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PRELIMINARY REPORT ON THE GEOLOGY AND WATER RESOURCES OF THE BITTERROOT VALLEY, MONTANA

By

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WITH A SECTION ON CHEMICAL QUALITY OF WATER

By

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This circular has been prepared by the United States Geological Survey, Water Resources Division, under a cooperative agreement with the Montana Bureau of Mines and Geology.

Montana School of Mines
Butte, Montana

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INTRODUCTION

Increasing water requirements for irrigation, industry, and domestic use have expanded interest in a comprehensive evaluation of the total water resources of Montana. The total water resources available for use by man are: (1) the water that is visible in streams, lakes, and reservoirs (surface water); (2) the water that occurs in the zone of saturation beneath the land surface (groundwater); and (3) rain and snow which are the ultimate source of the surface water and groundwater. This report, which is a contribution to a program for the development, conservation, and use of the water resources of Montana, summarizes the results to date of an investigation of the water resources of the Bitterroot Valley. Further data on surface water and precipitation are being collected and will be included in a more detailed report to be prepared for future publication.

The investigation was made by personnel of the U. S. Geological Survey in cooperation with the Montana Bureau of Mines and Geology. It is one of three cooperative investigations begun since the 1955 State Legislature appropriated funds to the Montana Bureau of Mines and Geology for cooperation with the U. S. Geological Survey to investigate the availability and quality of the groundwaters of the State. (See fig. 1.) The Federal Government and

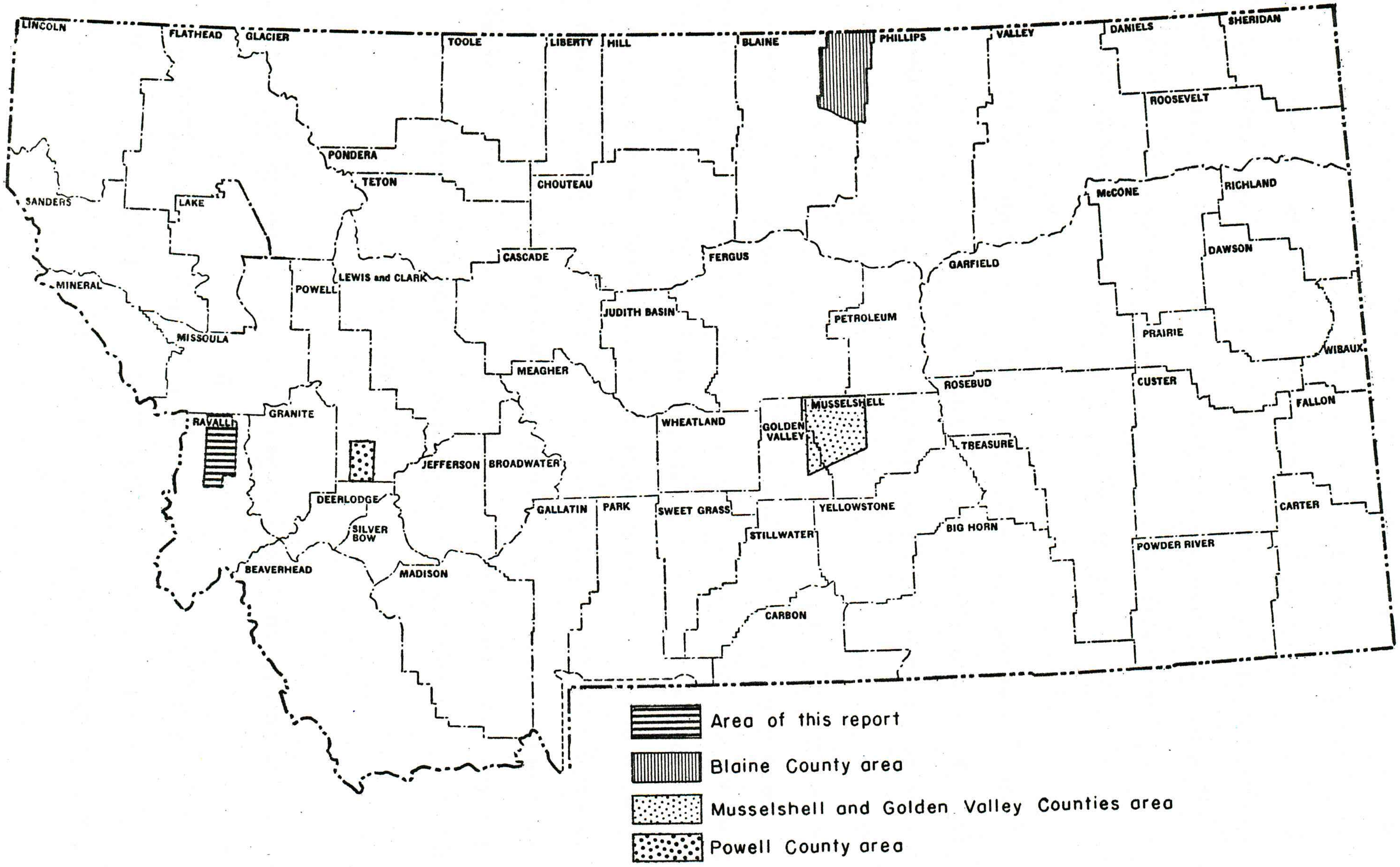

Figure 1 — Map of Montana showing the location of cooperative ground-water investigations, 1955-58

the State of Montana share equally the cost of these cooperative investigations.

The general purpose of this investigation is to appraise the water resources of the Bitterroot Valley. The main objectives were to determine (1) the manner and amount of inflow into the valley and outflow from the valley; (2) the character and extent of the water-bearing rocks; (3) the mode of occurrence, direction of movement, and availability of groundwater; (4) the annual, seasonal, and long-term fluctuations in the amount of water in storage underground; (5) the chemical quality of the water; and (6) the areas from which substantial supplies of groundwater of good quality can be obtained.

An inventory was made to gather pertinent data on many of the wells and springs in the area. (See table 6.) The locations of the wells of most significance to the study are shown on plate 1.

