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HYDROGEOLOGY AND GEOTHERMAL RESOURCES OF THE LITTLE BITTERROOT VALLEY, NORTHWESTERN MONTANA

by
Joseph J. Donovan

Little Bitterroot Valley.

Memoir 58

1985

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Preface

Ground water has historically played a significant role in the economy of the Little Bitterroot valley, and has become the focus of controversy among water users when increasing demands cause declines in ground-water levels. This report is intended as an aid in water rights administration and management and as a guide to further ground-water development.

Field work was performed from 1978 to 1983, with assistance from Art Middlestadt, Fred Schmidt, Pete Norbeck, John L. Sonderegger, Roger Noble, and others of the Montana Bureau of Mines and Geology; Tom Reed of the U.S. Geological Survey; and Steve Gary of the Water Resources Program of the Confederated Salish and Kootenai Tribes. Support was provided by funds from the Montana Department of Natural Resources and Conservation, U.S. Department of Energy, and the Montana Bureau of Mines and Geology. The Renewable Alternative Energy Program of the Montana Department of Natural Resources and Conservation funded a test well (Well 88).

For completeness, this report includes published and file data from others who have worked in this area, including Arnie Boettcher and Bob Earhart of the U.S. Geological Survey, Steve Gary of the Confederated Salish and Kootenai Tribes, and Merle Axtell and Bill Slack of the Flathead Irrigation District. In addition, Steve Slagle of the U.S. Geological Survey was very cooperative in sharing preliminary drilling data while his project is still ongoing. The valuable contributions of these individuals are noted in the report where possible. Responsibility for interpretations is mine.

John L. Sonderegger provided encouragement, logistic support, ideas and his inimitable style of criticism. Sheila Roberts supplied a fresh and strong editorial review at a late stage, when I thought the manuscript was beyond all help. The assistance of both was welcome and indispensable to the completion of the report.

Residents of the Little Bitterroot valley shared their knowledge regarding wells and ground water, and allowed access to their property and wells. Of special help were two long-time residents, Charles Baxter and Arvid Kopp.

Thanks also to Judeykay Schofield for computer support and to Lester Zeihen for assistance in x-ray diffraction.

Helpful review comments on the manuscript were provided by Richard B. Berg, Robert N. Bergantino, Chuck Brassi, Arvid Kopp, Steve Slagle and John L. Sonderegger.

Joseph J. Donovan
Hydrogeologist
Montana Bureau of Mines and Geology

Billings
June 20, 1985

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Front cover—*Little Bitterroot valley,* by H. L. James, MBMG.
Scene is looking north along Highway 382 from Markle Hill.

Abstract

The Little Bitterroot valley is a 4- by 20-mile (6 by 32 km) artesian basin. Aquifers in the valley occur in shallow alluvial gravels, valley-margin alluvial gulches, fractured bedrock, and an extensive artesian gravel bed that is confined throughout most of the valley beneath 200 to 350 feet (60 to 105 m) of Glacial Lake Missoula silty clay.

This artesian gravel aquifer is the most productive aquifer in the valley. Because many of the wells tapping it are located in the vicinity of Lonepine, in this report the hydrostratigraphic nomenclature "Lonepine aquifer" will be applied to this aquifer. Wells below an elevation of 2,780 feet (847 m) flow up to 800 gallons per minute (2,300 liters per minute, or L/min), but are subject to declines in pressure and yield due to well interference. This causes conflict between irrigation water users. Aquifer monitoring and testing indicate that flow in the aquifer is from northwest to southeast at a very gentle gradient. The aquifer is highly transmissive (0.03 to 0.15 m^2/s; 200,000 to 1,000,000 gallons per day/foot) and has a low storativity (0.0003); therefore, aquifer drawdown in response to irrigation occurs rapidly and extensively, although total drawdown is less than 20 feet (6 m) and recovery following irrigation is rapid. Valley-margin boundary effects strongly influence aquifer response. Sources of recharge include valley-margin alluvium, geothermal flow, and infiltration from unconfined gravels coupled to the aquifer at the north end of the valley. Recharge is sufficient that ground water is not currently being mined, although during dry years increased irrigation lowers aquifer levels.

Warm water in a geothermal system beneath the valley in the Camp Aqua area flows through a bedrock fracture system, discharging upward into the Lonepine aquifer at an estimated 1,000 gallons per minute (3,800 L/min). Temperature is estimated at 77°C, based on dilution of silica during mixing, but because of conductive cooling and dilution with cooler water, the warmest temperature found to date in the gravel is 52°C. An attempt to find hotter water in bedrock beneath the gravel was unsuccessful. The Camp Aqua flow system has no near-surface connection with Camas Hot Springs, seven miles (4.4 km) to the southeast, whose flow (100-150 gallons per minute, 400-600 liters per minute) and temperature (47-51°C) are slightly lower.

The aquifer shows haloes of elevated concentrations of Li^+, B, Cl^-, and F^-, related to the geothermal recharge. Waters peripheral to the warmest zone contain high As concentrations. Cation (Na-K-Ca) geothermometry calculations yield unrealistically high temperature estimates for the Camp Aqua system, caused by reactions involving Ca^{2+} in the gravel. Silica geothermometry calculations yield credible temperature estimates, if chalcedony is assumed to be the controlling phase.

A two-dimensional digital model was constructed utilizing aquifer characteristics and boundary conditions interpreted from this study. The model was calibrated using field data for steady-state conditions (no irrigation stress) and transient conditions (stress produced both by aquifer testing and by irrigation). Agreement between model and field data is acceptable. In the future, the model will require refinement as data are collected in areas where there are now few wells. It may be used to predict impacts of irrigation in currently undeveloped portions of the aquifer.

Introduction

Location of study area

The Little Bitterroot valley lies within an elongate N-NW-trending intermontane basin located in northwestern Montana **(Figure 1)**. Its headwaters reach Little Bitterroot Lake to the northwest. Within the valley, the Little Bitterroot river flows south nearly 30 miles (48 km) to its mouth along the Big Bend of the Flathead River, near Sloan Ferry.

The valley has an upper and lower catchment. In the mountainous upper catchment north of Niarada, much of the annual precipitation falls as snow. Runoff from snowmelt constitutes much of the river's discharge and provides water for downstream irrigation in the summer months. In contrast, the lowland portion of the valley, from near Niarada south to the Flathead River, is a semiarid intermontane basin, with a few ephemeral drainages and numerous dry tributary gulches. The 16-mile (26 km) long upper portion of the Little Bitterroot valley, north from Oliver Gulch, is from 2 to 4 miles (3 to 7 km) wide and is extensively irrigated. The lower part, from Oliver Gulch to Sloan Ferry, is sinuous, narrow—about a mile (1.6 km) wide, and about 14 miles (22 km) long. It is not extensively irrigated.

Purpose of Study

Water from both ground and surface sources is a foundation of the economy of the valley. Surface water resources are being utilized to near existing capacity; ground water may become increasingly utilized for additional development, but its capacity and limits have not been clearly defined. Before such development is undertaken, it would be prudent to evaluate ground-water potential and the likely impact of new development on the claims of existing appropriators.

The purpose of this study was (1) to collect basic information quantitatively describing aquifer characteristics and chemical quality and (2) to develop interpretations of the nature and extent of ground-water resources in the Little Bitterroot valley.

This investigation had a base of existing data from several previous studies. Meinzer (1916) presented a classic study of artesian ground-water resources of the valley from data collected in 1915, in the early homestead years before surface water irrigation was established. His well inventory lucidly chronicles the initial development of ground-water irrigation using wells (some of them warm) developed along the Little Bitterroot River. He reported early piezometric levels and instances of interferences between flowing artesian wells. Boettcher (1982) presented ground water and geophysical data collected as part of a reconnaisance hydrogeological investigation of the Flathead Indian Reservation.

In addition to these two investigations, most hydrogeologic work and data have been described in various reports and correspondence. File correspondence from E.S. Perry of the Montana Bureau of Mines and Geology (MBMG) to the Flathead Irrigation Project in 1941 and 1942 evaluated ground-water conditions in the valley regarding development of a high-yield well (1,200 gallons per minute, 4,200 liters

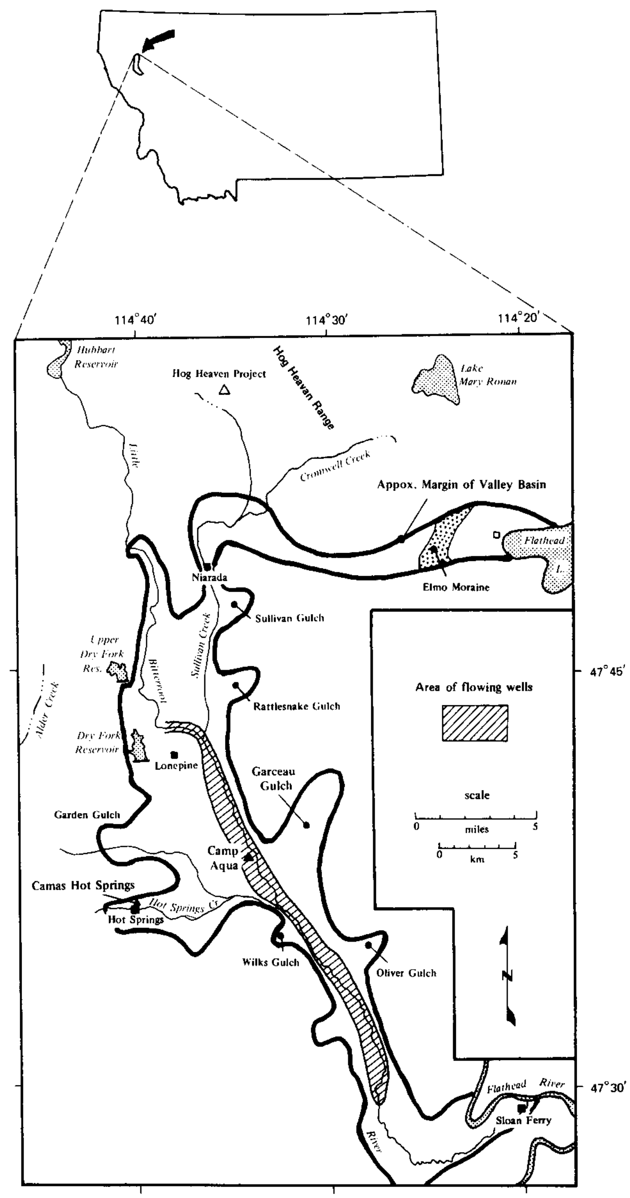


Figure 1—Location map of the Little Bitterroot valley and surrounding area.

per minute) drilled to supplement surface water storage of Dry Fork Reservoir during dry years. Crosby and others (1974) and Earhart (1977), working under contract to the Confederated Salish and Kootenai Tribes (CSKT), described geothermal investigations in the Little Bitterroot and Hot Springs areas. Gary (1982) described a spring development program and hydrogeological investigation at Camas Hot Springs. Results of geothermal exploration and drilling in the Camp Aqua geothermal area were presented by Donovan and others (1980), Donovan and Sonderegger (1981), and Nork (1981). Numerous staff reports dealing with ground-water appropriation requests in the Little Bitterroot valley are on file in the Helena office of the Montana Department of Natural Resources and Conservation (DNRC). Hydrometrics (1984) presented results of a ground-water development program along Sullivan Creek at the north end of the valley, approximately three miles (5 km) northeast of Niarada. Their data include a pump test evaluating the characteristics of a gravel aquifer that is probably continuous with the Lonepine aquifer.

Drilling and aquifer testing in portions of the Little Bitterroot valley are in progress by the U.S. Geological Survey (USGS) in cooperation with the CSKT. Preliminary drilling and water level data from that investigation through 1984 were available for this report (Slagle, personal communication, 1985). A complete report describing this work will be published by the USGS.

Climate

Orographic effects cause precipitation in the study area to vary spatially. The climate is driest in the lowland portions of the valley and in the hilly uplands to the east. Both temperature and precipitation vary with altitude.

At the Lonepine 1 WNW (National Oceanographic and Atmospheric Administration designation) and Hot Springs climatological stations, long-term annual rainfall averages are 11 and 14 inches (28 and 36 cm) respectively, with years on record as dry as 6 inches (15 cm) and as wet as 20 inches (51 cm) **(Figure 2)**. Precipitation is light but reasonably uni-

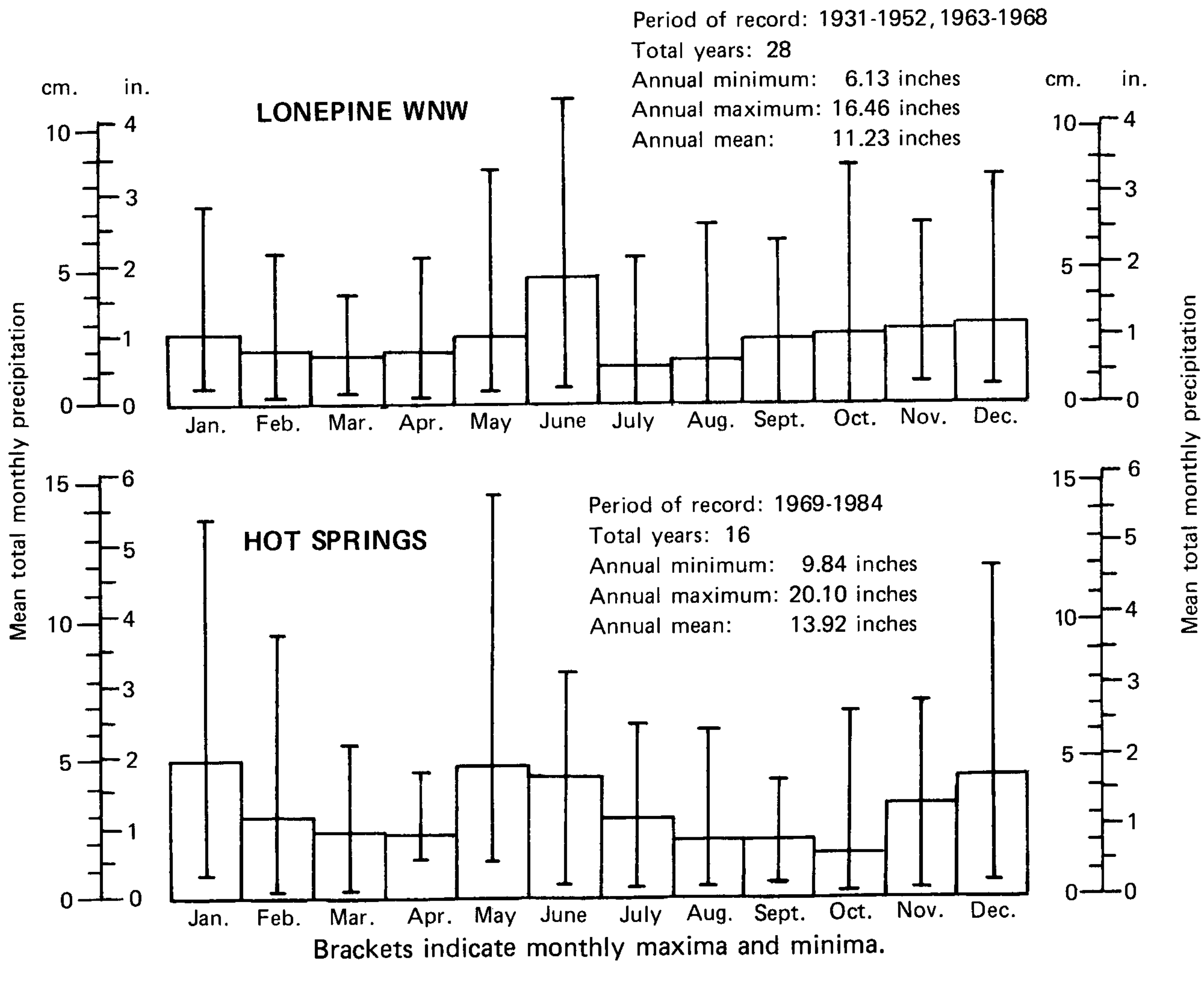


Figure 2—Precipitation data for stations in the Little Bitterroot valley.

form from September through April. May and June are usually the wettest months. The summer months are commonly dry, bringing occasional drought. Temperatures are hot in summer, up to a monthly average of 70°F (21°C), and reach as low as an average 27°F (-3°C) during the winter. Data for the Lonepine 1 WNW station show that this central part of the valley, bounded on the west by sheltering mountains, is somewhat drier than other parts. In the valleys, about 40 percent of the precipitation falls as snow.

In the mountains, temperatures are cooler and a greater percentage of precipitation falls as snow. Total annual precipitation is estimated to be at least 20 inches (50 cm), with as much as 100 inches (250 cm) annual snowfall (Soil Conservation Service, 1978). The climate is sufficiently cool and moist to sustain commercial stands of coniferous timber. Snowmelt and spring runoff begin in March and can extend into early May or June. Depending on snowpack thickness and air temperature, the late spring discharge of the Little Bitterroot River system can be high and provide water for irrigation.

Location reference system

Geographic locations of wells referred to in this report have been assigned location and identification numbers.

The location number is based on the General Land Office System of land subdivision and shows the location by township, range, section and tract **(Figure 3)**. Letters (A, B, C or D) specifying tract location within a section are assigned in a counterclockwise direction, beginning with "A" in the northeast quarter. For example, a well numbered 20 N 21 W 23 ADD2 specifies the second well located in the SE ¼ of the SE ¼ of the NE ¼ of Section 23, Township 20 N, Range 21 W.

For ease of reference within this report, map identification numbers, in ascending order by township and range, have been assigned to compiled and inventoried wells, as shown on **Sheet 1 (back pocket)**. (For example Well 53 refers to map identification number 53 on Sheet 1.) These well numbers, shown on **Sheet 1,** are cross referenced with location numbers in the table of inventoried wells **(Appendix A)**.

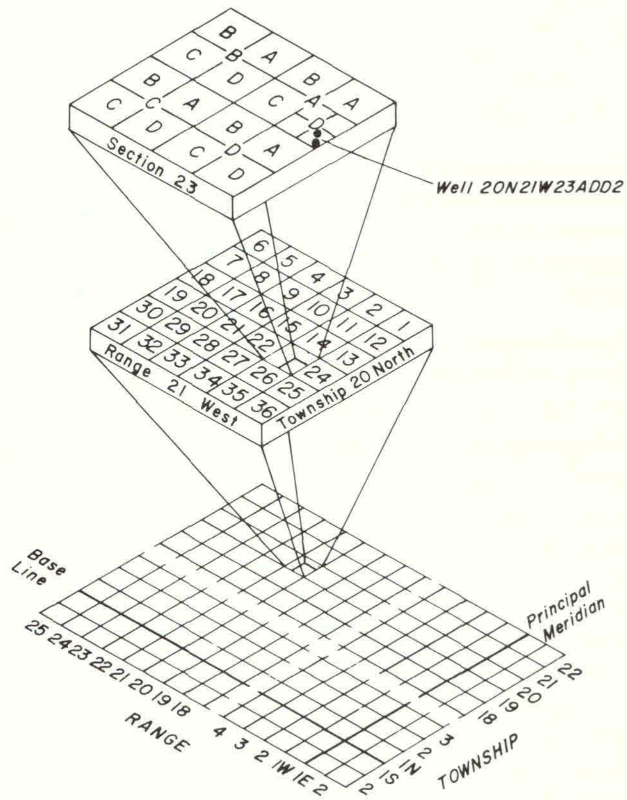


Figure 3—Location reference system, specifying legal description of land by township, range, section and tract.

Water use in the Little Bitterroot valley

History of ground-water development

Before the arrival of homesteaders on the Flathead Indian Reservation, ground water was not utilized except at springs. Agriculture became established in the valley soon after it was first opened to homesteaders in 1910, and towns, supported by this economy, arose at Hot Springs (originally called Pineville) and Camas. Early homesteaders initially attempted cultivation without irrigation of a variety of crops including grains, vegetables and forage. As it became evident that the hot dry summers required regular irrigation to assure yields, attempts were made to develop dependable summer water supplies. The first irrigation source above the bottomlands was ground water from the Lonepine aquifer. By 1915, plans had been laid for the Flathead Irrigation Project (then under the U.S. Reclamation Service), to develop surface water for irrigation.

Drill rigs closely followed the first homesteaders. The early rigs employed a jetting technique, using large mud pumps to circulate fluid down the drill rods and wash/bore through the soft lacustrine sediments. The method was well suited to silty clays, but was not capable of penetrating more than a few feet into the hard quartzitic gravels common in the valley. Early wells were of open-bottom construction and of 3 or 4 inch (8 or 10 cm) diameter. While some of these wells still exist, most (except the flowing wells) have been abandoned and silted in.

The first flowing wells were drilled along the Little Bitterroot River between Lonepine and Oliver Gulch. Unexpectedly, some of these wells yielded warm water, up to 52°C. Yields from flowing wells were good despite the crude completion techniques and they were used for both flood irrigation and stock watering. Meinzer (1916) reported yields up to 365 gallons per minute (gpm) (1,380 L/min). Nonflowing wells were drilled on the glacial lake plain between Lonepine and Hot Springs.

The Flathead Irrigation Project was completed in 1928, and the availability of Project water south of Lonepine attracted additional homesteaders. Many new wells, including some new flowing irrigation wells, were drilled as domestic and stock supplies.

According to local residents, drilling problems were common during early attempts to develop wells in the artesian aquifer beneath the valley. The high temperature of some of the early flowing wells was unexpected and difficult to handle. Casing of Well 85 (51.6°C) was complicated because of such problems, and after completion in 1915, a 40-foot (12 m) diameter washout of silt occurred around the well **(Figure 4)**. A timber was laid across the pit, allowing workers to try to seal off flow from the well by dropping a variety of hardware items into it, reportedly including a long buggy axle. The well was successfully rehabilitated using larger diameter casing and is in service today at the Camp Aqua spa. Around 1940,

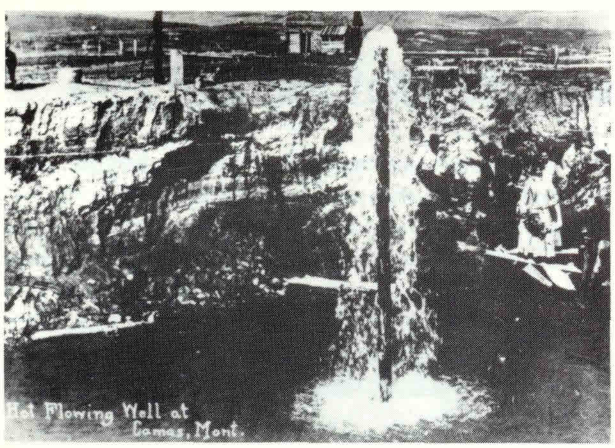


Figure 4—Large washout around Well 85 at Camas, Montana, circa 1916. (Photo courtesy Dave Kemp.)

at another well location at low elevation along the river, a hole for a new well was drilled and left uncased while the drillers drove to Spokane, Washington to obtain casing. Upon their return, they found that aquifer pressure had displaced the drilling fluid from the hole and washed out a cavity several feet in diameter, causing considerable discharge of water and much excitement among local irrigators and ranchers. The massive spring formed around the hole was finally sealed off using numerous truckloads of fill, and the drillers proceeded to another location with greater caution.

Conflicts over ground-water use and rights date back to the early homesteading days. Interference between the first few flowing irrigation wells was noted, and aquifer pressures declined to progressively lower levels in summer months as more wells were drilled for irrigation. It is likely that the aquifer has never in recent years completely recovered to its original pre-1910 pressure level. Meinzer (1916) recommended that the U.S. Reclamation Service (later the Bureau of Reclamation) purchase the artesian flowing wells from their owners and regulate their irrigation flow to prevent waste of ground water; however, this recommendation was never implemented.

A water use conflict of long duration subsequently developed. Many of the homesteaders used irrigation systems based on the transient pressure of flowing wells, which was lowest in the summer. During dry years, when withdrawals were highest, aquifer pressure and flowing yields were lowest. The problem could have been solved by installing pumps, but most of the existing wells were of inadequate diameter for high-capacity pumps and lacked access to power. Also, if a few ranchers had drilled large-diameter pumped wells, the aquifer pressure would have declined even further, making the remaining flowing wells useless for irrigation. There has been traditional sentiment among those with flowing wells to limit development of new ground-water irrigation, particularly by high-capacity pumped wells. Because of public objections, few attempts have been made to develop such pumped wells. The intent of flowing-well users has been to protect the existing water utilization practices of a large number of individuals from being endangered by new development that might benefit only a few individuals.

One pumped irrigation well that was successfully drilled in spite of public objections was an 18-inch (46 cm) diameter water well (Well 211) 0.5 miles (0.8 km) northwest of Lonepine. This well was drilled by the Flathead Irrigation Project in April 1941 to supplement storage in Dry Fork Reservoir during dry years. Details regarding the drilling, completion and production of this well and the controversy it caused are preserved in file correspondence for 1940-1942 between the Project office and E. S. Perry and G. C. Taylor, ground-water geologists for the MBMG and USGS, respectively.

The well penetrated the entire thickness of the Lonepine aquifer—at this location, 58 feet (15 m)—and was completed using perforated casing. Initial development and testing indicated that the well was capable of pumping up to 1,595 gpm (6,000 L/min). Project records show that the well was initially put into production at a mean discharge of 770 gpm for 68 days, between March 20 and May 28, 1941. This pumping drew almost immediate complaints from ranchers with flowing irrigation wells three to eight miles (5 to 13 km) down valley, who claimed it was lowering aquifer pressure in their wells. A 1,200 gpm (4,600 L/min) pump test of unknown duration was therefore performed under Project supervision in 1942, during which water levels and flows were monitored in down-valley wells. Because Project personnel apparently measured aquifer pressure by keeping observation wells continually flowing and monitoring their discharge with weirs, it is probable that much of the drawdown effect observed was caused by flow from the observation wells in addition to pumping from Well 211. However, the impact of Well 211 as far as eight miles (13 km) south was nevertheless interpreted to be real, and the Project voluntarily decommissioned their well. Unfortunately, the data from this early aquifer test were apparently not preserved.

Occasional ground-water appropriation requests for irrigation have continued to the present time, in some cases for irrigation of lands to which Project water is unavailable. These requests often meet with concerted opposition from ranchers with flowing wells.

Current water use and concerns

Because summer evaporation rates far exceed precipitation, intensive agriculture in the valley is possible only with irrigation. Irrigation water is obtained from both ground and surface sources.

Much of the surface water in the valley is obtained from a system operated and managed by the Flathead Irrigation Project of the U.S. Bureau of Indian Affairs. Runoff for this system is stored in upland retention and control facilities at Little Bitterroot Lake (capacity 26,400 acre-ft) and Hubbart Reservoir (capacity 12,125 acre-ft), from which water is seasonally diverted to fill a lowland offstream reservoir near Lonepine (Dry Fork Reservoir, capacity 3893 acre-ft) at an elevation of 2,856 feet (870 m). Upper Dry Fork Reservoir (capacity 2,845 acre-ft), at an elevation of 2,900 feet (884 m), is filled by diversion from Alder Creek, a tributary to the Little Thompson River on the west side of the Little Bitterroot drainage divide. Water is distributed from these reservoirs to ranches down valley via four canal systems. Most project-irrigated acreage is south of Lonepine. Annual irrigation quotas based on supply projections for the coming summer are established each spring by the local water user's association in Hot Springs. Quotas are based on a number of factors, including water in storage, snowpack thickness, spring rainfall, and anticipated irrigation requirements. Quotas are in effect only when water is not being spilled from Project reservoirs. The number of users of this water is fixed, with no projected additions without an increase in storage capacity. At present, Project water is used to irrigate approximately 6,000 acres.

Additional irrigation is performed by diversion of water during spring runoff from the Little Bitterroot River, Hot Springs and Garden creeks, and Sullivan Creek. Surface water rights on non-tribal lands are administered by the Montana DNRC.

Ground water is applied for irrigation on a total of approximately 3,000 to 3,500 acres, dominantly at elevations below 2,780 feet (95 m) along the Little Bitterroot River. Much of this irrigation is seasonally supplemented by surface-water irrigation. Appropriation of this ground water on non-tribal lands is also administered by the Montana DNRC. Ground-water irrigation has historically depended on flowing artesian wells, used either to flood irrigate or to fill private storage reservoirs from which water is later pumped to operate sprinkler systems. An estimated 5,000 gpm (22 acre-ft/day, or 0.32 m^3/s) of water is appropriated for irrigation on a seasonal basis from the Lonepine aquifer. An estimated 500 gpm (2.2 acre-ft/day, or 0.032 m^3/s) is consumed for stock and residential use on a yearly basis, and an additional 800 gpm (3.5 acre-ft/day, or 0.05 m^3/s) is wasted from uncontrolled flowing wells. The quantities actually applied for irrigation vary annually, depending on spring and summer precipitation and on availability of surface water.

An extensive (600-acre) area in the valley has warm water from 25-52°C, obtained from the Lonepine aquifer. Camp Aqua, the most recent of a series of bathhouse facilities at the warmest well near the center of this area, was constructed in the 1960s. The Camp Aqua geothermal area, as it will be referred to in this report, is in the center of the zone of flowing artesian wells. The quantity of warm water available from the aquifer is considerable. Recently, a private firm appropriated 500 gpm (1,900 L/min) from DNRC for a proposed geothermally assisted ethanol production plant. Other non-irrigation appropriation requests may be submitted in future years for utilization of this geothermal water.

Between the towns of Hot Springs and Camas, warm water (47 to 51 °C) discharges from Camas Hot Springs. A bathhouse and spa, operated for a number of years by the CSKT at these springs, was closed in 1981. Since then, it has been open under short-term lease to other operators. A similar operation or other use of these springs may be developed in the future. Domestic wells in the town, 250 feet (75 m) or deeper, are developed in fractured bedrock and tap warm water whose source is related to the springs. In this report, the area of Camas and Hot Springs where warm ground water has been found will be referred to as the Camas geothermal area.

Investigation procedures

Ground-water inventory and monitoring

A field inventory was performed to determine location, use, depth, yield and available drilling information for existing wells.

Conductivity, temperature and (when possible), static water level were measured. This information is summarized in **Appendix A**, with reference to map locations on **Sheet 1 (back pocket)**. Selected drillers' logs for these wells are presented in **Appendix B**.

An intensive monitoring program was performed from June 1979 to February 1982. Water level depth (or, for flowing wells, wellhead pressure), temperature and electrical conductivity were monitored every one to three months for approximately 30 wells throughout the valley. The purpose was to observe seasonal changes in response to recharge and irrigation withdrawals. Six wells were monitored with continuous water level recorders. Four additional wells were simultaneously monitored as part of the USGS statewide observation well network; one of these was monitored continuously. Monitoring data and well hydrographs are compiled in **Appendix C**.

Water quality samples were obtained from 32 wells. Electrical conductivity, pH, alkalinity and hydrogen sulfide (H_2S) were determined in the field. Three samples (raw, filtered unacidified and filtered acidified), were collected from each well and submitted to the MBMG analytical laboratory for chemical analysis. Analytical results, compiled with other analyses from this valley (Boettcher, 1982), are presented in **Appendix D**.

Geophysical surveys

Seismic refraction lines were run in the Camp Aqua geothermal area using a Geometrix 1200F engineering seismograph and a hammer source, to determine stratigraphy and bedrock depth. Results yielded approximate estimates of bedrock depth where it was shallower than 300 feet (90 m). The energy source used was insufficient for examining bedrock at greater depth.

Natural gamma ray logs were run in three water wells by the USGS. The results provide stratigraphic information on the Lonepine aquifer and Glacial Lake Missoula sediments.

Drilling investigation

In January 1980, a test well (Well 88) was drilled in the Camp Aqua geothermal area. The purpose was to investigate the potential for development of geothermal water from the bedrock fracture system beneath the Lonepine aquifer, so that it would not be necessary to utilize the irrigation aquifer itself as a source of hot water. The test well was drilled using an air rotary rig and cased to bedrock with 6-inch (15-cm) diameter casing. The well was continued open hole to a depth of 1,002 feet (305 m). Drilling and geophysical logs (SP, resistivity, gamma ray, neutron and temperature) are included in **Appendix E**. Additional details regarding test results and interpretation are presented in Donovan and Sonderegger (1981).

Aquifer testing

Aquifer tests were performed in March and April, 1980-1983 on a total of six wells, to determine characteristics of the Lonepine aquifer. Two test wells (Wells 84 and 86) in the Camp Aqua geothermal area, drilled into the gravel by a private firm attempting to develop geothermal water, were available for sampling and testing for this study. All tests were run before irrigation started, to reduce the risk of interference from concurrent well use. Flowing wells were tested and interpreted using the overflow technique (Jacob and Lohman, 1952; Rushton and Rathod, 1980), opening each well from an initially shut-in condition and measuring the decrease in discharge as a function of time. Discharge was measured using a magnetic paddle-wheel flowmeter coupled with a continuous analog recorder (resolution 1 percent, accuracy 5 percent of full scale). Recovery was monitored and interpreted using corrected values of time (Jacob, 1963). Drawdown and recovery were monitored at observation wells throughout the valley for tests 4, 5 and 6. Some of these wells were monitored continuously using Stevens 1-, 2- and 4-day recorders or recording pressure transducers. For others, response was measured at selected time intervals using steel tape, electric tape, pressure gauges or pressure transducers.

Aquifer tests performed and observation wells monitored are listed in **Table 1**. Aquifer test data and plots are on file with the MBMG (Donovan, 1985).

