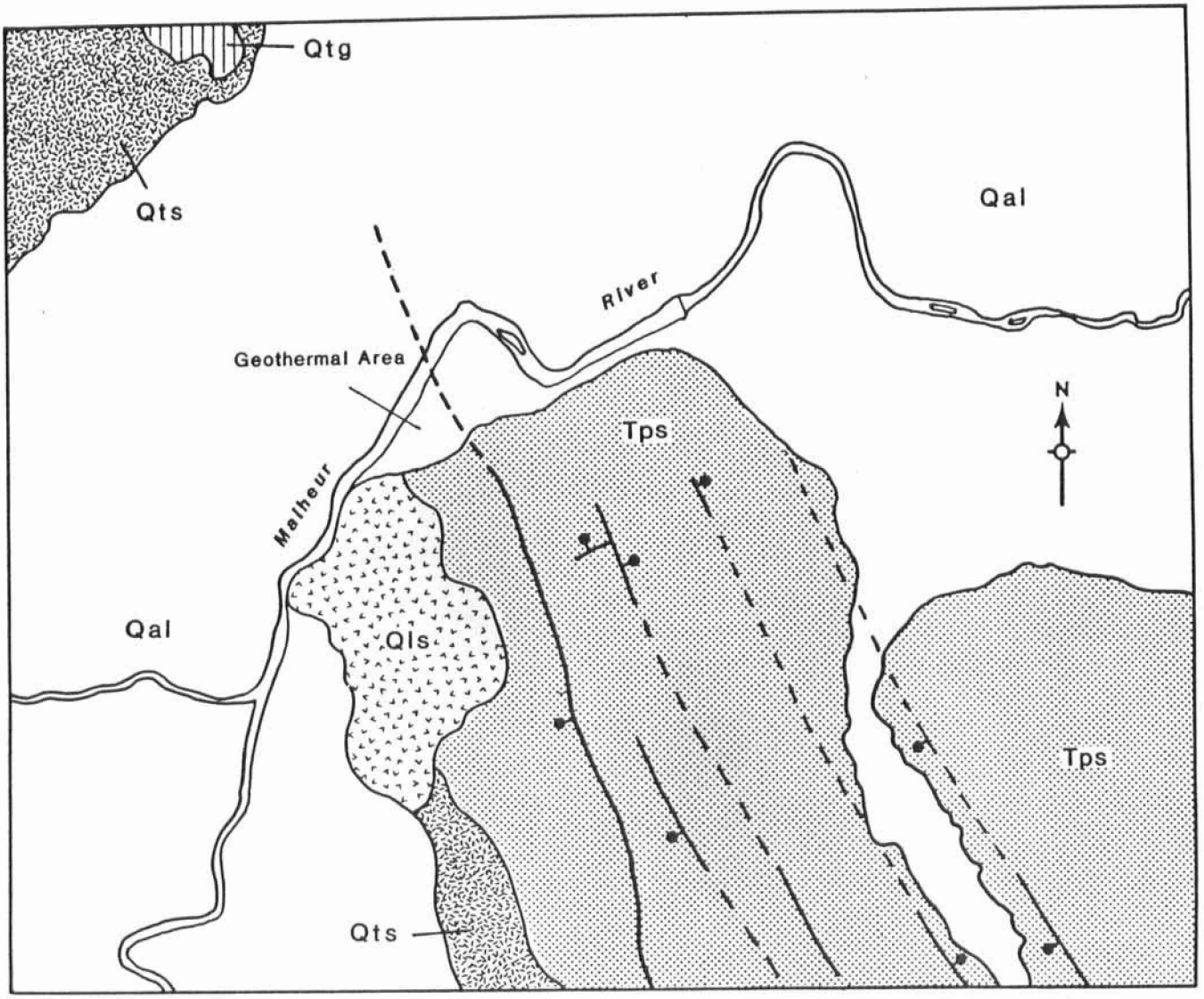
Geology of the Vale Geothermal Area

The following discussion of the detailed geology is limited to the northern part of Rhinehart Buttes, and is based on field observations by the author and on published mapping.

The northern part of Rhinehart Buttes consists primarily of fine grained tuffaceous siltstones with interbedded sandstone and pebble conglomerate (Figure 4). The sandstone and conglomerate appear to be more abundant toward the top of the buttes, though well logs indicate these rock types also occur below the base of the buttes. The northern part of Rhinehart Buttes is broken up by numerous faults, making detailed stratigraphic analysis extremely difficult and beyond the scope of this study. A large landslide occurs on the western side of the buttes near the geothermal area.

The sandstone and conglomerate on Rhinehart Buttes are completely silicified (all the open spaces have been in-filled and some minerals replaced with silica). In many places, the finer grained siltstone is also totally silicified where it is adjacent to the sandstone and conglomerate. This silicification took place prior to formation of the current landscape, and is thought to be the result of an earlier (fossil) hydrothermal system. (Bowen and Blackwell, 1975).

The sandstone and conglomerate were probably permeable when deposited, allowing for the movement of mineralized fluid through them. On the other hand, the fine grained



EXPLANATION

Qal	Recent alluvium and sedimentary deposits	Qts	Pliocene to Pliestocene, unconsolidated, poorly graded tuffaceous mudstones, siltstones, sandstones and volcanic conglomerates
Qls	Landslide deposits	Tps	Pliocene, well lithified to friable, thin to massively bedded, poorly graded tuffaceous siltstones, sandstones and conglomerates
Qtg	Pleistocene terrace gravels		Major fault. Dashed where covered or inferred. Dot on downthrown side

Figure 4. GEOLOGIC MAP OF THE VALE AREA.
Modified from Brown (1982)

siltstones were probably relatively impermeable, which precluded the movement of mineralized fluids. Mineralized fluids moving through the permeable sediments probably deposited the large amount of silica observed today. Eventually, silica deposition may have become so extensive that the open spaces became completely filled and most, if not all, of the original permeability of the rock was destroyed. The relatively impermeable siltstones are generally not silicified, except where in close proximity to the coarser sediments. Some amount of mineralized fluid may have diffused outward into the siltstone from the permeable coarser sediment.

Much of the silicification probably took place prior the faulting that is responsible for the current landscape. The silicified sandstone and conglomerate are extremely hard and brittle. As the area has been faulted and stressed, the silicified sediments have been broken and fractured and these open fractures have reestablished permeability. The non-silicified siltstones, on the other hand, are not competent enough to support open fractures and remain relatively impermeable.

The interconnected open fractures in the silicified sandstone and conglomerate provide an avenue for the movement of ground water and thermal fluids. This secondary fracture permeability adjacent to the fault zone is probably the main conduit for the current geothermal system. The producing zones in many of the geothermal wells in the Vale geothermal aquifer are described as "fractured sandstone" or "fractured claystone" on the drillers logs. Fractured silicified sediment in fault zones observed in outcrop on Rhinehart Butts have a large amount of secondary calcite precipitated in the open spaces, suggesting movement of geothermal fluids. Geothermal fluids from the hot well area have precipitated calcite where boiling has occurred at the surface.

The Willow Creek Fault zone cuts Rhinehart Buttes. One fault appears to cut the developed geothermal area. This fault is exposed in bedrock on Rhinehart Buttes, but cannot be seen in areas where bedrock is covered by soil or erosional debris. If the observed trend of this fault is projected northward, it cuts the developed geothermal area.

There are no areas of extensive hydrothermal deposits, such as travertine, which can be attributed to the current hot springs, presumably because they discharge mostly into the river. A large amount of calcite deposited in and around the well and cooling tanks at the old swimming pool apparently resulted from boiling at the surface.

Heat Flow and Geothermal Systems

To explain the geology and hydrology of the Vale geothermal system, a brief discussion of heat flow is necessary. The surface of the earth is radiating heat everywhere. It is a continual process in which the planet is losing it's internal heat to space. The flux of heat being lost from the earth at the surface is called the "heat flow." The temperature of the earth increases with depth. The increase in temperature with depth is called the "geothermal temperature gradient" or "geothermal gradient." Heat

energy moves in response to the geothermal gradient just as water moves in response to a pressure gradient. The heat flow of an area can be determined by measuring the geothermal gradient in drill holes. The higher the geothermal gradient, the higher the heat flow. Areas of geothermal activity have elevated heat flow. This high heat flow is in some cases due to the presence of hot or molten rock at shallow depths, as in areas of recent volcanic activity. In areas where there is no recent volcanic activity, such as Vale, high heat flow is generally thought to result from hot water upwelling from relatively great depths (thousands or tens of thousands of feet).

There is a large area of anomalously high heat flow associated with the Vale geothermal area (Bowen and Blackwell, 1975; Blackwell and others, 1978). The area of anomalous heat flow is about ten miles long and 2 miles wide. Heat flow in the anomaly is at least three times that of the surrounding area. The heat flow anomaly coincides with the Willow Creek fault zone and includes the developed geothermal area (Figure 5).

The association of the heat flow anomaly with the Willow Creek Fault Zone suggests a connection. Blackwell and others (1978) state that the geothermal activity is probably due to the presence of the fault. The association of geothermal systems and major faults is very common in the Basin and Range Province of Oregon and Nevada, where geothermal systems are commonly associated with range front faults.

The role of the fault zones is generally thought to be two-fold. Faults often juxtapose rocks of different hydrologic characteristics, impeding lateral flow of ground water across the fault. The fault zones themselves often consist of highly fractured or crushed rock which may be quite porous and permeable. Therefore fault zones may not only impede continued lateral movement of ground water, but they may also provide an avenue for that water to rapidly flow vertically toward the surface under normal artesian pressure (Figure 6). If the ground water is diverted from a great depth (on the order of several thousand or tens of thousands of feet) where the temperature of the earth is high, a geothermal system will occur. This is probably the case with the Vale geothermal system.

Regional ground water flow in the Vale area is generally to the east-northeast, roughly paralleling the flow of the Malheur River toward the Snake River. The Willow Creek fault zone runs perpendicular to this flow direction. It is probable that eastward flowing deep regional ground water is diverted upward to relatively shallow depths by the Willow Creek fault zone. This upward flow must occur fast enough such that the water does not have a chance to cool. At the surface, the occurrence of hot springs is controlled by the location and nature of permeable materials in the shallow sub-surface.

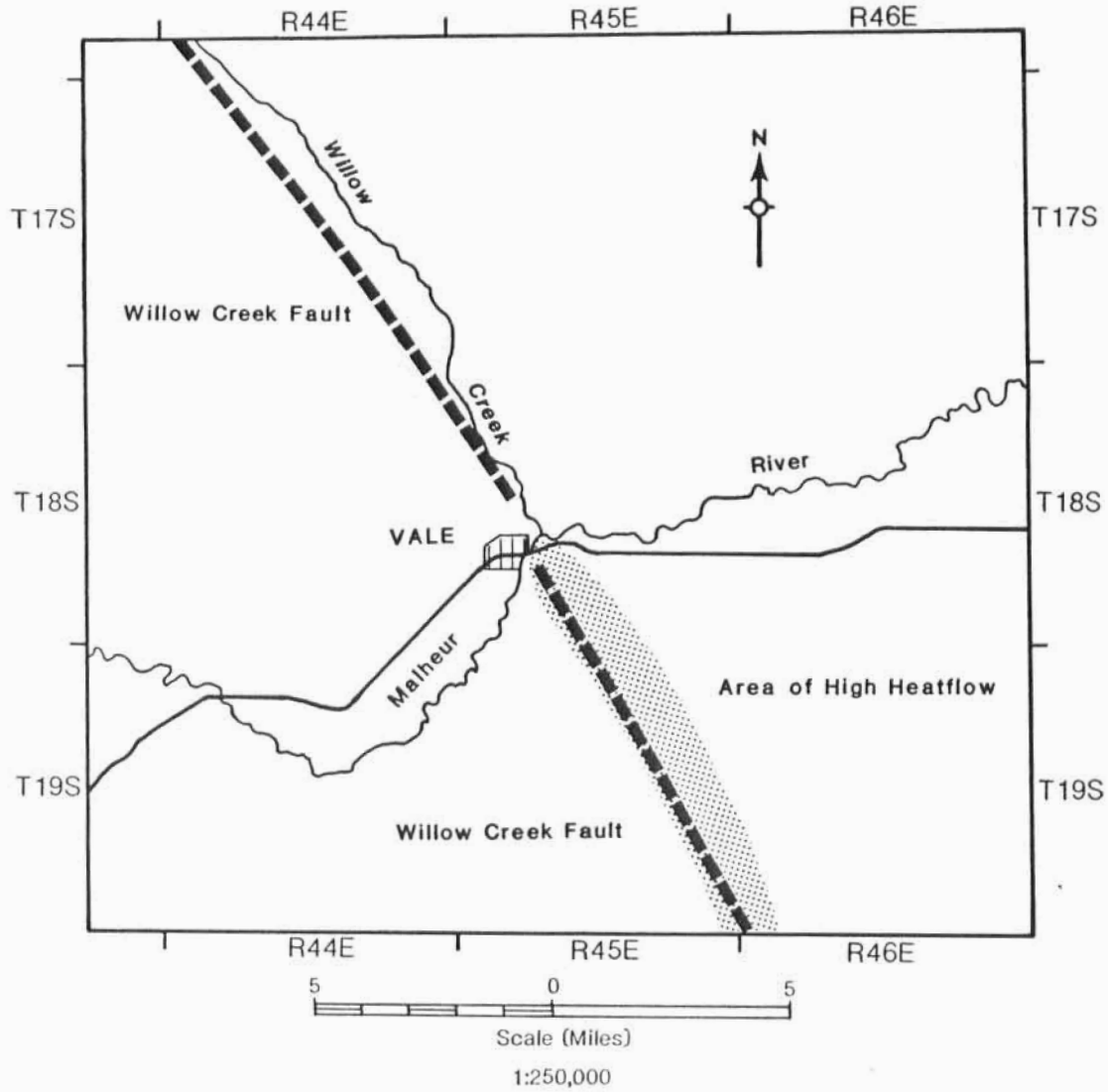


Figure 5. LOCATION OF THE WILLOW CREEK FAULT ZONE AND THE AREA OF ANOMALOUS HEAT FLOW. From Bowen and Blackwell (1975) and Blackwell and others (1978).