The wells are assigned numbers that are based on their location within the system of land subdivision used by the U. S. Bureau of Land Management. (See fig. 2.) As all wells lie within the northwest quadrant of the Montana Principal Meridan and Base Line system, the prefix letter B is omitted for convenience. The first numeral of the well number denotes the township, the second the range, and the third the section in which the well is located. Lower case letters after the section number indicate the location of the well within the quarter section and the quarter-quarter section, respectively. Lower case letters are assigned to the quarter and quarter-quarter sections. Suffix serial numbers, assigned in the order that wells are inventoried, are added to the

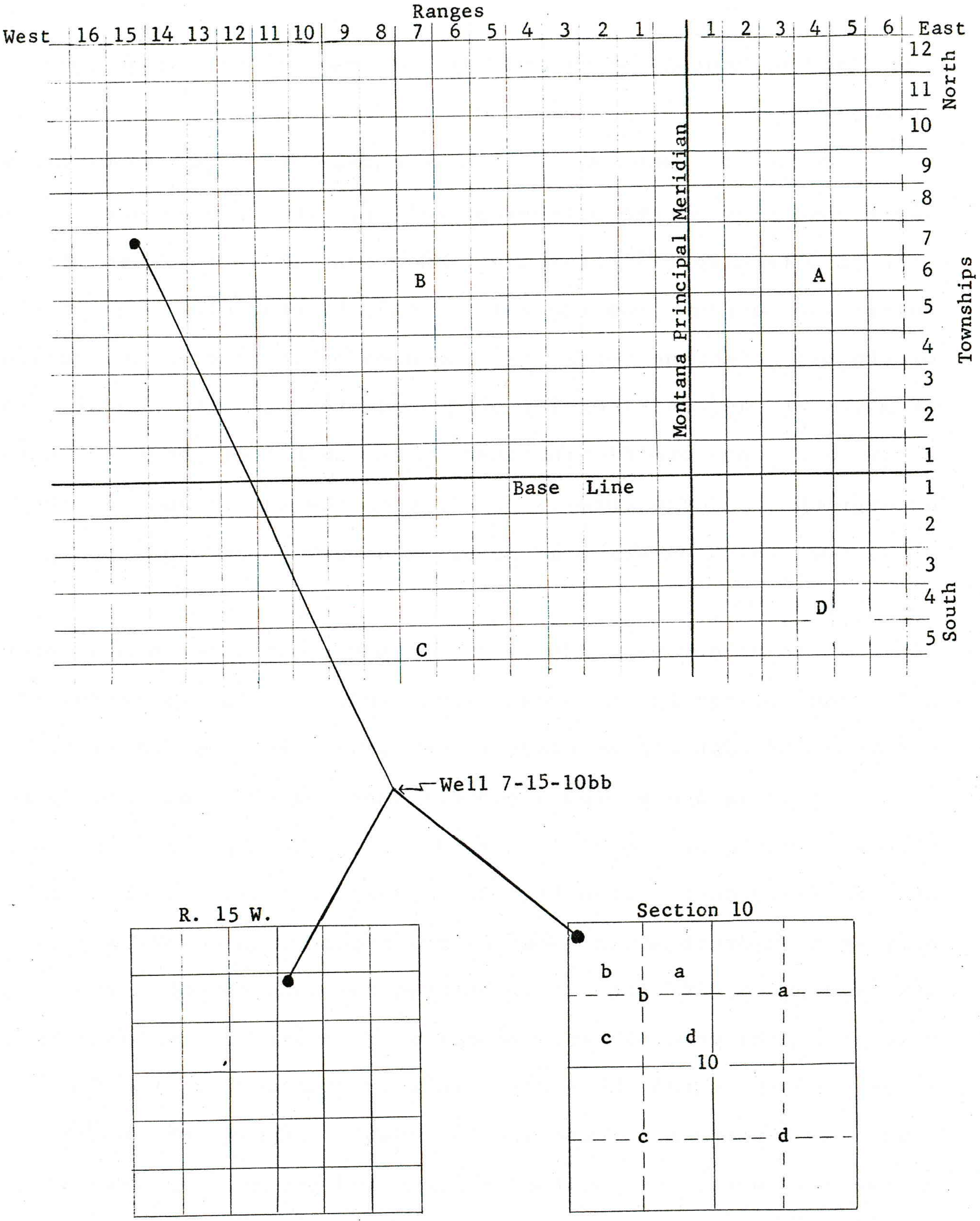

Figure 2.--Sketch showing well-numbering system.

well numbers when more than one well is inventoried in a quarter-quarter section. Springs are numbered in the same manner.

Appreciation is expressed to the residents of the valley and to the organizations and agencies that contributed to the investigation. Special thanks are given to residents who freely supplied information and permitted the use of their wells and access to their lands. The cooperation of the U. S. Soil Conservation Service, Forest Service, and Weather Bureau, The Ravalli County Improvement Association, and the Rural Electric Cooperative is gratefully acknowledged.

PREVIOUS INVESTIGATIONS

Waldemar Lindgren (1904), in a paper entitled "Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho," included the first generalized geological description of the Bitterroot Valley. E. Douglas (1909) spent considerable time during the years 1889, 1901, and 1905 searching for vertebrate fossils in an attempt to date the valley's Tertiary sediments. His conclusions were published in 1909 and have been cited by many, if not most, of the later workers as a basis for their own Tertiary correlations. C. M. Langton (1935) and C. P. Ross (1952) described the regional stratigraphy and the rocks peripheral to the valley. J. T. Pardee wrote several papers relating to Pleistocene Lake Missoula; in a paper (1950) summarizing the late Cenozoic history of the northern Rocky Mountains, he described parts of the Bitterroot Valley.

The Soil Conservation Service (1947) prepared an extensive report entitled "Water Control, Use, and Disposal, Bitterroot River

Drainage Basin, Ravalli County, Montana," which furnishes comprehensive data relating to present water use, problems in water use and distribution, and prospective developments. It also stresses the need for an extensive ground-water survey prior to the adoption of any proposed plan using only surface water to alleviate shortages. The Bureau of Reclamation (1949) prepared a report describing alternate plans and their relative merits for the use of the valley's surface waters to alleviate late-season irrigation shortages. The Montana Bureau of Mines and Geology (McMurtrey, R. G., and Konizeski, R. L., 1956) published a progress report on the cooperative study of the geology and ground-water resources of the eastern part of the Bitterroot Valley which included some of the data used in the present report.