Table 1—List of aquifer tests and observation wells.

Test no.	Date	Flow period	Production well(s)	Mean discharge	Observation wells
1	3-26-80 to 3-28-80	48 hrs.	59	385 gpm	56, 57
2	4-30-80 to 5-03-80	67.5	89	90 gpm	none
3	5-04-80 to 5-05-80	20	11 + 12	480 gpm	none
4	4-14-81 to 4-17-81	70	88	508 gpm	Recorders: 59, 64, 85, 98, 118, 144, 159, 196, 211
5	3-10-83	3.2	84	780 gpm	Recorders: 24, 64, 85, 98, 118, 144, 159, 177, 196, 207, 211 Others: 35, 59, 82, 89, 95, 110, 134, 172, 184, 185, 210, 213, 231
6	3-10-83	67.5	84 + 88	1110 gpm	as for Test 5

Ground-water geology

General

Geologic units in the Little Bitterroot valley and a geologic map modified from Harrison and others (1981) are presented in **Figures 5** and **6**, respectively.

Aquifers present in the valley include shallow aquifers, the Lonepine aquifer and bedrock aquifers:

(1) Shallow aquifers: Primarily Pleistocene sand and gravel deposits and Holocene fluvial terrace or colluvial deposits.

(2) Lonepine aquifer: Throughout the valley, from near Niarada south to beyond the south edge of the study area **(Sheet 1, back pocket)**, a permeable unconsolidated sand and gravel bed occurs below the lacustrine deposits. The extensive continuity and level nature of this bed suggest a glaciofluvial origin.

The Lonepine aquifer is not exposed, although terrace gravel deposits exposed along the Little Bitterroot River west of Niarada may be continuous with it. Fossilized silicified wood, probably of Tertiary age, was recovered from a flowing well (Well 71) in the aquifer but may be redeposited Tertiary material. The probable age is Pleistocene. The Lonepine aquifer is tentatively designated as the base of Pleistocene sediments in the valley.

The Lonepine aquifer overlies Tertiary (?) basin-fill deposits throughout most of the valley, except in the Camp Aqua geothermal area where it overlies a Precambrian bedrock shelf or knob evident on a Bouguer gravity anomaly map (Dresser, 1979) **(Figure 7)**.

(3) Bedrock aquifers: North of the Little Bitterroot valley, Tertiary volcanic rocks were deposited

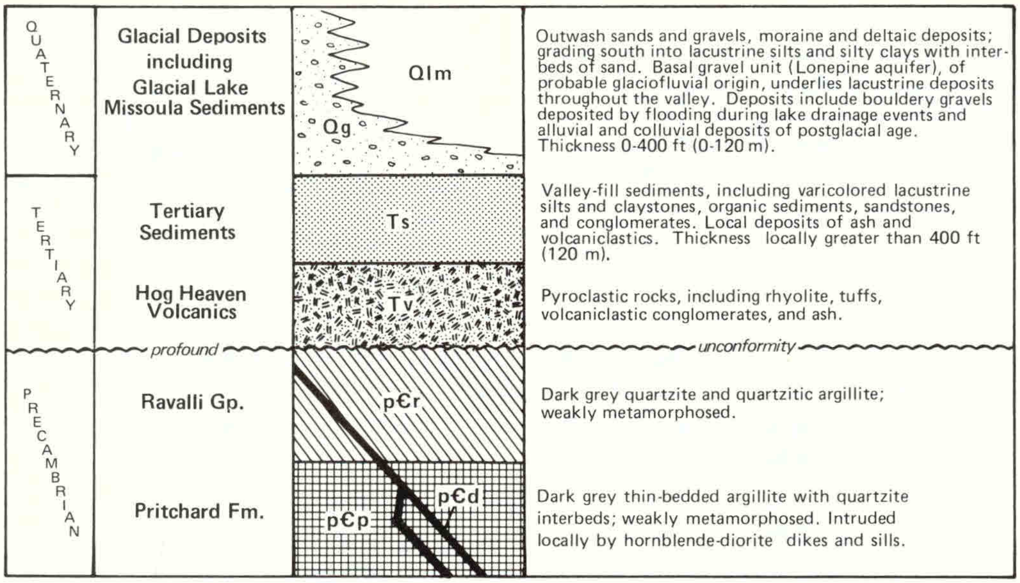


Figure 5—Stratigraphic section of geologic units in the Little Bitterroot valley.

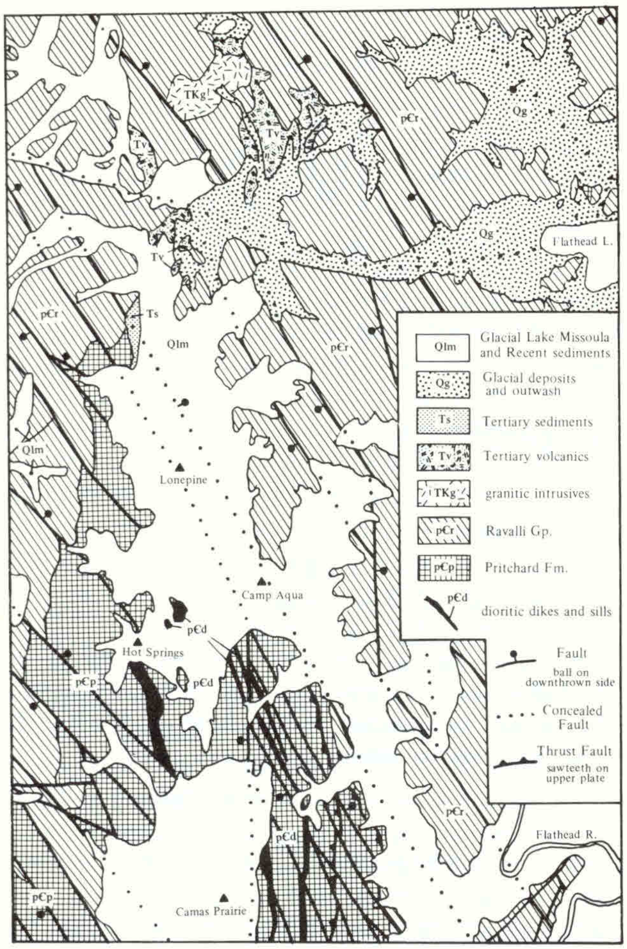


Figure 6—Generalized geologic map of the Little Bitterroot valley. ***(Modified from*** **Harrison and others, 1981.)**

around a series of eruptive centers in the Hog Heaven Range (Shenon and Taylor, 1936). Hydrothermal activity associated with the volcanics created silver deposits in this range, which have been worked at several locations including the currently active Hog Heaven Project (CoCa Mines, Inc.) 6 miles (10 km) northeast of Niarada. Possibly contemporaneous Tertiary volcaniclastic sediments are exposed to the southwest of these volcanics, along the north and west side of the valley near Niarada. These partially consolidated sediments consist of complexly interbedded conglomerates, lacustrine deposits with a diverse fossil flora and fine white volcanic ash **(Figure 8)**. The ash contains biotite phenocrysts that have not been dated. These sediments may be contemporaneous with similar sequences of Oligocene age in Western Montana.

Estimates of maximum valley-fill thickness (including Tertiary deposits) based on 2-dimensional modeling of gravity data (Dresser, 1979) range from 1,000 to 3,000 feet (300 to 900 m). The greatest thickness currently known from drill holes exceeds 870 feet (>265 m), at the south end of the valley near Sloan Ferry. A linear depression in the gravity data, probably an early or mid-Tertiary channel cut into Precambrian bedrock, appears to be continuous throughout the valley **(Figure 7)**.

The uplands to the west and east of the valley are underlain by low-rank metasedimentary rocks of the Precambrian Belt Supergroup **(Figures 5, 6)**, including the Pritchard Formation and units of the Ravalli Group. These units comprise a thick sequence of

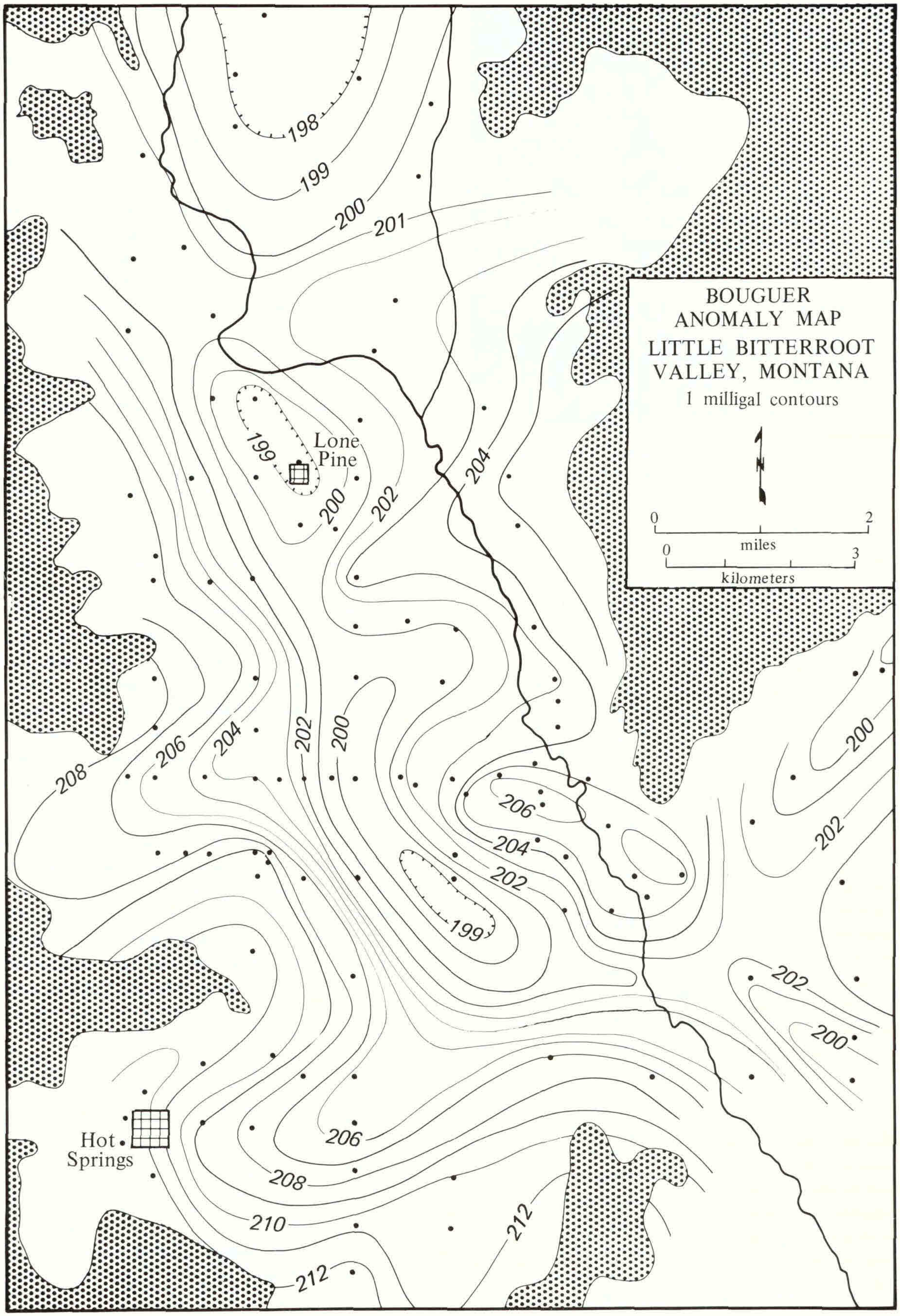


Figure 7—Detailed Bouguer anomaly map of the Little Bitterroot valley (*after* Dresser, 1979). Black dots indicate gravity stations.

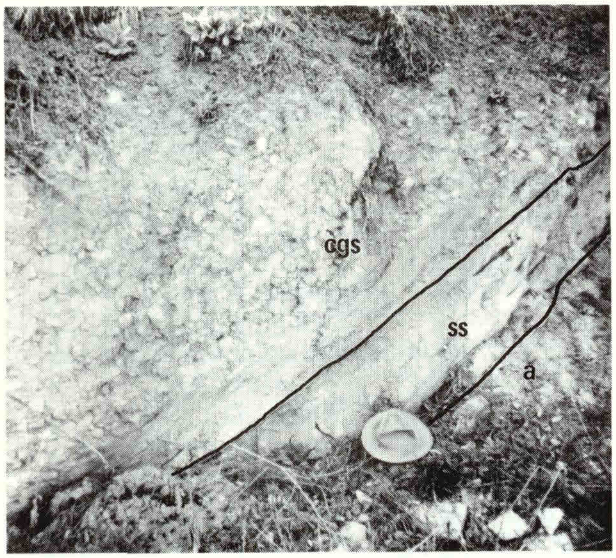


Figure 8—Photograph of Tertiary sediments northwest of Lonepine. From top to bottom: (cgs), conglomeratic sandstone, possibly of mudflow origin; (ss), laminated siltstone with abundant deciduous flora; and (a), white volcanic ash with biotite phenocrysts.

slightly metamorphosed interbedded argillites and quartzites. The rocks are folded along the axis of the Purcell anticlinorium, which extends south from the Canadian border. The east and west sides of the valley are probably bounded by high-angle faults, although there is disagreement about the geometry and nature of movement of this faulting at depth (Harrison and others, 1980). The Belt rocks form fractured aquifers which are generally of low permeability, but can provide sufficient water for domestic supplies. Along several fault or fracture zones, these rocks are more permeable and transmit appreciable quantities of deeply circulating geothermal water.

Shallow aquifers

Shallow alluvial aquifers include fluvial terrace deposits along the Little Bitterroot River north of Lonepine; outwash sand and gravel in the Sullivan Creek and Big Draw areas; and alluvium in tributary valley-margin basins and gulches.

Fluvial terrace deposits, of apparent post-Glacial Lake Missoula origin, occur along the north end of the Little Bitterroot River west of Niarada, where the river emerges from its steep mountainous course. At least two and possibly three terraces, becoming younger with lower elevation, occur along the east side of the river. The terraces cannot be traced farther south than Upper Dry Fork Reservoir. Approximately 35 feet (10 m) of bouldery gravels in the second highest terrace are exposed in a borrow pit just west of Well 183. An adjacent drillhole (Well 184) indicates that the gravels here are at least 72 feet (22 m) thick.

These bouldery terrace deposits are very permeable and form a productive water table aquifer tapped for irrigation by a few wells (Wells 184, 185). Irrigation from these wells has apparently not caused noticeable additional drawdown in flowing irrigation wells down valley to the south. Terraces preserved on the surface of these deposits are not overlain by Glacial Lake Missoula deposits and are plainly post-Glacial Lake Missoula in age. It is unlikely, therefore, that the terrace gravels themselves correlate stratigraphically with the Lonepine aquifer down valley, which is overlain by over 200 feet (60 m) of glaciolacustrine sediments. However, these gravels are at least 72 feet (32 m) thick in the vicinity of Well 184, and may be thicker in the center of the valley beneath the river, where they may overlie older gravels that are hydrogeologically continuous with the Lonepine aquifer.

Sands and gravels in the Big Draw area are also clean and permeable, ranging from 200 to 480+ feet (60 to 146+ m) thick. They are tapped by a number of wells, none of which are currently used for irrigation. Recharge is thought to be derived mainly from local precipitation, and from losses attributed to Cromwell and Sullivan creeks. Ground-water flow systems in Tertiary volcanic bedrock, driven by precipitation in the uplands, could also recharge this alluvium. Ground water in this small basin is thought to flow south into the Little Bitterroot valley through the narrow valley of Sullivan Creek at Niarada. The limited thickness of clean gravel and narrow width of the channel in this gap may restrict the rate of recharge.

Numerous tributary creeks and gulches are found along the margins of the Little Bitterroot valley, including Hot Springs Creek, Garceau Gulch, Garden Creek, Wilks Gulch, Sullivan Gulch and Rattlesnake Gulch. Small springs occur in most of these gulches, some of which have been developed by local ranchers. Spring location is probably controlled by topography and underlying stratigraphy and bedrock depth. Along Hot Springs and Garden creeks, wells have been drilled into shallow alluvium, mainly sand interbedded with lacustrine deposits. These wells are of variable productivity but generally yield only enough for domestic or stock use; a few exhibit artesian flow. The aquifers appear to dip into the valley fill of the Little Bitterroot valley and may discharge into permeable zones within the Glacial Lake Missoula sediments or the Lonepine aquifer. However, test holes drilled in Rattlesnake and Sullivan gulches penetrated no permeable alluvial or glacial deposits (Steve Slagle, personal communication, 1985). In these gulches, varicolored silt, sand and gravel of probable Tertiary age underlie glaciolacustrine sediment within 100 feet (30 m) of the surface.

In Rattlesnake Gulch, these Tertiary sediments continue to a depth of at least 570 feet (173 m).

Shallow sand and gravel alluvial aquifers capable of well yields of up to several hundreds of gpm are found in Garceau and Oliver gulches (Steve Slagle, personal communication, 1985). A well in Oliver Gulch (Well 1), pumped at 256 gpm (970 L/min) for 3.5 hours, exhibited 11.0 feet (3.3 m) of drawdown while Well 54 in Garceau Gulch exhibited 1.4 feet (0.4 m) of drawdown after pumping at 65 gpm (246 L/min) for 1.7 hours. These moderately transmissive aquifers occur within 100 feet (30 m) of the surface in sediments interpreted by this author as Pleistocene.

Alluvium along the bottomlands of the Little Bitterroot River south of Lonepine is not a productive aquifer; its permeability is reduced by silt derived from erosion of lacustrine deposits.

Lonepine aquifer

Wells and water use

Ground water from the Lonepine aquifer is used throughout the valley for stock and domestic supply. At elevations below 2,780 feet (847 m) southeast of Lonepine, wells flow and many are used for irrigation. Irrigation is performed using flooding techniques or pumping from storage reservoirs filled by flowing wells. Most of these wells are cased through the Glacial Lake Missoula sediments and completed open bottom a few feet into the gravel, without perforations.

Non-flowing domestic and stock wells are not regularly cleaned or developed by high-yield pumping and are susceptible to plugging by siltation or casing corrosion. Some plugged wells have been successfully reclaimed by blowing the bottoms clean with compressed air. Completion using a short length of well screen or finely-slotted casing would probably result in wells less prone to these problems.

Many flowing wells avoid siltation by high flow velocity, and some dating back to early in the century still flow efficiently today. However, inadequate well seals, casing corrosion and slow piping of silt around the casing have caused leaks around the casing of many wells, some of which cannot be shut in without causing an uncontrolled washout by substantial flow around the casing. These runaway wells are left to discharge large volumes of wasted water. The current estimated volume of water known to be wasted in this manner is from 700-1,200 gpm (2,600-4,600 L/min), excluding wells left flowing to water stock or prevent freezing.

Both flowing and non-flowing wells are subject to corrosion of casing by hydrogen sulfide, which occurs in high concentration (>0.25 mg/L) in many parts of the aquifer, especially in the geothermal areas. In non-flowing wells, such corrosion often occurs in the zone where the water level fluctuates. Slotted plastic liners could reduce the risk of such well damage.

Extent, thickness and depth

The Lonepine aquifer is the most productive water-bearing unit in the Little Bitterroot valley and is therefore the primary focus of this investigation.

Information regarding the Lonepine aquifer was compiled from water well drillers' logs and depths, a few geophysical logs and observations of its hydrogeologic response and chemistry. Many of the older wells were completed only 0-5 feet (0-1.5 m) into the gravel bed, and their depths allow a good estimate of the aquifer's top elevation. The aquifer consists of very clean gravel, composed dominantly of red, green and gray quartzite from the Belt Supergroup. It extends from at least as far north as Niarada, and as far south as the Flathead River. Test holes drilled in the lower valley south of Oliver Gulch penetrated finer and sandier deposits than in the upper valley (Steve Slagle, personal communication, 1985). This could indicate a transition from high-energy fluvial to low-energy fluvial or deltaic depositional environments. The bed is interpreted as outwash deposited during the Late Wisconsinan, when the Flathead lobe was at, or near, the Big Draw morainal position west of Elmo (Smith, 1977). This ice lobe was probably a major source of meltwater for the outwash system, with additional sources at ice-frontal positions in upland gaps north of the Little Bitterroot valley near McDonald, Little Bitterroot and Rogers lakes (Alden, 1953).

The overlying Glacial Lake Missoula sediments are dominantly silty clays with a few interbeds of fine sand and rare thin gravel seams. The interstratified zone occurs mainly in the lower portion of the lake deposits and is moderately transmissive. Its thickness increases from south to north, from about 40 feet (12 m) near Camp Aqua to about 200 feet (60 m) near Lonepine. Natural gamma-ray logs from Wells 88, 98 and 211 distinguish between homogeneous Glacial Lake Missoula clays and the interstratified zone.

The transition to the underlying Lonepine aquifer is abrupt, often described by drillers as a hard "caprock". Interpolated structure contours of the aquifer top are presented in **Sheet 1 (back pocket)**, with elevations accurate to ± 10 feet (± 3 m). In the northern part of the valley, the aquifer top is reasonably level, dipping at a gradient of 0.02 percent (1 ft/mile) from north to south. From Oliver Gulch south, this gradient increases slightly to 0.06 percent (3 ft/

mile). Local variability in the top elevations in the north is attributed to meandering of outwash channels across the valley.

Because so few wells fully penetrate the aquifer, its thickness is not well known. Wells that have fully penetrated the aquifer include:

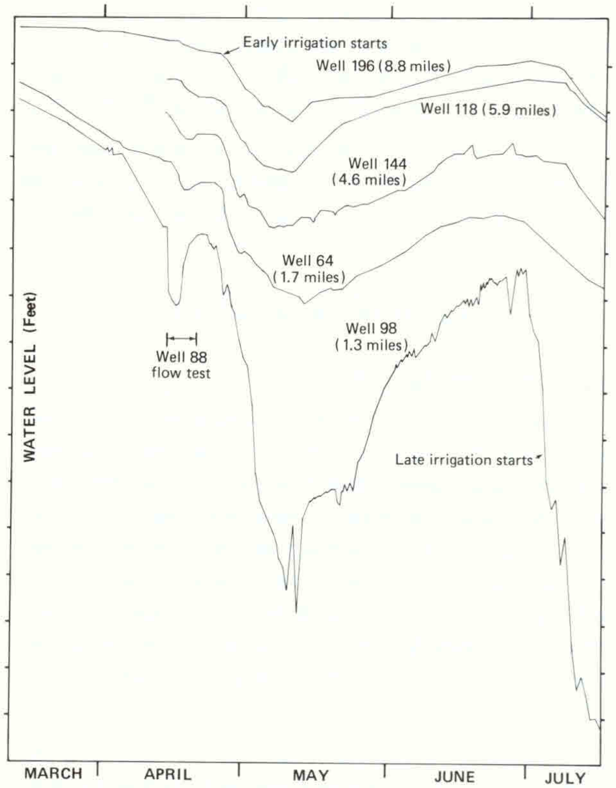
Well	Thickness of Lonepine aquifer
237	21 feet (6.4 m)
211	58 feet (17.7 m)
88	24 feet (7.3 m)
84	19 feet (5.7 m)
24	23 feet (7.0 m)

These data suggest that the aquifer thins from approximately 60 feet (18 m) in the north to 20 feet (6 m) or less in the south. However, data are sparse at both ends of the valley, and it is likely that there is local variation.

Potentiometric fluctuations

Substantial interference between high-yield flowing wells occurs during the irrigation season (April-September). Monitoring was performed from 1979 to 1981 to determine the magnitude of this interference. Potentiometric data from the monitoring wells confirm hydraulic continuity of the aquifer throughout much of the valley and rapid decline in head in response to irrigation from wells.

Hydrographs for several wells that were continuously monitored during 1981 are typical of the pattern of ground-water fluctuation during years of intensive irrigation (**Figure 9A, B**). During both flow testing and irrigation, extremely rapid response was observed in wells as far as 9 miles (14 km) from the center of the artesian flow area. Aquifer pressure was highest in late winter (March 1981), after seven months of water level recovery since the previous irrigation season. Because the previous summer had seen unusually high rainfall and little irrigation, this peak pressure was probably at its highest level in recent years. A few ranchers filled their storage reservoirs with ground water in April, when aquifer pressures were still high. The summer irrigation season began with the onset of hot weather in May; drawdown continued during irrigation, showing temporary recovery in late July during a cool rainy period. Water level recovery promptly followed the shutting in of the last of the flowing wells in early September. Recovery occurred rapidly at first, slowing considerably by late fall. The aquifer had nearly completely recovered by the end of October, followed by continued recovery into the winter at a much slower rate. The pattern of drawdown and recovery in 1981, particularly the double-spiked appearance of the drawdown phase (**Figure 9B**), is typical of the aquifer's behavior, although variations from this pattern due to weather conditions are common. Aquifer response depends on local precipitation, not because of the recharge it provides, but because of its effect on irrigation demands.



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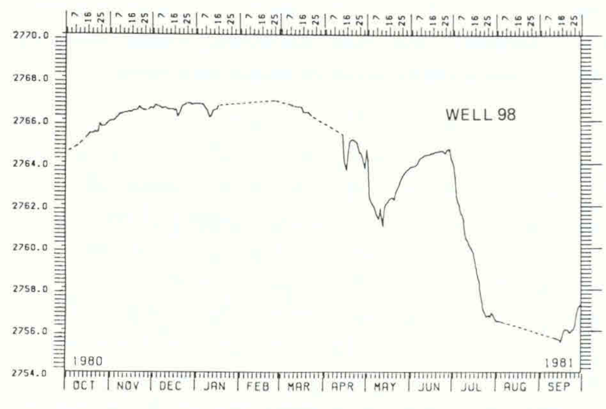

B

Figure 9—Hydrographs of observation wells in Lonepine aquifer during 1981: (A), Comparative hydrograph of 5 wells showing continuity of aquifer response throughout the valley; (B), hydrograph of Well 98 for 1981 water year.

Aquifer characteristics

Despite the extensive area of influence and of drawdown as a result of irrigation, the Lonepine aquifer is highly productive. Total drawdown caused by irrigation in a normal summer is approximately 20 feet (6 m) close to the area of flowing wells and from 2 to 20 feet (0.6-6 m) in peripheral parts of the valley. This is not an excessively high drawdown for an irrigation aquifer. Specific capacities of most irrigation wells lie between 100 and 200 gpm per foot of drawdown (0.006 to 0.013 m^2/s), indicating substantial well productivity.

Six aquifer tests were performed using the overflow technique, in which an initially closed-in well under a steady-state (equilibrium) condition is opened to flow freely and the decrease in well discharge is measured with time **(Table 1)**. Two of these tests (3, 6) were performed allowing two nearby wells to flow simultaneously; the other four utilized single production wells. Results of overflow tests (transmissivity and storativity estimates) at productions wells for tests 1 through 6 are listed in **Table 2**, and results for observation wells in tests 5 and 6 are listed in **Table 3**.

Results for test 1 (Well 59) were inconclusive because yields were inadequate to stress the aquifer. Results for test 2 (Well 89) were inconclusive because of an increase in well efficiency and yield during the test, caused by high flow after a winter dormancy period. Test 3 (Wells 11 and 12) yielded a good estimate of apparent transmissivity and boundary effects in the vicinity of Oliver Gulch. Tests 4, 5 and 6 (using Wells 88, 84 and 84 + 88, respectively) yielded detectable response at observation wells throughout the valley.

Aquifer response during testing was dominated by boundary effects, making the determination of true aquifer transmissivity difficult, especially for distant observation wells. Continuous observation well data from Well 98 during test 6 demonstrated this problem **(Figure 10)**. Drawdown was initially detected at 2,700 seconds (45 min). A succession of at least two and possibly three straight line segments can be fitted to the subsequent drawdown data:

Step	Time (in sec.) From	Time (in sec.) To	Apparent transmissivity m^2/s	Apparent transmissivity gpd/ft	Interpretation
1	7,000	12,000	0.106	740,000	Aquifer transmissivity
2	12,000	70,000	0.033	229,000	1st boundary
3	70,000	223,000	0.0196	137,000	2nd boundary (or boundary reflections?)

The transmissivity data for test 6 **(Table 4)** are listed according to this interpreted sequence of boundaries, as observed for Well 98. The sequence and magnitude of boundary effects vary not only with the location of the observation well but also with the location of the pumping well with respect to these boundaries. Because of the very high transmissivity of the Lonepine aquifer, its low storativity in comparison to water table aquifers, and the narrow

Table 2—List of aquifer test results for flowing production wells, tests 1-6.

Test no.	Production well(s)	Mean discharge (gpm)	Step no.	Apparent transmissivity, m^2/second (gallons/day/foot in parentheses) Drawdown test		Recovery test	
1	59	380		*		—	
2	90	90		**		—	
3	12 +	480	1st	0.030	(209,000)	—	
	11		2nd	0.0126	(88,000)		
4	88	508	1st	0.102	(708,000)	—	
			2nd	0.0204	(141,000)		
5	84	780	1st			0.0584	(406,000)
			2nd			0.0176	(122,000)
6	84 +	1110	1st	0.0655	(455,000)	0.0711	(494,000)
	88		2nd	0.0286	(199,000)	0.0156	(108,000)

* Indicates interpretation not possible due to well development during early hours of test.

** Indicates interpretation not possible due to insufficient flow.

Table 3—List of aquifer test results for observation wells, tests 5 and 6.

Well no.	Storativity	Step no.	Apparent transmissivity, m^2/second (gallons/day/foot in parentheses) Drawdown test		Recovery test	
Test 5 (Production well = 84, mean discharge = 780 gpm)						
85	7 X 10-5	1st	0.087	(604,000)	—	
		2nd	0.004	(97,000)	—	
88	9 X 10-4	1st	—	—	—	
		2nd	0.011	(76,000)	—	
Test 6 (Production wells = 84, 88, mean discharge = 1110 gpm)						
24	3 X 10-5	1st	—	—	—	
		2nd	0.029	(201,000)	—	
47			no response to test			
59	1.5 X 10-5	1st	—	—	—	
		2nd	0.022	(153,000)	0.053	(368,000)
63*	1 X 10-2	1st	1.17	(8,000,000)	—	
		2nd	0.188	(1,300,000)	—	
77	3 X 10-5	1st	—	—	—	
		2nd	0.019	(132,000)	0.010	(69,000)
82	4 X 10-5	1st	0.033	(229,000)	—	
		2nd	0.021	(146,000)	0.015	(104,000)
85		1st	—	—	0.059	(410,000)
		2nd	0.018	(125,000)	0.011	(76,000)
88	9 X 10-4	1st	—	—	0.0934	(653,000)
		2nd	—	—	0.010	(69,000)
89	7 X 10-5	1st	—	—	—	
		2nd	0.027	(188,000)	0.012	(83,000)
95	2 X 10-4	1st	—	—	—	
		2nd	0.022	(153,000)	0.023	(160,000)
98	3 X 10-4	1st	0.106	(736,000)	0.075	(521,000)
		2nd	0.032	(222,000)	0.020	(139,000)
118	5 X 10-4	1st	0.178	(1,240,000)	—	
		2nd	0.058	(403,000)	0.059	(410,000)
144	1 X 10-4	1st	0.213	(1,480,000)	0.117	(812,000)
		2nd	0.036	(250,000)	0.018	(125,000)
159*	2 X 10-3	1st	—	—	—	
		2nd	0.089	(618,000)	0.098	(680,000)
177			no response to test			
183			no response to test			
196*	2 X 10-4	1st	—	—	2.28	(15,000,000)
		2nd	1.03	(7,000,000)	—	
207*	3X 10-4	1st	1.03	(7,000,000)	—	
		2nd	0.112	(778,000)	—	
Frolin Pit (T23N R24N 02BDD)			no response to test			

* Results of questionable validity.

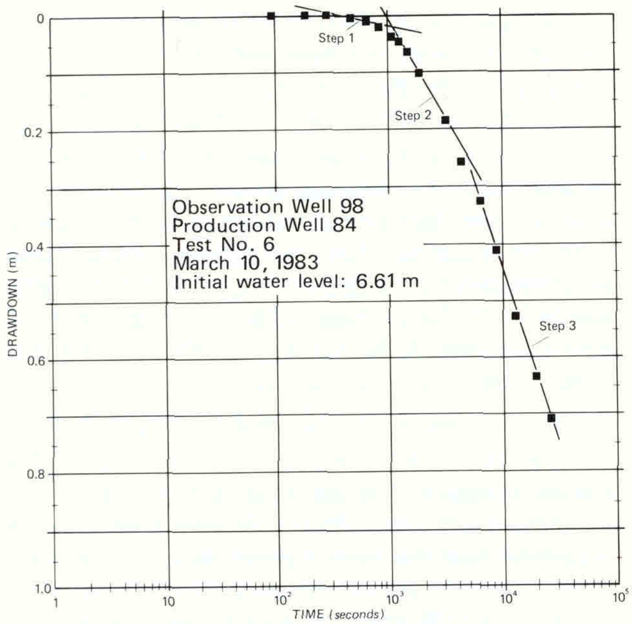

Figure 10—Drawdown vs. log time (Jacob) plot of aquifer response at Well 98 during test 6.

dimensions of the valley, most of the observation well transmissivity data interpreted from the tests are thought to represent apparent values, reduced by barrier boundaries.

Aquifer test results can be summarized as follows:

(1) The aquifer is hydraulically continuous throughout the portion of the valley investigated.