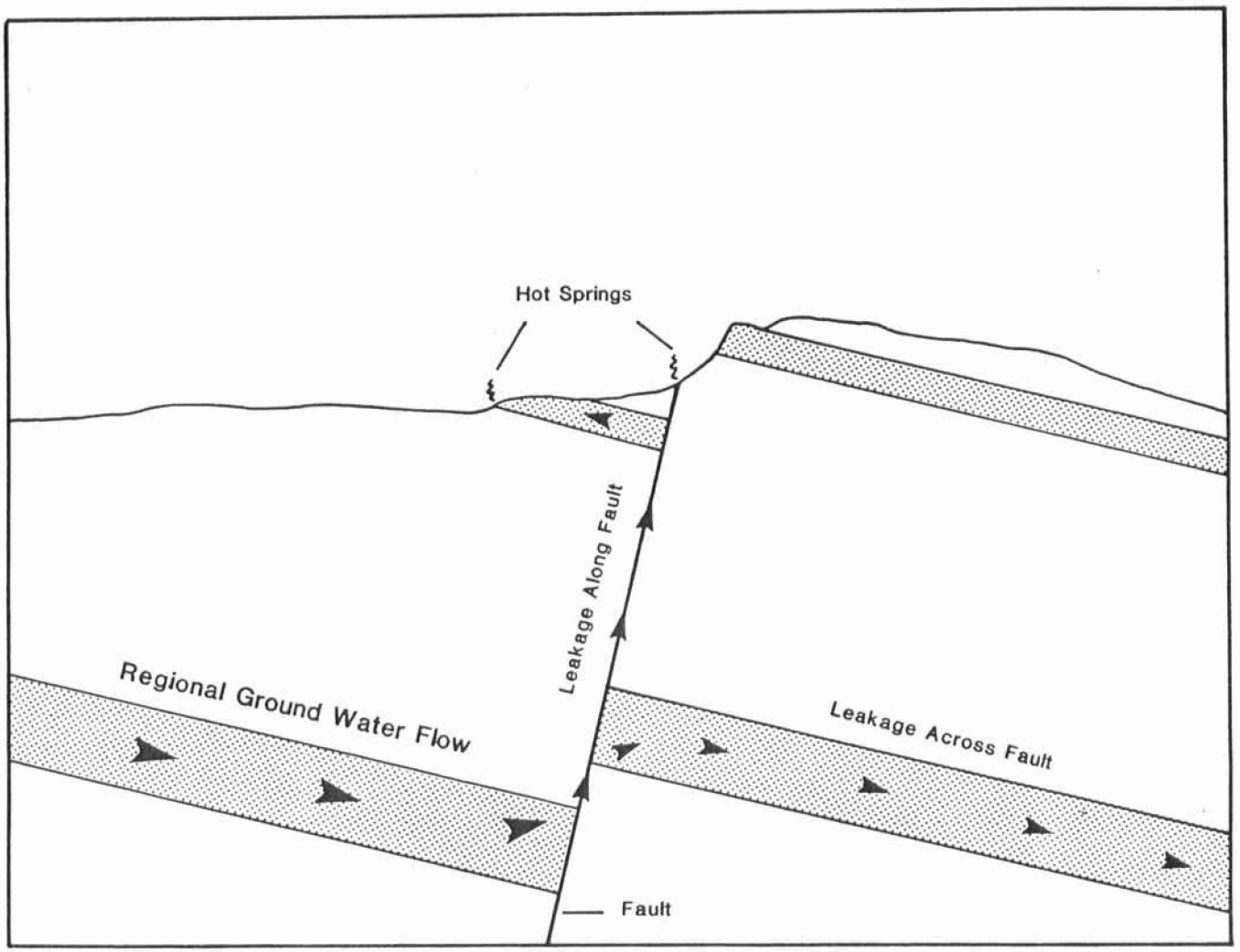


Figure 6. SCHEMATIC REPRESENTATION OF THE RELATIONSHIP BETWEEN DEEP FAULTS, REGIONAL GROUND WATER FLOW AND GEOTHERMAL FEATURES. Shaded areas represent permeable units.

Hydrogeology of the Known and Developed Geothermal Aquifer

The Vale geothermal aquifer probably results from the shallow discharge of deep-circulating hot regional ground water. In the shallow sub-surface, the movement of these thermal waters is controlled by the occurrence of permeable zones, probably in the fractured silicified sedimentary rocks. Geothermal fluid migrates upward along the fault zone and spreads out in the shallow sub-surface to eventually discharge into the Malheur River. As the water moves away from the upflow zone toward the river, it loses heat by conduction and through mixing with nonthermal ground water.

As is mentioned above, at least one fault within the fault zone cuts the developed geothermal area. This fault acts as a hydrologic boundary. It divides the area into two distinct parts with different hydrogeologic characteristics. Aquifer test results and water level trends indicate that the water bearing zones on either side of the fault are somewhat isolated from one another. It is likely that there are additional faults or geologic structures which cut through the developed area, but there is not sufficient information available to identify or locate them.

Figure 7 is a map of the developed geothermal area showing well locations and production temperatures from well logs. Also shown is the approximate location of the hydrologic boundary. The hottest wells, with measured temperatures of up to 230°F, occur to the west of the apparent fault. Water level contours and temperature logs suggest that this area is the main upflow zone feeding the developed area. A water level map (Figure 8) shows that water levels are generally higher in the western part than elsewhere in the developed geothermal area. Temperature gradients in this area are typically very high and positive to about 45 feet below ground level where they remain positive, but become lower (Figure 9).

Results of well tests indicate hydraulic characteristics are not uniform west of the fault. This suggests there may be additional structural or stratigraphic complexities. Wells near the buttes have reported yields of 80 to 640 gpm, while wells of roughly similar depth toward the river have reported yields of 20 to 30 gpm. The wells nearest the buttes also have considerably higher temperatures and higher water levels. As would be expected in fracture controlled aquifers, temperatures and yields of wells differ dramatically over relatively short distances.

The area east of the fault has an entirely different character (Figure 9). The most striking feature of these gradients is the reversal between 40 and 80 feet. This indicates that there is a zone of hot water (175 to 195°F) at this depth. The lower temperatures below 40 to 80 feet suggests that cooler water underlies this zone, or that the hot water in the 40 to 80 foot zone is a fairly recent phenomena. The gradient for OTM 5 exhibits relatively high temperatures at 210 feet underlain by another gradient reversal suggesting that there may be a zone of hot water at that depth in that well. In general, the gradients on the east side of the fault reflect the presence of one or two relatively thin zones of lateral hot water flow.

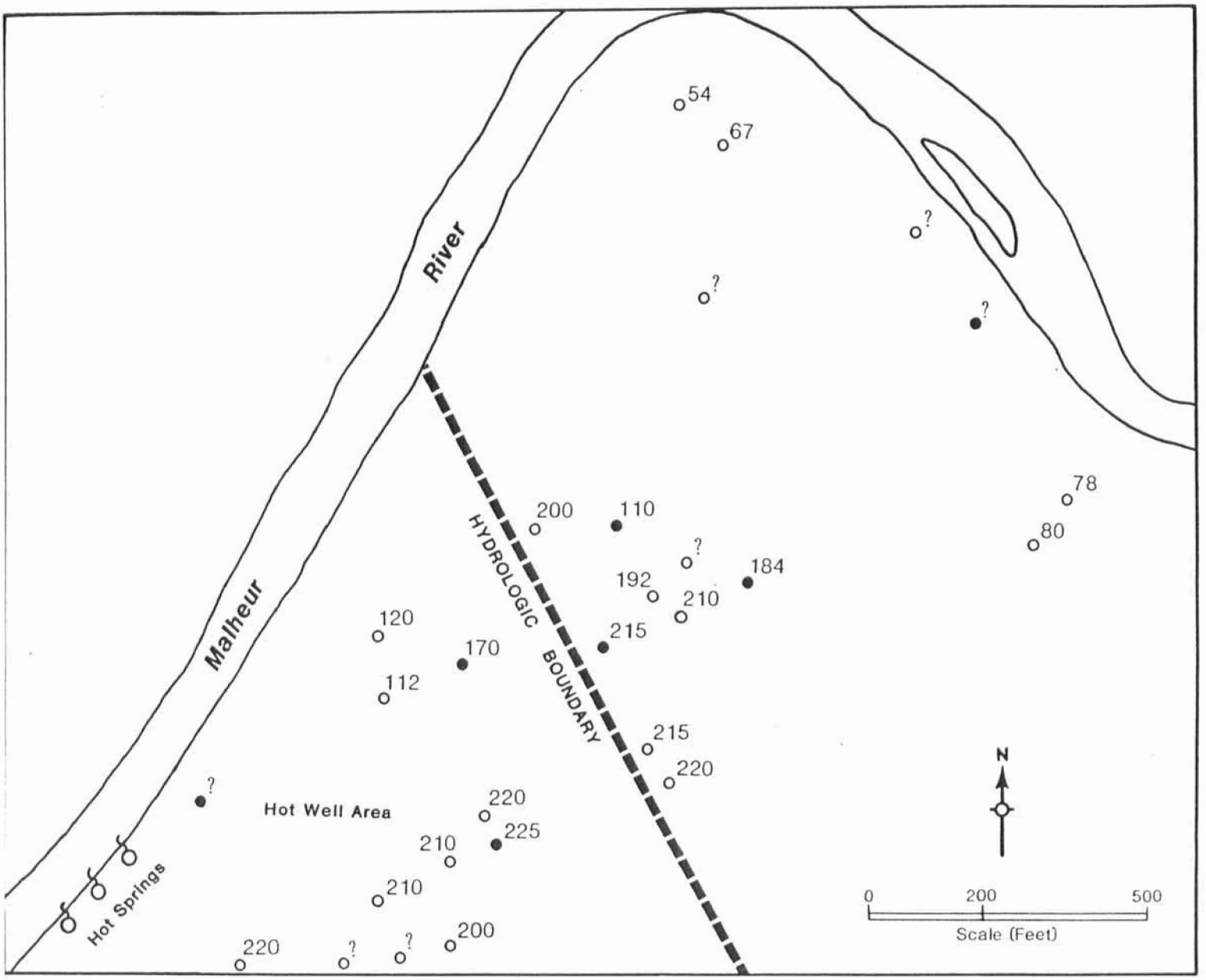


Figure 7. WELL LOCATIONS, PRODUCTION TEMPERATURES, AND LOCATION OF THE HYDROLOGIC BOUNDARY. Well production temperatures are measured or from well logs. Filled circles are active production or injection wells.