GEOGRAPHY

The Bitterroot Valley, an intermontane basin in the Rocky Mountains of western Montana, is bounded on the east by the Sapphire Mountains and on the west by the higher and more rugged Bitterroot Mountains. (See fig. 3.) The area described in this report extends down the valley from Darby to the north edge of Ravalli County. It is about 45 miles long, averages about 7 miles in width, and includes an area of about 300 square miles.

The Bitterroot River and its tributaries drain all of Ravalli County, an area of about 2,400 square miles. The main stream, formed by the confluence of the East and West Forks of the Bitterroot River at Conner, is joined by 20 major tributaries from the west and 5 major tributaries from the east.

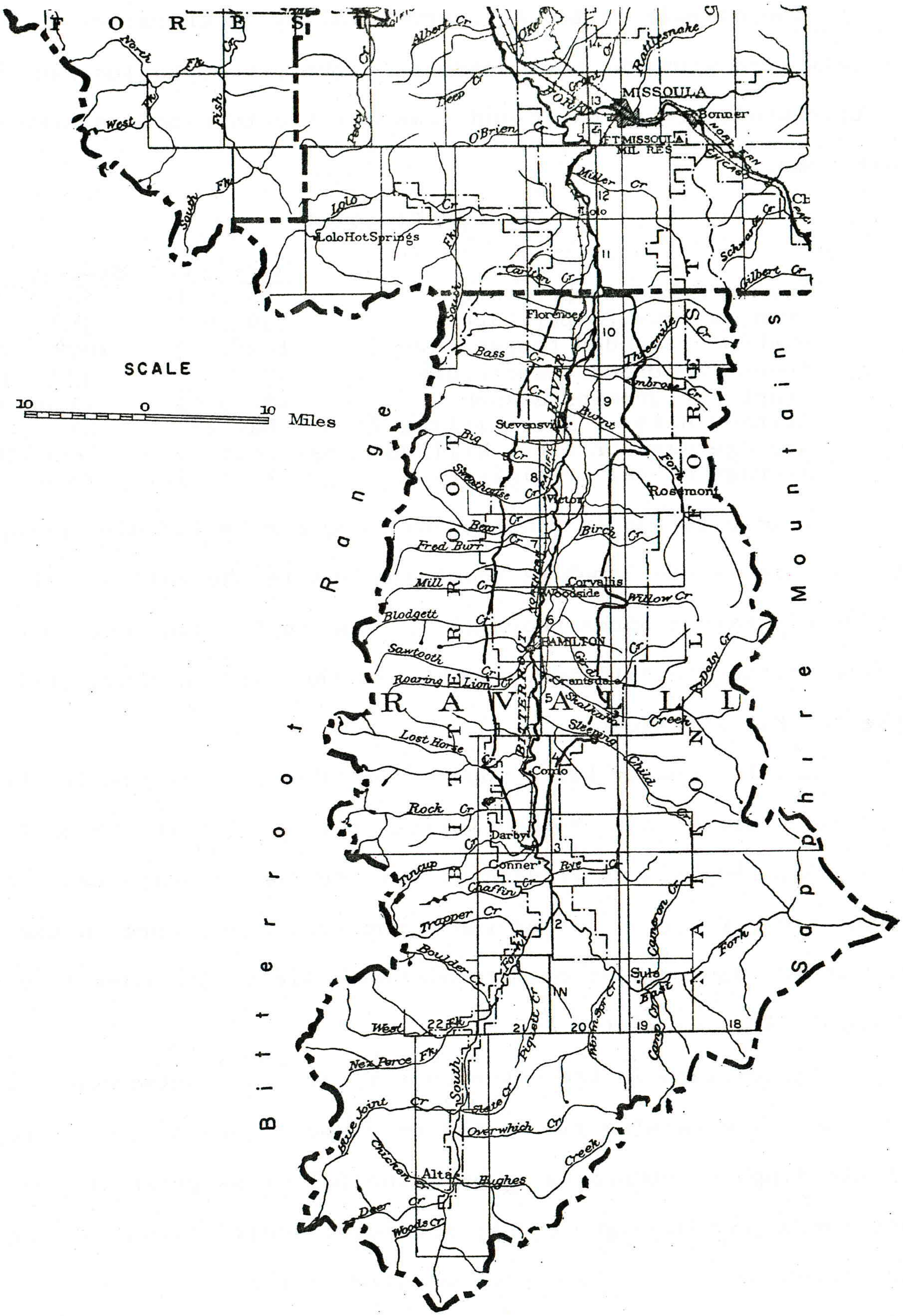

Figure 3 Map of Ravalli County showing the principal topographic features in the Bitterroot Valley area.

The climate of the Bitterroot Valley is characterized by relatively mild winters, cool summers, light precipitation, and very little wind. Large daily and seasonal fluctuations in temperature are common.

CLIMATIC DATA

	Hamilton	Stevensville
Mean minumum temperature	33.2° F	30.2° F
Mean maximum temperature	59.2° F	58° F
Highest recorded temperature	103° F	102° F
Lowest recorded temperature	-39° F	-37° F
Length of growing season	130 days	113 days
Average date of last killing frost	May 16	May 25
Average date of first killing frost	Sept. 23	Sept. 15
Average annual precipitation	12.16 in.	12.64 inches

Precipitation is considerably greater in the Bitterroot Mountains than in the Sapphire Mountains and in the valley. The pattern of precipitation shows two maxima. One in May and June is characteristic of the Great Plains; another in the fall is characteristic of the Pacific Northwest.

Ravalli County had a population of 13,101 people in the 1950 census. Most of the residents live in the main Bitterroot Valley. Hamilton, the leading trading center and county seat, has a 1950 population of 2,678. Other important trading centers in the area and their 1950 populations are Stevensville (772), Corvallis (500), Darby (415), and Victor (350).

Agriculture in the Bitterroot Valley is predominantly irrigation farming. Dry farming is limited to a small area on the western slope of the Sapphire Mountains. The principal crops grown in the valley are forage crops, sugar beets, potatoes, small grains, and fruit. In addition, most farms have beef or dairy cattle.