(2) True aquifer transmissivity in the portion of the valley studied is a very high value, 0.086 m^2/s (600,000 gpd/ft) or greater in the northern part of the valley, and 0.03 m^2/s (200,000 gpd/ft) or greater in the southern part.

(3) The best (mean) estimate of aquifer storativity is about 3×10^{-4}.

(4) After 24-48 hours, the apparent aquifer transmissivity is reduced by boundary effects to between 0.0144-0.0864 m^2/s (100,000 to 600,000

Table 4—Steady-state fluxes for aquifer model.

Source	Description	No. of nodes	Total flux gpm	Total flux L/min	Constant head (H) or flux (F)
Recharge					
Alluvial aquifers					
Upper Sullivan Creek	N. boundary	4	190	720	F
Garden Creek	W. boundary	10	130	480	F
Hot Springs Creek	W. boundary	17	160	600	F
Wilks Gulch	W. boundary	2	30	120	F
Oliver Gulch	E. boundary	2	30	120	F
Garceau Gulch	E. boundary	8	260	960	F
Geothermal	Underflow	21	930	3,540	F
Little Bitterroot gravels	N. boundary	8	0	0	H
		Total	1730	6,540	
Discharge					
Uncontrolled flowing wells		2	-950	3,600	F
Discharge area	S. end of model	4	-780	3,000	F
Irrigation wells		20	0	0	F*
Test wells	88, 84	2	0	0	F*
		Total	-1730	6,600	

* Used for transient simulations (Runs 2, 3, 4) only.

gpd/ft), with higher values in the north. The significance of transmissivity data calculated by testing for distant observation wells is limited, as these may be strongly affected by recharge.

Ground-water flow

An interpolated profile of the aquifer potentiometric surface from north to south in March (A) and August (B) 1981 is presented in **Figure 11**. Profile A is of the recovered aquifer approaching steady-state and Profile B is of the aquifer under stress during the irrigation season.

The potentiometric gradient of Profile A slopes gently (gradient 0.01 percent, 0.5 ft/mile) from north to south, steepening south of Well 85, in the Camp Aqua geothermal area (0.06 percent, 3 ft/mile). This increase in slope accompanies a marked narrowing of the valley near Oliver Gulch and possibly a decrease in transmissivity. In the north, head in the confined aquifer appears to approach that of the water table in the Little Bitterroot terrace gravels near Well 185, approximately 2,783 feet (848 m).

Profile B shows drawdown caused by irrigation, most pronounced in the area of flowing wells, but extending to north of Lonepine. The interpolated gradient between Well 185 and 196, 1.7 miles (2.7 km) southeast, appears steepened during irrigation, while south of Well 196 it is only slightly altered.

For the nearly steady-state flow conditions of Profile A, approximate calculations of aquifer flux can be made. Testing indicates that transmissivity is on the order of 0.086 m^2/s (600,000 gpd/ft) in the upper valley and 0.03 m^2/s (200,000 gpd/ft) in the lower valley south of Oliver Gulch. Based on reported gravel thicknesses from drillhole data, the mean hydraulic conductivity is calculated at 0.5 cm/s, a reasonable value for outwash gravel. Aquifer width is about 3 miles (4.8 km) north of Camp Aqua and about 1.5 miles (3.2 km) in the narrow lower valley. Based on these conditions and on the potentiometric gradients for Profile A **(Figure 11)**, flux is estimated at about 700 gpm (2,850 L/min) in both the upper and lower valley.

Potentiometric data, surficial geology and aquifer test results suggest that significant recharge of the Lonepine aquifer may be induced from the terrace gravels near the Frolin Ranch. As discussed above, it is possible that this terrace gravel aquifer is vertically continuous with the Lonepine aquifer. Between Well 185 and Well 196 there could be induced recharge or leakage to the aquifer and a transition from water table (unconfined) to artesian (confined) conditions. The following observations support this hypothesis:

(1) After recovery from stress an extensive portion of the aquifer approaches, but never exceeds, a steady-state elevation of 2,783 feet (848 m).

(2) Most early potentiometric levels reported in Meinzer (1916) are in agreement with those of March 1981, and also do not exceed 2,783 feet (848 m).

(3) Coarse bouldery sand and gravel is logged (Well 184) to at least 72 feet (21 m) in depth (ele-

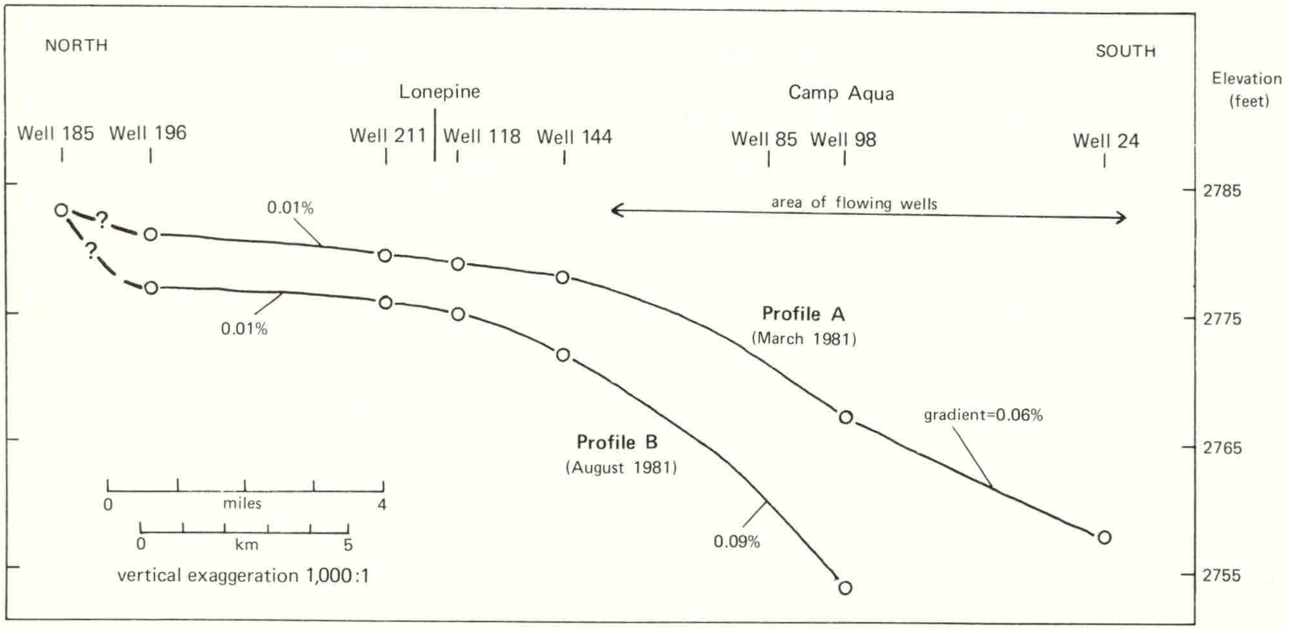

Figure 11—Potentiometric profiles during March and August 1981.

vation 2,724 ft, 828 m). This gravel deposit contains a water table adjacent to, and in hydraulic continuity with, the Little Bitterroot River, which may be hydraulically continuous with the Lonepine aquifer.

Response to test 6 (wells 84 and 88) was not observed in the water table near Well 185, but, by calculation, the test would have induced less than 0.05 ft (0.01 m) of drawdown in the gravels, an insignificant amount relative to short-term fluctuations in river stage that probably control the alluvial water table level. During the actual test, non-systematic fluctuations of up to 0.1 ft (0.03 m) occurred in this water level.

Additional recharge water may also move into the aquifer from the upper Sullivan Creek-Big Draw area; the quantity would be controlled by gravel width and transmissivity at Niarada (near Well 237).

Flathead Lake is a potential recharge source for the northern end of the Little Bitterroot valley and the Sullivan Creek area. The most likely path for this recharge would be through the thick, permeable outwash gravels of Big Draw, and from there into the Little Bitterroot valley through the narrow portion of the valley at Niarada. However, initial data do not support this hypothesis. Narrow aquifer width and limited thickness is indicated by current drilling data in the Niarada gap (Well 237); these factors could restrict the rate of recharge moving south into the valley. In addition, Well 221, in outwash gravels near the center of Big Draw, had a water table elevation of 2,906.8 feet (886.2 m) on November 6, 1984, significantly higher than that of Flathead Lake on that date (2,890.48 ft/881.24 m at the Somers Station). Therefore, flow through Big Draw from Flathead Lake cannot be invoked as a recharge mechanism for the Lonepine aquifer, unless a deeper aquifer isolated from the shallow gravels found at Well 221 is the conduit.

Near Camp Aqua and elsewhere, some geothermal water also enters the Lonepine aquifer through its base, as discussed in the *Geothermal resources* section of this report.

Confined ground water in the Lonepine aquifer is known to occur as far south as a well in Section 23, T 20N, R 22W, approximately 10 miles (16 km) south of Camp Aqua. From there, ground water in the aquifer may discharge water either into alluvium of the Flathead River or into deeper aquifers within the Flathead Valley. Field data collection in the discharge area was not a focus of this investigation.

Bedrock aquifers

Bedrock aquifers occur in semiconsolidated Tertiary sediments, including sand, sandstone and conglomeratic gravel; in fractured Tertiary volcanics in and surrounding the Hog Heaven Range north of the Little Bitterroot valley (Shenon and Taylor, 1936); and in fractured quartzite and argillite of the Belt Supergroup.

Information on aquifers in Tertiary basin-fill sediments is currently incomplete, but drilling and testing data (Steve Slagle, personal communication, 1985) indicate more limited potential than for the Lonepine aquifer. Testing of a well south of the study area (T20N, R22W, Sec. 28 ABCB) induced 81.7 feet (24.9 m) of drawdown after pumping at 11.4 gpm (43 L/min) for two hours. The deepest Tertiary deposits appear to consist of sandstone-siltstone-coal successions, probably deposited by a south-flowing fluvial system. In one test well (Well 54), a potential sandstone aquifer was noted. These deposits grade upward into probable lacustrine deposits. Tertiary fluvial and lacustrine sediments appear to have filled in all depressions in the Little Bitterroot valley to approximate elevations of 2,535 feet (773 m) at Niarada, 2,510 feet (765 m) at Lonepine, and 2,410 feet (735 m) at the mouth of the Little Bitterroot. This represents an ancient late Tertiary land surface gradient of 4 percent, very similar to that which exists today. All investigations for gravel aquifers of irrigation potential below the Lonepine aquifer (including one recommended by Perry in 1941 during the drilling of Well 211) have been unsuccessful.

A few wells tap Tertiary volcanic aquifers in the upper Sullivan Gulch area north of Niarada. Locally these volcanics have highly fractured or altered zones, and the potential for adequate yields for domestic use is good.

Numerous wells in fractured Precambrian bedrock have been successfully drilled in the town of Hot Springs. Both transmissivity and storage in these fracture-porosity aquifers is low. Some of these wells produce warm water very similar in chemistry to that discharging from Camas Hot Springs. Yields of 1-10 gpm (4-40 L/min) are obtained. Camas Hot Springs yields water from a valley-margin bedrock fracture system from which water seeps through thin alluvium and discharges as springs.

Water quality and geochemistry

Ground water in the valley contains low total dissolved solids concentrations and is acceptable for human consumption.

A plot of electrical conductivity for water wells in the valley (**Figure 12**) indicates that the dominant pattern is a linear NW-trending anomaly, centered on

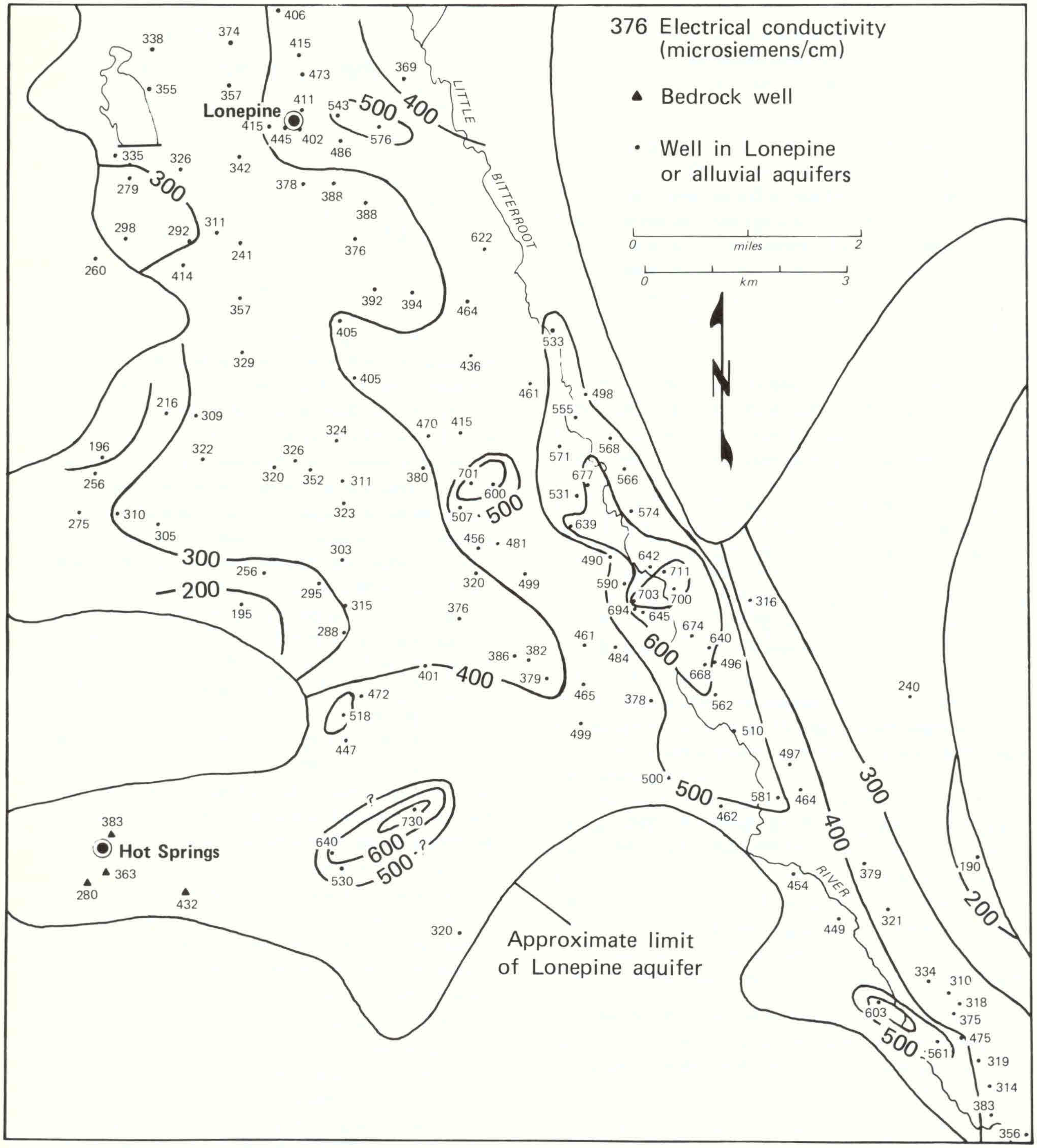

Figure 12—Electrical conductivity in Lonepine aquifer water.

the Camp Aqua geothermal area and extending from north of Lonepine to Oliver Gulch. Conductivity within this anomaly (450-720 microsiemens/cm) is higher than the background values in the aquifer (250-350 microsiemens/cm). This anomaly corresponds to areas of warm water discharge from bedrock into the Lonepine aquifer. Conductivity values exceed 700 microsiemens/cm in the warmest wells; lower values in cooler water are apparently produced by dispersive mixing of this geothermal recharge with cold aquifer water and with recharge from the valley margins. In addition to Camp Aqua, there is a small area east of Hot Springs where chemistry indicates some leakage of geothermal water into the aquifer. Bedrock wells in Hot Springs, as well as Camas Hot Springs, exhibit a uniform conductivity of about 400 microsiemens/cm and are probably developed within a single groundwater reservoir. Alluvial wells in Hot Springs and on the perimeter of the valley yield water of conductivity 150-250 microsiemens/cm.

Geothermal water in the Lonepine aquifer contains detectable concentrations of minor and trace constituents, including boron **(Figure 13)**, lithium **(Figure 14)**, and chloride **(Figure 15)**.

Fluoride **(Figure 16)** is also elevated (up to 8.6 mg/L) but its anomaly pattern is erratic and not clearly related to the thermal water. Halos associated with all these constituents, except fluoride, correspond closely to that for conductivity and are similar to the isotherm pattern **(Figure 17)** for this ground water. Geothermal water contains detectable H_2S concentrations; dissolved sulfate (SO_4) concentrations are very low throughout much of the aquifer.

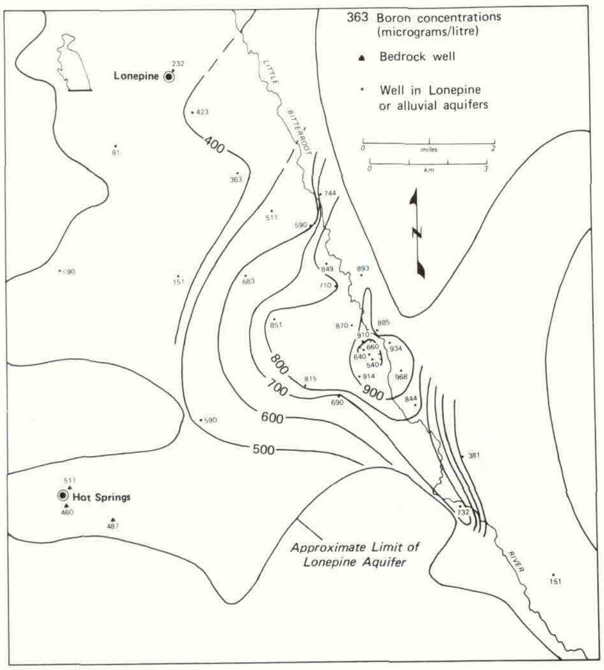

Figure 13—Boron concentrations in Lonepine aquifer water.

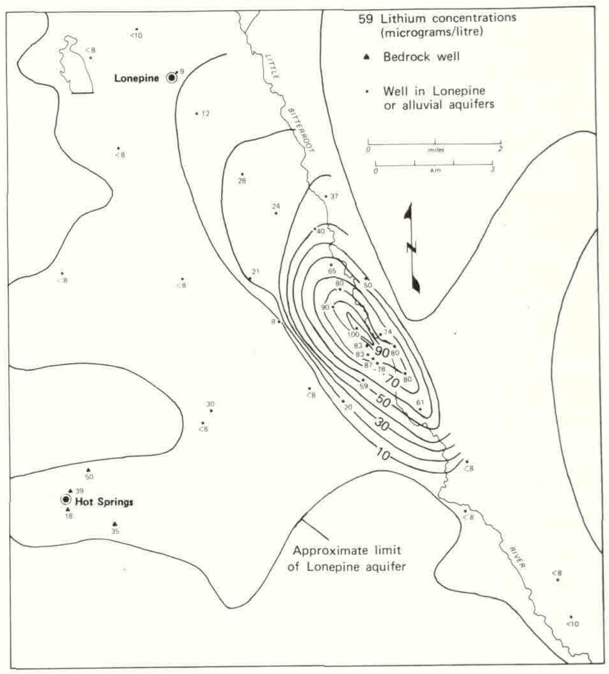

Figure 14—Lithium concentrations in Lonepine aquifer water.

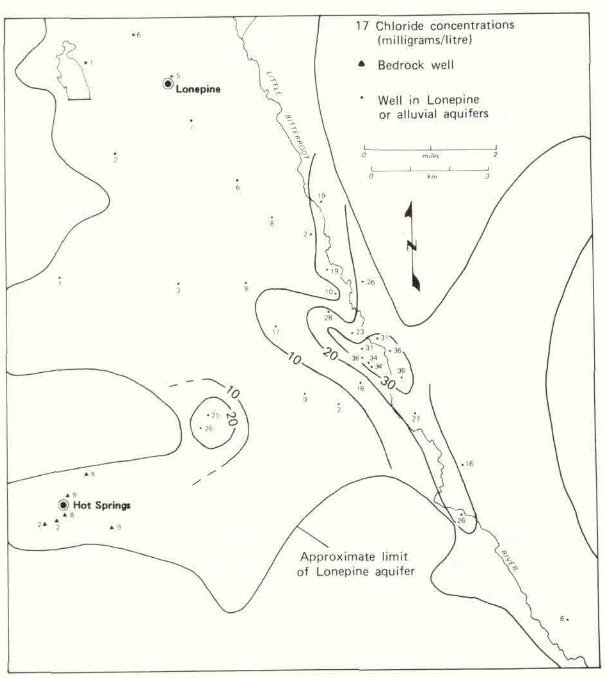

Figure 15—Chloride concentrations in Lonepine aquifer water.

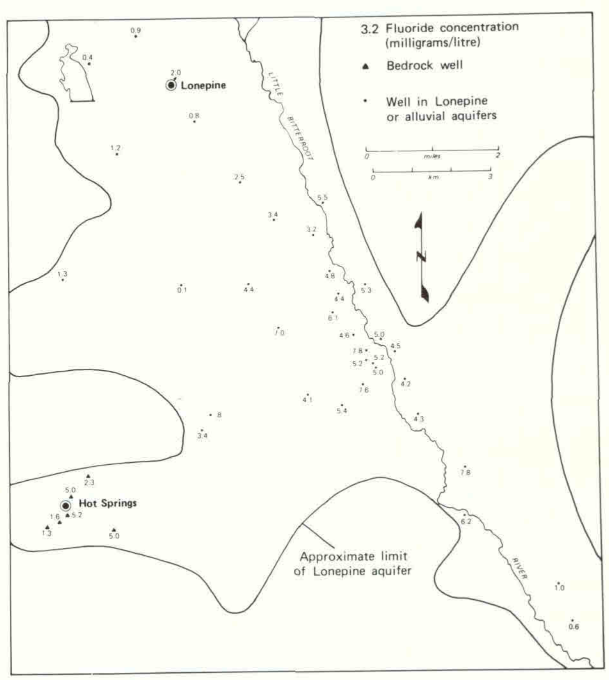

Figure 16—Fluoride concentrations in Lonepine aquifer water.

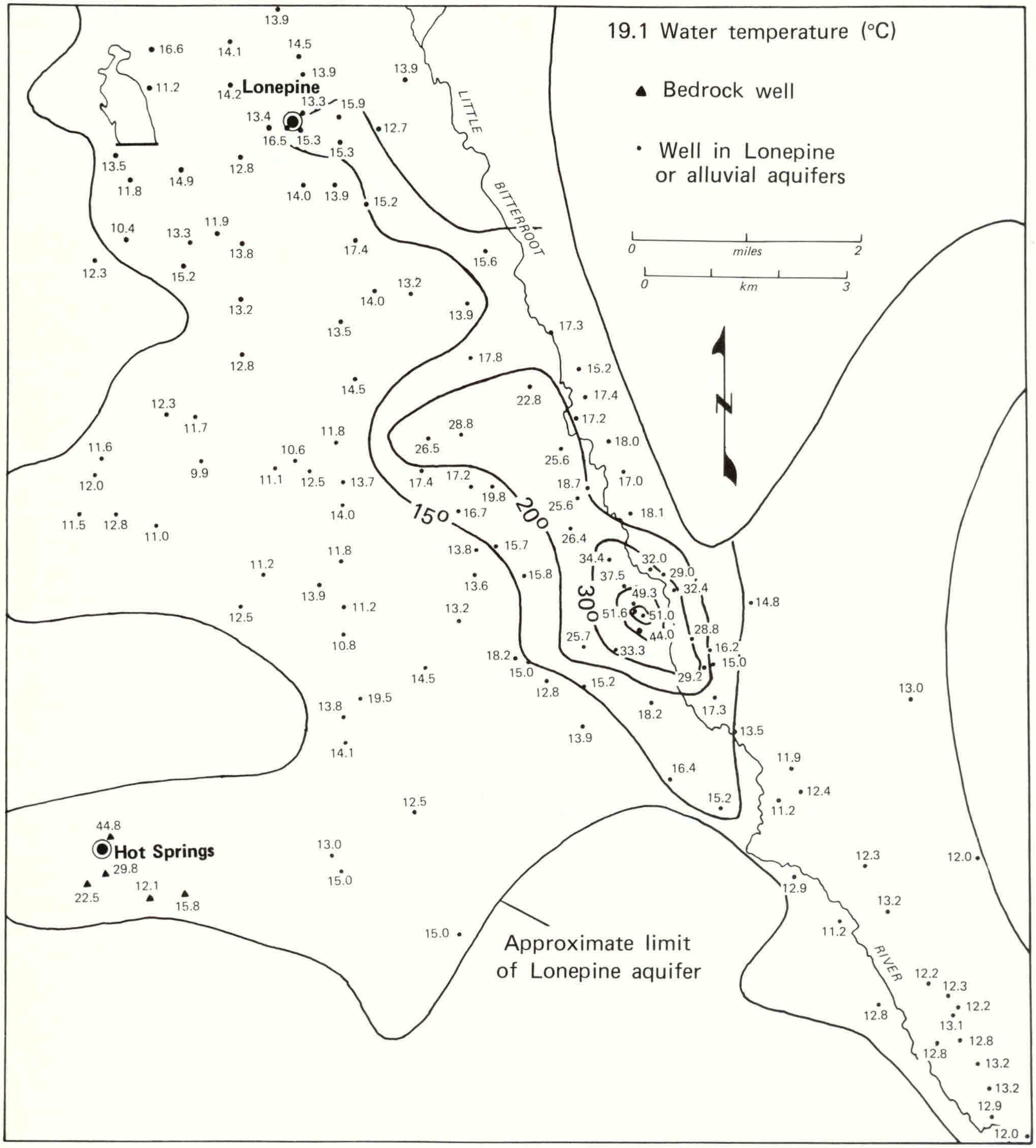

Figure 17—Observed ground-water temperature in the Lonepine aquifer.

Both of these may be caused by bacterial reduction processes, maintaining a low oxidation potential within the gravel.

The solubility of silica in geothermally influenced waters is controlled by a silicate phase as a function of temperature. Silica-rich warm-well discharge commonly forms a milky-white silica precipitate when cooled.

The elevated H_2S and silica concentrations in the geothermal water make it aesthetically less desirable as drinking water for some individuals than less mineralized water. Also, exsolving H_2S gas can corrode steel casing and elevate iron concentrations in well water. A more serious aspect of the geothermal water is the moderate concentrations of arsenic (As) **(Figure 18)** found in some wells. Water from 15 wells

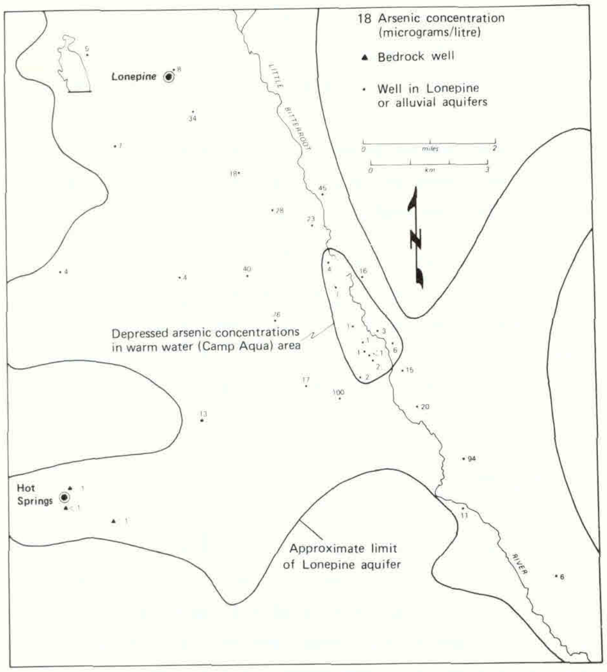

Figure 18—Arsenic concentrations in Lonepine aquifer water.

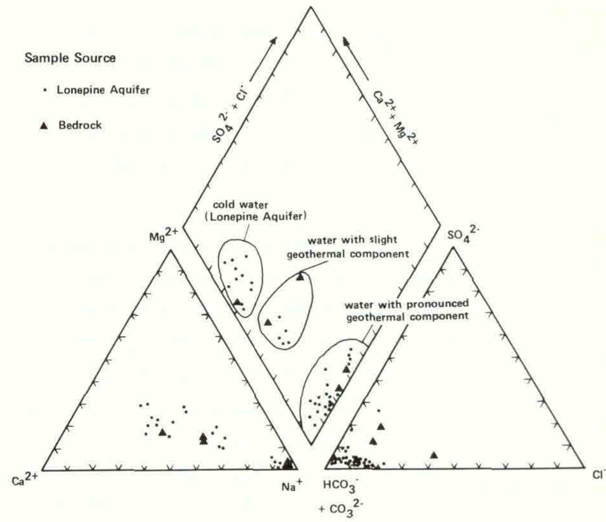

Figure 19—Piper plot of ground waters in the Little Bitterroot valley.

had As concentrations in excess of 10 parts per billion (ppb), with three in excess of 50 ppb, the recommended upper limit for potability (U.S. Environmental Protection Agency, 1975). The highest concentration observed was 100 ppb. Temperatures in these wells range from 10.0 to 28.8°C; those with concentrations greater than 40 ppb were from 11.8 to 17.3°C. Wells with the highest As concentrations are found on the periphery of the warmest zone of the Camp Aqua geothermal area. The warmest wells show undetectable (less than 0.1 ppb) As. Redox conditions may exert control over As solubility. While As concentrations are only moderately high, the long-term effects of As consumption at these levels in drinking water are not known. Local residents who utilize high As ground water for drinking may wish to consider alternate sources of drinking water as a precaution.

A Piper diagram of ground waters from the Little Bitterroot valley is presented in **Figure 19**. Anions in nearly all waters are dominated by carbonate species, with Cl concentrations ranging up to 20 percent. With the exception of a few bedrock wells in Hot Springs, the waters are very low in sulfate. Three groupings based on cation composition are noted. Waters with a strong geothermal component, including all wells in the Camp Aqua geothermal area, are strongly Na dominant. Cold ground water from the Lonepine aquifer is Ca-Mg dominant, with 25-45 percent Na. A small intermediate grouping between the two represents ground water with a minor, possibly diluted, geothermal component.

Geothermal resources

Camas geothermal area

The Camas geothermal area is located along the contact between bedrock and valley fill north of the town of Hot Springs. The springs are aligned along a 1,000-foot (300 m) E-NE trend, probably corresponding to an underlying valley-bounding fault in bedrock. Overburden beneath the site consists of about 28-35 feet (8.5-10.7 m) of gravelly and silty clay, probably Glacial Lake Missoula sediments. These deposits are underlain by argillites and quartzites of the Pritchard Formation. At a drillsite 0.5 miles (0.8 km) north of the springs (Well 177), a dark-colored igneous rock was logged within the Pritchard Formation at a depth of approximately 80 feet (24 m). This unit may correspond to an igneous sill that crops out on the hill north of town.

A hydrogeological investigation of Camas Hot Springs was performed by Gary (1982) in order to improve collection efficiency and increase temperature of the water collected. A well inventory and water quality survey of the Camas geothermal area was performed in the current study, concentrating on wells that might be associated with the warm water system.

Observed temperatures and flows

Warm water has historically been collected in a system of sumps dug out around the individual springs and then piped by gravity flow downslope to the bathhouse. The warmest spring yields water about 49°C. Total flow of all springs was estimated at 75 gpm (300 L/min).

Two pronounced hot areas around major springs were defined based on a shallow thermal survey (Gary, 1982). Two wells were drilled into bedrock over these anomalies. Well 34, near the eastern spring, yielded a sustained 115 gpm (430 L/min) at 51°C. Well 35, near the main (western) spring supplying the Camas bathhouse, yielded a sustained 50 gpm (190 L/min) at 49°C. Well 34 is thought to be close to the most transmissive portion of the springs. Transmissivity of the bedrock fracture system was estimated at 0.00072 to 0.0014 m^2/s (5,000 to 10,000 gpd/ft) by pump testing (Gary, 1982). In addition to the moderately low transmissivity, considerable interference was noted between the two wells (about 300 feet, or 90 m apart) during pump testing, and it is probable that continued pumping at the sustained yield of these wells would soon cause the springs to cease flowing.

The producing aquifer for both wells is fractured green and gray quartzite of the Pritchard Formation. During drilling, fractures yielded water and abundant quantities of pyrite, quartz and blue-gray "wash" material (probably clay and silica). Quartzite cuttings showed slickensided surfaces. The thickness of the water-producing fracture zone was about 35 feet (10.7 m) at Well 35, and greater than 25 feet (7.6 m) at Well 34.

Several other wells in the town of Hot Springs (Wells 39, 41, 42 and the Symes Hotel well) tap warm water at reported depths from 300 to 400 feet (90-120 m) in bedrock. Water from these wells ranges from 16 to 34°C and is very similar in chemistry to water from Camas Hot Springs. Well temperature progressively decreases with distance from the hot springs. Insufficient data exist to indicate whether these warm wells are localized along linear trends or fracture zones. The extensive occurrence of ground water of similar chemistry suggests that a single large cool to warm water reservoir in fractured bedrock may exist at considerable depth. The warm water aquifer is overlain by a cold water aquifer in bedrock, recharged from shallow depth. One well (Well 42) is completed and sealed in two separate bedrock zones at different depths, with temperatures of 14.0 and 29.8°C, respectively. (The higher temperature was recorded in the deeper zone.)