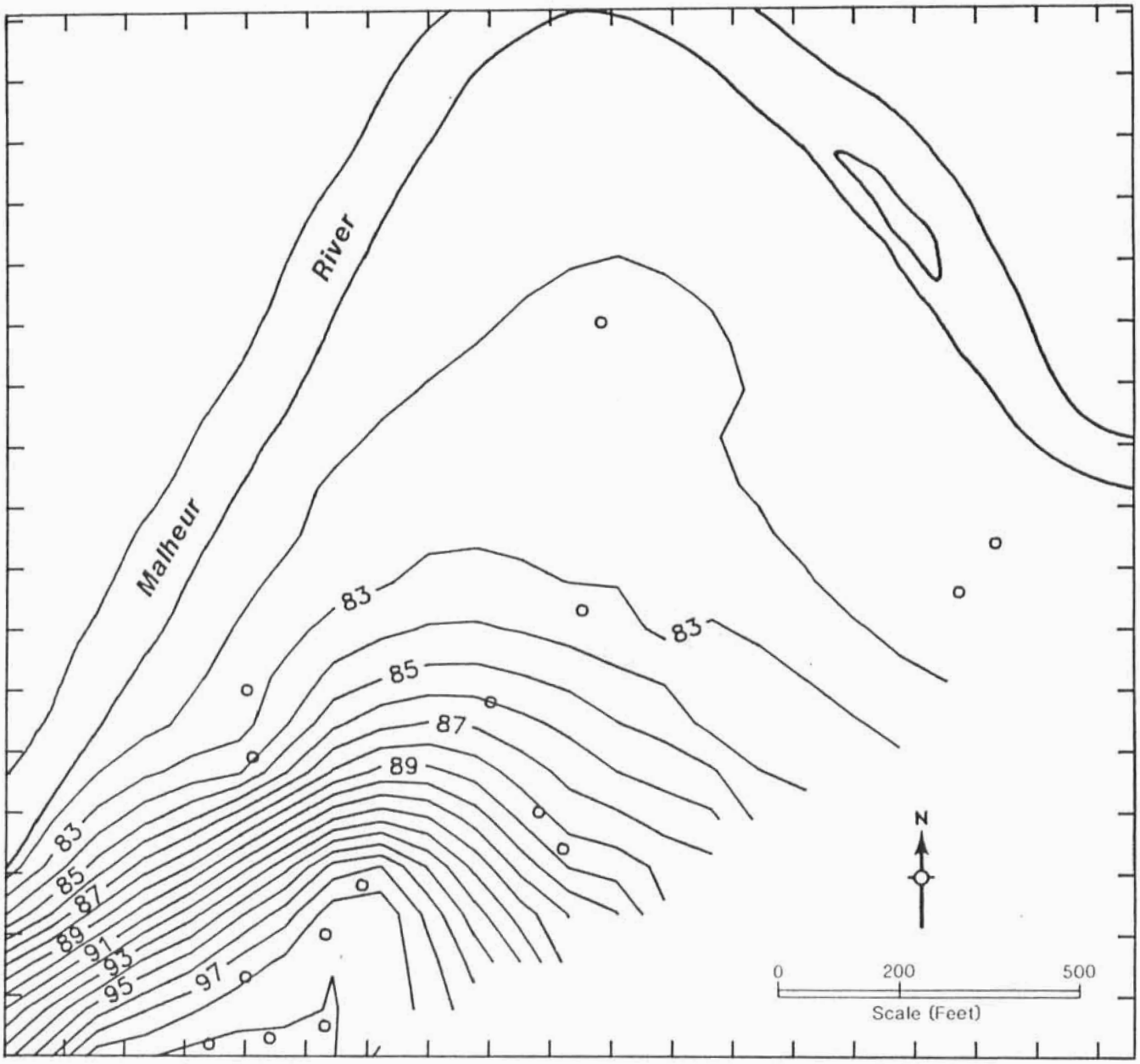


Figure 8. APPROXIMATE PIEZOMETRIC SURFACE OF THE GEOTHERMAL AQUIFER, DECEMBER 1984. Contour elevations are relative to the benchmark on the west end of the north highway bridge which is arbitrarily set at 100 feet.

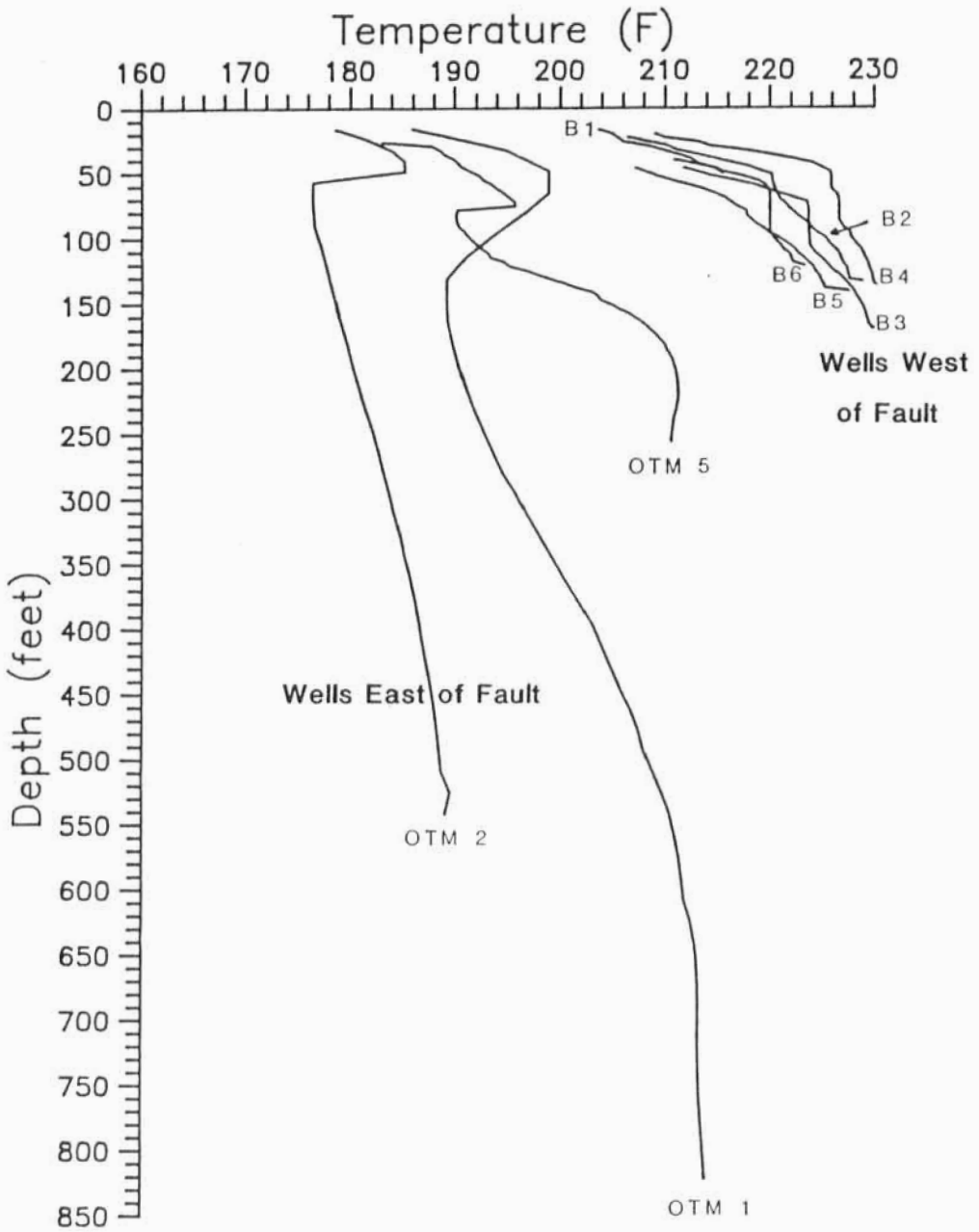


Figure 9. TEMPERATURE / DEPTH PROFILES OF REPRESENTATIVE WELLS EAST AND WEST OF THE HYDROLOGIC BOUNDARY.

Most of the hot water east of the fault appears to occur in the zone from 40 to 80 feet. Wells as deep as 800 feet have encountered no appreciable permeability below this zone. A water level contour map (Figure 8) shows that water in this shallow hot aquifer is flowing from the vicinity of the fault toward the river.

An examination of well logs in the developed geothermal area indicates that fine grained sediments predominate the sub-surface to a depth of about 540 feet. Below 540 feet, logs show basalt interbedded with the sediments. The sedimentary materials are described primarily as clay and claystone of various shades of gray, blue and brown. Some intervals are described as hard or fractured. Sandstone is also present but in lesser amounts than clay and claystone. Sandstone is described as hard or fractured more often than claystone, which agrees with observations of outcrops. Fractured sandstones are often described as water bearing. Basalt is interbedded with the sediments below 540 feet. The basalt does not appear to yield significant amounts of water.

No detailed stratigraphic correlations are possible from the information on well logs. No generalizations can be made about differences in the sub-surface across the fault. Hot water appears to come primarily from intervals of sedimentary rock described as hard or fractured, suggesting they might be silicified.

Geothermal Water Chemistry

This study uses water chemistry to estimate the maximum water temperatures which may exist in the deeper parts of the geothermal system. It also uses water chemistry to evaluate processes, such as mixing of thermal water with cool ground water, that might be occurring in the shallow sub-surface. The data used in this study (Table 2) include six chemical analyses of Vale geothermal water from the published literature, one analysis submitted to OWRD by a private party, and several chloride analyses conducted by OWRD staff for this study.

Estimating the maximum water temperature at depth is important when considering development or management of a geothermal resource. This information can help developers estimate, before drilling, the likelihood of achieving certain temperatures. It can also help those concerned with resource management determine the uses for which the resource is likely to be suitable.

To estimate maximum water temperatures in the subsurface a technique called "geothermometry" is used. Geothermometry is based on the assumption that temperature dependent chemical reactions between water and rock-forming minerals occur at depth, and that the final chemistry of the water will reflect the temperatures at which the reactions occurred. There are other assumptions and considerations, however, a thorough explanation is beyond the scope of this report. For the purposes of this report it is sufficient to say that, in general, reservoir temperatures estimated in a given area by geothermometry agree favorably with reservoir fluid temperatures

actually measured in drill holes or from production wells. For a more detailed discussion of geothermometry the reader is directed to Fournier and others (1974), Ellis and Mahon (1976), Henley and others (1984), and Truesdell (1975).

Table 2. GEOTHERMAL WATER CHEMISTRY IN THE VALE AREA

Source	Butler 81-2***	Hammond No.1***	OTM No. 3****	Vale Hot Spring***	Vale Hot Spring*	Vale Hot Spring**	Vale Hot Spring**
Date	-	-	Sep-84	-	1974	Aug-84	Jun-80
T°F	208.8	198.5	179	191.7	163.4	194	185
pH	8.1	7.4	7.8	7.3	7.5	8.3	7.2
EC	-	-	1590	-	1530	1400	1400
TDS	1060	2022	970	1070	-	882	850
SiO2	78	78	113	81	130	82	74.4
Na	246	259	290	271	310	190	232
K	14	14	12	14	16	13.2	12.4
Ca	17	21	20.3	31	19	31.2	25.6
Mg	-	-	-	4	0.8	7.4	3.8
B	9	9.6	7.3	8.9	9.4	-	7.33
F	6.3	6.6	6.2	3.6	6.1	2.8	4.3
Li	0.29	-	-	0.31	0.28	-	0.22
Cl	383	380	358	479	360	153.1	270
SO4	117	110	116	81	100	71.1	101

All data in units of mg/l except T, EC (µmhos) and pH

* From Bliss (1983)
** From Brown and others (1980)
*** From Dellinger and others (1982)
**** Submitted to OWRD by well owner

Two types of geothermometers were primarily used in this study: alkali geothermometers and silica geothermometers. Alkali geothermometers are based on the relative proportions of Sodium (Na), Potassium (K) and Calcium (Ca) in the water. The concentrations and proportions of these elements are generally considered to be controlled by reactions involving feldspar minerals. The silica geothermometers are based on the amount of silica in the water, which is controlled chiefly by the temperature dependent solubility of quartz.

Table 3 shows reservoir temperatures estimated using the seven complete chemical analyses available for geothermal water from Vale. This table shows generally good agreement between the different samples and techniques. Alkali geothermometer temperatures range from 293 to 370 degrees Fahrenheit and average about 322 degrees. The quartz conductive geothermometer (the most appropriate silica geothermometer for this situation) gives results ranging from 250 to 306 degrees and averages 268 degrees.

The slight discrepancy between average temperatures indicated by the two methods may be due to the thermal water mixing with nonthermal water as it rises to the surface. The alkali geothermometers are based on the ratios of Na, K and Ca. Mixing small amounts of nonthermal water with the thermal water may reduce the concentration of these constituents, but the ratios are relatively unaffected. Therefore, the calculated temperatures are not greatly affected. The silica geothermometers, on the other hand, are based on the actual amount of silica in the water. Dilution of the thermal water by nonthermal water tends to reduce the amount of silica, and calculated temperatures are low as a result. If the difference between the average alkali geothermometer temperature and the average silica temperature is due entirely to mixing, then the geothermal fluid produced at the surface at Vale could be up to one-third nonthermal ground water.