GEOLOGY

The Bitterroot Valley is one of many north-south-trending structural troughs in the northern Rocky Mountain physiographic province. The eastern slopes of the Bitterroot Mountains are dip-slope surfaces on the flanks of the Idaho batholith. A series of en echelon faults parallel the western margins of the valley, and movements involving vertical displacement have been observed as recently as 1898. Several randomly oriented faults have been mapped along the base of the Sapphire Mountains at the east side of the valley.

The broad, irregular flood plain of the Bitterroot River is bounded throughout most of its length by low terraces. Remnants of a higher set of terraces are preserved between tributary valleys (fig. 4). The high terrace remnants slope gently upward to the mountains. Wave-cut benches of Pleistocene Lake Missoula occur along both sides of the valley at altitudes up to 4,200 feet.

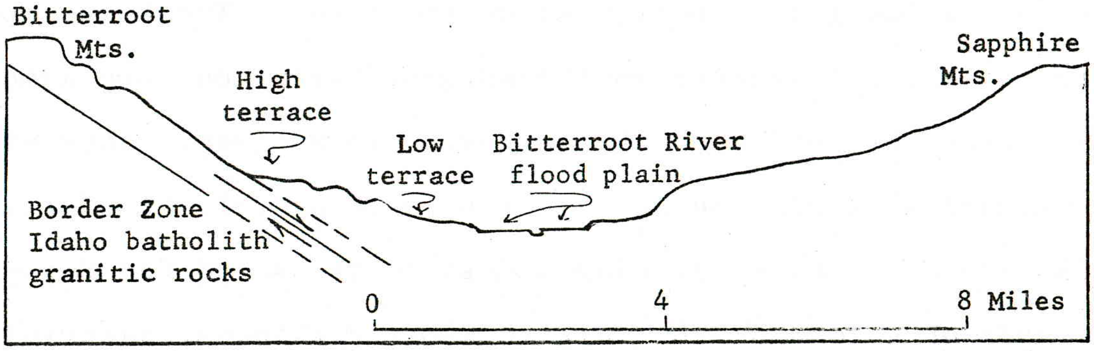

Figure 4.--Diagrammatic east-west section showing topography and structure of Bitterroot Valley. Vertical scale exaggerated.

Bedrock marginal to the valley on the northeast consists mostly of dense Precambrian argillite, quartzite, and limestone. Bedrock immediately adjacent to the remainder of the valley consists mostly of relatively impermeable Cretaceous "border-zone gneiss" believed to be the result of intrusion and metamorphism of ancient Precambrian rocks during the emplacement of the Idaho batholith. Very little weathered material mantles the bedrock of the Bitterroot Mountains, but weathering has developed to a considerable depth in the Sapphire Mountains.

The Bitterroot Valley is underlain by an unknown, but great, thickness of unconsolidated to semiconsolidated Tertiary sediments (plate 2). These sediments are largely rock waste derived from the peripheral bedrock by weathering and erosion, but there are some intercalated beds of volcanic ejecta. A well in sec. 6, T. 6 N., R. 20 W., east of Corvallis, reportedly was drilled through 1,450 feet of Tertiary sediments without reaching bedrock. Only about 250 feet of Tertiary sediments are exposed. Most of the exposures border the high terrace remnants in the eastern part of the valley, but there are a few small areas west of the river. The beds dip valleyward at about 5 degrees in the marginal areas but are almost horizontal near the center of the valley. The sediments consist of arkosic channel sand containing thin lenses of gravel, flood-plain and lacustrine or slack-water clay and silt, talus and fan deposits, and some beds of volcanic ash. Within short distances, materials of different texture interfinger and intergrade both laterally and vertically in accordance with changes in the original environments of deposition, and with the degree of volcanic activity in the region.

Quaternary deposits mantle about 200 square miles of the Bitterroot Valley. They are extremely variable in composition and sorting, but in general are better sorted in the southern and eastern parts of the valley than in the northern and western. In the high terrace remnants to the west they consist mostly of glaciofluvial and glaciolacustrine deposits derived from the Bitterroot Mountains. Extensive talus deposits have also accumulated at the base of the steeper mountain slopes in Quaternary time. The high terrace remnants on the east side of the valley are formed on both Tertiary and Quaternary deposits (fig. 5). The Quaternary deposits here consist mostly of moderately well- to well-sorted stream-transported silt, sand, and gravel containing only small amounts of glacial debris; all are derived from the Sapphire Mts. Talus deposits are at a minimum, owing to the relative gentleness of the mountain slopes.

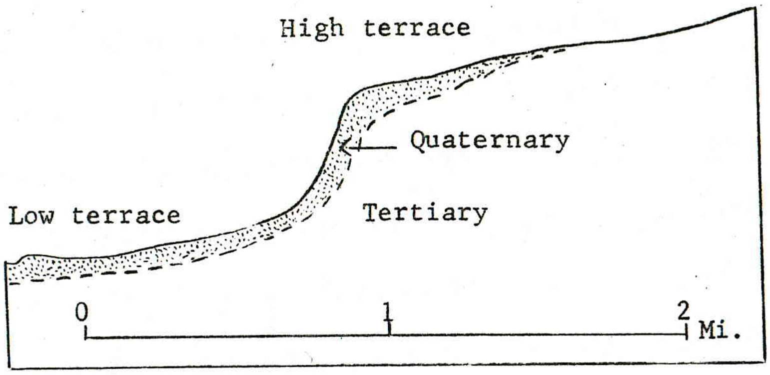

Figure 5.--Diagrammatic east-west section showing relationship of Quaternary to Tertiary strata across ends of high terraces. Vertical scale exaggerated.

The low terraces are developed on deposits of poorly to well-sorted fluvial gravel, sand, and silt. Fluvial deposits of reworked Cenozoic sediments occur also beneath the flood plains of the Bitterroot River and its tributaries. Numerous outwash fans of boulders, gravel, and sand head at moraines occupying the mouths of tributary canyons in the Bitterroot Mountains. These fans extend mostly along the flood plains of the tributary streams but also overlie some of the high terraces. Well-developed soils of Recent age are found locally throughout the valley, but soil development has not progressed far in a large part of the valley.