The warm wells probably tap fractures linked only peripherally to the main zone of hot water ascent at the springs themselves. Wells drilled to depths of more than 300 feet (90 m) to find warm water in the Hot Springs area have some limited chance of success, with locations close to the hot springs being the most favorable. However, prediction of the depth and temperature of warm water based on existing data may be unreliable.

Several warm wells in the town were monitored during the pump testing at the springs (Gary, 1982), but no response was detected. The low transmissivity of the bedrock fracture system limits interference effects between wells to less than about 0.5 miles (0.8 km).

Geothermometry

Concentrations of chemical constituents in geothermal water are influenced by water-rock equilibria, mixing with cold water and kinetic rates of equilibrium reactions. For this study, several chemical geothermometers were examined to determine if effects related to strictly temperature-dependent rock-water interaction can be isolated from the mixing and kinetic effects and to estimate subsurface temperature of the deep geothermal flow system before cooling of the ascending waters. Using ground-water chemical data, geothermometer calculations were performed:

(1) Using silica concentrations assuming quartz and chalcedony controlling phases (Fournier and Rowe, 1966).

(2) Using Na/K/Ca concentrations assuming feldspathic controlling phases (Fournier and Truesdell, 1973).

(3) Using Na/Li concentrations (Fouillac and Michaud, 1981).

The first is an equilibrium and the latter two are empirical approaches. Results are presented with the water quality analyses in **Appendix D**.

Geothermometry calculations were performed for spring water and water from warm wells. Results were 79-88°C for the silica (chalcedony) geothermometer at the springs and 70-90°C for surrounding wells. The Na-Ca-K geothermometer yielded 102-106°C for springs and 53-98°C for wells. The temperature estimates based on cation ratios are unreasonably high, perhaps the result of carbonate equilibria effects. The chalcedony values (70-90°C) probably provide the best estimate of maximum subsurface temperature. The similarity in silica content between the warm wells and the hot springs suggests that the decreased temperatures around the hot springs are related less to mixing with shallow cold water than to conductive cooling peripheral to the springs outlet.

Camp Aqua geothermal area

Observed temperatures

Ground water in the Lonepine aquifer is warm in an elongate zone between Lonepine and Oliver Gulch, one mile (1.6 km) at its widest **(Figure 17)**. The zone of warm wells corresponds to the areas of geochemical anomalies for B, Li^+, Cl^-, and F^-, shown in **Figures 13-16**. Ground water in the aquifer north of Lonepine is cold. Despite the southerly piezometric gradient in the aquifer, ground water south of the area of warm wells is also cold and of low conductivity. The isotherm pattern shows two less pronounced cross-valley NE trends, one intersecting the main NW trend at Camp Aqua and the other about two miles north. These secondary trends may represent leakage into the aquifer from cross-valley faults.

Over most of the Camp Aqua geothermal area, wells produce water between 13 and 25°C with conductivity from 350 to 550 microsiemens/cm. Well water temperature shows little seasonal variation. Some flowing warm wells exhibit a surging behavior, with slightly warmer water under higher pressure being delivered intermittently at 5- and 20-second intervals. This may be a partial-penetration effect caused by temperature and potentiometric pressure stratification within the aquifer.

The central part of the Camp Aqua geothermal area (Sections 20 and 29, T. 21N., R 23W.), exhibits the highest temperatures, (up to 25-52°C) and conductivities (from 550-720 microsiemens/cm). Detailed Bouguer gravity data **(Figure 7)** show that this area corresponds to a NW-trending gravity high, interpreted as a shallow bedrock shelf or knob. Seismic and drilling data confirmed that Belt bedrock (probably Ravalli Group rocks) directly underlies the Lonepine aquifer in this area at a depth of approximately 240-300 feet (74-90 m) (Donovan and Sonderegger, 1981). At the Precambrian bedrock-gravel contact, geothermal water discharges from bedrock fractures directly into the aquifer; the highest aquifer temperatures are found over this bedrock high. Tertiary lakebed sediments were either never deposited here or have been removed by subsequent fluvial erosion.

Temperature profiles were obtained for test holes in the Camp Aqua geothermal area at Well 86 to a depth of 260 feet (79 m) (Nork, 1981) and at Well 88 to a depth of 1,002 feet (305 m) (Donovan and Sonderegger, 1981). The temperature and geophysical logs from Well 88 are presented in **Appendix E**. There are few irregularities in the thermal profile between the surface and 240 feet (73 m); temperatures define a smooth conductive cooling curve above the geothermal water contained within the gravel. The temperature increases about 2°C from the top to the bottom of the aquifer; thermal water discharged into the base of the aquifer is horizontally stratified. In bedrock, water-producing zones at multiple depths between 28 and 420 feet (8.5 and 128 m) below the gravel become progressively cooler with depth, from 48.6°C at the base of the gravel to 40.8°C 420 feet (128 m) below it. At Well 88 flowing discharge from bedrock fracture zones is about 650 gpm (2,500 L/min). In Well 88, the distance probably increases with depth between water-producing borehole fractures and their points of intersection with the Lonepine gravel, from which they derive recharge. Because ground water in fractures becomes cooler with depth, these fractures are interpreted to intercept the gravel in a direction away from the main geothermal vent, which is probably not more than 1,000 feet (305 m) from the well. The test well did not encounter fractures connected to the main geothermal flow system; this vent could be peripherally sealed by precipitation of hydrothermal minerals and may be steeply dipping. The upper 500 feet (152 m) of bedrock exhibits good hydraulic connection with the overlying gravel aquifer. The transmissive bedrock fractures must be dominantly sub-horizontal to obtain the observed temperature variations, and they may be parallel to bedding.

The test well encountered abundant gray "wash" material (probably silica and clay) and fine-grained pyrite in fractures, similar to the Camas test wells (Gary, 1982). Sample recovery was poor in these zones. Petrographic and x-ray study of fracture-filling material from drill cuttings found hydrothermal minerals including calcite and a zeolite phase, either heulandite or clinoptilolite. Age and sequence of this mineralization has not been determined.

Geothermometry

Calculated temperatures using dissolved silica concentrations ranged from 45 to 96°C for quartz and from 40 to 64°C for chalcedony control. Observation of drill cuttings suggest that a fine-grained silica phase other than quartz is present to a depth of several hundred feet in bedrock and may control solubility of aqueous silica. These data are uncorrected for mixing with shallow cold waters during ascent. A plot of silica concentration vs. enthalpy **(Figure 20)** allows interpolation of a mixing curve using field temperatures and laboratory analyses of silica. Projection of this curve allows estimation of subsurface reservoir temperature at about 77°C. This technique is similar to that presented in Truesdell and Fournier (1977) but uses chalcedony rather than quartz solubility; the latter yields an unrealistically high temperature estimate (124°C). Because of the high back-

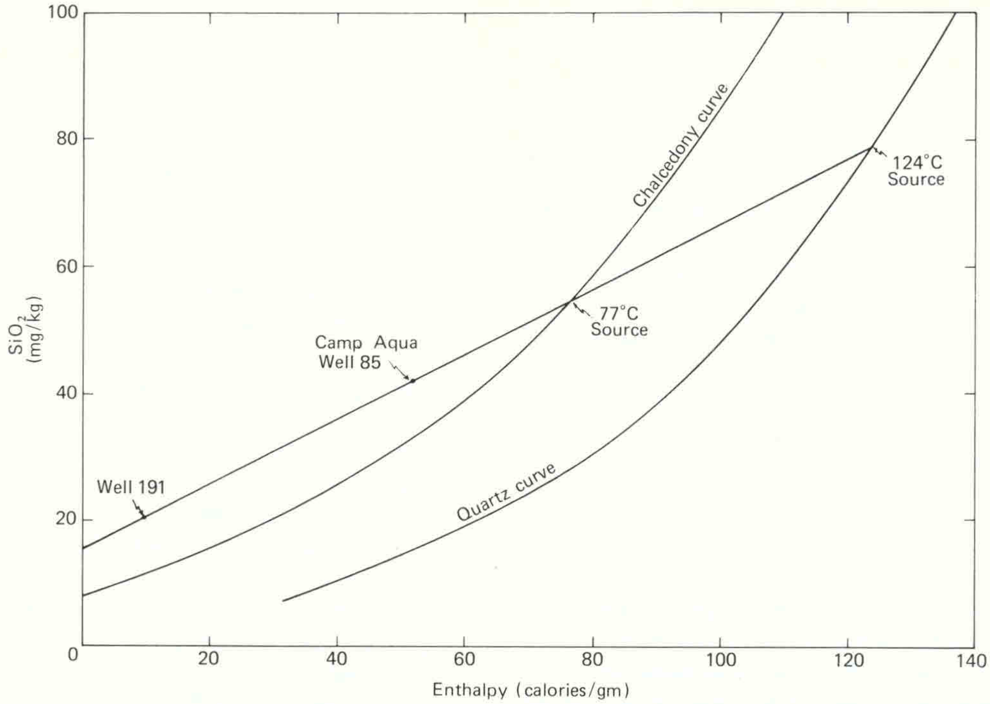

Figure 20—Silica concentration vs. enthalpy in Lonepine aquifer.

ground level (about 20 mg/L) of silica in the aquifer, the cold water portion of the curve does not originate on the chalcedony equilibrium curve. Chalcedony temperatures of ground-water samples taken from bedrock zones beneath the gravel at Well 84 ranged from 53 to 60°C; these cooler estimates were affected by induced flow from cooler portions of the gravel aquifer.

Geothermometer temperatures for Na/K/Ca range from 60 to 112°C for samples from the Lonepine aquifer and from 73 to 77°C for samples from bedrock fractures in Well 84, all uncorrected for mixing effects. There is a consistent difference between the cation temperatures in the gravel and in bedrock, caused by higher Ca^{2+} in bedrock (10-13 mg/L vs. 2.8-3.2 mg/L). Low Ca^{2+} concentrations in the gravel may be caused by a high buffered pH, maintaining a saturation level with respect to carbonates and keeping Ca^{2+} solubility low. This saturation may be maintained by activity of sulfate-reducing bacteria. The poor reliability of the cation geothermometer in high-CO_2 waters is described by Paces (1975), and modification of cation ratios in near surface mixing environments is described by Weissberg and Wilson (1977). Calculated cation temperatures for samples from the Lonepine aquifer can therefore be disregarded as being unrealistically high.

Temperatures based on the Na^+/Li^+ ratio range from 10 to 56°C (**Figure 21**). There is surprisingly good correspondence between observed and calculated temperatures below about 25°C. Above 25°C, calculated temperatures are consistently slightly higher than observed values. This deviation may be related to mixing effects or to slow reequilibration kinetics during cooling. The relationship described by the Little Bitterroot valley data may not be identical to the empirical one developed by Fouillac and Michard (1981); however, using their relationship, the Na^+/Li^+ ratios indicate a thermal source

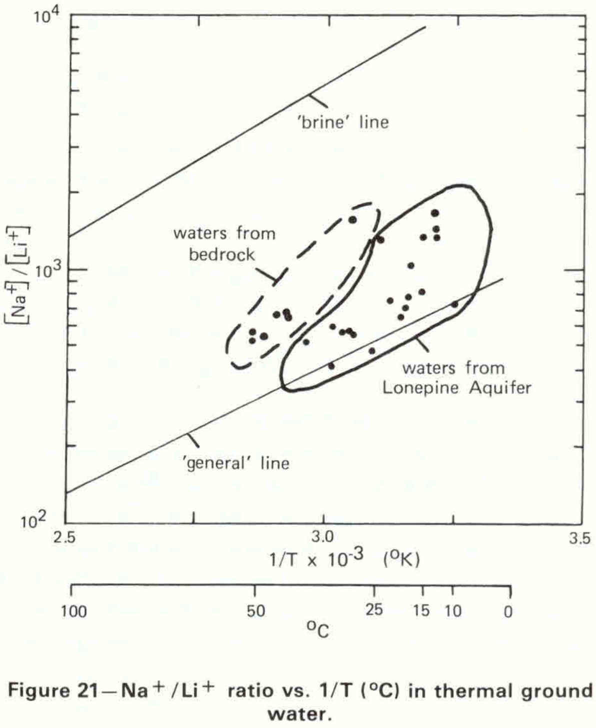

Figure 21—Na^+/Li^+ ratio vs. 1/T (°C) in thermal ground water.

at least as warm as 56°C. Lower lithium concentrations from bedrock warm water zones suggest that the lithium may be derived from exchange reactions with clays occurring in the gravel, and that equilibration rates for this exchange reaction may therefore be rapid and unrelated to deep circulation of ground water.

Aquifer mixing processes are difficult to model with geochemical data using simple mixing curves, because of the probability of multiple discharge points into the aquifer and the effects of chemical change during cooling in the shallow aquifer (Fournier and others, 1974). Silica geothermometer calculations corrected for mixing with cold water suggest that the deep source temperature may be about 77°C, assuming silica is not lost as the ascending thermal water cools. Temperature at the point of discharge into the Lonepine aquifer near Camp Aqua is probably lower than 77°C but higher than the highest temperature encountered in the Lonepine aquifer to date (52°C).

Flow system

The main NW-trend of the thermal anomaly **(Figure 17)** is probably related to deep fractures in Precambrian bedrock, which provide an avenue of vertical ascent for fluid circulation. Based on the geothermometer estimates of 77°C, the greatest depth of this circulation would be about 2 miles (3 km) under a typical western Montana thermal gradient (25°C/km), assuming that dilution and cooling during ascent are negligible.

The area of warmest ground water, near Camp Aqua, is underlain by a bedrock shelf directly beneath the Lonepine aquifer. Fractures in this bedrock can freely discharge thermal water directly into the gravel under sufficient pressure differential to allow substantial flow **(Figure 22)**. The degree of bedrock fracturing in this area may be enhanced by the intersection of the N-NW-trending valley-bounding fault with a NE-trending structural feature related to the sediment-filled depression to the east in Garceau Gulch. This NE-trending feature may be structurally related to the interpreted cross-valley fault beneath Camas Hot Springs. However, the Lonepine aquifer apparently extends no closer than approximately two miles (3 km) east of Camas Hot Springs. While the Camas and Camp Aqua thermal systems may have similar underlying structure and may even share a deep thermal reservoir, they are not hydraulically interconnected in the near-surface environment (< 500 meters deep). Well production at either location is unlikely to interfere with the quantity of geothermal discharge at the other.

Cooler portions of the Lonepine aquifer do not appear to be directly underlain by bedrock. Some thermal water may enter the aquifer beneath these areas through fractures that have propagated upward from bedrock through Tertiary sediments; however, because the water is probably conductively cooled before it enters the aquifer, it is difficult to estimate the quantity of this recharge. In cold portions of the aquifer near Lonepine, trace element (Li^+ and B) concentrations are low but above background levels, indicating some cold recharge from bedrock fractures.

Uncooled thermal water appears to be discharged into the Lonepine aquifer from several centers and in fact may be leaking extensively along a valley-bound-

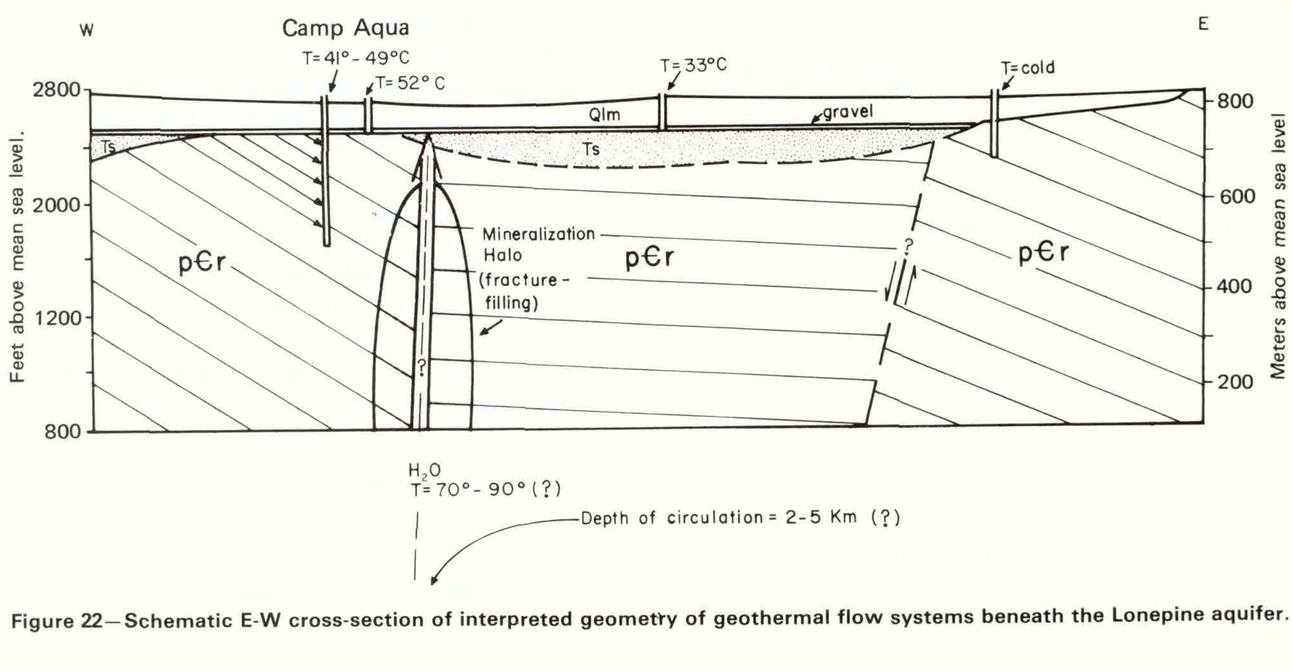

Figure 22—Schematic E-W cross-section of interpreted geometry of geothermal flow systems beneath the Lonepine aquifer.

ing fault. Heat transport occurs by dispersive mixing with cold water in the gravel; heat loss occurs by conduction to the surface. In the Camp Aqua geothermal area, at the center of flowing irrigation wells, several thousand gpm of thermal water is withdrawn from the aquifer during the irrigation season. The remainder appears to discharge through the narrow south end of the aquifer. At this point it has cooled and dispersively mixed with recharge water from alluvial gulches along the east side of the valley, so that its temperature is reduced to a uniform 10-12°C and its conductivity to 300-450 microsiemens/cm. Mixing between thermal water and alluvial recharge water flowing from Garceau Gulch is apparent at the eastern boundary of the aquifer (**Figure 17**); note that Well 81 (15.0°C) and Well 82 (29.2°C) to the west are located only 150 feet (45 m) apart.

The quantity of uncooled thermal water flowing into the gravel is difficult to estimate. Silica mixing calculations suggest a net proportion of thermal water of about 0.30. Based on this value and total estimated aquifer flux and withdrawals, a crude estimate of average geothermal flow volume is 1,000 gpm (3,800 L/min), although the water temperature at the points of discharge into the aquifer is an important unknown in this calculation.

Silica (chalcedony?), carbonates and other geothermal minerals precipitated during cooling and dilution occur as void fillings within bedrock fractures and possibly within the gravel. The annual quantity of silica alone lost within the aquifer may be on the order of 3 to 6 x 10^4 kg, corresponding to a volume of about 12 to 24 m^3/year. Evidence of void-filling precipitates plugging fractures was common during drilling in the bedrock. Some permeability reduction may also occur in the gravel. If there is detectable permeability reduction in the gravel, it would be an indication that the geothermal circulation system is very old (at least 100,000 years) or that the thermal fluids were at one time significantly hotter and richer in dissolved solids.

Finite difference aquifer model

A finite difference model of the Lonepine aquifer was developed using the numerical model of Trescott and others (1976). The governing equation used is for 2-dimensional, anisotropic, heterogeneous artesian flow:

$$\partial/_{\partial x}\,(T_{xx}\,{}^{\partial h}/_{\partial x}) + \partial/_{\partial y}\,(T_{yy}\,{}^{\partial h}/_{\partial y}) = S\,{}^{\partial h}/_{\partial t} + W(x,y,t)$$

where:

T_{xx}, T_{yy}	=	Principal components of transmissivity tensor.
h	=	Hydraulic head.
S	=	Storativity.
W	=	Source term (volumetric recharge or discharge flux per unit area of aquifer).
t	=	Time.
x,y	=	Directions of principal components of transmissivity.

The aquifer is assumed to be anisotropic with principal component directions parallel and perpendicular to the long axis of the Little Bitterroot valley. The model was constructed using a north-south grid, which approximates this orientation. It was assumed that there are no evapotranspirative losses within the aquifer and that no leakage occurs through the overlying confining bed.

Aquifer boundaries were drawn based on well inventory information. A rectilinear 38-column by 63-row block-centered grid was superimposed. A 1320 x 1320-foot (402 x 402-m) block size representing a square one-quarter mile on each side was used over most of the model area, except at the south end where a slightly expanded grid spacing was used near the discharge boundary. The finite difference grid is shown on **Sheet 2 (back pocket)**, with constant head (recharge), constant flux (recharge and discharge), and well nodes noted.

The objective of numerical modeling was to match observed aquifer response to testing and to irrigation, using aquifer test data from this study and aquifer recharge and discharge calculations. This indirect approach was applied because, while extensive accurate water level data are available describing aquifer response to stress, direct determination of aquifer characteristics by testing is difficult (owing to its high transmissivity, low storativity and pronounced boundary effects). While extension of transmissivity data to create the model is subjective and non-unique, empirical calibration using field data collected during irrigation and testing provides a method to verify the model. The approach uses observed heads and drawdowns to extrapolate from limited field transmissivity data.

Boundary conditions

The following boundary conditions are known:

(1) Recharge enters the aquifer from the upper Sullivan Creek area through the gap at Niarada,

although the narrow width of this gap (less than 0.6 m/1 km) and the limited thickness (7ft/2m) of gravel suggest that the rate of recharge may be limited.

(2) A water table hydraulically continuous with the Little Bitterroot River west of Niarada may provide a source of recharge to the Lonepine aquifer.

(3) Alluvial aquifers are absent in Sullivan and Rattlesnake gulches.

(4) Alluvial aquifers of moderate transmissivity along Garden and Hot Springs creeks probably recharge the Lonepine aquifer in minor amounts from a lateral direction.

(5) An alluvial aquifer in Garceau Gulch exhibits a gentle head gradient (0.1 percent) into the Lonepine aquifer. This gradient and the pattern of chemical and thermal mixing in the aquifer indicate that its recharge contribution is greater than the Garden and Hot Springs creeks aquifers.

(6) Based on aquifer test data, steady-state head gradients and aquifer geometry, the flux through the Lonepine aquifer near Oliver Gulch is calculated at 700 gpm (2,700 L/min).

(7) The aquifer is recharged by upward flow from bedrock fractures, part or all of which is warm. Using dilution estimates based on geothermometry, this recharge is estimated at 1,000 gpm (3,800 L/min).

Based on these conditions and estimates, boundaries were assigned:

(1) To nodes [1, 2] through [1, 9] at the north end of the valley, using a constant head (recharge) elevation of 2,780 feet (847.3 m).

(2) To nodes along the east, west and north margins of the valley, at locations corresponding to alluvial aquifers, using constant flux (recharge) values totalling 790 gpm (3,000 L/min) **(Table 4)**.

(3) To nodes at the south end of the valley, [64, 35] through [64, 38], using constant flux (discharge) values totalling 790 gpm (3,000 L/min) **(Table 4)**.

All boundary nodes were treated as no-flow boundaries by assigning a transmissivity of zero to nodes outside the boundary.

Other constant flux rates were assigned:

(1) To a series of nodes in the Camp Aqua geothermal area corresponding to areas of geothermal recharge (total recharge = 930 gpm, 3,500 L/min).

(2) To nodes in which uncontrolled flowing wells are located (total discharge, 2 wells x 475 gpm each = 950 gpm, 3,600 L/min).

Ground-water withdrawals for domestic and stock use were not incorporated into the model, because these amounts are small in relation to irrigation withdrawals and are spread uniformly over the area.

Recharge boundary fluxes approximately balance the discharge boundary fluxes (including uncontrolled flowing wells). For this reason, under steady-state conditions without pumping stress, no recharge is induced from the constant head gravels at the north edge of the model.

Aquifer characteristics

For steady-state runs, the right hand side of equation (1) is zero, and storativity was set equal to zero. For transient runs, it was set equal to 3×10^{-4}, the average value from test 6.

Because true transmissivity data from the test results are limited, transmissivity was assigned assuming that hydraulic conductivity is reasonably uniform throughout the aquifer and that transmissivity variations are therefore related mainly to thickness variations. Isotropic values of transmissivity were used, due to lack of firm data describing anisotropy; however, it is likely that transmissivity is greater in a north-south direction than in an east-west direction, because of the fluvial origin of the deposit. Transmissivity used in the north of the model was about three times the value in the south, proportional to the southerly decrease in thickness of the aquifer. During steady-state modeling, transmissivity along the axis of the aquifer (the interior nodes of the model) was adjusted to 25 percent greater than along the margins of the valley, to more closely match field steady-state elevation heads. Assignment of anisotropic transmissivity values would have had a similar effect. Slightly lower values were also assigned in the Camp Aqua geothermal area during transient modeling, to more closely match aquifer test data. This may be attributed to thinning of the aquifer over the bedrock high at this location or, more speculatively, to plugging of aquifer porosity by precipitation of hydrothermal minerals.

Final transmissivity assignments for the model **(Sheet 2, back pocket)** are as follows:

Area	T(m^2/s)	T(gpd/ft)	Description
T1	0.106	750,000	North part of aquifer, axis.
T2	0.085	600,000	North part of aquifer, margins.
T3	0.053	370,000	Camp Aqua geothermal area.
T4	0.032	220,000	South part of aquifer.
T5	0.0004 to 0.0013	3000 to 9000	Alluvial aquifers, Warm Springs and Garden creeks (boundary).

Steady-state simulation

Steady-state conditions were used to provide an initial calibration of the model to field data (March 1981), describing the potentiometric surface when the aquifer had recovered almost completely from irrigation withdrawals. Initial and boundary conditions outlined previously were used, proceeding to steady state by transient iteration until a convergence tolerance of 0.005 m was attained. Storativity was set to zero for all except constant flux nodes. Solution was by the strongly implicit procedure (Trescott and others, 1976).

Run 1 **(Sheet 2, back pocket)** produced a steady-state potentiometric surface that is in reasonable agreement with the March 1981 field data. Deviations are less than about 6 feet (2 m), approximately the same order of accuracy obtained in estimating potentiometric elevations using topographic maps. Mass balance **(Table 4)** for steady-state conditions is as follows:

Induced recharge from water table in terrace gravels.	0%	
Geothermal recharge.	54%	
Valley-margin alluvial recharge.	46%	
Sullivan Creek		11%
Garceau Gulch		15%
Hot Springs Creek		9%
Garden Creek		7%
Wilks Creek		2%
Oliver Gulch		2%

Transient simulation

Comparison of model results to drawdowns produced under transient conditions is a more rigorous calibration of model parameters. Run 2 was performed as a transient simulation of test 6 (Wells 84 + 88). The aquifer was at steady state at the start of the test, and all drawdown observed was assumed to be caused by pumping (change from steady-state condition) alone. Aquifer head was therefore not of concern and only calculated drawdown was compared to field values for test 6. The flow was 68 hours at 1,100 gpm (4,200 L/min), including 300 gpm (1,200 L/min) at node [37, 20] and 800 gpm (3,000 L/min) at node [38, 21]. These correspond to field conditions for test 6.

In most cases, calculated drawdown at the end of run 2 **(Table 5)** provided a reasonable (±30%) estimate of field drawdown, using the adjusted transmissivity in the Camp Aqua geothermal area. There is discrepancy between calculated and field data for wells close to the test wells, because the nodal distance upon which the calculated value is based does not correspond to the true distance between the wells. Interpolation of drawdowns at true distance yields acceptably close agreement (within 10 percent).

Run 3 was performed as a transient simulation of a typical irrigation season, using the initial and boundary conditions of run 1 and starting from steady state. The 20 irrigation nodes correspond to existing well locations, each of which was assigned a constant discharge of 100 gpm (380 L/min). Pumping at this rate was continued for 90 days, representing 800 acre/ft of total irrigation. These conditions are simplified from actual irrigation conditions, in which irrigation withdrawals at individual wells are generally higher than 100 gpm (380 L/min), but are intermittent and not concurrent. Also, much of the irrigation water comes from ground water that is stored in reservoirs before irrigation starts. The model withdrawals used, however, approximate total irrigation withdrawals during a typical year. The resulting calculated potentiometric surface for run 3 **(Sheet 2,**

Table 5—Comparison of calculated (model) to actual (field) drawdowns at observation wells for run 2 (test 6).

Well	Row	Column	Drawdown (m) Actual	Drawdown (m) Calculated
59	36	17	1.02	1.04
64*	33	15	0.06	0.83
77**	36	21	1.86	1.32
82	39	23	1.15	1.13
85**	38	21	2.92	1.26
89**	39	20	2.11	1.21
95+	40	18	0.80	1.09
110+	21	10	0.48	0.41
118	22	03	0.10	0.37
134+	26	13	0.49	0.57
144	29	05	0.24	0.56
159*	36	07	0.03	0.66
172+	37	09	0.84	0.77
98	43	21	0.71	1.07
24	55	35	0.38	0.45
84**	38	21	2.51	1.26
196	03	11	0.01	0.07
207	16	14	0.09	0.31
210+	16	04	0.17	0.28
213+	19	03	0.40	0.32

* Indicates well exhibiting delayed response.

** Indicates well close to test wells, for which map distance and model distance are substantially different.

+ Indicates domestic wells cyclically pumped during test.

back pocket) is a good approximation of aquifer head at the peak of the irrigation season in August 1981.

Run 4 was performed as a transient simulation of a totally hypothetical irrigation season, using the pumping wells and discharges (20 wells at 100 gpm, or 380 L/min) of run 3 for 90 days. This run used an additional 30 pumping wells at 50 gpm (190 L/min) each, scattered throughout the valley in areas where wells in the aquifer do not flow. The net irrigation amount was 1400 acre/ft. This run was performed to assess the impact of increasing irrigation withdrawals by 75 percent. The results **(Sheet 2, back pocket)** indicate that the potentiometric surface would be very similar in shape to that of run 3, with an additional 3 to 5 feet (1 to 1.5 m) of drawdown. The model calculates slightly more additional drawdown in the south end of the valley than in the north, as a result of induced infiltration from the recharge gravels. Although the discharge of run 4 is 75 percent greater than that for run 3, additional drawdown for run 4 is not proportionally higher than aquifer drawdown as simulated in run 3. This suggests that an increasing rate of recharge in response to irrigation could mitigate the amount of additional drawdown caused by new irrigation development.

Significance of results

Despite the available data describing aquifer characteristics, the aquifer is difficult to model unambiguously. The model is sensitive to minor variations in storativity, within the range of field values. In addition, there is substantial uncertainty regarding the mass balance for the basin and the relative amounts of recharge from various sources in the valley. The quantity of geothermal recharge is unverifiable. Because of the large number of possible combinations of boundary conditions and recharge quantities, the model presented here should be considered as tentative and only one of a large number of possibilities.

However, this model is consistent with available hydrogeologic data and favorably reproduces aquifer response. It would be possible to substantially improve the accuracy of the model with additional data describing quantities of recharge in alluvial aquifers and aquifer characteristics in the northern part of the valley. In addition, induced infiltration from the Little Bitterroot River into the aquifer is a critical assumption and requires testing and verification.

Summary and conclusions

The Lonepine aquifer is continuous throughout most of the Little Bitterroot valley. It receives recharge from sources including a geothermal flow system beneath the aquifer, valley-margin alluvial aquifers, and shallow gravel aquifers at the north end of the area, including coarse terrace and outwash deposits. Because of very high transmissivity and the tightly confined nature of the aquifer, it is possible that recharge is induced from the terrace gravels in response to irrigation approximately 8 to 10 miles (12 to 19 km) down valley to the south. The aquifer's characteristics account for the strong interference between flowing wells observed soon after irrigation commences.

Drawdown caused by irrigation is from 2 to 20 feet (0.6 to 6 m) in most years, a small amount in comparison to that available (200+ft, 60+m). Currently, water-use conflicts in the valley revolve not around available quantity but around flowing yield. While it would be feasible to significantly increase aquifer yield by installing pumps in new or existing irrigation wells, such development close to the flowing well area would probably further reduce artesian heads and cause most or all of the existing flowing wells to be useless for summer irrigation. Substantial additional ground-water development would be feasible only if the loss of year-round artesian flows were to be considered acceptable.

However, based on unverified results for the aquifer model devised, it is possible that some level of new development could take place in the north end of the valley surrounding interpreted recharge gravels. Such development could have a minor impact on existing flowing wells if much of the water removed was replenished by induced recharge. Test drilling and aquifer characterization are required to prove the extent of this aquifer potential, and new production wells would have to be located in order not to wholly intercept the path of recharge down valley.

Test drilling results in the Camp Aqua geothermal area show that it probably cannot be developed separately from the Lonepine aquifer. If additional withdrawals are made from the aquifer for alternative energy development, the impacts on agriculture could be reduced by limiting warm water withdrawals during the irrigation season, or possibly by reinjecting the water after use.