Table 3. ESTIMATED SUBSURFACE TEMPERATURES IN THE VALE GEOTHERMAL SYSTEM BASED ON CHEMICAL GEOTHERMOMETRY (Degrees F)

Source	Sample Date	Silica, Quartz Conductive	Silica, Quartz Adiabatic	Alkali, Na-K-Ca	Alkali, Na-K
Butler 81-2***		255	250	318	343
Hammond 1***		255	250	313	336
OTM 3****	9/84	291	282	293	304
Vale Hot Spring***		259	253	304	331
Vale Hot Spring*	1974	306	293	315	331
Vale Hot Spring**	8/74	259	255	320	370
Vale Hot Spring**	6/80	250	246	306	336

* Data from Bliss (1983)
** Data from Brown and others (1980)
*** Data from Dellinger and others (1982)
**** Data submitted to OWRD by owner

One oxygen isotope analysis is available for the thermal water at Vale from the U.S. Geological Survey GEOTHERM water chemistry database (Bliss, 1983). This allows for the application of the water-sulfate oxygen isotope geothermometer. For a discussion of this technique see Truesdell (1974), Ellis and Mahon (1977) or Henley and others (1984). This geothermometer gives a calculated temperature of 322°F which is in general agreement with the alkali geothermometers.

Chemical geothermometry suggests that maximum temperatures at depth in the Vale Geothermal System are in the neighborhood of 320 degrees F. The thermal water produced at the surface probably includes some nonthermal component, possibly as

much as one-third. When considering these results, it is important to remember that there are numerous pitfalls and sources of error in the application of chemical geothermometry. Calculated temperatures presented here are not absolute figures, but rather general indicators.

Chloride content and discharge temperatures of thermal fluids were used to evaluate possible mixing of thermal water with river water or nonthermal ground water in the shallow sub-surface. Chloride is a common constituent of most natural waters and occurs in elevated amounts in thermal waters. Chloride does not readily take part in chemical reactions in water or form precipitates. Variations in chloride concentrations in near-surface thermal waters usually result from dilution by low-chloride nonthermal water. Table 4 presents chloride and temperature data for thermal waters at Vale. The chloride and temperature data used are from a variety of sources. OWRD personnel analyzed the Malheur River and a number of thermal waters for chloride. We have no chloride data for nonthermal ground water in the immediate vicinity of Vale. However, chloride data provided by the Department of Environmental Quality for ground water in the Ontario area average about 65 mg/l.

Water Resources Department measurements of chloride content of the Malheur River in the Vale area range approximately from 20 to 25 mg/l depending on location and time of year.

Table 4. CHLORIDE CONTENTS OF THERMAL WATER IN VALE

Well/Source	Sample Date	CL (mg/l)	T°F
Butler 81-2***		383	208
Hammond 1	7/16/87	360	212
Hammond 1***		380	198
Humphrey Dryer Well	11/4/87	336	169
Humphrey Rental Well	7/16/87	131	88
Humphrey Residence	7/16/87	353	167
OTM 3****	9/14/84	358	176
Vale Hot Spring*	1974	360	163
Vale Hot Spring**	8/74	153	185
Vale Hot Spring*	8/7/74	350	194
Vale Hot Spring**	6/80	270	185

* From Bliss (1983)
** From Brown and others (1980)
*** From Dellinger and others (1982)
**** Submitted to OWRD by owner

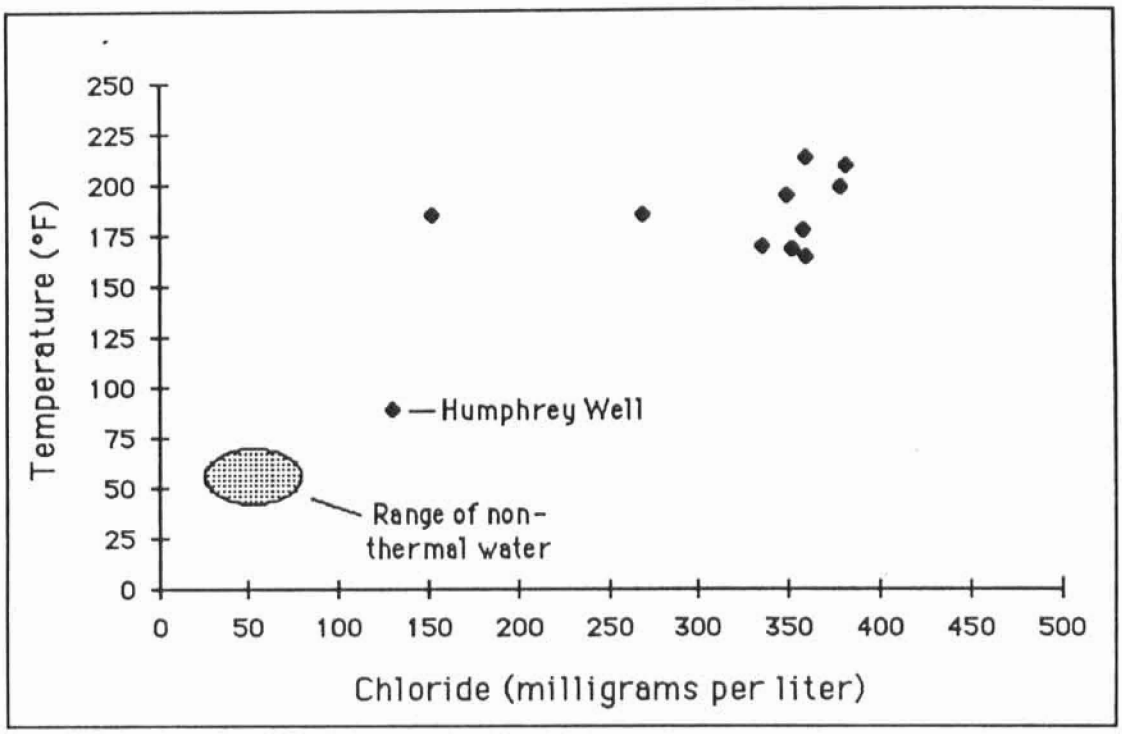


Figure 10. CHLORIDE CONTENT VERSUS DISCHARGE TEMPERATURE OF GEOTHERMAL WELLS AND SPRINGS

Figure 10 is a graphical presentation of the above data. Also plotted is the range of nonthermal waters in the area. When thermal water is mixed with nonthermal water of lower chloride content, the resulting mix will have a lower temperature and lower chloride content than the thermal water, and will plot along a line between the two types of water. If the thermal water loses heat by conduction to the surrounding rock, the temperature is reduced but the chloride content remains constant.

Most of the thermal waters analyzed cluster together on this plot. Only two samples depart significantly from the the others. One of them is the analysis of hot spring water with a chloride content of 152.1 mg/l. This chloride value is anomalous and is considered questionable. The other sample which shows significant departure is the Humphrey rental house well. This sample, analyzed twice by OWRD, appears to be a mixture of hot-spring type water and nonthermal ground water or river water.

Effects of Development

Current Pumpage

Although there are several users of geothermal water in the Vale geothermal area, there are only three which use significant amounts: Oregon Trail Mushroom Company, Ag-Dryers, and the greenhouses.

Based on flow meter data from April 1986 to April 1987, Oregon Trail Mushroom continuously pumps approximately 225 gallons per minute. This equals 363 acre-feet per year. Ag-Dryers pumps about 60 gallons per minute (measured by OWRD) for periods ranging form 30 days per year to 90 days per year and averaging about 67 days per year (Hugh Humphrey, personal communication), which equals about 18 acre-feet per year. The greenhouse is estimated to have pumped an average of about 174 days a year for the last few years based on power consumption records for 1985, 1986 and 1987. Their flow rate was measured at the discharge outlet at about 40 gallons per minute, which equals about 31 acre-feet per year. The combined total of the withdrawal by these three major pumpers equals approximately 412 acre-feet per year. The combined pumping of all the other users is estimated to be less than 10 acre feet per year.

Water Level Changes

The Oregon Water Resources Department started collecting water level data in the Vale area in August 1984. Water level data from about 20 wells in the developed geothermal area have been collected quarterly since December of that year. Well elevations were determined to one hundredth of a foot by differential leveling. Leveling results are presented in appendix 1. This information, along with water level data from well logs, has enabled us to determine the probable predevelopment conditions in the area and to evaluate the impacts of development on the system. Water level plots (hydrographs) of monitored wells are presented in appendix 2.

Figure 11 is a map of the geothermal area showing water level contours in December 1984 and April 1987. Water levels on the 1984 map are highest in the western part of the area and to the south near Rhinehart Buttes. Water levels decrease away from this area to the east across the fault, and to the northwest toward the river. The river acts as a constant head boundary which surrounds the area on three sides. The steep gradient to the northwest toward the river indicates that hot water is moving in that direction. That is where the hot springs occur. The area of highest water levels is also the area of highest measured temperatures. The area to the east shows a more modest hydraulic gradient toward the river.

The April 1987 water level contour map in Figure 11 shows some striking differences from the December 1984 map. The most notable difference is the relatively large loss in

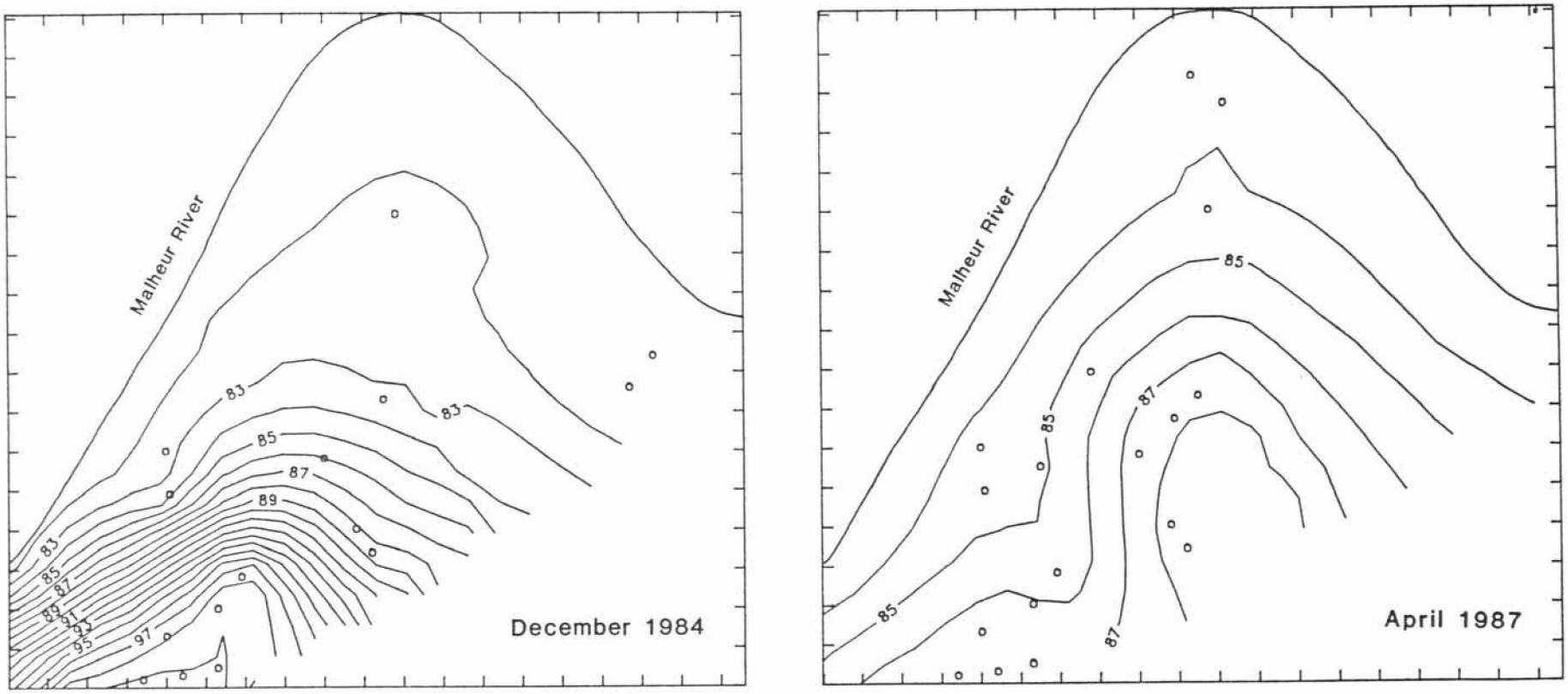


Figure 11. APPROXIMATE PIEZOMETRIC SURFACE OF THE GEOTHERMAL AQUIFER IN DECEMBER 1984 AND APRIL 1987. Elevations are relative to the benchmark on the west end of the north highway bridge which is arbitrarily set at 100 feet. Note difference in river stage.

water level head in the western part of the developed area. Comparison of water levels measured in December of 1984 with those indicated on well logs from the 1970s and early 1980s indicates that water levels were relatively stable prior to 1985.

Figure 12 is a hydrograph which shows the typical water level trend in the hot well area west of the fault. The observed loss of head is attributed to continuous pumping by Oregon Train Mushroom Company which started in 1985. Most of the observed decline is considered to represent an acute pumping effect and not long term depletion of the resource. This is thought to be the case because water levels in hot wells east of the fault have not dropped. Because the pumping is continuous, the resulting effect on water levels has persisted and has had time to effect the ground water flow field and temperature distribution.