Geologic evidence indicates that the Bitterroot Valley probably originated in the Cretaceous period as a marginal flexure concurrent with the intrusion of the Idaho batholith (Ross, 1950). However, part of the present relief is apparently due to recurrent faulting along the margins of the valley (Pardee, 1950). Deposition of a great thickness of fill followed formation of the valley but was interrupted at about the end of the Tertiary period (Pliocene epoch), when conditions changed and erosion predominated over deposition. At this time large amounts of Tertiary sediments were removed and the major physiographic features of the present Bitterroot Valley were sculptured. The ancestral Bitterroot River eroded a broad valley into the Tertiary sediments and its tributaries cut their valleys downward to the base level of the master stream. Local evidence indicates that a second system of narrow inner valleys may have been eroded still deeper within the Tertiary sediments (fig. 6).

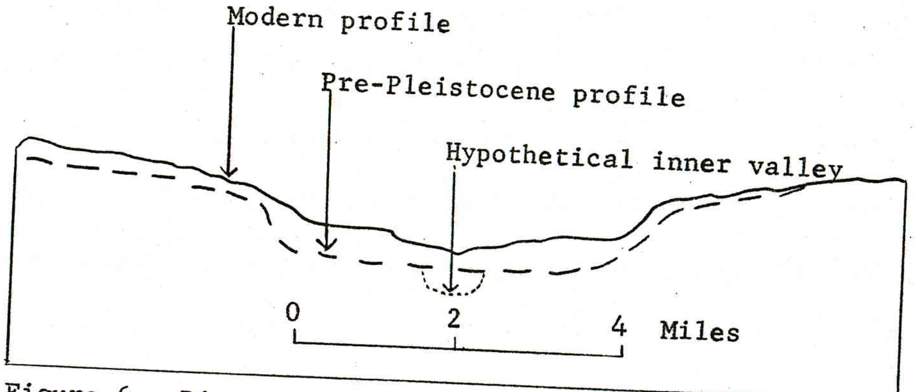

Figure 6.--Diagrammatic east-west section showing hypothetical inner valley. Vertical scale exaggerated.

During at least part of Pleistocene time the waters of the Clark Fork were ponded by a lobe of the Cordilleran ice sheet. Concurrently the Bitterroot Valley was flooded and became an embayment of the first of several glacial Lake Missoulas. Glaciation was intense in the Bitterroot Mountains, and glacial debris accumulated in the western part of the valley while stream deposits accumulated to the east. As the waters of the ancient lake rose, deltas were formed at the mouths of streams. Later, as the margins of the lake became filled with debris, huge fans developed above the deltaic deposits.

During an interglacial (interlacustrine) interval, the Bitterroot River and its tributaries eroded their present valleys. Lag gravel accumulated over the bottom of the valley as the finer-grained materials were carried downstream. Moraines were subsequently formed at the mouths of many of the tributary canyons of the Bitterroot Mountains during recurrent glaciation. Remnants of the youngest (Wisconsin) moraines still exist in many localities.

The older, pre-Tertiary rocks marginal to the valley yield only a little water from surficial weathered and creviced zones (table 1). The Tertiary sediments are highly variable in composition and degree of sorting and thus are variable in their ability to yield water to wells. Most of the Tertiary sediments are unconsolidated to semi-consolidated silt and lesser amounts of sand. The sand generally yields water supplies adequate for domestic and stock needs.

Pleistocene and Recent terrace deposits and alluvium are the most important aquifers in the Bitterroot Valley. In general, these sediments are of larger grain size and are better sorted and thus have higher transmissibility and storage coefficients than the Tertiary sediments.

SURFACE WATER

The flow of streams entering the Bitterroot Valley is marked by high peaks and volume in May and June, when about 60 percent of

Table 1.--Water-bearing properties of rocks in the Bitterroot Valley, Montana

SYSTEM	SERIES	FORMATION	FEET	DESCRIPTION	WATER-BEARING QUALITIES
QUATERNARY	RECENT	Alluvium	0 - 20	Stream-deposited clay, silt, sand, gravel, and boulders reworked from older Cenozoic deposits.	Alluvium is most prolific aquifer in area; yield is somewhat variable but dependable for domestic and stock needs, in places sufficient for irrigation, municipal, or limited industrial requirements.
	PLEISTOCENE	Glacio-fluvial, glacio-lacustrine, morainal, talus, and fan deposits	0 to 100	Unsorted morainal and talus deposits ranging in size from clay to boulders; and stratified to poorly stratified glacio-fluvial, glaciolacustrine, & fan deposits.	Yield generally adequate for domestic and stock needs, variable depending on degree of sorting and thickness of water-bearing zones.
TERTIARY	PLIOCENE & OLDER?	Flood-plain and channel deposits; some tuff beds	0 to 1,600+	Silt and clay deposited on flood plains; sand and gravel deposits, in places tuffaceous, in Tertiary stream channels; and some relatively pure tuff beds.	Yield small supplies adequate for stock and domestic needs where saturated channel sand and gravel are encountered. Fine-grained deposits yield little, if any, water.
PRE-TERTIARY	UNDIFFEREN-TIATED	Undifferentiated in this study	?	Dense, relatively impermeable sedimentary, metamorphic, and igneous rock marginal to the Bitterroot Valley.	Small supplies yielded from weathered and jointed surficial material.

the yearly runoff and inflow to the valley occurs. Recession in July is rapid, and the minimum flow for the year is occasionally reached in August or September. Recovery is noted after frost in the fall months, and is followed by a gradual decrease in flow as late fall and winter precipitation accumulates in the mountain snow pack. Sustained low flows, generally the lowest of the year, are common in

February and March. The snowmelt from the narrow band of foothills produces a sharp increase in flow in April, prior to the prolonged warm weather which results in depletion of mountain snow cover and in the highest flows of the year.

Some small streams disappear into the coarse alluvium as they emerge from the mountains; others now discharge through canals rather than through the natural channels. Direct runoff from the valley floor is minor. The regimen of outflow from the valley is modified by irrigation use. The sum of May-June outflow is about 53 percent of the yearly total; distribution through the remaining months is more uniform. The distribution of estimated inflow and outflow to the study area during the water years 1938-57 is illustrated in figure 7.