Evidence for decreased transmissivity as a result of partial plugging of the gravel around Camp Aqua is incomplete, but it raises additional questions. The system would probably have to be in excess of 100,000 years old to accomplish this scale of void reduction in the gravel, if the current estimated flow and temperature are assumed to have been about the same in the past. The Camas and Camp Aqua geothermal circulation systems appear to be hydrologically unconnected although they exhibit similar host-rock lithologies and structures (high-angle, valley-bounding faults). Both exhibit abundant fracture mineralization including vein-filling (hydrothermal?) pyrite. These sulfides may not be the product of the modern circulation system. One hypothesis that could explain these observations is that the modern thermal flow regime was established along a transmissive fracture system of a much older and hotter hydrothermal system. Data regarding the temperature of formation and age of these fracture-filling minerals might be obtained from isotopic and fluid-inclusion studies.

Water-management alternatives that may be considered to mitigate the ground-water irrigation use conflict in the valley include:

(1) Scheduled management of ground-water withdrawals over a longer period (from March to July), so that there is less concurrent use of the aquifer and a sustained period in which pressure is adequate to fill reservoirs; additional construction of on-farm reservoirs would be required.

(2) Conversion from flowing to pumping wells with a common fund to be established by local users for compensating flowing-well users to replace their existing installations with pumping wells and equipment.

(3) Development of artificial recharge schemes.

All of these alternatives share two common requirements—the need for a local self-regulating ground-water users' association, and for long-term collection of ground-water data, including systematic accurate monitoring of both aquifer water levels and irrigation flows.

Part of the water-use conflict in this area could be reduced if the non-beneficial and wasteful uses of flowing ground water (mainly uncontrolled flowing wells) are pinpointed and eliminated. Meinzer's (1916) observation is still valid today:

> *...decline in yield should serve to emphasize the fact, frequently demonstrated but seldom appreciated by well owners, that an artesian supply is a definitely limited quantity of water, and that the extent to which it is wasted determines the quantity remaining available.*

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Appendix A—Well inventory data.

SWL and PWL
SWL = static water level
PWL = pumping water level
F = flowing
+ = calculated shut-in water level, in feet of water above ground

Source of Data
C = Confederated Salish-Kootenai tribes
D = Driller's files
O = Owner
U = U.S. Geological Survey
W = Well appropriation

Aquifer Identification codes
112LONE—Lonepine Aquifer (Pleistocene)
112LKML—Lake Missoula Sediments (Pleistocene)
112ALVM—Alluvium (Quaternary)
112OTSH—Glacial outwash (Pleistocene)
120SDMS—Sediments (Tertiary)
120VOLC—Volcanic rocks (Tertiary)
400RVLL—Ravalli Gp. (Proterozoic)
400PRCD—Pritchard Gp. (Proterozoic)

Well Use
A = Abandoned
C = Commercial
D = Domestic
H = Space heating
I = Irrigation
M = Municipal
O = Water level observation
R = Research
S = Stock
U = Unused

Flow measurement
M = measured
E = estimated

All electrical conductivity values reported in microsiemens (or micromhos) per centimeter.

Map Number	MBMG Site I.D.	Location T., R., Sec., Tract	Elevation (feet)	Reported Well Data: Total Depth (feet)	PWL (feet)	SWL (feet)	Yield (gpm)	Source of Data	Aquifer	Aquifer Top Elevation (feet)	Perforated Interval (feet)	Date Completed	Use	Diameter (inches)	Field Well Data: Agency	Date	Total Depth (feet)	SWL (feet)	Yield (gpm)	Temp. (°C)	E. C. @ 25°C
1	LB-403	21N22W07CDCA	2800	192				U	112ALVM	2660		1984	R	6	USGS	09/28/74		27.44			
2	LB-155	21N23W02DBB	2770						112LONE				U		USGS	07/30/74		11.0		12.0	190
3	LB-049	21N23W03DBB	2730						112LONE				IS	4	MBMG	12/01/79		+28.4	20-E	12.3	379
4	LB-050	21N23W04AADA	2742						112LONE				SD	4	MBMG	11/30/79			50-E		
5	LB-051	21N23W04BABB	2727						112LONE				IS	4	MBMG	07/08/79		+36.8	350-E	15.2	462
6	LB-052	21N23W04DAAC	2718						112LONE				S	4	MBMG	11/30/79		F	75-M	12.9	454
7	LB-054	21N23W10AABC	2735						112LONE				I	4	MBMG	09/02/79			100-E		
8	LB-053	21N23W10ABAA	2738	240			200	O	112LONE	2500			I	4	MBMG	09/02/79		+12.6	100-E	13.2	321
9	LB-055	21N23W10BABA	2717						400PRCD				DS	4	MBMG	09/02/79		+53.2	10-E	11.2	449
10	LB-130	21N23W10DDBB	2718	200		F	1	W	112LONE			1931	D	4	MBMG	06/08/80				12.8	603
11	LB-057	21N23W11CACC	2730						112LONE				I	4	MBMG	09/02/79		+26.6	250-E	12.3	310
12	LB-056	21N23W11CBCC	2728				700	O	112LONE				I	4	MBMG	09/02/79			250-E	12.2	334
13	LB-121	21N23W11CDBA	2732						112LONE				IS	4	MBMG	03/27/80		+20.9	50-E	12.2	318
14	LB-122	21N23W11CDBD	2728						112LONE			1930	DHS	4	MBMG	03/27/80		+25.3	25-E	13.1	375
15	LB-134	21N23W13CACC	2725	282		F	90	W	112LONE	2445		1923	S	4	MBMG	05/30/80		+31.6		14.6	335
16	LB-135	21N23W13CCAB	2720	272				D	112LONE	2461		1965	IS	6	MBMG	05/30/80		F			
17	LB-118	21N23W14ACAB	2720	267		F	200	D	112LONE	2490		1974	I	6	MBMG	06/10/80			250-E	13.2	319
18	LB-151	21N23W14ACBA	2720	286		F	85	W	112LONE			1921	DI	4	MBMG	06/10/80					
19	LB-131	21N23W14ACCD	2722	283		F	92	W	112LONE			1945	I	6	MBMG	06/10/80		F		13.2	314
20	LB-123	21N23W14BABB	2718						112LONE				IS	4	MBMG	03/27/80		F		12.8	475
21	LB-124	21N23W14BBAD	2717						112LONE				ISD	4	MBMG	03/27/80		+40.6	100-E	12.8	561
22	LB-132	21N23W14DCAB	2710	260		F	150	W	112LONE	2452		1932	A	6	MBMG	05/30/80	197	F	1-M	12.9	383
23	LB-152	21N23W14DDDB	2709						112LONE				S	4							
24	LB-133	21N23W23AADB	2725	310		+35	200	W	112LONE	2468	258-272	1975	I	6	MBMG	05/30/80		F	250-E	12.0	356
25	LB-126	21N24W01ABBC	2759	100				U	112LONE	2661			C		USGS	07/14/75		0.2		12.5	730
26	LB-325	21N24W01BCBB	2770	189		F	40	W	112LONE	2582		1960	C	4							
27		21N24W01CADD	2765	200		F	50	W	112LONE	2567		1911	DS	4	USGS	07/14/75		+17.0		15.0	530
28	LB-302	21N24W02ADA	2770	82		F		D	112LONE			1952		6							
29	LB-328	21N24W02ADC	2780	141	136	10	10	D	112LONE	2960		1972	C	6	USGS	07/14/75		6.7		13.0	640
30	LB-326	21N24W02BCCC	2792	103	15	F	25	D	112LONE	2640		1971	DS	6							
31	LB-303	21N24W02BCDD	2786	220	50	14		D	112ALVM	2689		1971	DS	6							
32	LB-327	21N24W02DAAA	2772	132			18	W	112ALVM		187-220	1971	D	6							
33	LB-306	21N24W03ACBB	2800	67		F	15	W	112ALVM	2734		1960	D	6							
34	LB-324	21N24W03BBCA	2805	100	17	F	117	C	400PRCD												
35	LB-323	21N24W03BBDB	2860	100	11	F	107	C	400PRCD		60-100	1982	I	8							
36	LB-308	21N24W03CACC	2832	40	35	10	15	D	112ALVM	2795	36-39	1972	D	4	MBMG	10/08/79				10.8	180
37	LB-309	21N24W03CACC	2835	300	31	F	8	D	400PRCD			1969	D	8	MBMG	10/08/79		+6.2		12.1	
38	LB-304	21N24W03DBAB	2801	347	260	F	4	D	400PRCD		240-260	1974	D	4							
39	LB-305	21N2' N03DCBB	2805	103	0.0	F	30	D	400PRCD			1972	D	6	MBMG	12/04/79		+35.2	20-E	15.8	432
40	LB-311	21N24W04ACAC	2925	119	115	62	13	D	400PRCD			1978	D	6							

41	LB-310	21N24W04ADAB	2950						400PRCD				D	6	MBMG	12/03/79	+22.0		44.8	383
42	LB-313	21N24W04DABD	2952	420		F	90	W	400PRCD			1977	D	6	MBMG	12/03/79	+57.3		29.8	363
43	LB-314	21N24W04DBDA	2875	383	99	9	340	D	112ALVM	2681	195-198	1963	M	10	USGS	07/14/75	9		22.5	280
44	LB-316	21N24W09ABC	3000	54	28	14	30	D	112ALVM		49-52	1971	D	6						
45	LB-322	21N24W09CABC	3010	46	16	11	20	D	112ALVM		15-17	1972	D	6						
46	LB-330	21N24W12AAD	2775	52		F	7	W	112LKML			1910	IS	4	USGS	08/08/74	F		15.0	320
47	LB-317	21N24W12BBBB	2770	132	21.5	0.0	10	D	112LKML			1968	D	6						
48	LB-332	21N24W12CCCC	2810	430		F	2	D	400PRCD			1973	D	6	USGS	07/14/75	+1.4		11.5	335
49	LB-318	21N24W24BACB	2920	57	25	6	18	D	400PRCD		53-57	1971	D	6	USGS	07/14/75	5.8		11.5	225
50	LB-001	22N23W07BBDB	2765	245	189	+12.1	550	D	112LKML	2567	200-217	1974	IS	8	MBMG	07/09/79	F	10-E	15.6	622
51	LB-002	22N23W07CBBB	2824	305		45	20	W	112LONE	2521		1910	DS	4	MBMG	10/09/79		10-E	13.9	464
52	LB-003	22N23W07DBDB	2738	229		+39.3	665	O	112ALVM	2515		1964	I	6	MBMG	11/30/79		500-E	17.3	533
53	LB-404	22N23W15CDDD	2833	240				U				1984	RA							
54	LB-405	22N23W15DCDC	2835	96			20-30	U	112ALVM	2783	60-80	1984	R	6	USGS	10/11/84	47.82			
55	LB-004	22N23W17BBCB	2745	226		F	340	O	112LONE	2521		1918	IS	4	MBMG	11/30/79	+30.3	200-E	15.2	
56	LB-116	22N23W17BCB	2750	235				O	112LONE	2517		1916	IS	4	MBMG	11/30/79	+31.6	250-E	17.4	498
57	LB-005	22N23W17CBBB	2730	230	F	F		O	112LONE	2510		1918	IS	4	MBMG	09/28/78	+40.1	300-E	17.2	555
58	LB-006	22N23W17CDB	2745	233				O	112LONE	2514		1918	ID	4	MBMG	09/27/79	F	300-E	18.0	568
59	LB-007	22N23W18ACAA	2740	230		F	340	W	112LONE	2512		1918	IS	4	MBMG	09/27/79	+37.9	360-M	22.8	461
60	LB-008	22N23W18BBBB	2814	290		45.5	15	W	112LONE	2526		1925	DS	4	MBMG	10/09/79	45.5		17.8	436
61	LB-009	22N23W18CCCC	2814	300				O	112LONE	2516		1932	A	4	MBMG	09/07/79				
62	LB-010	22N23W18DDAD	2740	232		F	500	W	112LONE	2510		1916	IS	4	MBMG	12/03/79	+38.2		25.6	571
63	LB-011	22N23W19ADDA	2785						112LONE				A	4	MBMG	09/06/75				
64	LB-013	22N23W19BBCC	2815	300				D	112LONE	2517		1935	A	4	MBMG	07/09/79	37.9		17.2	701
65	LB-012	22N23W19BBDA	2810	293				O	112LONE	2519			D	4	MBMG	09/08/78		5-E	19.8	600
66	LB-014	22N23W19CACC	2819	300			2	W	112LONE	2521		1935	DS	4	MBMG	07/12/79			15.7	481
67	LB-015	22N23W19CBCD	2815	310				W	112LONE	2507		1925	D	4	MBMG	07/12/79	43.3		13.8	456
68	LB-016	22N23W19CCCD	2815	297	39		15	D	112LONE	2520	284 297	1978	DS	6	MBMG	09/03/78			13.6	320
69	LB-017	22N23W19DAAA	2760	240		F	200	W	112LONE	2522		1920	S	4	MBMG	07/12/79	F	2.2-M	26.4	639
70	LB-018	22N23W19DCCA	2802	297		35	8	W	112LONE	2507		1935	D	3	MBMG	07/09/79			15.8	499
71	LB-022	22N23W20ACCB	2740	224		F	340	W	112LONE	2518		1918	IS	4	MBMG	12/04/79	+34.3	200-E	18.1	574
72	LB-019	22N23W20BAAD	2740						112LONE				DS	4	MBMG	09/05/78	+38.8	250-E	17.0	566
73	LB-020	22N23W20BBCD	2755	250				O	112LONE	2507		1915	S	3	MBMG	09/06/78	F	2-E	18.7	677
74	LB-021	22N23W20BCCB	2750			F			112LONE			1918	IS	4	MBMG	09/06/78	+27.4	200-E	25.6	531
75	LB-023	22N23W20CDBC	2750	262		F	250	D	112LONE	2514		1979	DHI	4	MBMG	09/07/78		20-E	34.4	490
76	LB-024	22N23W20DCDB	2728						112LONE				U	4	MBMG	07/08/79	F	400-E	32.0	642
77	LB-025	22N23W20DDCC	2732						112LONE				I	4	MBMG	07/08/79	+42.0	300-E	29.0	711
78	LB-026	22N23W28ABCC	2798	339		28		D	400RVLL	2770		1974	S	6	MBMG	09/07/78			14.8	316
79	LB-027	22N23W28CBBB	2744	230		F		U	112LONE	2512		1915	I	4	MBMG	07/08/79	+31.8	300-E	28.8	674
80	LB-028	22N23W28CBDB	2740	230		F		U	112LONE	2512			I	4	MBMG	07/09/79	+41.8	250-E	16.2	640
81	LB-029	22N23W28CCAA	2739						112LONE				DI	4	MBMG	07/09/79		100-E	15.0	496
82	LB-030	22N23W28CCAC	2736						112LONE				IS	4	MBMG	07/09/79	+41.0	150-E	29.2	668
83	LB-031	22N23W29AADB	2740	240		F		U	112LONE	2502		1918	IS	4	MBMG	07/09/79	+41.8	100-M	32.4	700
84	LB-143	22N23W29ACAB	2754	261	F	F	850	D	112LONE	2513	241 251	1982	U	8	MBMG	03/22/83	+23.2	820-M	51.0	645
85	LB-032	22N23W29ACBB	2753	244	F	F		O	112LONE	2511		1913	CH	6	MBMG	09/12/78	+25.5	150-M	51.6	703
86	LB-142	22N23W29ACCD	2754	247	F	F	175	D	112LONE	2512		1982	R	6	MBMG	03/02/83			44.0	
87	LB-033	22N23W29BAAC	2740	230	F	F		O	112LONE	2512		1916	ID	4	MBMG	09/06/78	F		37.5	590
88	LB-141	22N23W29BADD	2753	1002	F	F	650	D	400RVLL	2509	364 1002	1981	R	6	MBMG	01/12/80	+25.0	550-M	49.3	694
89	LB-034	22N23W29CACA	2760	260	F	F		U	112LONE	2522		1913	IS	3	MBMG	07/13/79	+19.2	95-M	33.3	484
90	LB-035	22N23W29CBBC	2770	274		F		U	112LONE	2504		1914	S	3	MBMG	07/07/79	+9.4	40-E	25.7	461
91	LB-036	22N23W29CCCC	2796	303				U	112LONE	2495		1914	DS	4	MBMG	07/07/79		15-E	15.2	465
92	LB-037	22N23W30BABB	2815	315		20	5	W	112LONE	2502		1913	D	4						
93	LB-038	22N23W30CADD	2805	302		25	30	W	112LONE	2505			DS	4	MBMG	09/07/78			18.2	386
94	LB-039	22N23W30DBCD	2805	305		27	30	W	112LONE	2502		1938	DS	4	MBMG	09/07/78			15.0	382
95	LB-040	22N23W30DDCB	2803	308				D	112LONE	2497		1936	S	4	MBMG	09/07/78	28.9	15-E	12.9	379

Appendix A—*continued.*

				Reported Well Data												Field Well Data					
Map Number	MBMG Site I.D.	Location T., R., Sec., Tract	Elevation (feet)	Total Depth (feet)	PWL (feet)	SWL (feet)	Yield (gpm)	Source of Data	Aquifer	Aquifer Top Elevation (feet)	Perforated Interval (feet)	Date Completed	Use	Diameter (inches)	Agency	Date	Total Depth (feet)	SWL (feet)	Yield (gpm)	Temp. (°C)	E. C. @ 25°C
96	LB-041	22N23W32ABAA	2755						112LONE				D	4	MBMG	09/07/78			10-E	18.2	378
97	LB-042	22N23W32BCBC	2800	289				D	112LONE	2513			D	6	MBMG	07/12/79				13.9	499
98	LB-119	22N23W32DBBB	2785						112LONE	2485		1966	IO	10	MBMG	03/27/80	305	19.62			
99	LB-120	22N23W32DDBA	2735						112LONE				I	4	MBMG	03/27/80		F	250-E	16.4	500
100	LB-043	22N23W33BABA	2746	258		F	30	D	112LONE	2504	242 258	1968	D	6	MBMG	07/30/79					
101	LB-044	22N23W33BABB	2736	249		F	200	D	112LONE	2498		1973	IS	6	MBMG	07/08/79				17.3	562
102	LB-045	22N23W33BDAB	2730			+ 18		U	112LONE				I		USGS	08/10/75				13.5	510
103	LB-046	22N23W33DADB	2740	242		F			112LONE	2500			IS	4	MBMG	07/08/79		F	75-E	11.9	497
104	LB-048	22N23W33DDAD	2738						112LONE				I	4	MBMG	07/08/79		+ 29.0	250-E	12.4	464
105	LB-047	22N23W33DDCC	2722						112LONE			1932	D	4	MBMG	07/09/79		F		11.2	581
106	LB-154	22N23W34AAA	2805	97				U	112ALVM				S		USGS	08/01/75		45.2		13.0	240
107	LB-058	22N24W01BBAB	2840	323		55	4	D	112LONE	2519		1933	DS	4	MBMG	10/10/79				12.7	576
108	LB-059	22N24W01CAB	2840	305		58	7	W	112LONE	2537		1918	DS	4							
109	LB-140	22N24W01CBDC	2840	309	64	62	20		112LONE	2536		1960	D	6	MBMG	07/30/79		70.9		15.2	388
110	LB-060	22N24W02AADD	2840				9	W	112LONE			1968	DS	6	MBMG	10/10/79		69.15		15.3	486
111	LB-061	22N24W02ABBB	2857	300	97	85	10	W	112LONE	2562	295 299	1968	D	6	MBMG	10/10/79		81.9		15.3	402
112	LB-127	22N24W02BAAB	2857						112LONE				C		USGS	07/11/77				16.5	445
113	LB-062	22N24W02BABA	2856	300		40	9	W	112LONE	2558		1930	DS	4	MBMG	07/12/79				13.4	415
114	LB-063	22N24W02BCBC	2850						112LONE				DS	4	MBMG	07/30/79				12.8	342
115	LB-064	22N24W02DAAB	2843	306			15	W	112LONE	2541		1932	DS	4	MBMG	07/30/79				13.9	388
116	LB-065	22N24W02DBBA	2845	300			9	D	112LONE	2547		1936	D	4	MBMG	07/23/79		65.0		14.0	378
117	LB-066	22N24W03ACCB	2848	331	100	60	60	W	112LONE	2522		1977	D	6	MBMG	07/30/79				14.9	326
118	LB-067	22N24W03BCCC	2835						112LONE				O	4	MBMG	07/29/79		61.98		11.8	279
119	LB-139	22N24W03DABA	2846	330		54	50	D	112LONE	2524		1959	D	6							
120	LB-068	22N24W03DDCD	2842	330				D	112LONE	2514		1935	D	4	MBMG	07/11/79				11.9	311
121	LB-069	22N24W04ADAA	2840	330				O	112LONE	2512		1930	DS	4	MBMG	07/11/79				13.5	335
122	LB-136	22N24W04CADD	2890						112ALVM				D	4	USGS	07/11/77				11.0	128
123	LB-128	22N24W09ACAB	2880						112ALVM				D		USGS	07/11/77				12.3	260
124	LB-070	22N24W10AABD	2844	320				D	112LONE	2826		1935	D	4	MBMG	07/20/79					
125	LB-071	22N24W10ABBA	2840	314			20	D	112LONE	2528		1935	DS	4	MBMG	07/11/79				13.3	292
126	LB-073	22N24W10ACBA	2822						112LONE				S	4	MBMG	07/29/79			10-E	15.2	414
127	LB-072	22N24W10BBBB	2838	278		60	5.5	W	112LONE	2562			D	4	MBMG	07/11/79				10.4	298
128	LB-156	22N24W10DDA	2820	316				D	112LONE	2506					USGS	07/17/75		53.9			
129	LB-074	22N24W11ADCC	2827	300			30	W	112LONE	2529		1930	A	3	MBMG	07/29/79					
130	LB-075	22N24W11BBBB	2835	320			20	D	112LONE	2517		1937	D	4	MBMG	07/29/79				13.8	241
131	LB-137	22N24W11BCCC	2830	316	55	55	20	W	112LONE	2519		1962	D	6							
132	LB-076	22N24W11CBBB	2833	312		65		W	112LONE	2523		1935	D	4	MBMG	07/11/79				13.2	357
133	LB-077	22N24W11DADC	2827	314	47	47	10	D	112LONE	2525		1971	D	6	USGS	07/17/75		59.3		13.5	405
134	LB-078	22N24W12ACCC	2834	308	300	63	100	W	112LONE	2533		1979	DS	6	MBMG	10/09/79		54.0		13.2	394
135	LB-079	22N24W12BBBB	2835	300		55	9	W	112LONE	2537		1912	DS	4	MBMG	07/30/79				17.4	376
136	LB-080	22N24W12BDCC	2830	299			10	W	112LONE	2533		1916	D	4	MBMG	10/02/79				14.0	392
137	LB-081	22N24W13BCBB	2815						112LONE				D		USGS	07/17/75		47.8		14.5	405
138	LB-125	22N24W13DADD	2808			39	6	W	112LONE	2504		1948	DS	4	MBMG	05/05/80	306	41.23		28.8	415
139	LB-082	22N24W13DBDC	2810	304				D	112LONE	2508		1940	DS	4	USGS	07/11/77		45.1		26.5	470
140	LB-129	22N24W14BBBB	2810	303		35	5	W	112LONE	2509		1948	DS	4	MBMG	10/08/79				12.8	329
141	LB-083	22N24W14CABA	2824	325	46	46	100	D	112LONE	2508		1961	D	6	MBMG	10/04/79					
142	LB-084	22N24W14CDDD	2814	315		40	13	W	112LONE	2501		1934	DS	4	MBMG	07/10/79				10.6	326
143	LB-085	22N24W14DDAB	2822						112LONE				D	4	MBMG	10/11/79		52.57		11.8	324
144	LB-086	22N24W15ABAD	2825	300			2	W	112LONE	2528		1920	O	4	MBMG	07/20/79		51.78			
145	LB-087	22N24W15ADDD	2821	317		40	10	W	112LONE	2506		1917	A	3	MBMG	07/20/79					

146	LB-089	22N24W15CABA	2819	156		30	10	W	112LONE	2669			DS	4	MBMG	07/11/79		18.4		12.3	216
147	LB-088	22N24W15CBBA	2842	40	F	2	W		112LONE				DS	4	MBMG	07/20/79		F			
148	LB-090	22N24W15DBAB	2817	200				O	112LONE	2620			S	6	MBMG	07/11/79				11.7	309
149	LB-091	22N24W15DCDD	2808	317		13	15	W	112LONE	2493		1925	D	4	MBMG	07/10/79				9.9	322
150	LB-092	22N24W16DDCD	2835		F	F	4	W	112ALVM			1920	S	4	MBMG	07/10/79		+8.0	1.5-M	11.6	196
151	LB-093	22N24W21AABB	2830			F	1	O	112ALVM				DS	4	MBMG	07/10/79		F		12.0	256
152	LB-094	22N24W21ACDC	2832	99.5	80	33	20	D	112ALVM	2735		1959	D	6	USGS	07/18/75		37.6		11.5	275
153	LB-095	22N24W21DAAA	2823	158		40	20	W	112ALVM	2677		1936	DS	4	MBMG	07/10/79				12.8	310
154	LB-096	22N24W22CABB	2816	184		40	10		112LONE				D	4	USGS	07/18/75		34.6		11.0	305
155	LB-097	22N24W23AAAD	2815	310			1	W	112LONE	2507		1915	DS	4	MBMG	10/09/79		46.1		13.7	311
156	LB-098	22N24W23ABAB	2814						112LONE				D	4	MBMG	07/10/79		20		12.5	352
157	LB-099	22N24W23ADAA	2809	301			1	W	112LONE	2510		1935	DS	4	MBMG	10/09/79		44.5		14.0	323
158	LB-100	22N24W23BABA	2806	300			3.5	W	112LONE	2508		1947	DS	4	MBMG	07/10/79				11.1	320
159	LB-101	22N24W23CDCC	2800	184				D	112LONE	2618		1936	A	4	MBMG	10/09/79	171	16.92		11.2	256
160	LB-102	22N24W23DDAA	2790	350			50	W	112LONE			1918	DS	4	MBMG	10/09/79		22.5	10-E	11.8	303
161	LB-103	22N24W24AABB	2807	246		24	8	W	112LONE	2563			A	4	MBMG	09/08/78					
162	LB-104	22N24W24ABBD	2810	295				D	112LONE	2517		1934	D	4	MBMG	09/08/78				17.4	380
163	LB-105	22N24W24ADAD	2810	306			6.5	W	112LONE	2520		1976	D	6	MBMG	07/09/79		44.5		16.7	507
164	LB-106	22N24W24BBBB	2819	305			30	W	112LONE	2516			A	3	MBMG	10/01/79					
165	LB-146	22N24W24BDDC	2802	270				W	112LONE	2534			D	4	MBMG	09/05/78					
166	LB-148	22N24W24DDCC	2805	300			10	W	112LONE	2507		1936	D	3							
167	LB-149	22N24W25AAAD	2808	300			5	W	112LONE	2510		1911	A	4	MBMG	09/08/79		19.01			
168	LB-107	22N24W25ADAD	2790			F	100	W	112LONE			1907	DS	4	MBMG	09/05/78		12.5		13.2	376
169	LB-150	22N24W25CCCC	2772	169		6	2	W	112LONE	2605		1943	A	4							
170	LB-108	22N24W25DCAB	2765	300		F	5	W	112LONE	2467		1912	S	4	MBMG	07/13/79		+7	4-E	14.5	401
171	LB-109	22N24W26AADD	2795	290		15	17	W	112LONE	2517		1947	DS	4	MBMG	10/09/79		28.1		11.2	315
172	LB-110	22N24W26ABAA	2800	300				O	112LONE	2516		1970	DS	6	MBMG	10/09/79		29.59	10-E	13.9	295
173	LB-111	22N24W26ADDA	2790	280			8	W	112LONE	2512		1915	S	4	MBMG	10/09/79		16.57		10.8	288
174	LB-112	22N24W26BBCC	2800	20				W	112ALVM				D	48	MBMG	09/06/79				12.5	195
175	LB-138	22N24W26DCBA	2796	62	7	F	16	D	112ALVM	2734		1971	S	6							
176	LB-113	22N24W27BBAA	2835	60		0	1	W	112ALVM	2835			DS	4	MBMG	09/05/79					
177	LB-301	22N24W34CCDC	2870	300				C	400PRCD				R	6	MBMG	09/10/79					
178	LB-114	22N24W35AADA	2775	198	F	F	20	W	112LONE	2582		1945	D	4	MBMG	10/08/79		+2.0		13.8	518
179	LB-115	22N24W35ADDD	2773	202		F	2	W	112LONE	2578		1940	DS	4	MBMG	10/08/79		F		14.1	447
180	LB-117	22N24W36BBBB	2771	229	40	F	40	D	400PRCD	2558		1973	C	6	USGS	10/12/76				19.5	472
181	LB-247	23N23W06CDBB	2845	308	63	43	7	D	112ALVM	2540	295 308	1968	D	6	MBMG	10/11/79				12.8	342
182	LB-406	23N23W20BCBB	2832	570			5	U				1984	R								
183	LB-201	23N24W02BDDA	2800	108		60		W	112ALVM				D	8	MBMG	05/03/80					
184	LB-202	23N24W02BDDD	2796	280	100	30	500	D	112ALVM	2744	52 72	1976	I	8	MBMG	05/03/80					
185	LB-203	23N24W02CBC	2786	8				O	112ALVM	2786		1974	I	72	MBMG	08/02/79		2.0		13.0	364
186	LB-231	23N24W02CCD	2800						112ALVM			1975	D		USGS	07/23/75	9	6.3		13.0	355
187	LB-252	23N24W03BABB	2850	240	200	85	12	D	400PRCD			1973	D	6	USGS	07/22/75		63.8		10.5	315
188	LB-253	23N24W10ADAC	2850	245				O	112LONE			1970	S	6	USGS	07/23/75		63.6		12.0	400
189	LB-243	23N24W10BCDA	2780	38			40	D	112LONE	2745		1973	D	6	MBMG	05/03/80		8.05		12.1	349
190	LB-205	23N24W10CBCD	2805	132	57	30	6	D	120SDMS		76 77	1968	D	6	MBMG	05/04/80				10.6	220
191	LB-211	23N24W10CCDC	2785	245				O	112LONE	2542		1975	D	6	MBMG	05/04/80		10.77		12.6	235
192	LB-206	23N24W11CACA	2830	240		45		U	112LONE	2592			D	4	MBMG	09/31/79		48.3		11.8	364
193	LB-207	23N24W11DCCA	2930	1175				D				1953	A	11	MBMG	08/01/79					
194	LB-250	23N24W12ACDB	2870	295	65	62	100	D	112LONE	2600		1973	DS	8							
195	LB-251	23N24W12ACDC	2870	280	77	71	20	D	112LONE	2592		1971	D	6							
196	LB-208	23N24W12CCCB	2877						112LONE				O	4	MBMG	08/02/79		105.68		10.0	207
197	LB-209	23N24W13AABA	2830										DS	4	MBMG	10/10/79	266	51.6		10.2	796
198	LB-210	23N24W15AAAB	2830	270		61		U	112LONE	2562		1935	D	4	MBMG	07/31/79				14.8	357
199	LB-212	23N24W15BBAA	2772						112LONE				D	48	MBMG	05/04/80	6	2.29		8.2	318
200	LB-245	23N24W15CBCC	2800	252	14	14	100	D	112LONE	2564		1962	D	6	MBMG	05/04/80		21.83		12.0	349

Appendix A—*continued.*

Map Number	MBMG Site I.D.	Location T., R., Sec., Tract	Elevation (feet)	Reported Well Data: Total Depth (feet)	PWL (feet)	SWL (feet)	Yield (gpm)	Source of Data	Aquifer	Aquifer Top Elevation (feet)	Perforated Interval (feet)	Date Completed	Use	Diameter (inches)	Field Well Data: Agency	Date	Total Depth (feet)	SWL (feet)	Yield (gpm)	Temp. (°C)	E. C. @ 25°C
201	LB-213	23N24W15DCAA	2792						112LONE	2536			D	4	MBMG	07/31/79	258	39.7		14.9	351
202	LB-214	23N24W21ADCC	2795	234				O	112LONE	2564		1948	D	4	MBMG	05/04/80		19.05		10.2	381
203	LB-230	23N24W21DCAA01	2921						112LONE			1935	A	4	MBMG	06/09/80					
204	LB-215	23N24W21DCAA02	2921	363				D	112LONE	2602		1978	D	6	MBMG	06/09/80				13.2	415
205	LB-255	23N24W22CA	2800	174	140	21	30	D	112LONE	2630		1980	S	6							
206	LB-246	23N24W24CAC	2820						112LONE				A	4	USGS	09/04/74					
207	LB-216	23N24W25DDAD	2785						112LONE	2696			U	7	MBMG	10/11/79	91	11.38		9.9	387
208	LB-217	23N24W25DDCA	2795	95				O	112LKML	2700		1942	DS	4	MBMG	10/11/79				12.3	288
209	LB-219	23N24W26CDCD	2765						112LONE				DI	4	MBMG	07/12/79		F	400-E	13.9	406
210	LB-220	23N24W27CDDD	2800						112LONE				A	4	MBMG	06/06/80	215	24.52			
211	LB-222	23N24W34ADAB	2884	531				D	112LONE	2572	312 368	1941	DO	18	MBMG	07/31/79		104.69	5-E	14.1	374
212	LB-229	23N24W34BDCC	2866						112LONE				D	4	MBMG	06/09/80				16.6	338
213	LB-221	23N24W34CBDD	2862	369	108.5	98.5	20	D	112LONE	2522			DC	6	MBMG	02/24/80		101.25		11.2	355
214	LB-223	23N24W34DADD	2867	306	120	76	5.5	D	112LONE	2565	302 306	1968	DS	6	MBMG	07/31/79				14.2	357
215	LB-249	23N24W34DCD	2865	360				D	112LONE				D	4	USGS	07/21/75		94.5		14.0	400
216	LB-224	23N24W35ACCB	2862						112LONE				D	4	MBMG	07/12/79				14.5	415
217	LB-225	23N24W35DBBA	2863	295				D	112LONE	2570		1935	D	4	MBMG	07/12/79				13.9	473
218	LB-226	23N24W35DCCC	2858	297	290	79	100	D	112LONE	2564		1979	D	6	MBMG	10/11/79		84 27		13.3	411
219	LB-227	23N24W35DDDC	2840	315				D	112LONE	2560		1976	D	6	MBMG	10/10/79	315	70.08		15.9	543
220	LB-228	23N24W36CAAD	2845						112LONE				DS	4	MBMG	10/10/79		70.80		13.9	369
221	LB-410	24N22W30BCCC	3153	480			80-100	U	112OTSH		436-445	1984	R	6	USGS	11/06/84		245.84			
222	LB-254	24N23W03ABAA	3040	120	50	11	6	D	120VOLC		46-48	1968	D	6							
223	LB-234	24N23W08DADD	2920	212				O	112OTSH				D	6	MBMG	06/09/80	180	11.83		10.5	420
224	LB-233	24N23W09ABBB	2960				500	D	112OTSH				U	6	MBMG	06/09/80	199	9.8		7.5	307
225	LB-241	24N23W16CBBB	2922	200				O	112OTSH				D	3	MBMG	06/09/80				10.4	316
226	LB-411	24N23W16BCBB	2916	283	43.5	22.6	400	D	112OTSH	2761	170-274	1984	R	8							
227	LB-236	24N23W16CBBB	2922	200				O	112OTSH				D	6	MBMG	06/09/80		22.51		10.4	316
228	LB-235	24N23W17BABA	2930	39	30	27	12	D	120VOLC			1968	D	6	MBMG	06/09/80	40	24.46		12.2	491
229	LB-237	24N23W17DACD	2922						112OTSH				D	3	MBMG	06/09/80				13.2	324
230	LB-238	24N23W20AABB	2920	220				O	112OTSH			1930	S	3	MBMG	06/09/80				13.4	274
231	LB-239	24N23W21BCDB	2928						112OTSH				A	4	MBMG	06/07/80	77	32.93			
232	LB-240	24N23W31BCBC	2852						112OTSH				D	4	MBMG	06/08/80				13.4	335
233	LB-408	24N23W32ADCC	2905		100			U	120SDMS			1984	RA	—							
234	LB-248	24N24W13BBAB	2950						112ALVM				D	48	MBMG	10/11/79	5	1.0		12.5	283
235	LB-232	24N24W14DDDD	2900						120SDMS				S	6	MBMG	06/09/80		21.43		10.8	232
236	LB-231	24N24W23BDAD	2998	185		90	200	W	120SDMS				DS	6	MBMG	06/09/80				10.8	257
237	LB-407	24N24W25DDBB	2858	328	81	78	50.5	U	112OTSH	2539	319-326	1984	R	6	USGS	10/10/84		78.35		13.0	335
238	LB-409	24N24W27ABDD	2840	217				U	120SDMS			1984	R	6	USGS	10/10/84		30.73			
239	LB-244	24N24W34ACDD	2838										D		MBMG	05/03/80				10.2	211
240	LB-242	24N24W35CDCA	2825	108		60		O	112ALVM				D	6	MBMG	05/03/80		27.30		10.7	175

Appendix B—Selected drillers' logs.