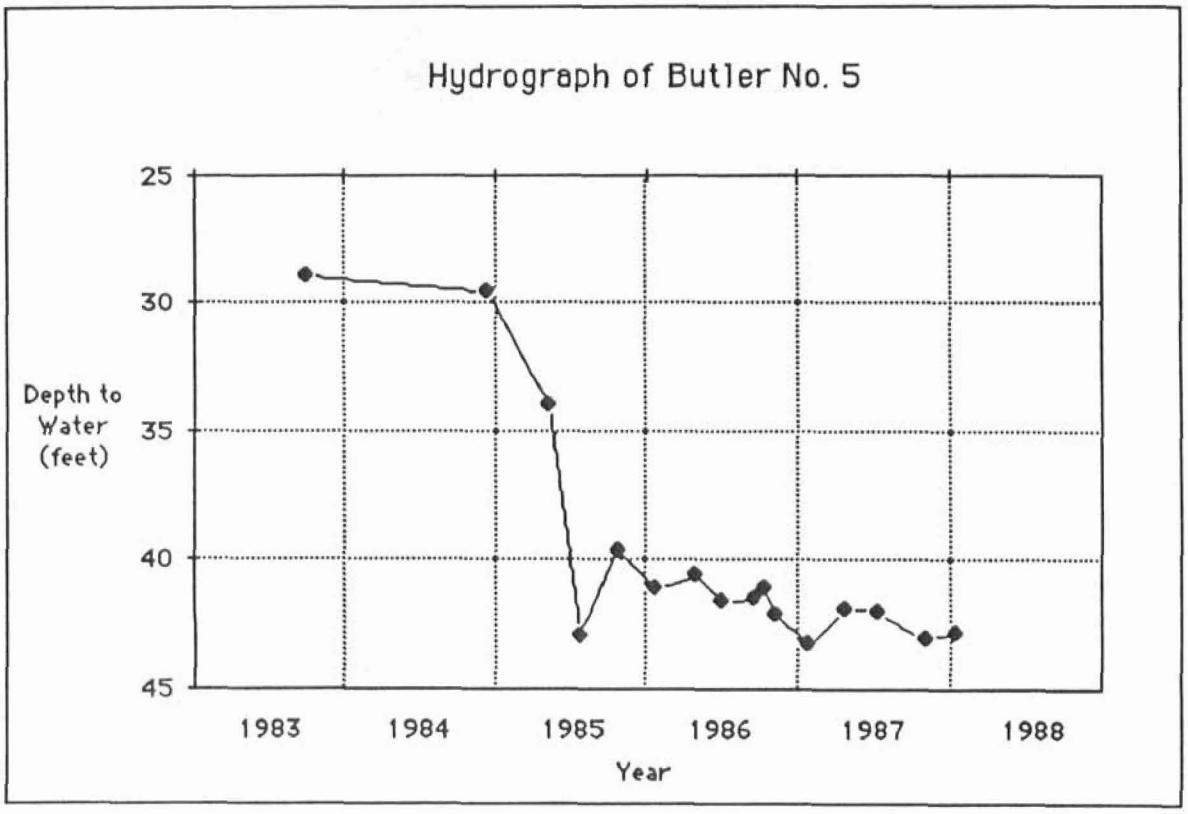


Figure 12. TYPICAL WATER LEVEL TREND IN THE AREA OF WATER LEVEL DECLINES

A number of effects are likely to result from the lowering of water levels and associated decrease in the hydraulic gradient between the up-flow zone and the river. The decrease in the gradient can be expected to reduce flow velocities toward the river and

reduce discharge from the natural hot springs. A decrease in velocity would mean a longer travel time for the hot water moving from the upflow zone to the discharge area, giving the water more time to conductively cool as it moves through the ground before reaching the hot springs. Reducing the hydraulic gradient can also be expected to change ground water flow paths, affecting the location of any zones where hot geothermal water mixes with cooler ground water, presumably moving any such zones toward the upflow zone or to a greater depth. Therefore, one would expect lower discharge rates and temperatures at the hot springs, and lower temperatures in the shallow aquifers feeding the springs.

Temperature Changes

Published measured temperatures at Vale Hot Springs range from 198.5°F (Russell 1903) to 207°F (Brown and others 1980). Unpublished measurements taken in 1974 available from the U.S. Geological Survey "GEOTHERM" data base (Bliss, 1983) range from 163 to 194°F. Surface discharge temperatures of 120°F were measured by OWRD personnel in July of 1987. A temperature probe inserted into the sediment at numerous locations in the hot springs area encountered a maximum temperature of 166.5°F. It appears that discharge temperatures of the hot springs may have dropped. One local resident has also observed that the river completely froze over adjacent to the hot springs in the winters of 1985 and 1986, and states that this has not happened in the past.

Local residents have reported temperature drops in three wells since 1985. One of these wells, the Humphrey rental house well, was drilled in May 1985 and has a discharge temperature of 170°F indicated on the well log. Maximum down-hole temperatures measured in this well by OWRD personnel range from 117.1°F in October of 1986, to 94.3°F in July 1987. The Ag-Dryers well which was drilled in July 1981 with a discharge temperature of 215°F indicated on the well log produced 169°F water in November 1987. Hawley Meat Packing drilled a new well in August 1986 reportedly because temperatures dropped in their old well, however, the Water Resources Department has no temperature measurements to substantiate this reported temperature drop.

There also appears to have been a drop of two to three degrees in the very hot wells near the Oregon Trail Mushroom Company production wells. Temperature logs of Butler No. 4 (Figure 13) show such a drop occurred between May 1986 and January 1988. Temperature records from the mushroom plant suggest a similar temperature drop may have occurred in their production well.

Temperature gradient measurements indicate temperature drops may be occurring in the shallow outflow zone on the east side of the fault. An April 1981 temperature gradient measurement in OTM-1 presented in Figure 14 clearly shows the effects of the shallow lateral flow of geothermal water at about 45 to 60 feet. A temperature gradient measurement in OTM-1 taken in May of 1986 indicates that the temperature has

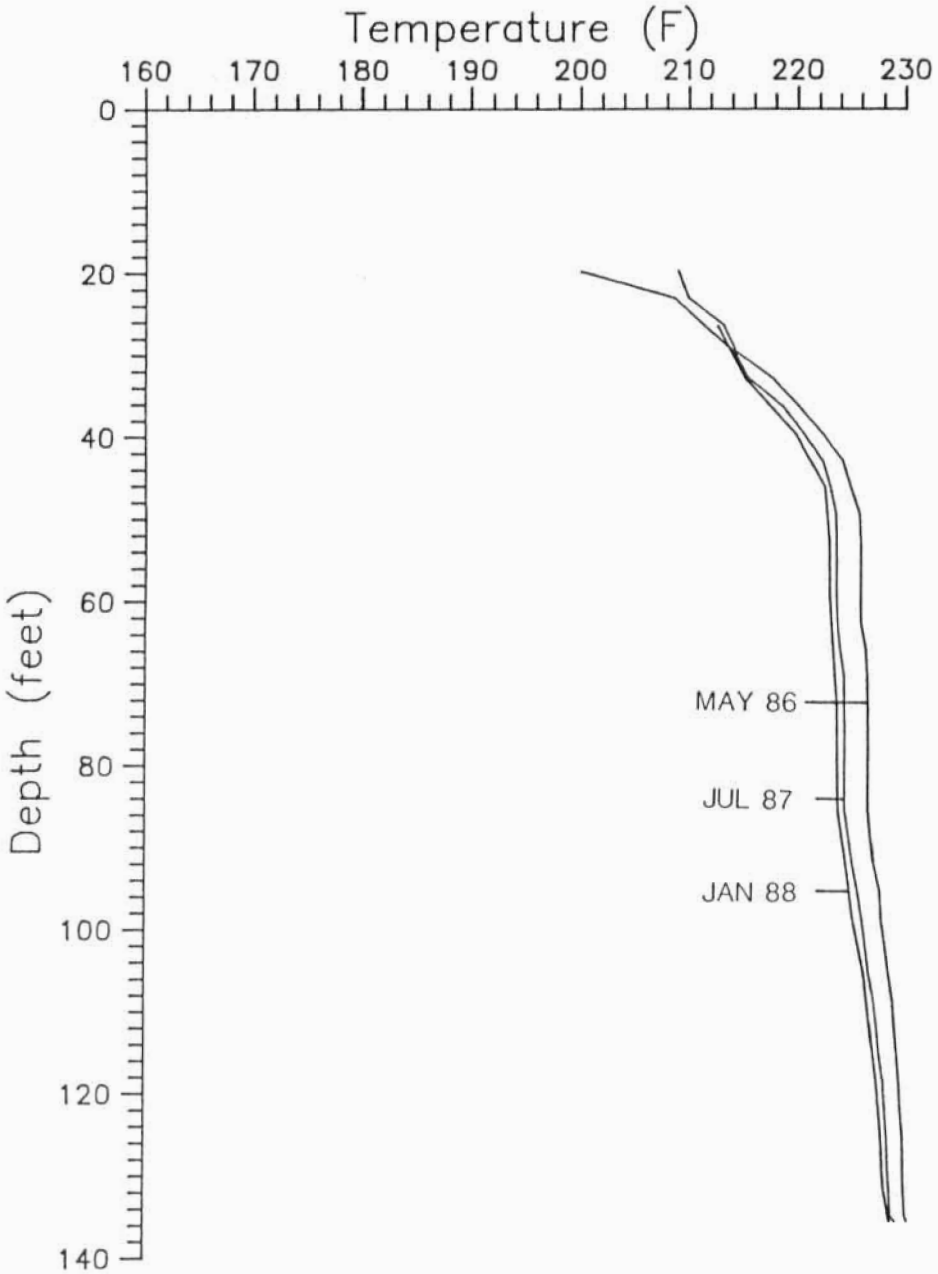


Figure 13. TEMPERATURE / DEPTH PROFILES OF BUTLER WELL NO. 4.
This figure shows the apparent temperature drop in wells
in the hot well area west of the fault.

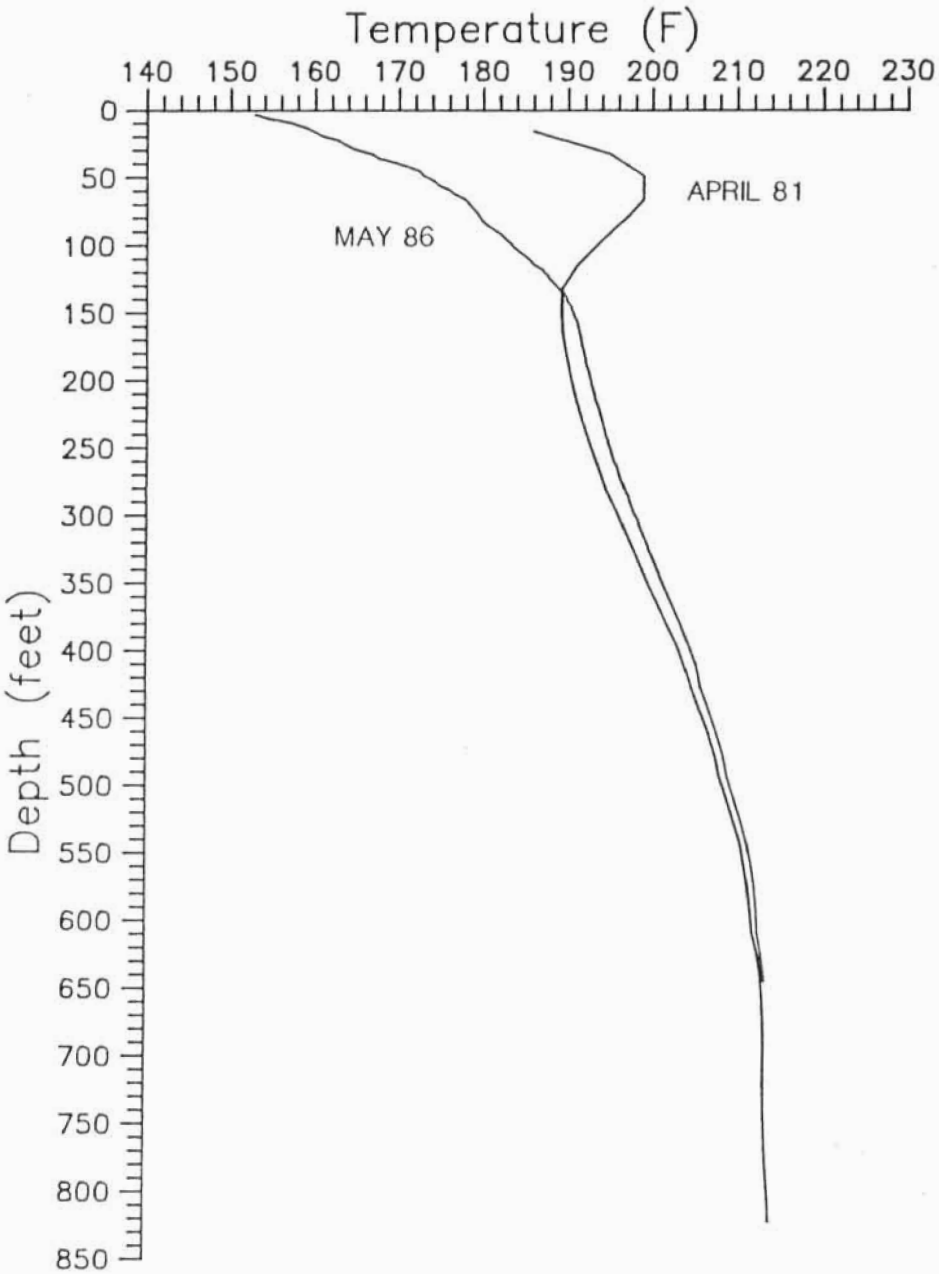


Figure 14. TEMPERATURE / DEPTH PROFILES IN OREGON TRAIL MUSHROOM COMPANY WELL NUMBER 1. This figure shows the apparent drop in temperature of the shallow out-flow zone east of the fault.

dropped about 22 to 23°F in the shallow aquifer in the vicinity of these wells, eliminating the "bump" in the temperature gradient observed in earlier measurements.