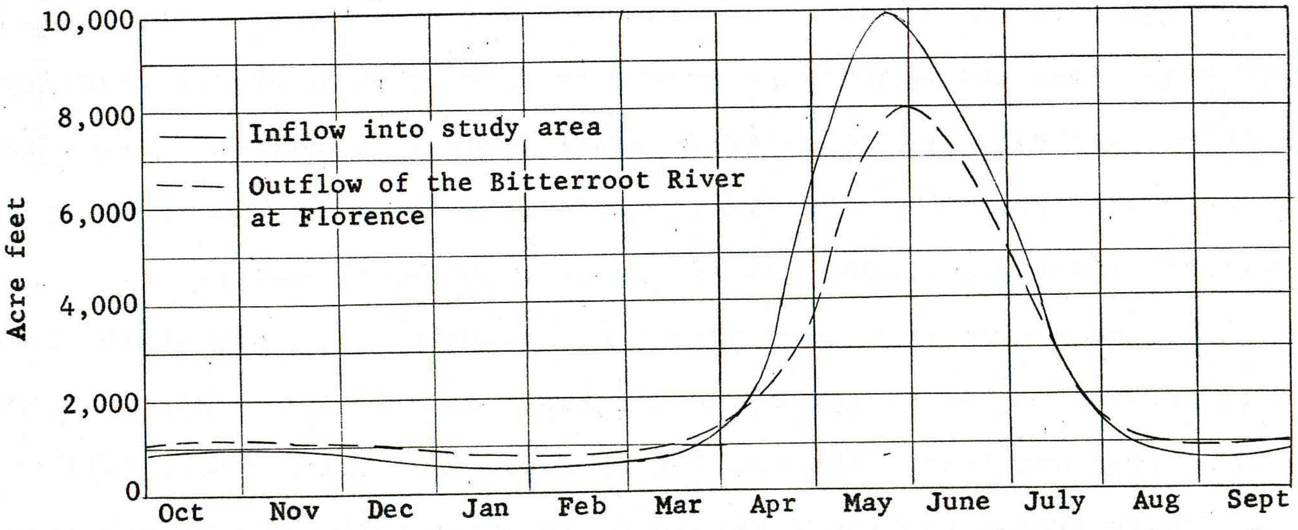

Figure 7.--Average monthly surface inflow to and outflow from the study area 1938-57.

Utilization of the surface-water resources has played an important part in the development of the valley since the irrigation of crops began at St. Mary's Mission in 1846 or 1847. The first significant irrigation project, the Hedges ditch, was constructed in 1883. The largest canal, operated by the Bitterroot Irrigation

District, had an initial capacity of 325 cfs (cubic feet per second). It supplies water for about 16,000 acres along the east side of the valley from Grantsdale to beyond Stevensville. Hundreds of smaller irrigation canals divert water from the numerous tributaries of the Bitterroot. There have been only minor fluctuations in irrigated acreage since 1905 because of the limitations of dependable water supply and readily irrigable land. Most of the irrigation is done from natural flow. Lake Como, serving the Bitterroot River Irrigation District, with a usable capacity of 34,800 acre-feet, and West Fork Bitterroot River Reservoir, with a capacity of 31,700 acre-feet, provide 83 percent of the available surface-water storage. The latter reservoir, built by the Montana Water Conservation Board, has not been fully utilized because of the lack of paid subscription. Extensive and perhaps excessive use is made of the streams during periods of high flow, and many crops served by water rights of low priority suffer from the lack of water for late-summer irrigation. There is little utilization of streams upstream from the study area, as there is only about 3,300 acres of irrigated land above that point.

Surface-water records have been collected on a few of the numerous streams in the Bitterroot River basin on a fairly continuous basis since 1937 and 1938. The outflow from the Bitterroot River Valley can be approximated from the differences in flow at the gaging stations on the Clark Fork above and below Missoula. Records from these stations have been collected since 1930. The listing of all discharge records pertinent to the study is given in table 2. It may be noted that many of the records of the following table were started in the fall of 1957 and in the spring of 1958. These newly established

Table 2.--Gaging stations in or related to the Bitterroot Valley

	Drainage area (Sq.mi.)	Period of record	Type of record collected
Clark Fork above Missoula	5,999	Mar. 1929-	a
Rattlesnake Creek at Missoula	79.7	June to Dec. 1899; Apr. 1958-	a a
Missoula Irrigation District Canal at Missoula		Apr. 1958-	b
Orchard Homes Canal at Missoula		Apr. 1958-	b
Flynn ditch at Missoula		Apr. 1958-	b
Grass Valley ditch near Missoula		Apr. 1958-	b
Bitterroot River:			
West Fork Bitterroot River reservoir near Conner	317	June 1940-	c
West Fork Bitterroot River near Conner	317	Apr. 1941-	a
East Fork Bitterroot River near Conner	381	Apr. 1956-	a
Bitterroot River near Darby	1,049	Apr. 1937-	a
Tin Cup Creek near Darby		Apr. 1958-	b
Burke Gulch near Darby		Mar. 1958-	b
Rock Creek:			
Como Lake near Darby	54.6	Oct. 1939-	c
Rock Creek near Darby	55.4	Apr. 1946 to Sept. 1953; Aug. 1957-	a a
Lost Horse Creek near Darby		Mar. 1958-	b
Camas Creek near Hamilton		Mar. 1958-	b
Sleeping Child Creek near Hamilton		Mar. 1958-	b
Little Sleeping Child Creek near Hamilton		Mar. 1958-	b
Skalkaho Creek near Hamilton	87.8	Dec. 1948 to Sept. 1953; Aug. 1957-	a a
Coffee Creek near Hamilton		May 1958-	b
Roaring Lion Creek near Hamilton		Apr. 1958-	b
Sawtooth Creek near Hamilton		Apr. 1958-	b
Gird Creek near Hamilton		Apr. 1958-	b
Blodgett Creek near Corvallis	26.4	Dec. 1946-	a
Willow Creek:			
Upper Horn ditch near Corvallis		June 1958-	b
Willow Creek near Corvallis	22.4	May 1920 to Apr. 1924; Sept. 1957-	a a
Little Willow Creek near Corvallis		Apr. 1958-	b

Table 2.--Gaging stations in or related to the Bitterroot Valley, cont'd.