Well No. 16
T 21N R 23W Sec. 13 CCAB
Drilled by: Camp Drilling, 1964

Feet	Depth	
0	27	Red clay
27	28	Gravel and water
28	80	Red and tan clay
80	215	Tan clay
215	226	Small gravel and clay
226	255	Gray sand
255	259	Clay
259	266	Clay, sand, small gravel and water
266	268	Clay and gravel
268	271.5	Gravel and water
Total depth		271.5 feet

Well No. 17
T 21N R 23W Sec. 14 ACAB
Drilled by: O'Keefe Drilling, Polson, 1974

Feet	Depth	
0	160	Tan clay
160	176	Light gray silt
176	230	Gray clay
230	264	Sand, fine gravel, water
264	267	Gravel, water, flowing 200 gpm
Total depth		267 feet

Well No. 24
T 21N R 23W Sec. 23 AADB
Drilled by: Camp Drilling, 1975

Feet	Depth	
0	220	Brown clay
220	245	Blue clay
245	257	Blue clay
257	263	Sand and gravel (some water)
263	268	Sand and gravel, water
268	278	Sand and gravel, water
278	281	Sand and clay
281	284	Sand
284	295	Clay and gravel
295	310	Clay and sand
Total depth		310 feet

Well installed to 282 feet

Well No. 28
T 21N R 24W Sec. 02 ADA
Drilled by: O'Keefe Drilling, Butte, 1968

Feet	Depth	
0	1	Soil
1	70	Light brown clay
70	75	Blue clay and mud
76	76	Sand, flowing water
76	80	Blue clay
80	82	Gravel and sand, water
Total depth		82 feet

Well No. 29
T 21N R 24W Sec. 02 ADC
Drilled by: Camp Drilling, 1972

Feet	Depth	
0	2	Gravel
2	56	Tan clay
56	116	Gray clay
116	123	Tan clay
123	140.5	Gray clay
140.5	140.8	Gravel, water
Total depth		140.8 feet

Well No. 30
T 21N R 24W Sec. 02 BCCC
Drilled by: Camp Drilling, 1971

Feet	Depth	
0	103	Clay
103	(?)	Sand, gravel and water
Total depth		103 feet

Well No. 36
T 21N R 24W Sec. 03 CACC
Drilled by: O'Keefe Drilling, Polson, 1972

Feet	Depth	
0	5	Surface dirt
5	25	Yellow clay
25	37	Green clay and heavy sand
37	40	Coarse sand and gravel
Total depth		40 feet

Appendix B—*continued.*

Well No. 38
T 21N R 24W Sec. 03 DBAB
Drilled by: Camp Drilling, 1974

Feet	Depth	
0	41	Tan clay
41	43	Clay, some gravel
43	45	Clay, shale-like gravel, seep of water
45	60	Brown clay, gravel and black sand
60	65	Green clay, black sand
65	83	Gray clay and black sand
83	103	Yellow clay and black sand
103	145	Brown clay and black sand
145	170	Brown clay, small gravel and black sand
170	171	Boulder
171	189	Green clay and small gravel
189	203	Blue clay, small gravel
203	204	Boulder
204	205	Sand, gravel and water
205	207	Hard green rock
207	347	Blue green rock, seeps of water
Total depth		347 feet

Well No. 39
T 21N R 24W Sec. 03 DCBB
Drilled by: Camp Drilling, 1972

Feet	Depth	
0	3	Black dirt
3	8	Gray clay
8	14	Tan clay
14	27	Tan clay, black sand, seep of water
27	28	Brown sand and water
28	35	Tan clay
35	43	Black sand and water
43	48	Tan clay
48	50	Black sand and water
50	52	Sand, gravel and water
52	54	Gray clay and gravel
54	58	Sand, gravel and water
58	74	Blue-green clay
74	86	Gray sand and clay
86	90	Blue-gray shale
90	103	Rock and water
Total depth		103 feet

Well No. 42
T 21N R 24W Sec. 04 DABD
Drilled by: Cass Drilling, Polson, 1977

Feet	Depth	
0	1	Black dirt
1	37	Tan clay and some gravel
37	54	Tan clay
125	146	Gravel imbedded in tan clay
146	234	Blue cemented gravel, some boulders with seams of gray clay, seeps of water
234	367	Medium to hard gray rock, water all through this rock
367	420	Very hard dark gray rock
Total depth		420 feet

Well completed in two zones:
intake at 280 feet (temperature = 10.1°C)
intake at 420 feet (temperature = 29.8°C)

Well No. 43
T 21N R 24W Sec. 04 DBDA
Drilled by: Camp Drilling, 1963

Feet	Depth	
0	6	Clay and gravel
6	30	Clay
30	60	Clay and gravel
60	118	Shale and clay
118	132	Shale, clay and gravel
132	145	Clay and gravel
145	191	Clay, gravel and boulders
191	194	Gravel and clay
194	216	Water, gravel, clay and boulders
216	239	Boulders and gravel
239	240	Clay
240	245	Gravel and water
245	261	Rock
261	379	Limestone
379	383	Porous limestone with water
Total depth		383 feet

Appendix B—*continued.*

Well No. 50
T 22N R 23W Sec. 07 BBDB
Drilled by: Camp Drilling, 1974

Feet	Depth	
0	2	Topsoil
2	15	Brown clay
15	55	Blue clay
55	78	Blue clay, fine sand
78	141	Brown clay
141	143	Blue clay, small gravel, fine sand and water
143	153	Blue clay, medium gravel and water
153	160	Blue clay, fine sand, gravel and water
160	163	Medium gravel and water
163	167	Fine blue sand and water
167	171	Medium gravel, fine blue sand, water
171	198	Fine blue sand (quick), water
198	217	Fine to coarse gravel, water
217	221	Clay, fine gravel, water
221	245.8	Broken rock, red-brown clay
Total depth		245.8 feet

Well No. 52
T 22N R 23W Sec. 07 DDBB
Drilled by: Lawrence and Charles Baxter, 1964

Feet	Depth	
0	223	Clay
223	229	Sand, gravel, water in coarse gravel
Total depth		229 feet

Well No. 68
T 22N R 23W Sec. 19 CCCD
Drilled by: O'Keefe Drilling, Polson, 1978

Feet	Depth	
0	2	Soil
2	120	Tan clay
120	180	Quick sand (water)
180	228	Tan clay
228	284	Silty clay
284	294	Sand
294	297	Gravel
Total depth		297 feet

Well No. 75
T 22N R 23W Sec. 20 CDBC
Drilled by: Camp Drilling, 1979

Feet	Depth	
0	163	Clay
163	169	Sand and water
169	236	Clay
236	244	Sand and water
244	255	Sand, small gravel and water
255	262	Sand, large gravel and water
Total depth		262 feet

Well No. 78
T 22N R 23W Sec. 29 ABCC
Drilled by: Liberty Drilling, 1974

Feet	Depth	
0	27	Brown sand in tan silty clay
27	184	Tan silty clay
184	204	Tan and gray clay
204	206	Gravel mixed in blue clay, seeps of muddy water
206	253	Blue-gray argillite
253	258	Tan-brown argillite
258	277	Green-gray argillite
277	278	Tan-brown argillite
278	313	Green-gray argillite
313	318	Tan-brown argillite
318	339	Green-gray argillite
Total depth		339 feet

Well No. 86
T 22N R 23W Sec. 29 ACCD
Drilled by: Northern Testing, 1982

Feet	Depth	
0	20	Sand
20	238	Clay and silty clay
238	242	Indurated clay
242	247	Sand, gravel and cobbles
Total depth		247 feet

Appendix B—*continued.*

Well No. 101
T 22N R 23W Sec. 33 BABB
Drilled by: O'Keefe Drilling, Polson, 1973

Feet	Depth	
0	95	Tan silty clay
95	191	Tan silt
191	230	Gray silty clay
230	238	Gray sandy clay
238	244	Gray gravel, some gray clay
244	250	Gray sand and gravel, water
250	268	Gravel imbedded in gray clay
268	269	Gray sand
269	284	Gravel imbedded in gray clay
284	286	Light brown colored rock
Total depth		286 feet

Well installed to 249 feet

Well No. 109
T 22N R 24W Sec. 1 CBDC
Drilled by: Camp Drilling, 1960

Feet	Depth	
0	124	Soft yellow clay
124	163	Tan clay and sand
163	265	Soft tan clay
265	285	Clay
285	304	Black silty sand and gray clay
304	309	Gravel, sand and water
Total depth		309 feet

Well No. 111
T 22N R 24W Sec. 2 ABBB
Drilled by: O'Keefe Drilling, Butte, 1968

Feet	Depth	
0	2	Topsoil
2	145	Tan sandy clay
145	205	Quick sand
205	290	Silty clay and water
290	295	Fine blue sand
295	300	Coarse sand and gravel (water)
Total depth		300 feet

Well No. 117
T 22N R 24W Sec. 03 ACCB
Drilled by: O'Keefe Drilling, Polson, 1977

Feet	Depth	
0	0.2	Black dirt
0.2	118	Tan clay
118	257	Silty clay—seeps water
257	290	Tan clay
290	298	Gray clay
298	321	Fine gray sand and water
321	326	Gray clay
326	331	Sand-gravel-water
Total depth		331 feet

Well No. 134
T 22N R 24W Sec. 12 ACCC
Drilled by: Camp Drilling, 1979

Feet	Depth	
0	215	Tan clay
215	286	Tight gravel, clay
286	301	Gravel, sand, water
301	308.5	Gravel and sand, more water
Total depth		308.5 feet

Well No. 163
T 22N R 24W Sec. 24 ADAD
Drilled by: D & N, Pablo, 1976

Feet	Depth	
0	1	Topsoil
1	13	Tan clay
13	16	Quick sand
16	120	Tan sandy clay
120	220	Quick sandy clay
220	280	Quick sand
280	290	Sand
290	292	Fine sand, gravel
292	302	Fine sand
302	306	Fine gravel, sand
Total depth		306 feet

Well No. 180
T 22N R 24W Sec. 36 BBBB
Drilled by: Camp Drilling, 1973

Feet	Depth	
0	189	Clay with streaks of hard pan
189	192	Blue clay
192	198	Blue clay and sand
198	203	Blue clay and water
203	210	Blue clay and sand
210	213	Blue-green clay
213	229	Blue shale (traces of water)
229		Blue rock and water
Total depth		229 feet

Well No. 184
T 23N R 24W Sec. 2 BDDD
Drilled by: Kane Drilling, 1976

Feet	Depth	
0	23	Soil, sand
23	24	Gravel
24	70	Fine sand, clay, gravel
70	280	Rock with cracks, water
Total depth		280 feet

Appendix B—*continued.*

Well No. 187
T 23N R 24W Sec. 03 BABB
Drilled by: O'Keefe Drilling, Polson, 1973

Feet	Depth	
0	8	Brown silty sand
8	26	Gravel and tan silt
26	118	Tan and yellow clay
118	140	Medium tan-colored rock
140	161	Medium gray rock
161	240	Medium light gray rock-seeps of water
Total depth		240 feet

Well No. 194
T 23N R 24W Sec. 12 ACDB
Drilled by: Liberty Drilling, 1973

Feet	Depth	
..0	1	Topsoil
1	28	Tan ropey clay
28	204	Gray silty sand
204	250	Tan ropey clay
250	270	Tan silty sand
270	295	Gray gravel and rock, water
Total depth		295 feet

Well No. 193
T 23N R 24W Sec. 11 DCCA
Drilled by: Premier Petroleum, Spokane, 1953
(Oil well test log by Virgil Chamberlain)

Feet	Depth	
0	700	Pleistocene lake bed material Loose-consolidated sands, gravels and clays. Color varies from white to light gray with streaks of pale green and pale pink. A few thin beds of fresh water limestone were noted. Gravels were varicolored with numerous fragments of quartzite and other metamorphic rock types.
700	825	Old Pre-Cambrian Surface Yellowish to light gray claystone with numerous inclusions of brown to black mica flakes. Thin streaks of siltstone and some clay were noted. A show of gas from 700-725′ was reported.
825	1125	Grinnel-Appekuny argillite Well-indurated claystones and shales metamorphosed into argillites. This formation is typically a light to medium gray, micaceous shale with large uniform black mica inclusions, hard.
Total depth		1175 feet

Well No. 200
T 23N R 24W Sec. 15 CBCC
Drilled by: Camp Drilling, 1962

Feet	Depth	
0	11	Sand and gravel
11	19	Clay and gravel
19	51	Clay
51	58	Sand
58	200	Clay
200	236	Clay
236	247	Sand and water
247	252	Sand, gravel and water
Total depth		252 feet

Well No. 204
T 23N R 24W Sec. 21 DCAA
Drilled by: Camp Drilling, 1978

Feet	Depth	
0	189	Tan clay
189	223	Silty clay, sand and water
223	319	Silty clay
319	357	Gray clay, sand and water
357	363.5	Gray clay, sand, very small gravel, and water
Total depth		363.5 feet

Appendix B—*continued.*

Well No. 205
T 23N R 24W Sec. 22 CA
Drilled by: Kane Well Drilling, 1980

Feet	Depth	
0	30	Clay
30	40	Fine sand, water
40	170	Clay, sand
170	174	Gravel, clay, water
Total depth		174 feet

Well No. 211
T 23N R 24W Sec. 34 ADAB
Drilled by: C.V. Ėnloe, 1941

Feet	Depth	
0	276	Lake bed silts, composed of clay and fine sand.
276	312	Lake bed silts, composed of heavy sticky blue clay showing definite stratification.
312	368	Well sorted gravel varying in size from 10 inches to a medium sand.
368	390	Small seams of coal, wood, peat, shale and clay which contain a large percentage of sand.
390	470	Stratified clay containing sand and pieces of wood. An occasional stratum of sand and angular pebbles. These strata of sand contain concretions of pyrite formed around pieces of wood.
470	500	Stratified clay containing about 50% fine sand; small pieces decayed vegetation; color of formation becomes darker with depth. At 500 ft color is chocolate brown.
500	531	Stratified clay, dense and "rubbery", colored brown by organic matter.
Total depth		531 feet

Well No. 213
T 23N R 24W Sec. 34 BCDD
Drilled by: John Farrell, Year unknown

Feet	Depth	
0	30	Brown clay
30	40	Fine brown sand
40	130	Brown clay
130	160	Dry fine sand, brown
160	190	Dark gray-blue wet quick sand
190	280	Dark gray-blue clay and fine sand
280	340	Dark gray-blue quick sand
340	352	Sharp water-bearing sand
352	356	Yellow gummy clay
356	363	Coarse sand, some gravel
363	369	Coarse heavy sand
369		Uniform gravel, no sand
Total depth		369 feet

Well No. 218
T 23N R 24W Sec. 35 DCCC
Drilled by: Camp Drilling, 1979

Feet	Depth	
0	150	Silty tan clay
150	260	Hard tan clay
260	294	Gray clay, seeps of water (sand)
294	296	Sand and water
296	297	Sand, gravel and water
Total depth		297 feet

Appendix C—Monitoring data and well hydrographs.

	Date	Static Water Level (ft)	Electrical Conductivity (micro-siemens/cm)	Temp (°C)
Well No. 5	10/8/79	+23.6	447	10.5
	12/2/79	—	462	15.0
Measuring point	1/10/80	+32.8	463	12.1
Elev. = 2729 ft.	2/24/80	+33.7	447	15.5
	3/25/80	+34.5	493	15.0
	5/1/80	+26.8	440	—
	6/8/80	+34.8	485	14.1
	7/17/80	+42.0	470	—
	10/17/80	+40.0	536	15.2
	12/3/80	+40.9	469	14.2
	1/13/81	+39.0	513	15.7
	2/2/82	—	488	14.9
Well No. 9	10/8/79	—	449	11.2
	2/24/80	+44.8	450	10.2
Measuring point	3/25/80	+44.1	501	10.1
Elev. = 2734 ft.	5/1/80	+35.6	440	—
	6/8/80	+46.5	474	10.0
	10/17/80	+50.8	509	11.1
	12/3/80	+52.2	459	9.4
	1/13/81	+49.7	513	10.0
	4/15/81	+44.3	462	10.5
	2/2/82	+46.9	473	—
Well No. 55	10/8/79	+23.6	501	15.0
	11/30/79	+27.6	520	15.2
Measuring point	1/10/80	+29.3	569	16.9
Elev. = 2745 ft.	2/24/80	+28.1	515	15.0
	3/25/80	+29.3	524	15.8
Well No. 57	10/8/79	+28.6	478	19.0
	12/2/79	+33.1	542	16.9
Measuring point	1/10/80	+32.3	491	18.5
Elev. = 2745 ft.	2/24/80	+33.0	500	17.3
	3/25/80	+34.9	531	17.1
	4/30/80	+34.4	517	16.9
	6/7/80	+36.3	553	17.0
	7/17/80	+37.9	521	—
	10/17/80	+38.6	555	17.2
	12/3/80	+39.7	599	16.7
	1/13/81	+37.4	578	17.2

Appendix C—*continued.*

	Date	Static Water Level (ft)	Electrical Conductivity (micro-siemens/cm)	Temp (°C)
Well No. 56	10/8/79	+19.6	447	18.0
	12/2/79	+23.9	503	16.9
Measuring point	1/10/80	+24.2	491	18.5
Elev. = 2752 ft.	2/24/80	+25.5	468	17.5
	3/25/80	+25.2	498	17.4
	5/1/80	+24.9	500	17.3
	6/8/80	+27.26	509	17.2
	7/17/80	+28.6	491	—
	10/17/80	+29.6	572	17.2
	12/3/80	+30.9	505	16.9
	1/13/80	+28.2	539	17.7
Well No. 59	11/30/79	+29.3	448	22.3
	1/10/80	+27.5	499	18.0
Measuring point	2/24/80	+32.0	425	20.8
Elev. = 2745 ft.	3/25/80	+30.7	423	22.1
	5/1/80	+30.5	434	22.3
	6/8/80	+32.3	442	41.8
	7/17/80	+33.3	430	—
	10/17/80	+34.9	485	22.4
	12/4/80	+36.0	435	25.1
	1/14/81	+34.0	553	22.2
	4/16/81	+33.2	447	25.6
	2/2/82	+31.6	396	21.1
Well No. 62	11/30/79	+29.8	495	20.3
	1/10/80	+22.9	498	23.2
Measuring point/	2/24/80	+30.5	503	25.8
Elev. = 2740 ft.	3/25/80	+30.9	515	24.5
	5/1/80	+30.7	491	20.7
	6/8/80	+32.2	547	24.6
	7/17/80	+31.4	508	—
	10/17/80	+34.6	—	—
	12/4/80	+36.3	551	21.9
	1/14/81	+34.0	571	25.6
	4/16/81	+32.6	506	—
	2/2/82	+31.6	542	—
Well No. 72	10/8/79	—	547	18.0
	2/24/80	+31.4	557	17.1
Measuring point	3/25/80	+32.6	566	17.0
Elev. = 2745 ft.	5/1/80	+31.4	548	16.8
	6/8/80	+33.4	610	16.5
	7/17/80	+35.2	600	—
	10/17/80	+35.8	—	—
	12/3/80	+37.2	593	17.4
	1/13/81	+35.1	614	17.0
	4/15/81	+33.5	554	18.0
	2/2/82	+32.3	548	12.8

Appendix C—*continued.*

	Date	Static Water Level (ft)	Electrical Conductivity (micro-siemens/cm)	Temp (°C)
Well No. 74	10/8/79	+15.0	509	23.0
	12/2/79	+18.2	463	25.2
Measuring point	1/10/80	+20.3	535	23.5
Elev. = 2753 ft.	2/24/80	+21.5	506	25.8
	3/25/80	+22.6	538	25.6
	5/1/80	+21.5	522	25.4
	6/8/80	+23.1	531	25.6
	7/17/80	+24.5	560	—
	10/17/80	+25.9	—	25.5
	12/3/80	+27.3	583	25.6
	1/13/81	+24.7	568	25.9
	4/15/81	+23.3	617	24.0
	2/2/82	+23.3	528	—
Well No. 77	10/8/79	+29.1	667	30.0
	12/2/79	+37.4	617	—
Measuring point	1/10/80	+37.2	643	26.0
Elev. = 2730 ft.	2/24/80	+40.9	680	27.0
	3/25/80	+42.2	711	29.0
	5/1/80	+40.9	636	—
	6/8/80	+43.4	701	—
	7/17/80	+45.3	685	—
	10/17/80	+46.0	—	—
	12/3/80	+47.1	763	28.6
	1/13/81	+44.1	674	29.8
	4/15/81	+40.4	640	25.4
	2/2/82	+40.9	704	24.0
Well No. 80	10/8/79	+22.2	700	15.0
	12/2/79	+28.4	640	15.9
Measuring point	1/10/80	+29.1	663	—
Elev. = 2745 ft.	2/24/80	+30.5	643	16.2
	3/25/80	+33.7	644	16.1
	5/1/80	+28.4	659	16.0
	6/8/80	+34.4	701	16.0
	7/17/80	+38.1	685	—
	10/17/80	+38.8	602	15.0
	12/3/80	+39.5	635	—
	1/13/81	+37.4	602	16.0
	4/15/81	+31.2	500	17.0
	2/2/82	+32.3	583	—

Appendix C—*continued.*

	Date	Static Water Level (ft)	Electrical Conductivity (micro-siemens/cm)	Temp (°C)
Well No. 82	1/10/80	+31.9	705	24.0
	2/24/80	+33.0	739	27.0
Measuring point	3/25/80	+35.6	719	23.9
Elev. = 2738 ft.	5/1/80	+30.7	698	—
	6/8/80	+36.8	682	28.7
	7/17/80	+40.9	723	—
	10/17/80	+40.0	758	26.0
	12/3/80	+40.4	707	23.1
	1/13/81	+39.5	700	25.0
	4/15/81	+32.3	728	28.8
	2/2/82	+34.9	644	25.1
Well No. 83	12/2/79	+24.5	636	30.6
	1/10/80	—	654	28.5
Measuring point	2/24/80	+36.7	738	29.5
Elev. = 2740 ft.	3/25/80	+39.5	700	29.6
	5/1/80	+36.7	681	—
	6/8/80	+39.7	718	30.3
	7/17/80	+41.1	744	—
	10/17/80	+41.3	—	29.2
	12/3/80	—	732	28.4
Well No. 85	10/8/79	+22.4	731	49.5
	12/2/79	+28.2	—	51.2
Measuring point	1/10/80	+29.4	719	—
Elev. = 2740 ft.	2/24/80	+28.8	—	51.6
	3/25/80	+32.1	713	51.6
	5/1/80	+29.1	680	—
	6/8/80	+24.0	703	51.6
	7/17/80	+35.6	730	—
	10/17/80	+33.5	798	52.0
	12/3/80	+35.1	698	50.7
	1/13/81	+32.6	719	50.9
	2/2/82	+29.3	667	49.5
Well No. 89	10/8/79	—	438	32.5
	12/2/79	—	439	32.6
Measuring point	1/10/80	+13.9	472	29.0
Elev. = 2766 ft.	2/24/80	+14.3	486	27.8
	3/25/80	+14.7	480	32.8
	5/1/80	+14.1	517	—
	7/17/80	+19.4	481	—
	10/17/80	+19.2	566	33.3
	12/3/80	+20.6	484	32.4
	1/13/81	+17.8	484	33.2
	4/15/81	+17.6	474	—
	2/2/82	+15.7	442	31.4

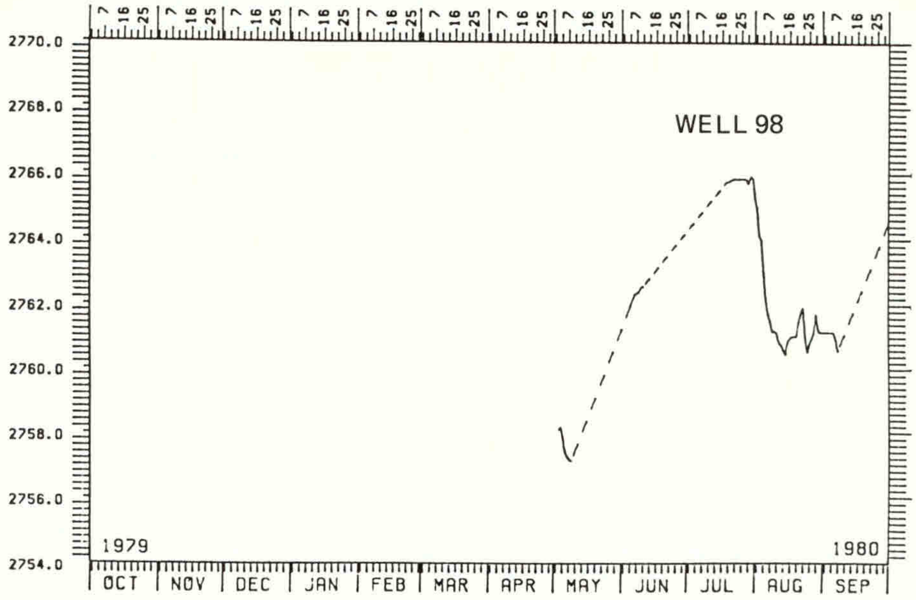
Appendix C—*continued.*

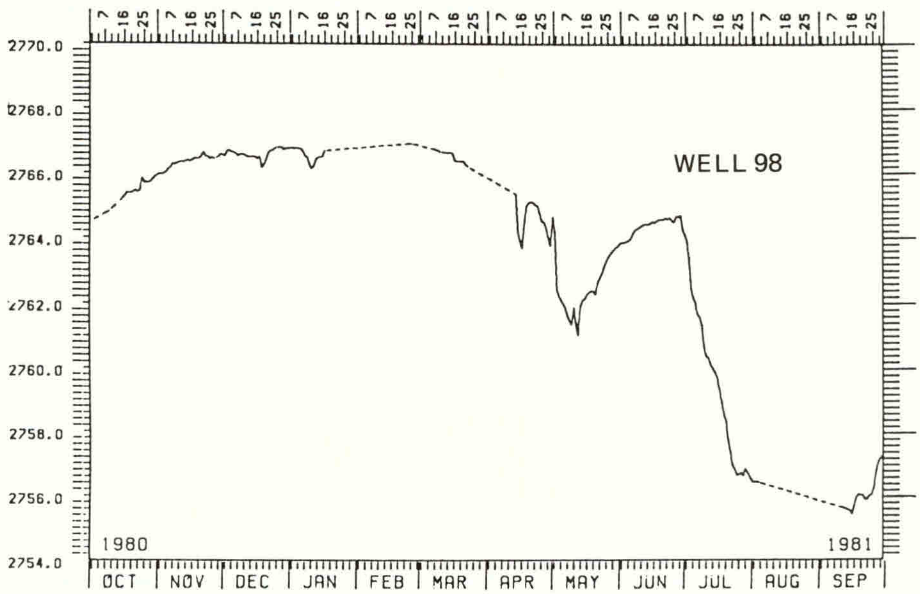
	Date	Static Water Level (ft)	Electrical Conductivity (micro-siemens/cm)	Temp (°C)
Well No. 104	10/8/79	+12.7	426	12.0
	12/2/79	+18.9	436	12.3
Measuring point	1/10/80	+21.5	477	12.0
Elev. = 2740 ft.	2/24/80	+22.5	461	11.2
	3/25/80	+20.6	467	12.3
	5/1/80	+14.1	—	—
	6/8/80	+23.3	454	12.2
	7/17/80	+31.2	542	—
	10/17/80	+27.5	464	12.4
	12/3/80	+28.9	422	12.2
	1/13/81	+26.2	474	12.7
	4/15/81	+22.4	424	13.1
	2/2/82	+23.3	468	12.2
Well No. 110	3/25/80	73.2		
	4/30/80	72.2		
Measuring point	6/8/80	70.7		
Elev. = 2840 ft.	7/17/80	70.4		
	10/16/80	69.1		
	12/2/80	68.2		
	1/14/81	68.8		
	4/14/81	68.2		
	2/2/82	70.3		
Well No. 134	11/30/79	58.7		
	1/11/80	53.9		
Measuring point	2/25/80	53.2		
Elev. = 2831 ft.	3/25/80	52.4		
	4/30/80	54.2		
	6/8/80	52.2		
	7/17/80	52.1		
	10/16/80	54.0		
	12/2/80	52.9		
	1/14/81	53.0		
	2/2/82	55.0		
Well No. 213	2/25/80	101.2		
	3/25/80	100.5		
Measuring point	4/30/80	101.6		
Elev. = 2862 ft.	6/8/80	100.2		
	7/17/80	99.9		
	10/16/80	98.6		
	12/2/80	97.6		
	1/14/81	97.7		
	4/14/81	98.1		
	2/2/82	102.7		

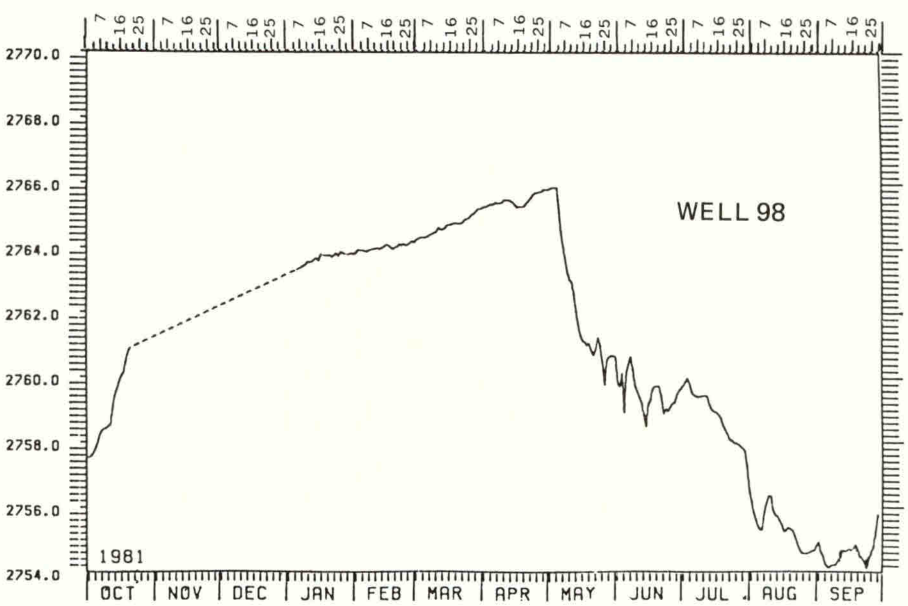
Appendix C—*continued.*

	Date	Static Water Level (ft)	Electrical Conductivity (micro-siemens/cm)	Temp (°C)
Well No. 218	11/30/79	83.1		
	1/11/80	80.9		
Measuring point	2/25/80	80.8		
Elev. = 2859 ft.	3/25/80	80.0		
	4/30/80	83.7		
	6/8/80	79.6		
	7/17/80	79.3		
	10/16/80	78.8		
	12/2/80	77.7		
	1/14/81	78.4		
	4/14/81	77.1		
	2/2/82	79.3		