To date, temperature drops in the hottest wells near the OTM production well have been very slight and the only significant temperature drops clearly not related to injection have occurred on the periphery of the geothermal area. At some greater rate of pumping it is possible that water levels in the pumping wells could be pulled below river level. In such a case, significant temperature drops would be expected in these wells.

Injection and Effluent Disposal

Although reinjection of low-temperature geothermal fluid is not specifically required by law in Oregon, the water rights system is set up to encourage the practice. The main reason for this encouragement is to conserve the resource. An additional benefit of injection is that spent fluids do not have to be discharged to surface streams.

Oregon Trail Mushroom Company is currently the only geothermal user in Vale injecting spent geothermal fluid. The water is pumped from the area of the up-flow zone on the west side of the fault and injected into two wells on the east side.

One of the injection wells, OTM-3 appears to be delivering fluid to the shallow hot water zone east of the fault. Fluid which leaves the plant at about 200°F is injected into this well at an average rate of about 70 gpm, based on records from April 1986 to April 1987. Wells near this injection well, including OTM-1 and the Ag-Dryers well, have experienced temperature reductions. It is not known to what extent the temperature reductions are due to injection and to what extent they are due to interference from the production well. It is important to note that the temperatures in these affected wells have dropped to 170 to 180°F. The thermal effects of this injection cannot be ascertained without knowing the temperature of the fluid as it enters the injection well. Injection into OTM-3 appears to cause a slight raising of water levels in nearby wells.

Water is injected into a second injection well, OTM-R3, at a rate of about 155 gpm. The temperature of this water is about 200°F as it leaves the plant. Well head pressures range from 60 to 80 PSI. The well is drilled to 220 feet and has casing set and cemented to 100 feet. The effect of this injection is observed at a 210 foot well about 180 feet northeast of the injection well, where a shut-in well head pressure of 24 PSI is now observed. There was no well head pressure prior to injection. No pressure effect of injection is observed in two wells 300 and 350 feet south of the injection well, indicating that there may be an intervening fault or other geologic structure. It is not known exactly where the fluid injected into the second well is going. However, during the winter and on cool mornings steam can be observed rising from the river and riverbank adjacent to the well, suggesting that the injected fluid is migrating back toward the surface fairly rapidly and entering the shallow ground water or surface water system.

It appears that the current injection practices are doing little to conserve the pressure and temperature in the geothermal system. Water is being withdrawn and injected on opposite sides of a major hydraulic boundary. Water levels have been lowered and temperatures appear to have been locally affected on the west side where the withdrawal is occurring. Injection on the east side of the boundary does not appear to have any effect on the west side where the withdrawal is occurring. Injection may be affecting temperatures in some wells on the east side of the fault and has raised water levels in some wells.

In order for injection to aid in conserving the resource, the injection needs to be on the same side of any major hydraulic boundaries (such as faults) as the withdrawal. If injection is to the same part of the system as withdrawal, some temperature reductions in the production well are likely. Eventually, an equilibrium between the natural input to the system and the amount, location and temperature of injected fluid would probably be achieved. The volume and temperature of injected fluid would have to be regulated to avoid lowering temperatures in production wells below acceptable limits.

Injection precludes the necessity to discharge spent geothermal fluid to surface water bodies. This may not be an important consideration in Vale, since the developed area is normally the natural discharge point for the geothermal system. There is natural discharge of hot water to the Malheur River in the form of hot springs and as seepage through the streambed below river level. Since development has occurred, natural discharge from the springs appears to have decreased, but discharge to the river through the streambed has probably increased down stream due to injection wells. The net effect of this process is most likely a slight drop in the temperature of the hot water discharging from the system, with the discharge volume remaining relatively constant.

Summary and Conclusions

Intense geothermal development has occurred near Vale, Oregon in a small area of about forty acres. The area is underlain by a relatively shallow hot aquifer with temperatures as high as 230 degrees Fahrenheit. This aquifer appears to be the discharge area for hot, deep circulating regional ground water ascending from depth along a major fault zone. The hot aquifer discharges to the Malheur river.

Although the geothermal anomaly in the Vale area is about ten miles long, there are no records of producing hot wells outside of the small developed area. Although the potential for hot water production probably exists outside the developed area, the location, depth, temperature, and production capabilities of possible aquifers are unknown.

Current pumping in the developed area has resulted in lowered water levels in part of the geothermal aquifer. The lowered water levels appear to have caused local temperature reductions. Some users have been adversely affected by these temperature reductions.

The observed water level decline is thought to be largely an acute pumping effect from the Oregon Trail Mushroom plant production well. Because pumping is continuous the effect is persistent and has had time to affect the ground water flow system and temperature distribution.

Current pumpage from the geothermal system is about 412 acre-feet per year. The maximum sustainable pumping the system can tolerate may be greater than this, but not without compromise. Increased pumping from the aquifer will very likely result in additional area wide water level declines and temperature degradation to some wells. If all the users continue to have individual wells, disputes due to interference are likely to increase with increased pumpage. If one or two large wells are used to supply all the users, some additional development may be possible. However, if additional development causes water levels in the main production area drop below river level, dramatic temperature drops will likely result in production wells.

Withdrawal from the geothermal aquifer can be minimized by using the water efficiently. This includes cascading tail water from one user to another. Cascading used water should be practical in the area, and only requires cooperation between users.

The effects of withdrawal can be minimized by following effluent injection practices which will benefit the resource. This includes careful location of injection wells and control of injection rates and temperatures. Current effluent disposal practices, including injection, are not benefiting the resource.

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Appendix 1

WELL ELEVATIONS

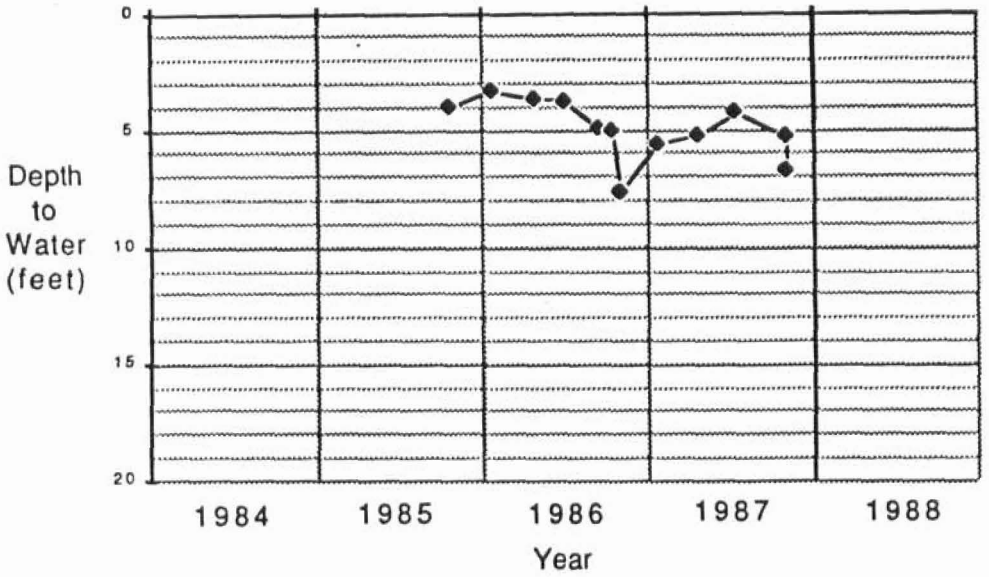
All elevations relative to the bench mark on the west end of the north highway bridge, which is arbitrarily set at 100.00 feet.

Well	Elevation (ft)	Description
Butler 1	103.88	Top of casing (TOC), south side
Butler 2	109.44	TOC, south side
Butler 3	129.23	TOC
Butler 4	108.39	TOC
Butler 5	129.36	TOC
Butler 6	124.32	Top of outer casing, north side
Butler R-1	94.03	TOC, north side
Butler R-2	94.08	TOC, north side
Floral 1	94.02	TOC
Floral 2	97.06	TOC
Fuhriman East	91.61	Top of sanitary seal
Furhiman North	91.77	Top of sanitary seal
Greenhouse Sump Well	90.80	Concrete well seal
Hawley Deep Well	94.51	Top of sanitary seal
Hammond 1	106.22	Top of pump base flange
Hammond 2	104.42	Lip of access port
Humphrey Dryer Well	90.54	Top of pump base flange
Humphrey Rental Well	93.12	TOC east side
Hysell Well	90.80	TOC, south side
OTM 1	96.08	Top of sanitary seal
OTM 4	98.97	Top of cap
OTM 5	115.02	Top of cap
OTM R-1	90.39	TOC
OTM R-2	89.10	TOC
OTM R-3	90.64	Top of cap
OTM R-4	92.62	TOC
OTM R-5	90.09	Top of cap