	Drainage area (Sq.mi.)	Period of record	Type of record collected
Bitterroot continued:			
Mill Creek near Hamilton		Apr. 1958-	b
Bear Creek near Victor	26.8	Apr. 1938 to Dec. 1954; Aug. 1957-	a a
Sweathouse Creek near Victor		Apr. 1958-	b
Gash Creek near Victor		May 1958-	b
South Fork Gash Creek near Victor		May 1958-	b
Big Creek near Victor		Apr. 1958-	b
Kootenai Creek near Stevensville	28.9	Dec. 1948 to Sept. 1953; Aug. 1957-	a a
Burnt Fork Creek:			
Sunset Canal near Stevensville		Apr. 1958-	b
Burnt Fork Creek near Stevensville	74.0	May 1920 to Aug. 1924; Apr. 1938-	a a
Bass Creek near Florence		Apr. 1958-	b
Sweeney Creek near Florence		Apr. 1958-	b
Bitterroot River at Florence	2,350	Sept. 1957-	a
Eightmile Creek near Florence	20.6	Sept. 1957-	a
Lolo Creek above Sleeman Creek, near Lolo	250	Nov. 1950-	a
Big Flat Canal near Missoula		Apr. 1958-	b
Clark Fork below Missoula	9,003	Oct. 1929-	a

a-Daily discharge.
b-Discharge measurements.
c-Month-end contents, in acre-feet.

records are to be used in determining with some exactness the inflow and outflow to the valley during the 1957 and 1958 seasons. Projection of the short-term records through correlation with records from longer established stations is planned. In all likelihood the actual and derived records will cover the period as far back as 1930.

At this early date, only approximations of the total inflow to, and outflow from, the study area of the Bitterroot Valley for the water years 1938 to 1957 are justified. For this preliminary report, the flow of Bitterroot River at Florence was derived from the relation of the observed monthly flow at Florence to the differences between the flow of the Clark Fork upstream and downstream from Missoula. Reasonable consistency was evident, although the period of record at Florence is extremely short. The inflow to the study area was determined from the actual record of Bitterroot River near Darby and estimates of west-side and east-side inflow. The estimate of west-side inflow was projected from the record of Bear Creek near Victor on a drainage-area relation, less a reduction of 5 percent for the lesser yields that might be expected from the smaller streams rising at lower elevations. The inflow from the east side was derived on a drainage-area basis from the records of Burnt Fork near Stevensville. The calculated values were reduced by 15 percent to compensate for the assumed dissimilarities of the other contributing basins. The drainage areas for which these estimates were made total about 1,000 square miles, or slightly less than the drainage area of Bitterroot River near Darby. The derived records of inflow and outflow are presented on an annual basis in table 3 for the water years 1938-57. The data are tabulated for water years beginning October 1 of the prior calendar year and ending September 30 of the named year.

Analysis of the records presented shows that the average surface-water inflow to the study area is more than 200,000 acre-feet greater than the outflow at Florence during the months April to July. During the succeeding eight months outflow exceeds inflow by about 100,000 acre-feet. A graphic presentation is given in figure 7. The direct runoff from the study area, which covers

Table 3.--Summary of yearly inflow to and outflow from study area in Bitterroot Valley in cubic feet per second

Water year	Bitterroot R. near Darby	Estimated inflow east side	Estimated inflow west side	Estimated total inflow	Estimated outflow, Bitterroot R. at Florence
1938	721	279	1,136	2,136	1,948
1939	729	224	964	1,917	1,740
1940	483	159	893	1,535	1,221
1941	491	141	760	1,392	1,122
1942	880	320	1,071	2,271	2,054
1943	1,227	420	1,456	3,103	3,025
1944	561	232	717	1,510	1,350
1945	681	181	1,010	1,872	1,458
1946	773	190	887	1,850	1,816
1947	1,351	360	1,533	3,244	2,990
1948	1,243	447	1,485	3,175	3,151
1949	978	278	1,184	2,440	2,366
1950	1,039	292	1,474	2,805	2,669
1951	1,116	399	1,467	2,982	2,832
1952	1,006	280	1,145	2,431	2,324
1953	905	251	1,051	2,207	1,915
1954	878	245	1,346	2,469	2,302
1955	858	302	1,379	2,539	2,175
1956	1,187	350	1,518	3,055	2,936
1957	880	269	1,137	2,286	2,188
Average 1938-57	899	281	1,181	2,361	2,179

about 300 square miles, is believed to be low. Its effect may be significant, however, in the interpretation of ground-water recharge and discharge.

GROUNDWATER

Occurrence

Water that occurs beneath the surface of the earth is hidden from view and it is often regarded by uninformed persons as shrouded in mystery. History gives us many varied and fanciful explanations as to its source and occurrence. However, scientific study shows that groundwater is an important component of the hydrologic cycle (fig. 8) and obeys certain physical laws and principles which, in general, are relatively simple and easily understood but are often quite complex in detail.

The rocks and unconsolidated overburden that form the outer crust of the earth generally contain many open spaces termed voids or interstices. Below a certain level the open spaces are filled with water and serve as a vast underground reservoir for the storage and transmission of water. This reservoir is replenished by downward percolation of water from precipitation and by seepage from irrigation and from streams and canals. The reservoir is depleted by discharge of water to the earth's surface through springs, wells, and effluent streams, or to the atmosphere by evaporation and transpiration.

The water in an underground reservoir may be under either artesian or water-table conditions. A formation, group of formations, or part of a formation that will yield groundwater in useful quantities is termed an aquifer. Groundwater that rises in a well above the point at which it is first encountered in an aquifer