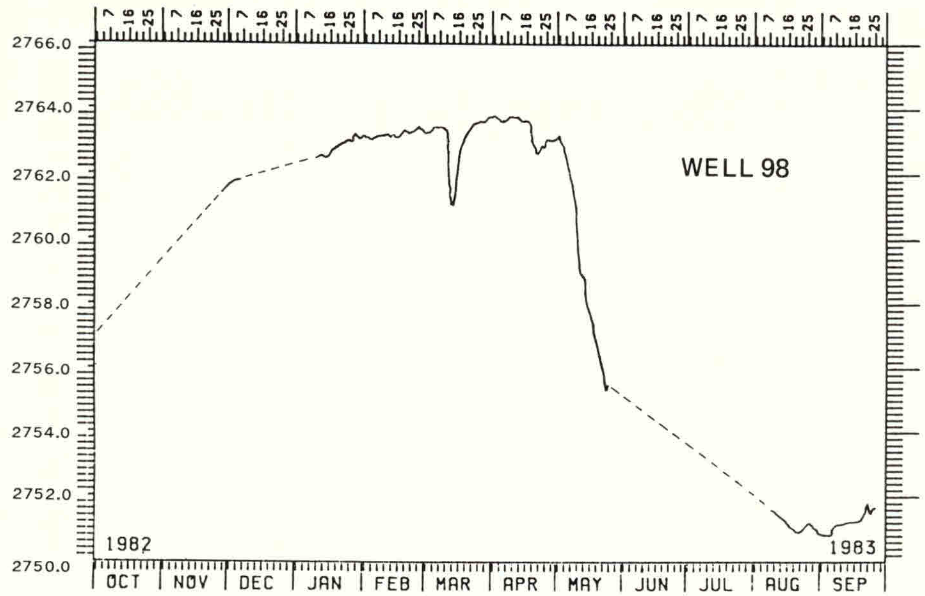
Appendix C—*continued.*

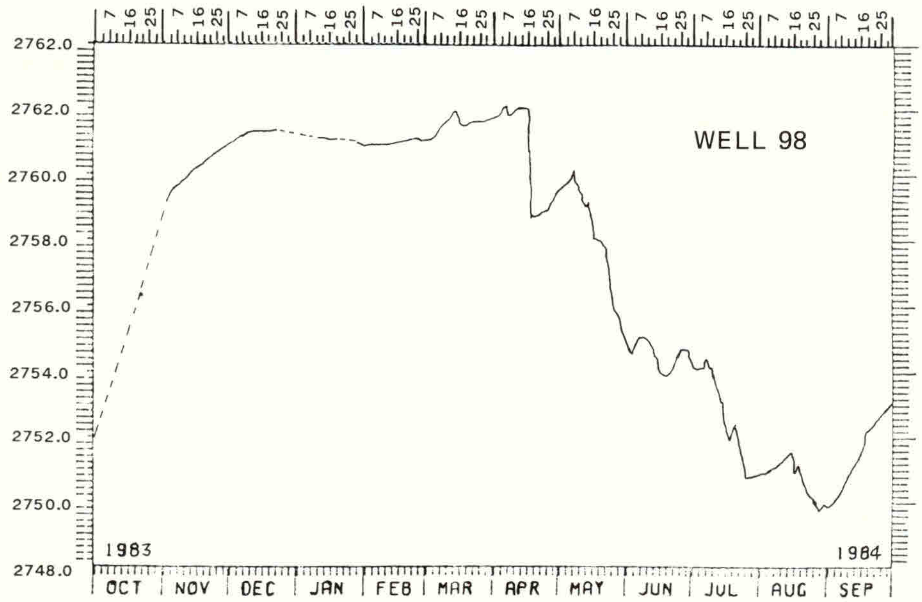


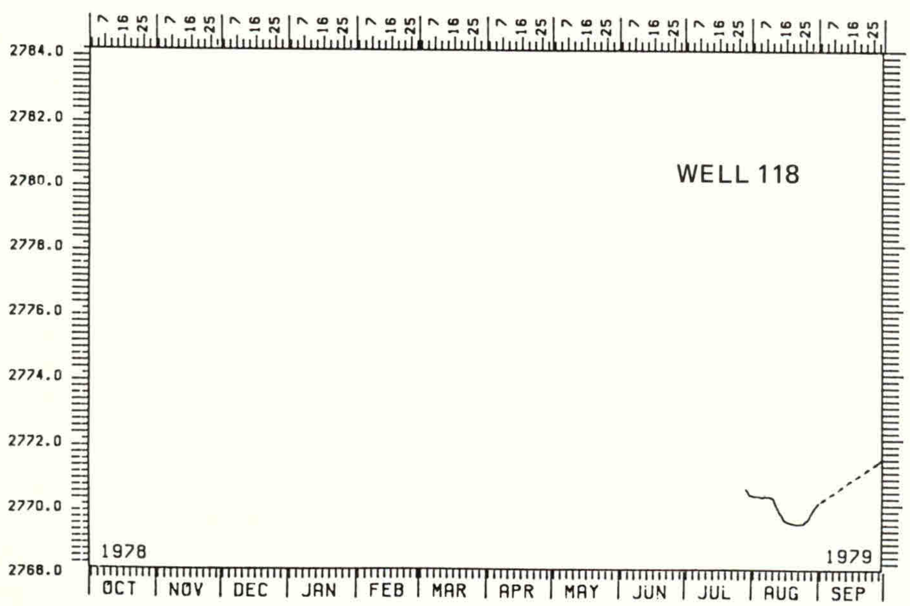




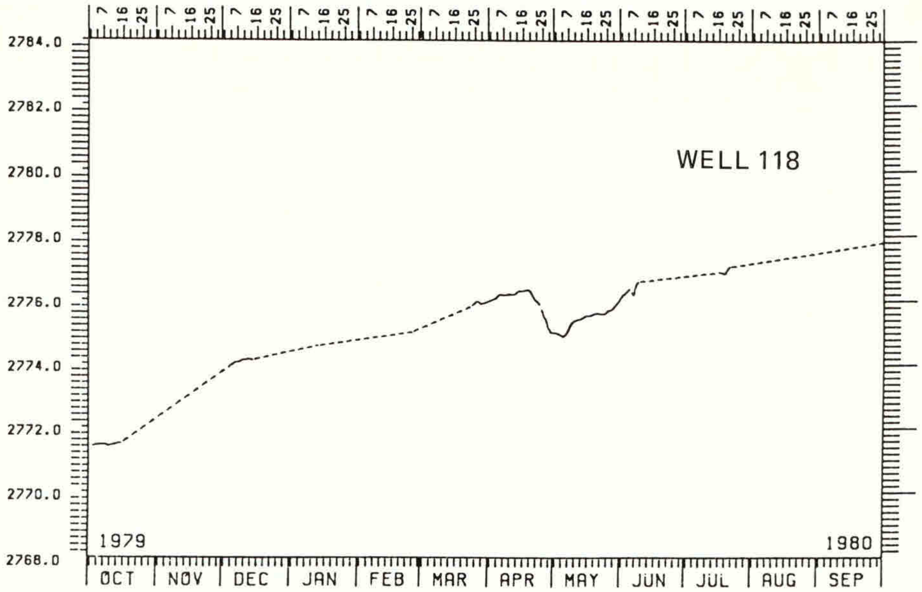
Appendix C—*continued.*

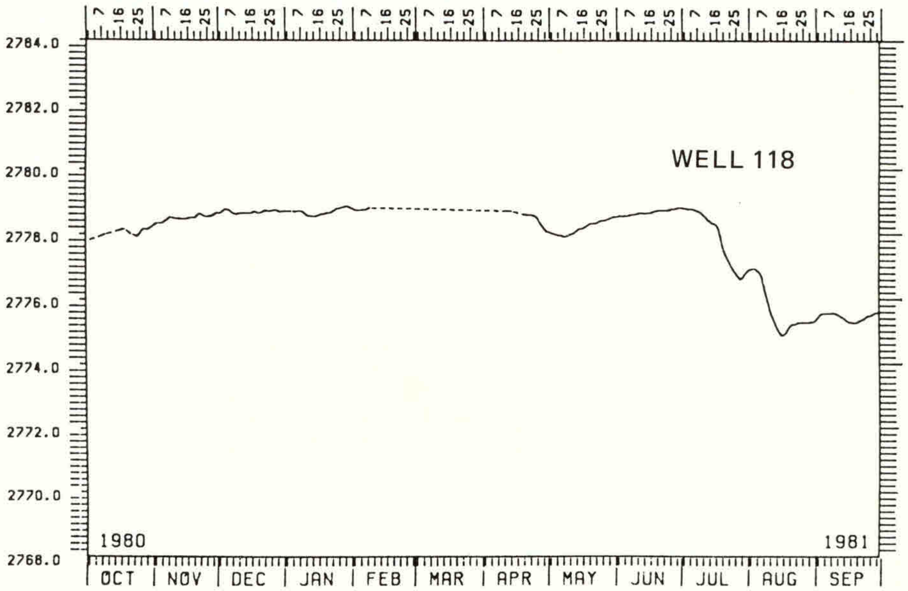


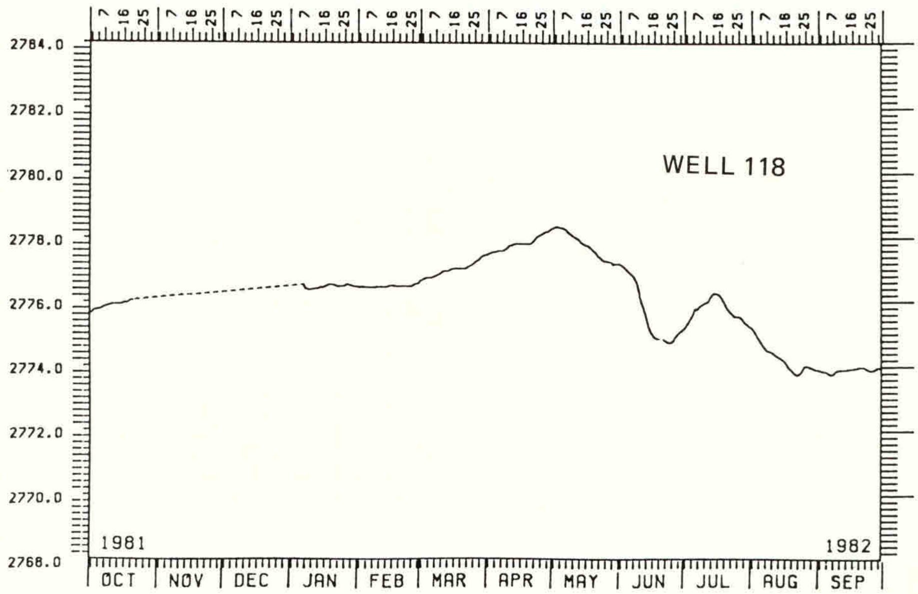




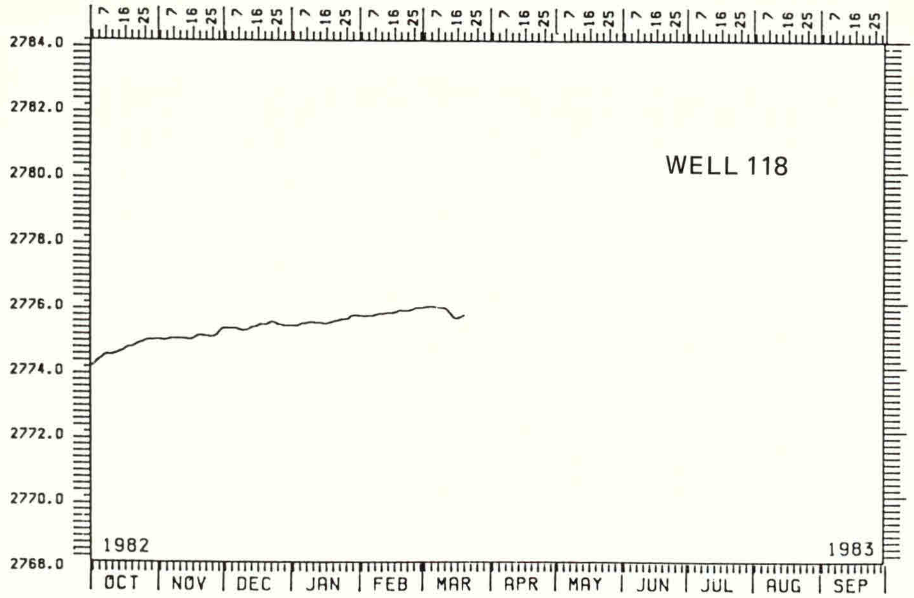
Appendix C—*continued.*

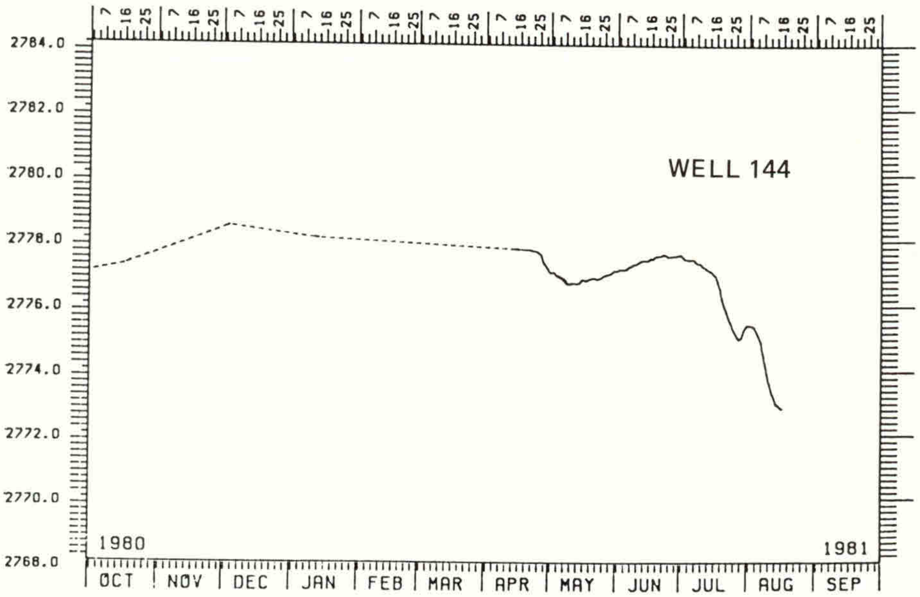


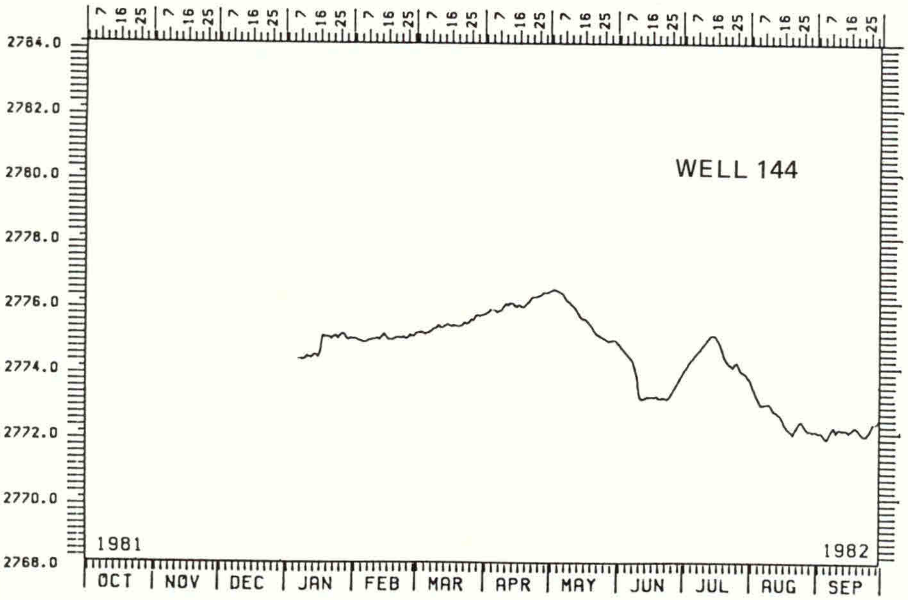


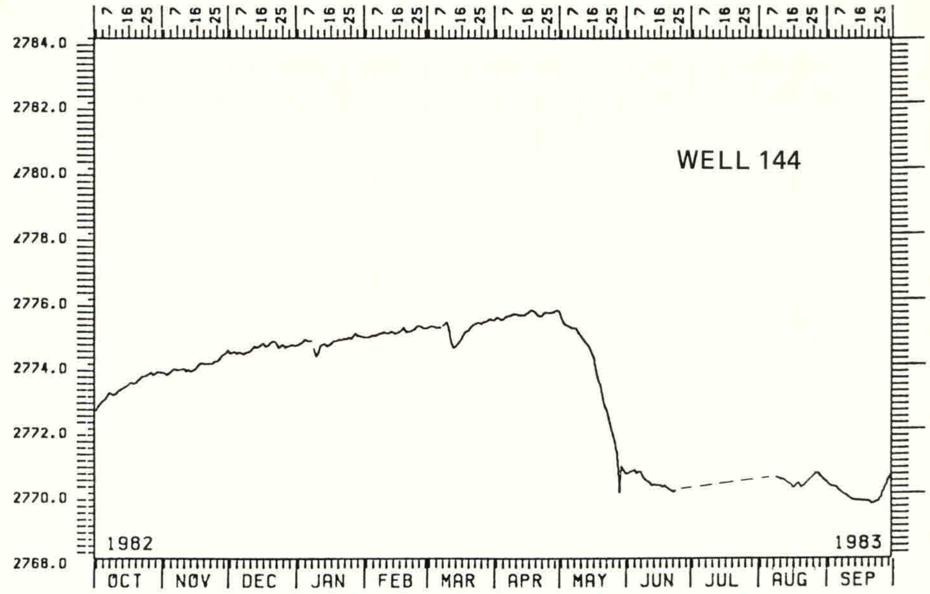


Appendix C—*continued.*





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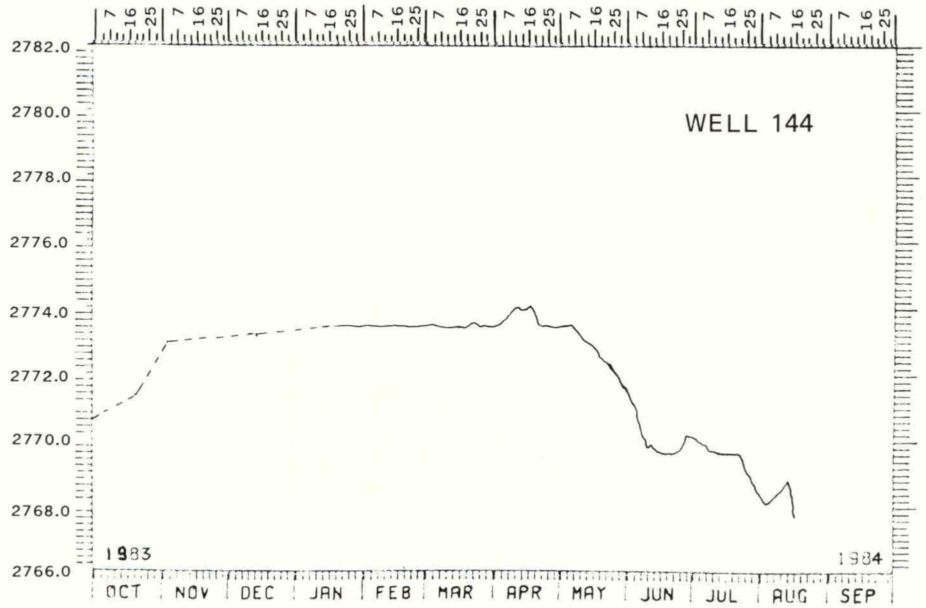
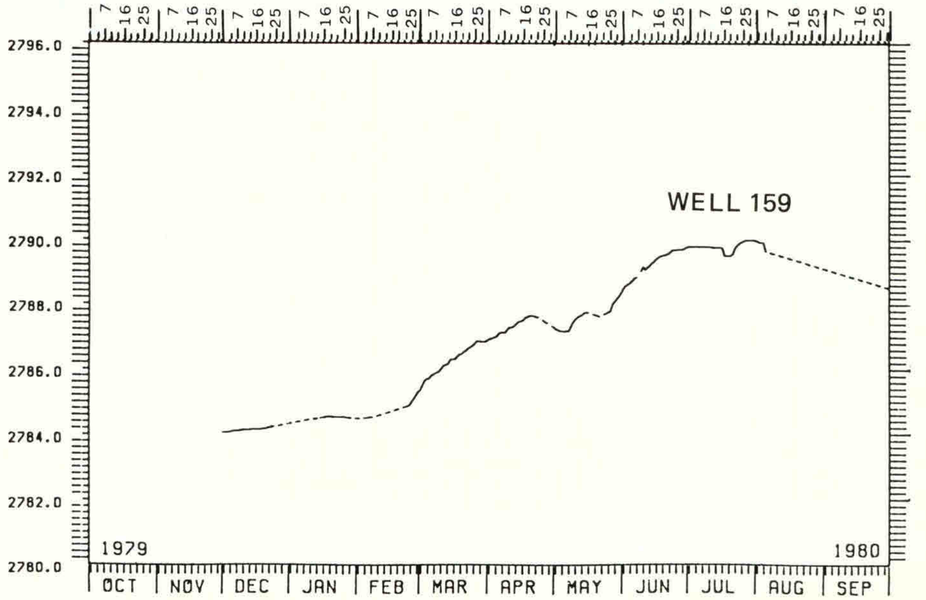
2782.0
2780.0
2778.0
2776.0
2774.0
2772.0
2770.0
2768.0
1982
1983
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP


WELL 144
2782.0
2780.0
2778.0
2776.0
2774.0
2772.0
2770.0
2768.0
2766.0
1983
1984
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP


WELL 159
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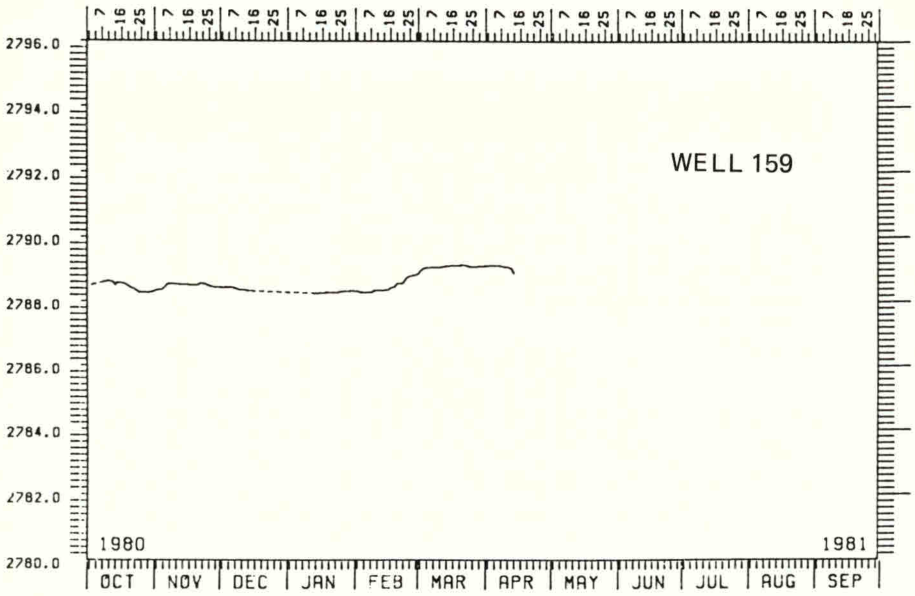
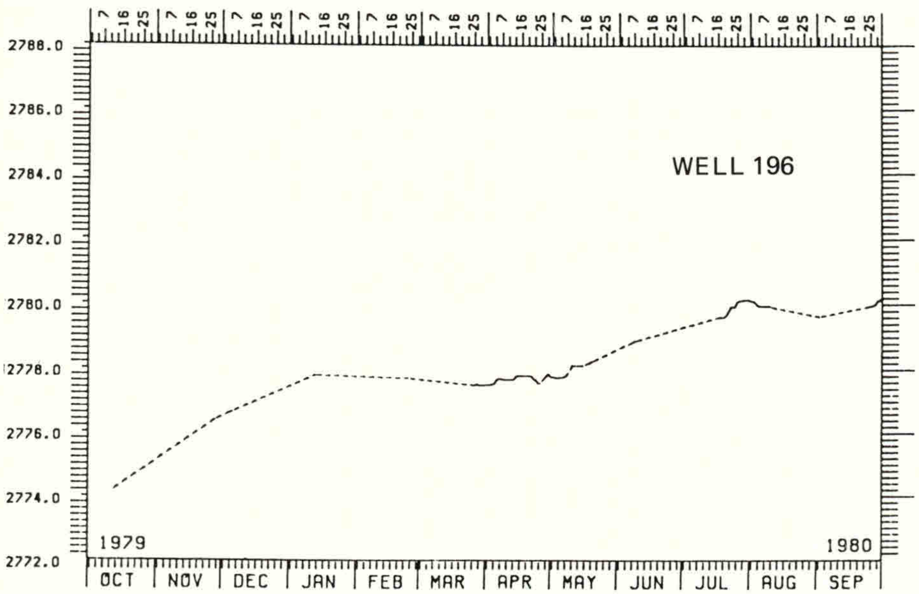
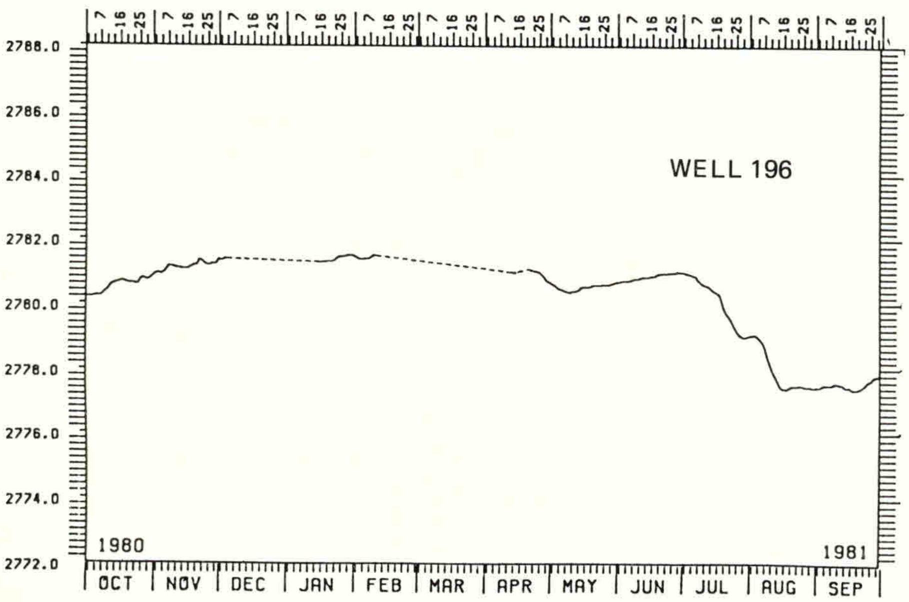
2794.0
2792.0
2790.0
2788.0
2786.0
2784.0
2782.0
2780.0
1979
1980
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