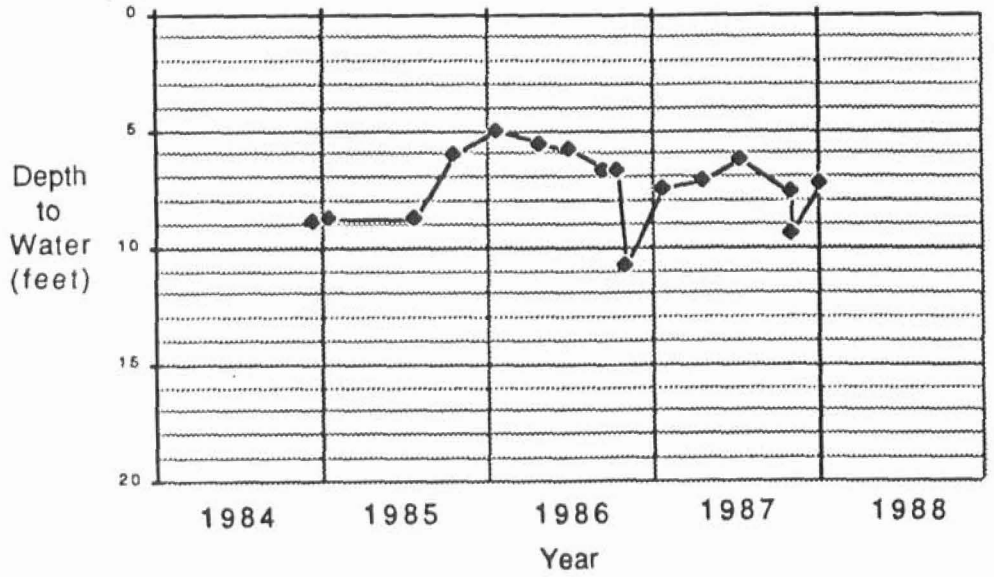
Appendix 2

HYDROGRAPHS OF SELECTED WELLS IN THE VALE GEOTHERMAL AREA

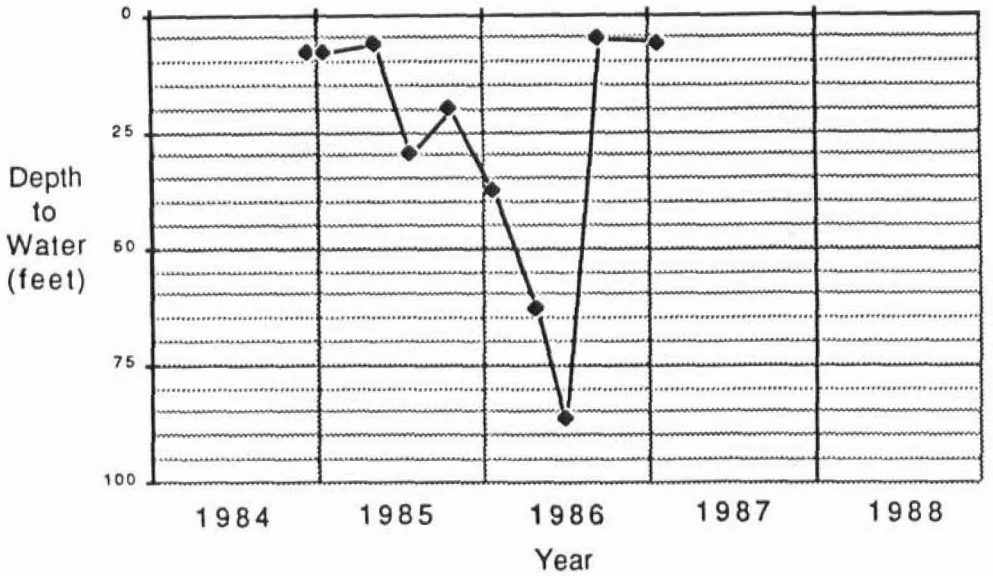
Hydrograph of Vale Floral No. 1



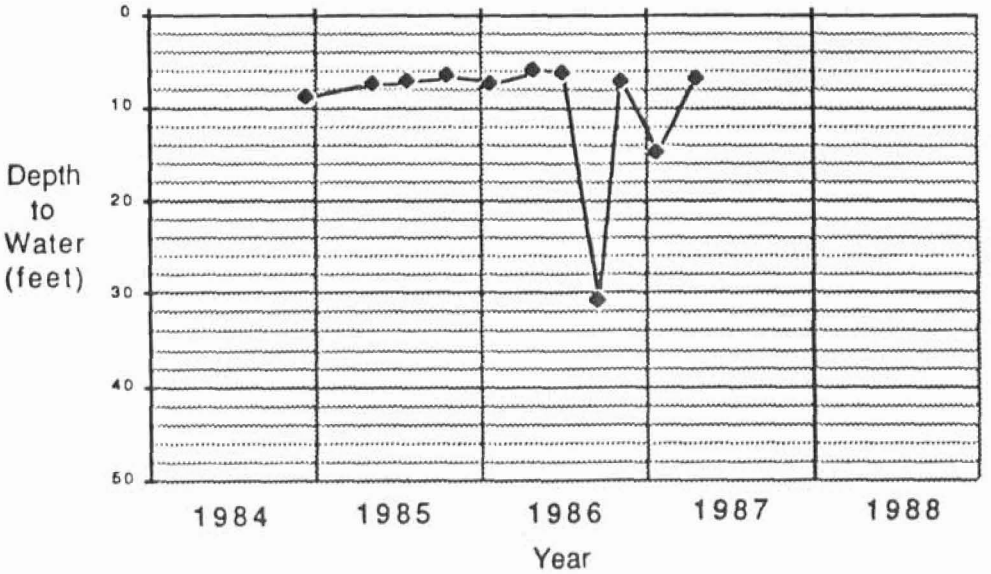
Hydrograph of Vale Floral No. 2



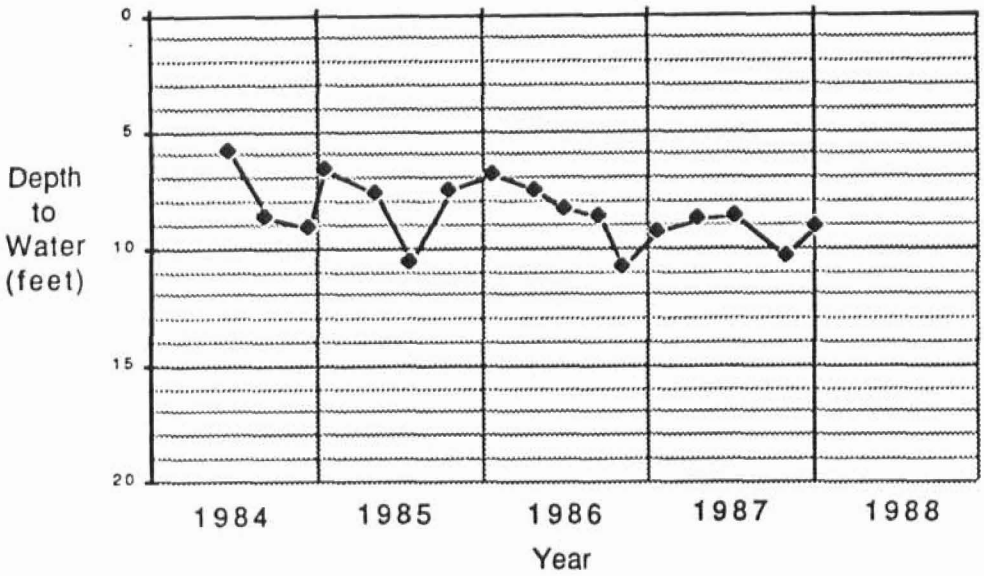
Hydrograph of OTM No. R-1



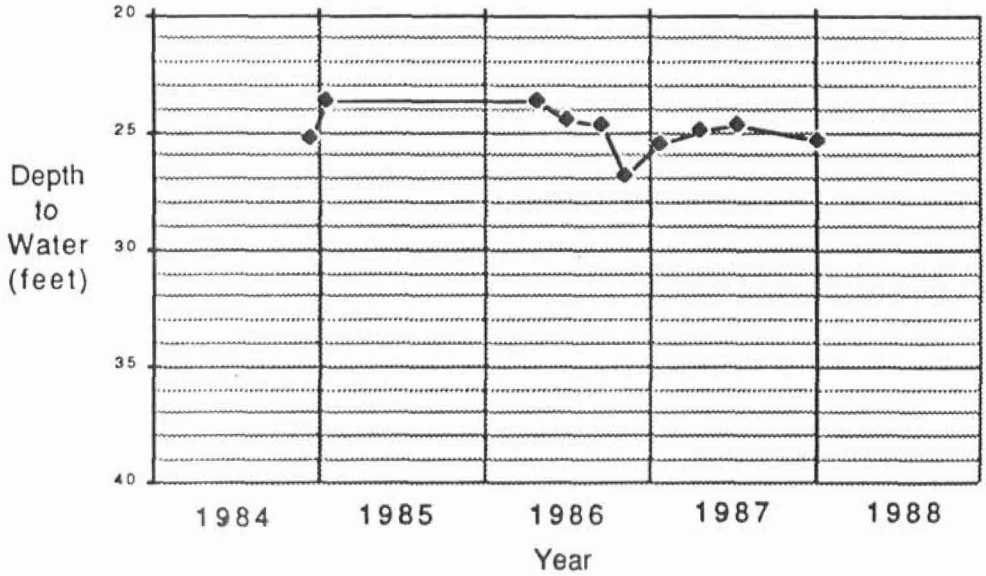
Hydrograph of OTM No. R-5



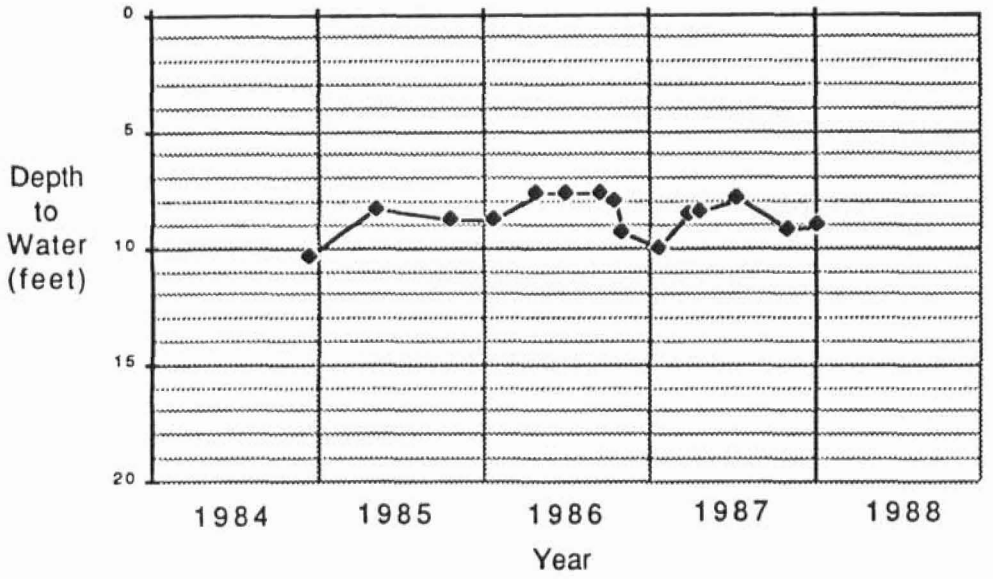
Hydrograph of OTM No. 4



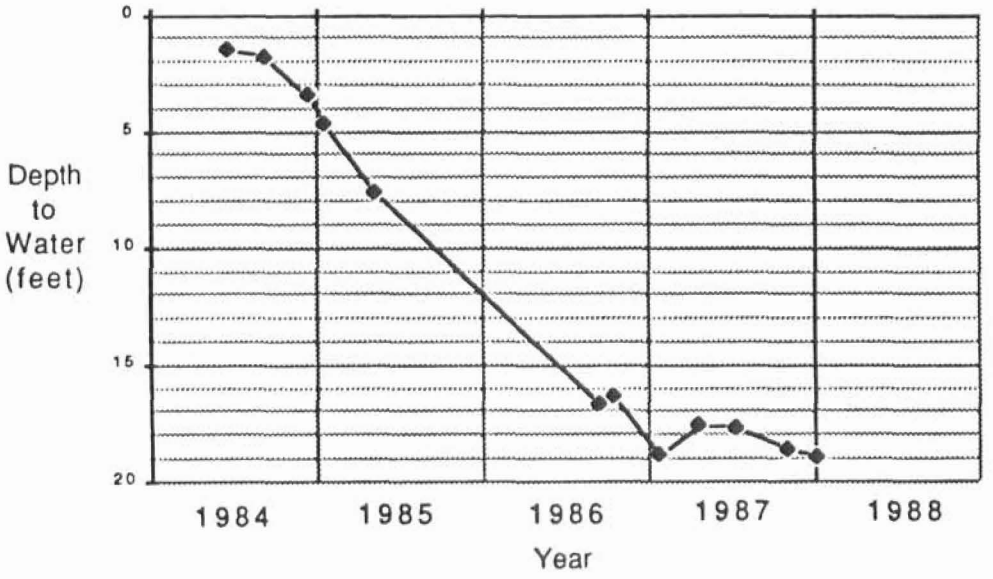
Hydrograph of OTM No. 5



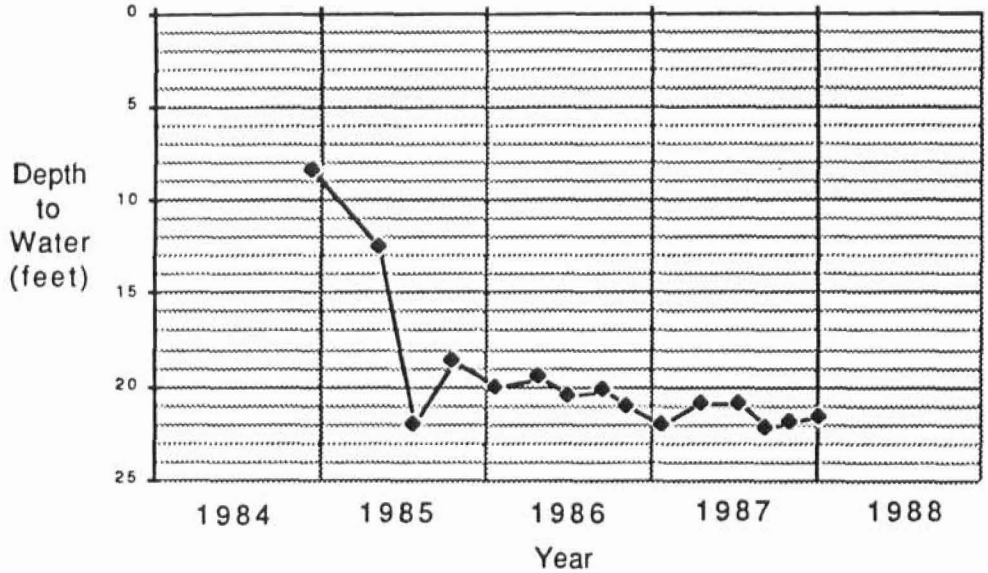
Hydrograph of Butler No. R-2



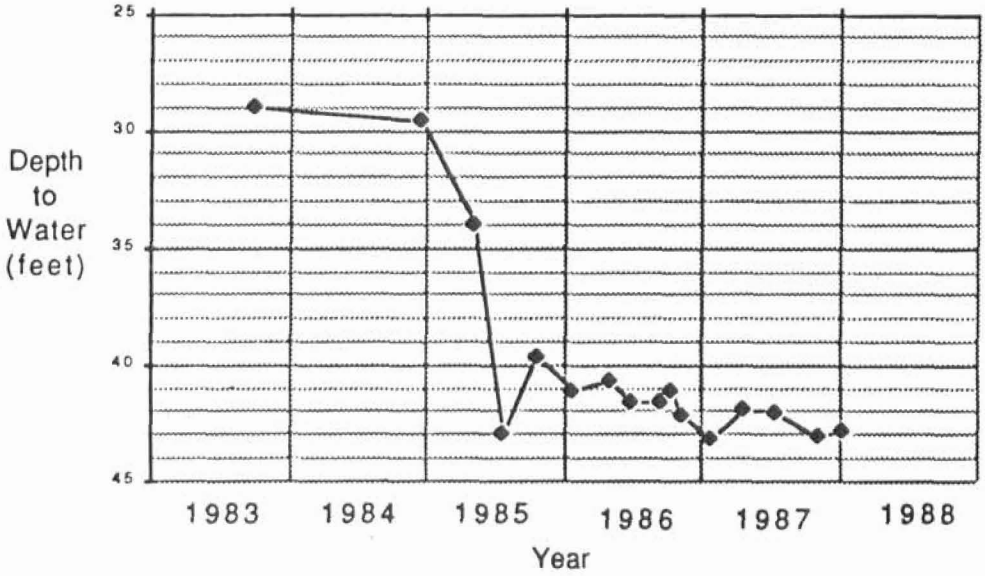
Hydrograph of Hammond No. 2



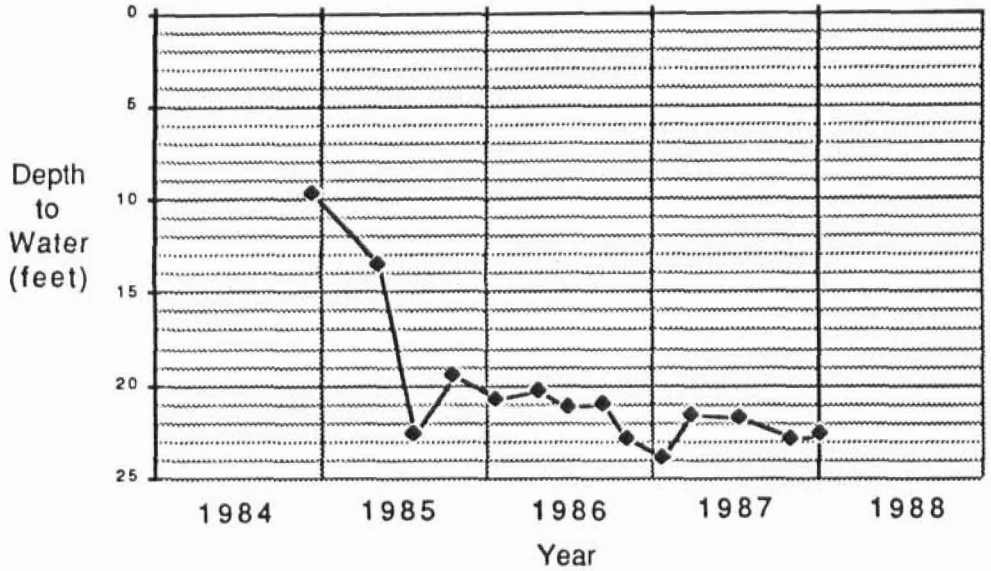
Hydrograph of Butler No. 4



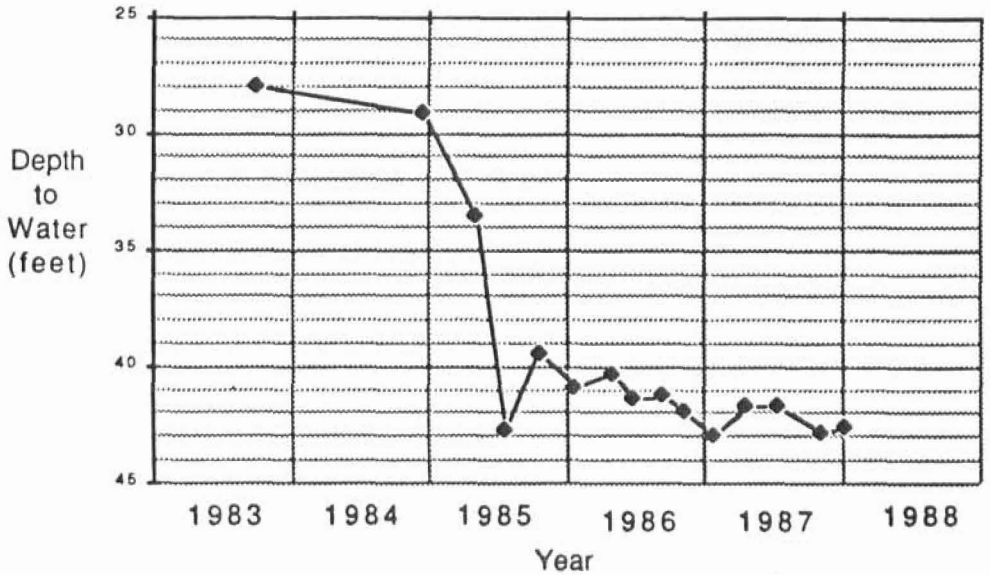
Hydrograph of Butler No. 5



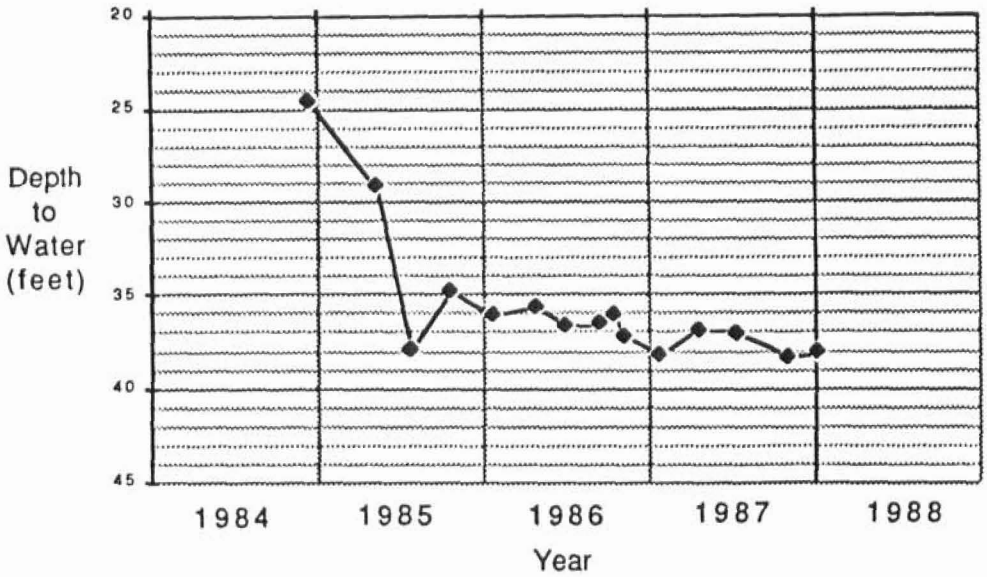
Hydrograph of Butler No. 2



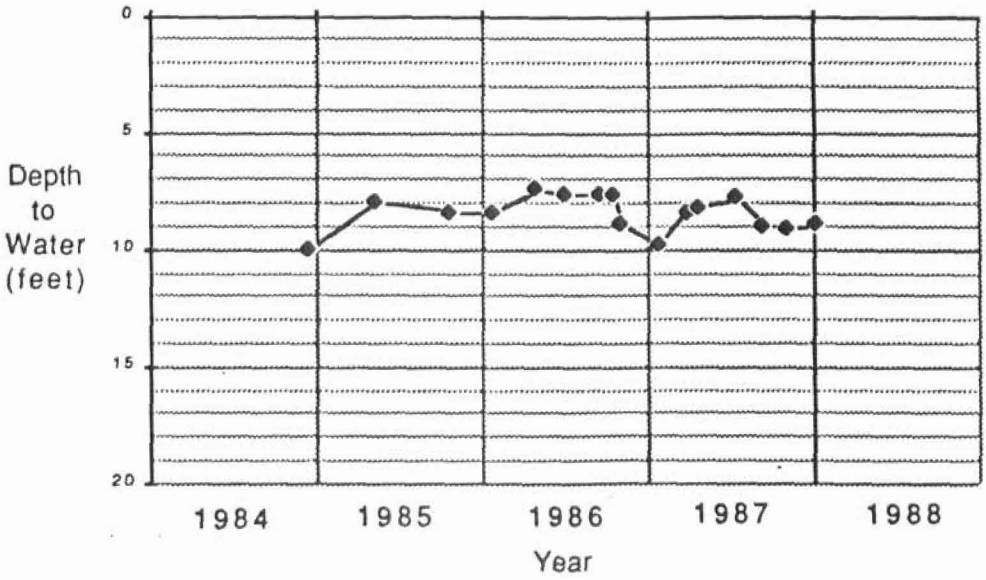
Hydrograph of Butler No. 3



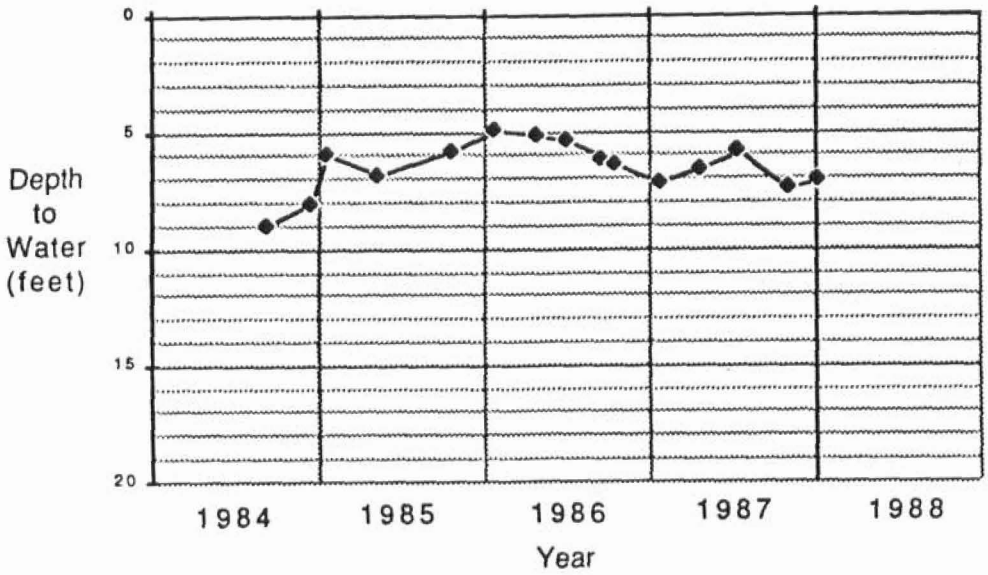
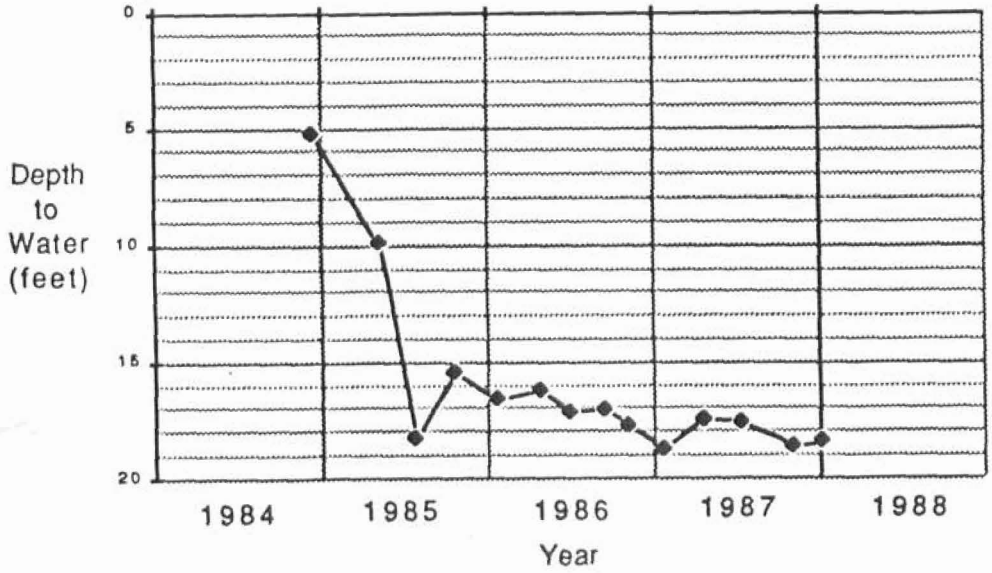
Hydrograph of Butler No. 6



Hydrograph of Butler No. R-1



Hydrograph of Ag-Dryers Well



Hydrograph of Butler No. 1