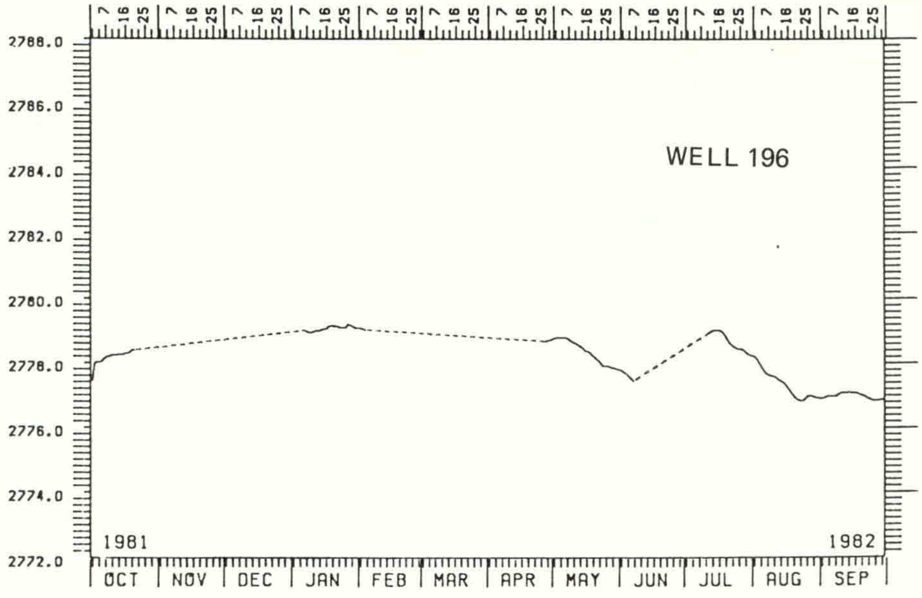
Appendix C—*continued.*

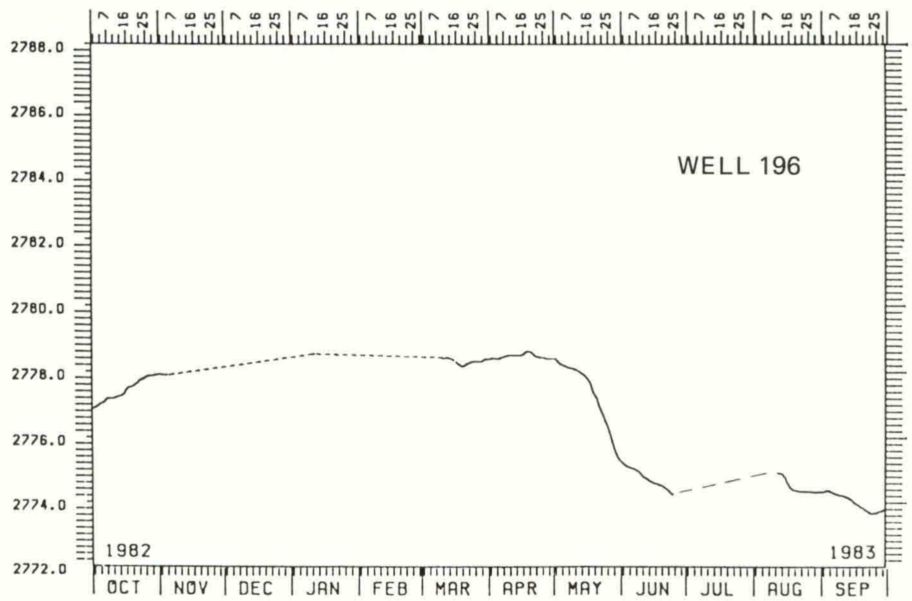


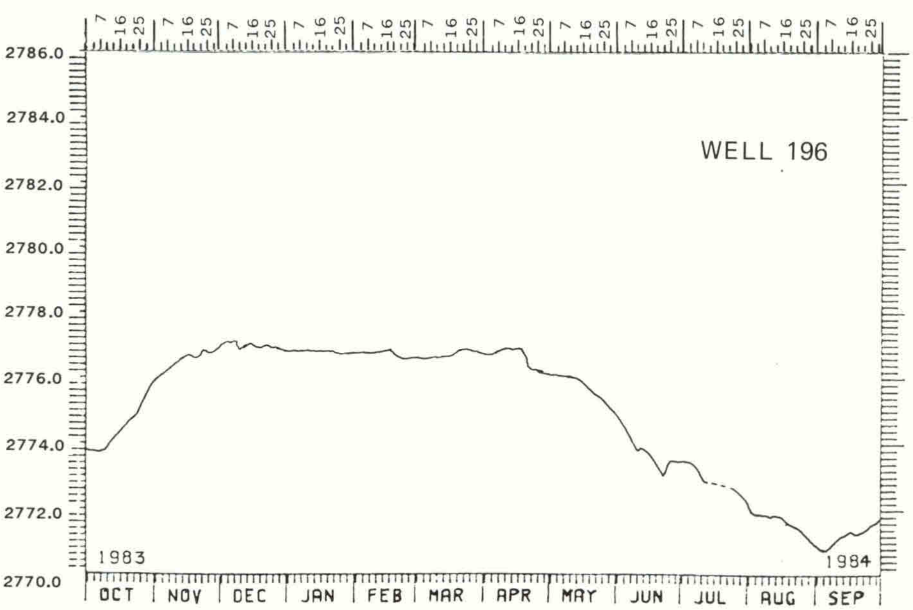




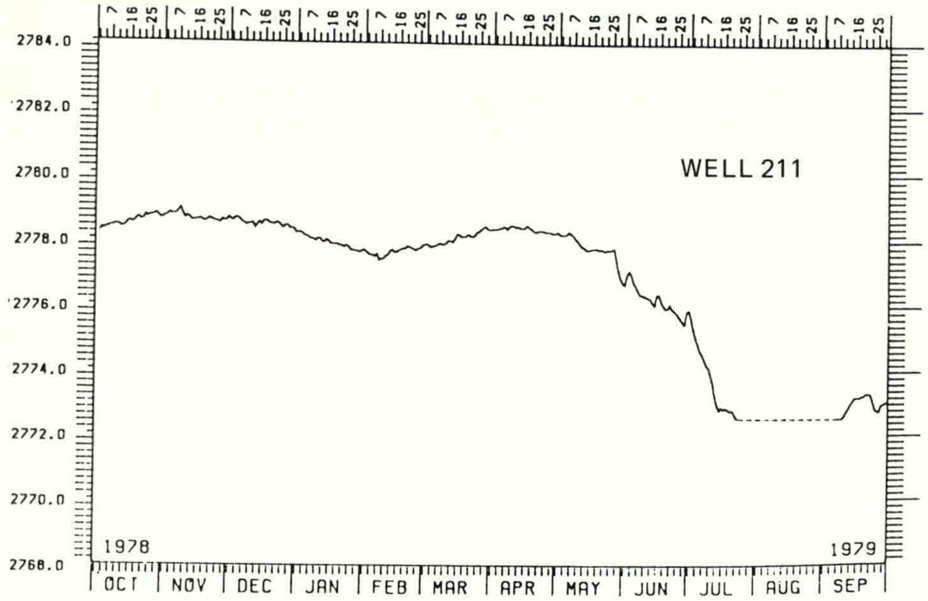
Appendix C—*continued.*

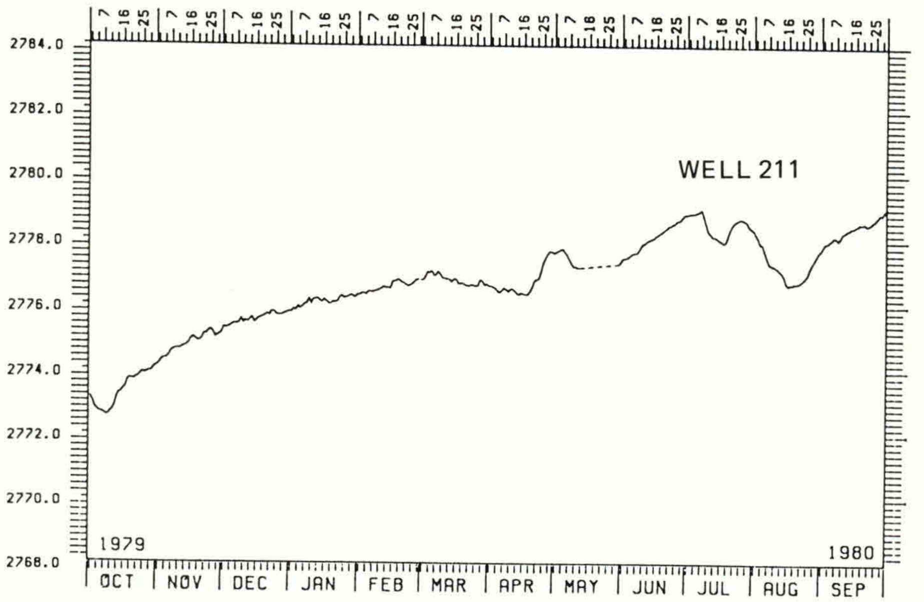


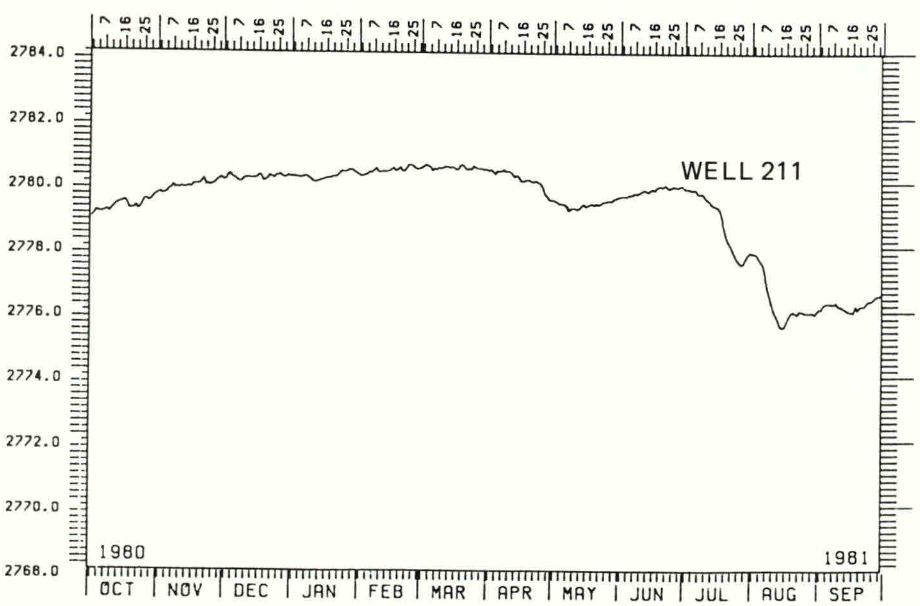




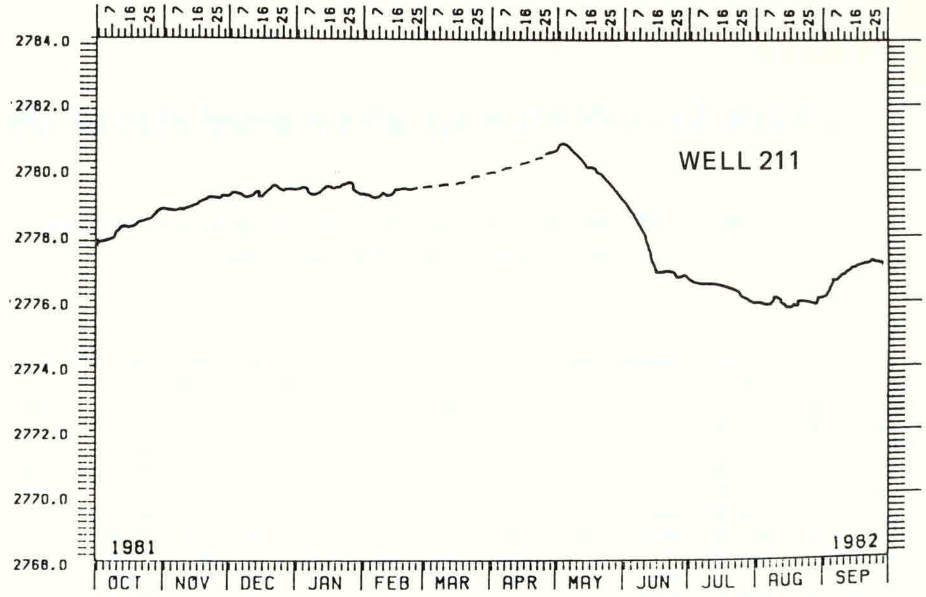
Appendix C—*continued.*

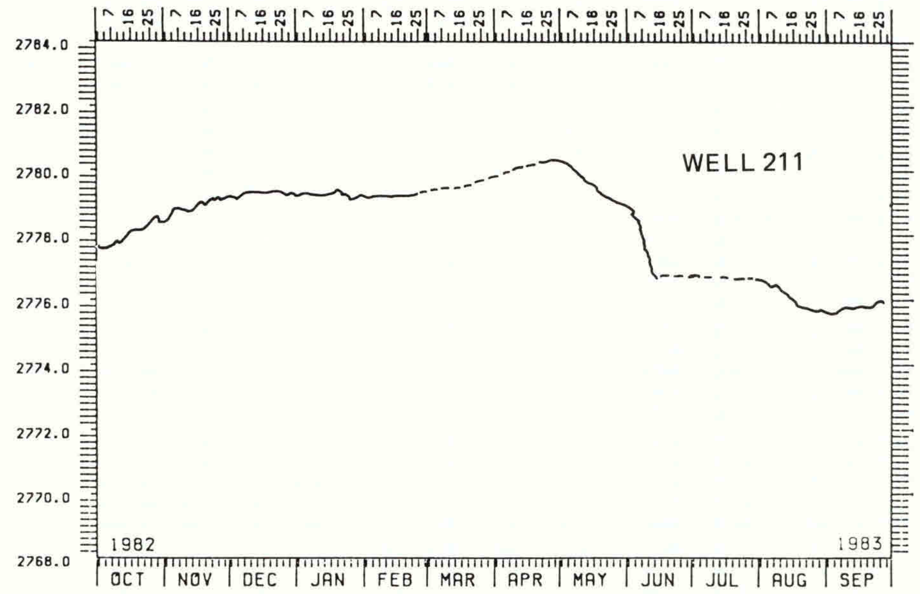


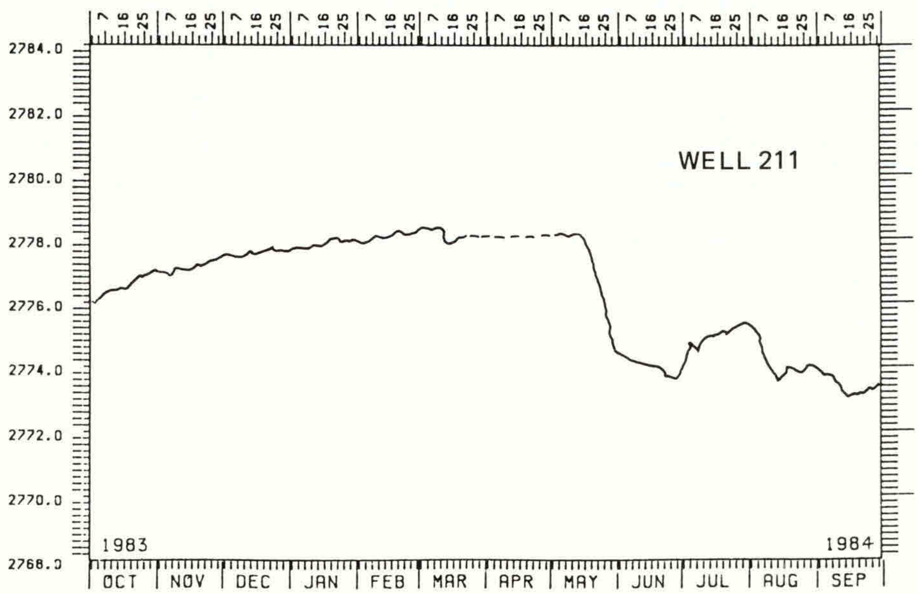




Appendix C—*continued.*







Appendix D—Water quality analytical data.

[Analyses by Montana Bureau of Mines and Geology. All constituents are dissolved and in milligrams per liter unless otherwise indicated.]

Well No.	MBMG Lab No.	Location	Sampling Date	Agency	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	Mn	SiO_2	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	NO_3^-	F^-
6	79Q3755	21N23W04DAAC	11-28-79	MBMG	7.3	2.1	99.9	1.1	0.45	0.20	10.5	232.0	.0	25.7	6.4	0.1	6.2
11	79Q3752	21N23W11CACC	11-28-79	MBMG	31.9	9.6	26.6	0.8	0.58	0.64	19.7	195.0	.0	5.2	6.4	0.3	1.0
17	76Q0139	21N23W14ACB	03-04-76	USGS	32.3	13.0	19.9	1.4	.01	0.50	16.2	196.9	.0	6.00	8.1	0.260	0.6
39	79Q3747	21N24W03DCBB	12-03-79	MBMG	1.2	0.1	95.0	0.6	1.10	.01	46.2	148.0	29.5	8.6	7.9	0.2	5.0
41	79Q3745	21N24W04ADAB	12-03-79	MBMG	0.9	.1	87.8	1.2	0.90	.01	67.4	100.0	31.2	9.0	34.7	0.067	5.0
42	79Q3764	21N24W04DABD	12-03-79	MBMG	0.9	.1	92.3	.1	0.61	.01	67.0	84.6	49.8	7.8	21.2	0.1	5.2
-	75Q1306	21N24W04DBCD	08-27-75	USGS	20.1	4.2	20.0	3.2	.53	.06	22.9	124.3	.0	2.35	3.6	0.158	1.3
43	75Q1307	21N24W04DBDA	08-27-75	USGS	15.2	3.6	33.0	3.0	0.17	.01	22.0	127.8	.0	2.20	12.1	0.249	1.6
52	79Q3760	22N23W07DBDB	11-30-79	MBMG	6.7	1.0	130.0	1.4	0.22	0.10	20.2	314.0	.0	19.0	0.6	0.4	5.5
59	79Q0873	22N23W18ACAA	09-08-78	MBMG	5.8	0.7	101.0	2.3	0.20	0.07	21.0	188.0	36.0	2.2	6.9	1.028	3.2
60	79Q3753	22N23W18BBBB	11-30-79	MBMG	5.7	0.7	105.0	1.3	0.17	0.05	19.5	255.0	.0	7.8	5.8	1.2	3.4
62	79Q3741	22N23W18DDAD	12-02-79	MBMG	3.3	0.4	135.0	1.7	0.09	0.03	28.6	287.0	8.9	19.0	2.1	1.0	4.8
67	79Q3766	22N23W19CBCD	12-05-79	MBMG	5.6	1.3	102.0	1.0	0.74	0.07	13.5	232.0	.0	16.5	2.7	1.0	7.0
69	76Q0748	22N23W19DAA	07-02-76	USGS	5.7	0.6	139.0	3.7	0.11	1.07	32.9	331.8	.0	28.25	1.2	.023	6.1
72	79Q3757	22N23W20BAAD	12-02-79	MBMG	5.5	1.4	131.0	1.3	0.27	0.06	24.9	318.0	.0	25.8	.11	0.1	5.3
74	79Q0872	22N23W20BCCB	09-06-78	MBMG	4.6	0.7	127.0	2.7	0.03	0.04	29.3	280.0	18.2	10.0	1.8	1.163	4.4
75	79Q0871	22N23W20CDBC	09-07-78	MBMG	3.6	0.6	150.0	3.4	0.02	0.02	36.5	326.0	9.6	23.1	2.1	1.130	4.6
76	79Q3754	22N23W20DCDB	12-02-79	MBMG	4.4	0.4	142.0	2.1	0.12	0.02	36.6	328.0	.0	30.9	0.6	1.0	5.0
79	79Q3744	22N23W28CBBB	12-05-79	MBMG	4.0	0.7	147.7	2.8	0.26	0.70	34.9	348.0	.0	34.8	0.6	1.1	4.2
83	79Q3756	22N23W29AADB	12-02-79	MBMG	3.3	0.4	154.4	2.6	0.13	0.03	43.6	354.0	.0	35.5	0.6	0.2	4.5
84	82Q0355	22N23W29ACAB	06-04-82	MBMG	2.9	0.2	152.0	3.1	.002	.009	43.2	327.0	11.0	24.0	0.6	0.05	5.0
85	75Q1491	22N23W29ACBB	09-15-75	USGS	2.8	0.3	150.0	3.4	.01	.01	40.0	352.3	.0	33.75	1.7	0.023	5.2
85	80Q2723	22N23W29ACBB	10-22-80	MBMG	3.2	0.3	152.0	4.0	0.17	0.01	42.2	361.0	.0	32.5	4.1	0.01	3.9
87	79Q3761	22N23W29BAAC	11-29-79	MBMG	4.8	1.0	144.0	2.8	0.65	0.33	41.4	314.0	3.6	31.3	1.3	0.75	7.8
88	80Q2812	22N23W29BADD	12-11-80	MBMG	4.2	1.2	156.0	3.4	1.65	0.07	50.6	339.0	11.0	36.1	0.1	0.56	5.2
88	80Q2813	22N23W29BADD	12-11-80	MBMG	3.4	0.3	159.0	3.2	0.23	.022	45.9	341.0	10.1	35.8	0.4	0.26	5.2
88	80Q2827	22N23W29BADD	12-15-80	MBMG	16.7	2.1	139.0	2.9	0.22	.027	38.8	348.0	.0	35.9	.1	0.12	4.6
88	80Q2826	22N23W29BADD	12-16-80	MBMG	12.3	2.4	132.0	3.4	.081	.044	38.5	345.0	.0	35.5	0.1	0.099	4.5
88	80Q2825	22N23W29BADD	12-16-80	MBMG	12.5	2.4	130.0	3.2	0.25	.019	37.7	344.0	.0	35.5	0.1	0.066	4.6
89	79Q3759	22N23W29CACA	11-29-79	MBMG	2.1	0.3	117.0	1.5	0.22	0.02	32.4	237.0	7.9	16.0	1.5	0.86	7.6
91	79Q0875	22N23W29CCCC	09-08-78	MBMG	6.6	1.6	88.1	1.9	0.39	0.12	14.3	221.0	.0	2.40	14.0	0.938	5.4
94	79Q3739	22N23W30DBCD	12-05-79	MBMG	4.4	0.1	102.0	1.7	0.11	0.02	26.8	176.0	12.7	9.0	64.4	0.2	4.1
101	79Q3742	22N23W33BABB	12-04-79	MBMG	5.5	1.0	139.0	2.1	0.28	0.07	35.0	324.0	.0	27.0	1.4	0.2	4.3
104	79Q3758	22N23W33DDDA	11-29-79	MBMG	23.4	7.4	75.2	1.5	1.5	0.43	19.3	265.0	.0	16.0	1.3	0.75	7.8
115	79Q3743	22N24W02DAAB	12-06-79	MBMG	23.3	4.7	66.1	1.8	0.84	0.25	17.4	239.0	.0	6.6	5.8	1.3	2.8
125	79Q3750	22N24W10ABAB	12-06-79	MBMG	28.4	7.8	23.6	2.2	0.30	0.41	15.9	164.0	.0	2.1	12.0	0.1	1.2
134	79Q3746	22N24W12ACCC	11-30-79	MBMG	22.8	3.8	67.3	2.3	1.08	0.22	18.0	240.0	.0	5.8	7.9	1.5	2.5
150	79Q3748	22N24W16DDCD	12-06-79	MBMG	9.7	2.4	29.9	0.7	0.12	0.03	19.2	98.0	4.2	1.4	5.0	0.2	1.3
156	79Q3751	22N24W23ABAB	12-06-79	MBMG	34.3	8.3	27.1	1.0	0.28	0.26	19.7	203.0	.0	3.2	5.6	0.4	0.1
162	79Q3740	22N24W24ABBD	12-05-79	MBMG	6.0	0.9	97.9	1.4	0.48	0.10	20.9	244.0	.0	8.0	2.7	0.9	4.4
177	76Q0278	22N24W34DCC	04-23-76	USGS	16.4	5.2	43.2	5.6	0.07	0.04	32.8	101.0	.0	3.60	61.2	0.262	2.3
178	79Q3749	22N24W35AADA	12-06-79	MBMG	26.3	12.7	78.9	1.8	0.22	0.82	39.2	294.0	.0	25.7	0.6	0.5	3.4
180	76Q1035	22N24W36BBB	08-17-76	USGS	37.0	11.9	46.0	3.9	5.8	0.10	21.9	264.5	.0	25.25	0.3	0.041	0.8
187	76Q0137	23N24W03BAB	03-04-76	USGS	10.6	5.2	14.8	4.2	8.20	0.35	14.3	104.1	.0	3.30	0.6	0.070	0.6
198	79Q3762	23N24W15AABA	12-06-79	MBMG	38.9	15.1	28.8	2.0	0.12	.01	27.3	293.0	.0	3.7	18.0	0.4	0.3
211	76Q0138	23N24W34ADA	03-04-76	USGS	39.8	11.6	32.8	1.7	.01	.01	18.2	235.9	.0	6.30	12.2	0.323	0.9
213	79Q3765	23N24W34CACC	12-06-79	MBMG	29.4	6.6	24.0	0.8	0.27	0.59	20.8	144.0	.0	1.4	23.8	0.38	0.4
218	79Q3763	23N24W35DCCC	12-06-79	MBMG	37.2	8.3	42.6	1.8	1.89	0.45	17.3	238.0	.0	5.0	7.9	1.1	2.0

Note: Analyses for well number 87 are for samples collected from the following depth intervals:

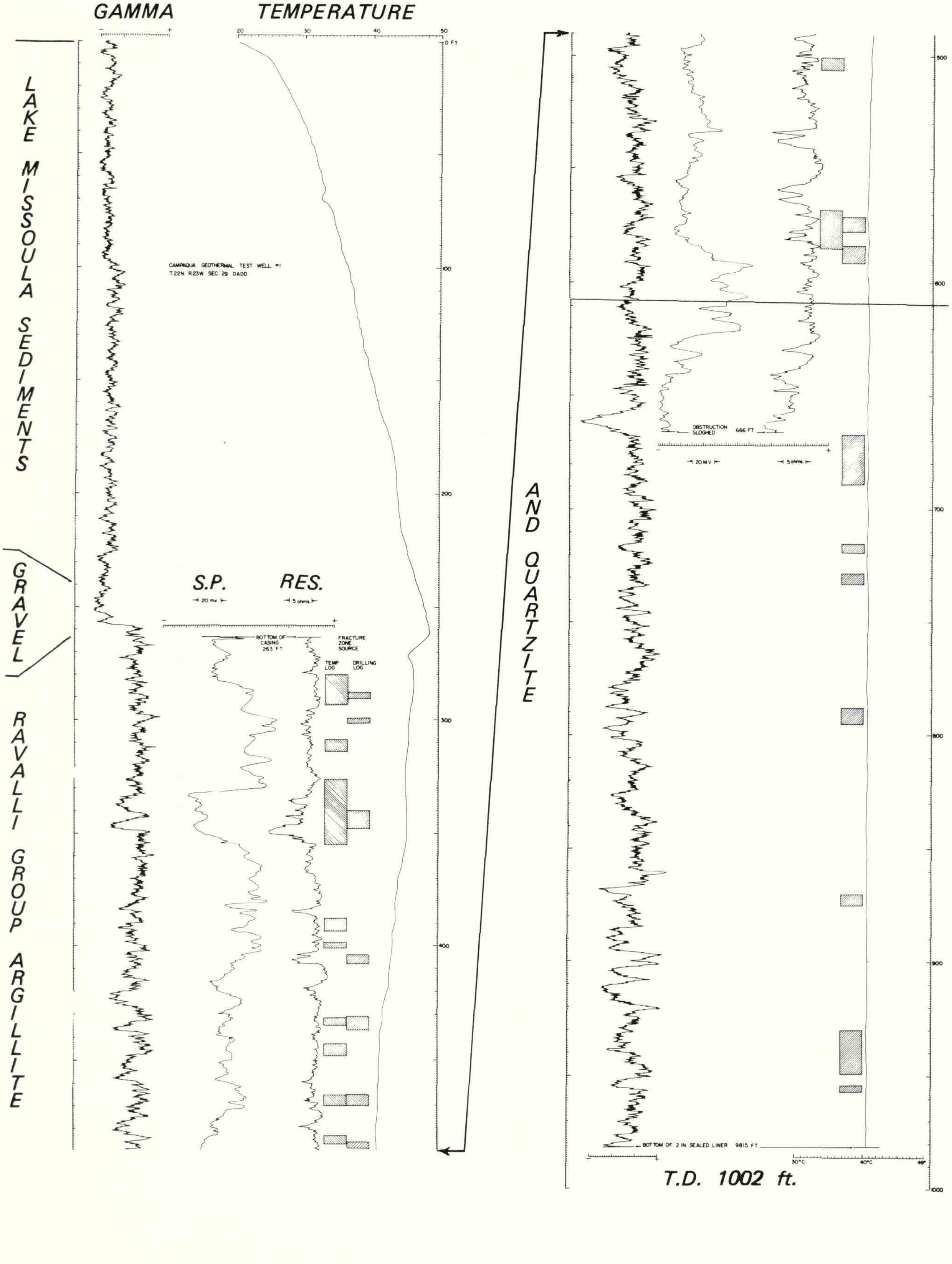
80Q2812	254-255 feet
80Q2813	264-265 feet
80Q2827	261-324 feet
80Q2826	261-362 feet
80Q2825	261-423 feet

*E.C. = Electrical conductivity, expressed in microsiemens (or micromhos) per centimeter.

[Columns are continuous across both pages.]

Calc. Dissolved Solids	Lab pH	Field pH	Lab E.C.* @ 25°C	Field E.C.* @ 25°C	Lab Alkalinity as $CaCO_3$	Field Alkalinity as $CaCO_3$	Trace Constituents Al	Li	B	As (micrograms per liter)	Field Temp. (°C)	Geothermometer Temperatures (°C) Na/K/Ca	Chalcedony	Na/Li
274	8.01	8.35	481	454	190	195	.188	.008	0.732	10.5	12.9	50.8	8.1	
199	7.77	8.02	320	310	160	165	.188	.008	0.151	5.9	12.3	8.8	30.8	
195	7.76		330	330	161			.01		21.5	18.6	23.4		
267	9.11	9.57	393	395	171	183	.118	0.035	0.487	.1	15.8	68.8	70.3	30.3
288	9.38	9.22	383	586	134	173	.188	0.039	0.511	.1	44.8	98.1	90.2	37.9
287	9.46	9.49	384	363	152	176	.188	0.018	0.460	.1	29.8	53.1	89.8	6.8
140	6.73		220	210	102						13.5	46.8	36.7	
156	6.74		246	280	105						18.5	54.8	35.1	
340	8.16	8.37	549	533	258	260	.188	0.037	0.744	44.8	17.3	61.9	31.7	10.5
273	9.45	7.72	442	440	214	228	0.10	0.04	0.54	23.0	22.8	77.1	33.3	33.4
276	7.90	8.33	447	397	209	220	.188	0.024	0.511	27.7	23.6	60.7	30.4	12.5
345	8.48	8.79	537	495	250	255	.118	0.065	0.849	4.2	20.3	83.1	46.0	41.9
266	7.74	8.54	438	429	190	234	.188	0.008	0.851	76.1	11.8	53.2	16.8	
381	8.18		617	600	272			0.09			24.0	97.9	52.1	54.6
352	8.05	8.42	599	582	261	271	.188	0.050	0.893	16.3	63.6	40.2	31.9	31.9
339	9.16	8.29	471	465	260	256	0.10	0.08	0.71	6.7	25.8	90.7	47.0	25.8
395	8.63	8.10	634	586	283	292	0.15	0.10	0.87	1.0	34.4	107.1	56.8	56.2
385	8.40	8.33	636	642	269	288	.188	0.074	0.885	3.3	32.5	84.4	56.9	45.0
403	7.89	8.53	657	633	285	299	.118	0.080	0.968	14.6	28.8	97.1	54.8	46.8
420	8.28	8.41	668	636	290	294	.188	0.080	0.934	5.6	30.6	99.6	65.2	44.8
513	8.53	8.28	651	645	287	303	.03	0.078	0.54	0.2	51.0	99.3	64.7	44.4
411	8.30		663	630	289						49.0	112.9	61.1	46.5
520	8.65	8.44	695		296	293	0.09	0.087	0.64	.1	52.0	116.8	63.6	49.2
394	8.38	8.38	594	554	264	268	0.130	0.081	0.910	0.7	38.9	92.5	62.7	48.4
437	8.71		693		296		1.56	0.083	0.66	0.8	49.2	103.8	72.5	47.0
432	8.72		694		297		0.10	0.083	0.64	0.5	49.3	97.0	67.6	45.1
406	8.18	7.82	657	653	285	328	.03	0.050	0.63	.1	47.2	75.3	59.6	29.5
399	8.21	7.74	652	644	283		.03	0.059	0.57	.1	47.2	77.3	59.3	38.4
396	8.26	7.96	657	667	282	310	.03	0.059	0.59	.1	44.9	73.3	57.8	39.1
304	8.71	8.84	472	439	208	216	.188	0.058	0.914	2.4	32.6	87.5	51.4	42.9
245	8.12	7.73	405	375	181	204	0.13	0.02	0.69	100.0	15.2	67.4	18.8	12.3
312	9.05	9.46	408	400	166	184	.188	.008	0.815	17.1	11.6	73.9	43.2	
375	8.06	8.44	593	561	266	266	.188	0.061	0.844	19.5	19.0	79.2	54.9	37.6
285	7.69	8.05	459	436	217	223	.188	.008	0.381	93.9	12.3	35.9	30.0	
249	7.81	8.02	413	406	196	210	.118	0.012	0.423	33.5	13.7	39.6	26.0	4.4
175	7.89	8.07	290	281	135	137	.188	.008	0.091	7.0	16.6	32.7	22.7	
251	7.89	8.24	406	390	197	212	.118	0.028	0.363	18.4	10.0	46.6	27.3	35.4
122	8.40	8.95	184	174	87	87	.118	.008	.09	3.8	10.6	24.3	29.8	
200	7.82	8.19	328	327	166	170	.118	.008	0.151	4.4	7.9	12.6	30.8	
264	8.10	8.48	428	414	200	203	.118	0.021	0.683	40.3	13.8	61.2	33.1	10.1
220	7.08		341	330	83			0.05			15.0	74.8	52.0	
335	7.49	7.68	528	521	241	256	.188	.008	0.590	13.0	10.8	39.0	60.1	
283	7.51	7.6	472	570	217			0.03			19.5	48.7	35.0	55.0
114	6.78		190	275	85			.01			10.0	63.8	18.8	
249	7.81	7.38	389	384	191	201	.188	.008	0.090	4.1	9.4	26.9	44.0	
240	7.93		399	400	193			.01			16.5	23.7	27.7	
179	7.52	8.26	286	256	118	124	.188	.008	.090	9.0	10.2	9.2	32.9	
243	7.66	8.14	412	395	195	201	.188	0.009	0.232	8.2	13.6	28.2	25.8	9.6

Appendix E—Well 88 test drilling data (drilling, temperature, geophysical logs).



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Back Pocket

Sheet 1— Hydrogeology of the Little Bitterroot valley.

Sheet 2— Finite difference model of the Lonepine aquifer.

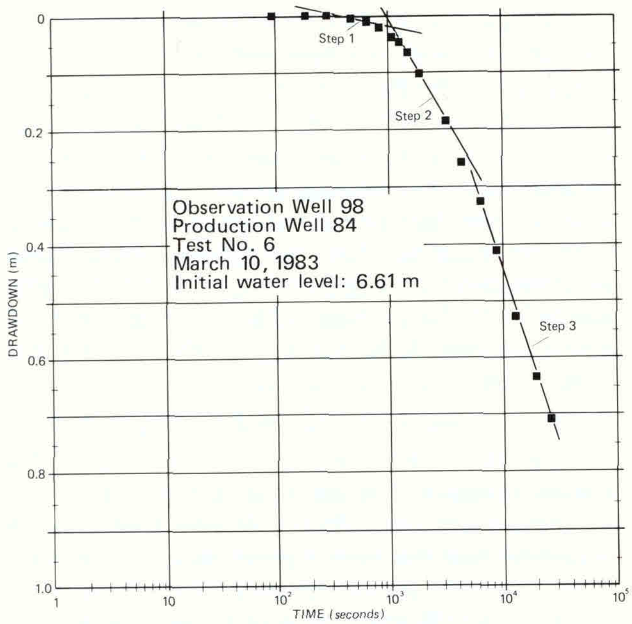

Figure 10—Drawdown vs. log time (Jacob) plot of aquifer response at Well 98 during test 6.

dimensions of the valley, most of the observation well transmissivity data interpreted from the tests are thought to represent apparent values, reduced by barrier boundaries.

Aquifer test results can be summarized as follows:

(1) The aquifer is hydraulically continuous throughout the portion of the valley investigated.

(2) True aquifer transmissivity in the portion of the valley studied is a very high value, 0.086 m^2/s (600,000 gpd/ft) or greater in the northern part of the valley, and 0.03 m^2/s (200,000 gpd/ft) or greater in the southern part.

(3) The best (mean) estimate of aquifer storativity is about 3×10^{-4}.

(4) After 24-48 hours, the apparent aquifer transmissivity is reduced by boundary effects to between 0.0144-0.0864 m^2/s (100,000 to 600,000

Table 4—Steady-state fluxes for aquifer model.

Source	Description	No. of nodes	Total flux gpm	Total flux L/min	Constant head (H) or flux (F)
Recharge					
Alluvial aquifers					
Upper Sullivan Creek	N. boundary	4	190	720	F
Garden Creek	W. boundary	10	130	480	F
Hot Springs Creek	W. boundary	17	160	600	F
Wilks Gulch	W. boundary	2	30	120	F
Oliver Gulch	E. boundary	2	30	120	F
Garceau Gulch	E. boundary	8	260	960	F
Geothermal	Underflow	21	930	3,540	F
Little Bitterroot gravels	N. boundary	8	0	0	H
		Total	1730	6,540	
Discharge					
Uncontrolled flowing wells		2	-950	3,600	F
Discharge area	S. end of model	4	-780	3,000	F
Irrigation wells		20	0	0	F*
Test wells	88, 84	2	0	0	F*
		Total	-1730	6,600	

* Used for transient simulations (Runs 2, 3, 4) only.