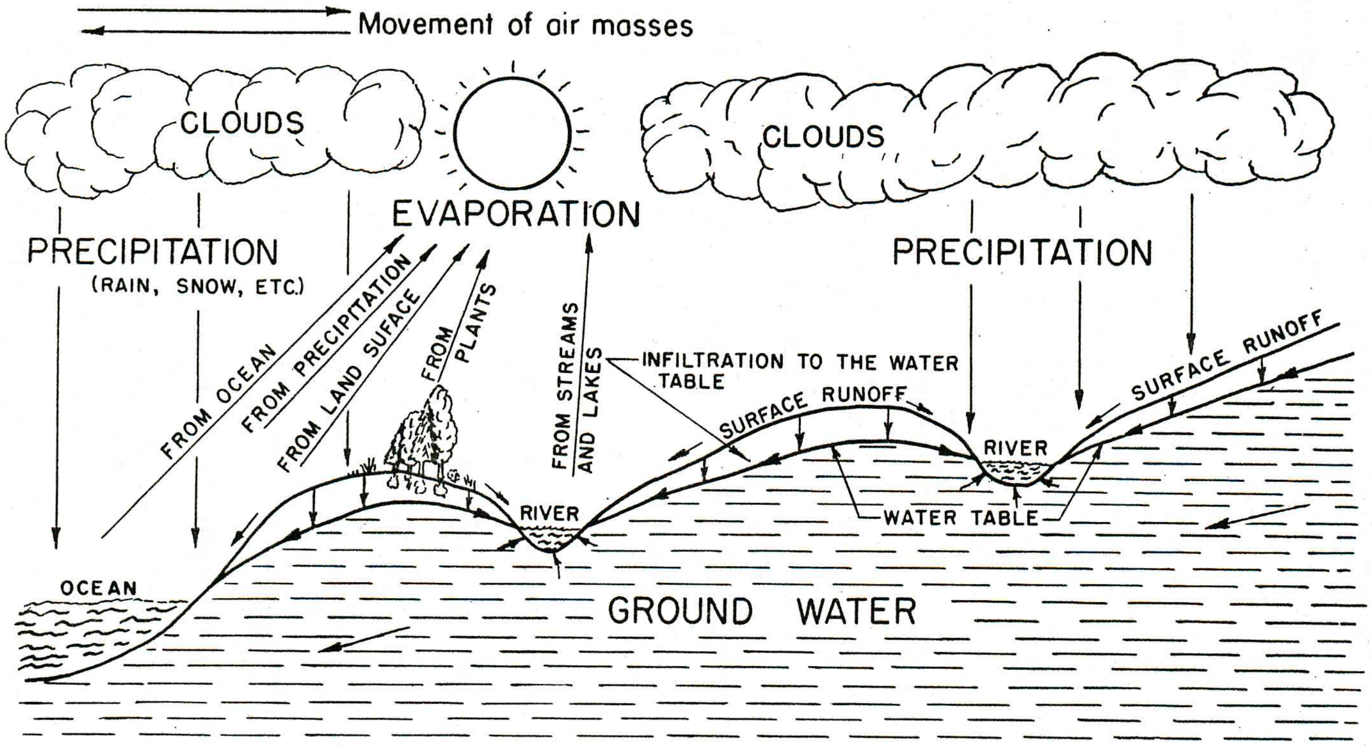

Figure 8. Hydrologic cycle, (Modified after USGS Circular 114, 1951)

is called artesian water. If the hydrostatic pressure in the aquifer is sufficient to cause water to flow at the ground surface, a well is called a flowing artesian well. If groundwater does not rise in wells above the level at which it is encountered in the aquifer it is said to be under water-table (nonartesian, unconfined) conditions. Both artesian and water-table conditions occur in the Bitterroot Valley.

The surface defined by the level at which water stands in nonpumped, tightly cased wells penetrating an aquifer is generally called the "piezometric surface" for artesian aquifers and the "water table" for nonartesian aquifers. The water table generally lies at higher levels under the terraces and hills than under the valleys; consequently, it is an irregular surface that reflects, in a subdued way, the more rugged features of the land surface. The water table is a dynamic surface that rises and falls as changes occur in the ratio of ground-water recharge to discharge.

Hydrologic Properties of Aquifers

The hydrologic properties of an aquifer (permeability, transmissibility, and coefficient of storage) are governed by the size, shape, and degree of interconnection of the interstices, and by confinement or lack of confinement of the aquifer. These properties control the movement of groundwater through the encompassing rock material from its point or area of intake to its point or area of discharge, and the ability of the aquifer to take water into and release it from storage.

The permeability of material making up an aquifer is a measure of its capacity to transmit water. The field coefficient of permeability is commonly expressed by the U. S. Geological Survey as the rate of flow of water, in gallons per day at the prevailing temperature, through a section of an aquifer that is 1 foot thick and 1 mile wide, and which has a hydraulic gradient of 1 foot per mile.

The coefficient of transmissibility relates the field coefficient of permeability of the aquifer to the thickness of the aquifer. It is commonly expressed as the amount of water, in gallons per day at the prevailing temperature, that is transmitted across each mile strip extending the saturated thickness of the aquifer, under a hydraulic gradient of 1 foot per mile. The coefficient of transmissibility is equal to the field coefficient of permeability multiplied by the saturated thickness of the aquifer, in feet.

The coefficient of storage of an aquifer is a measure of its capacity to store water. As defined by the U. S. Geological Survey, the coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The specific yield is a measure of the relative volume of water that saturated aquifer material will yield by gravity drainage; its value is a ratio that is obtained by dividing the volume of water that will drain from the material by the volume of the material. The water yielded from or taken into storage, in response to a change in the head of an artesian aquifer that remains saturated before, during, and after the change, is attributed solely to elasticity of the aquifer material and of the water. However, the water yielded from or taken into storage in response to a change in the head of a water-table aquifer is attributed not only to the slight elasticity of the aquifer material and the water, but mainly to gravity drainage or refilling of the interstices in the zone through which the water table moves. In most water-table aquifers the volume of water attributable to gravity drainage and refilling is so much greater than that attributable to elasticity that for all practical purposes it can be said that the coefficient of storage equals the specific yield.

Either laboratory or field methods may be used to determine the hydrologic properties of aquifers. An adequate number of relatively undisturbed samples from the aquifers is necessary to obtain acceptable results by laboratory methods. Because the collection of "undisturbed" samples from the aquifers in the Bitterroot Valley is very difficult, laboratory methods have not been used during this study.

The principal field method for determining hydrologic properties used during this study was the aquifer test, often called a "pumping test." Pumping from wells causes a drawdown, or lowering of the water level, in the well, produces a hydraulic gradient toward the well, forming a drawdown cone, or cone of depression, and induces groundwater to flow toward the well from the surrounding area. An aquifer test using only the pumped well is termed a "single-well test"; a test using the pumped well and one or more observation wells is termed a "multiple-well test." Seventeen single-well and nine multiple-well tests were made; eighteen values of the coefficient of transmissibility were obtained by these tests. None of the tests were of sufficient duration to enable accurate determination of the coefficient of storage. Aquifer test data are given in table 4.

Figure 9, which shows the theoretical drawdown for different values of the coefficient of transmissibility and for an assumed

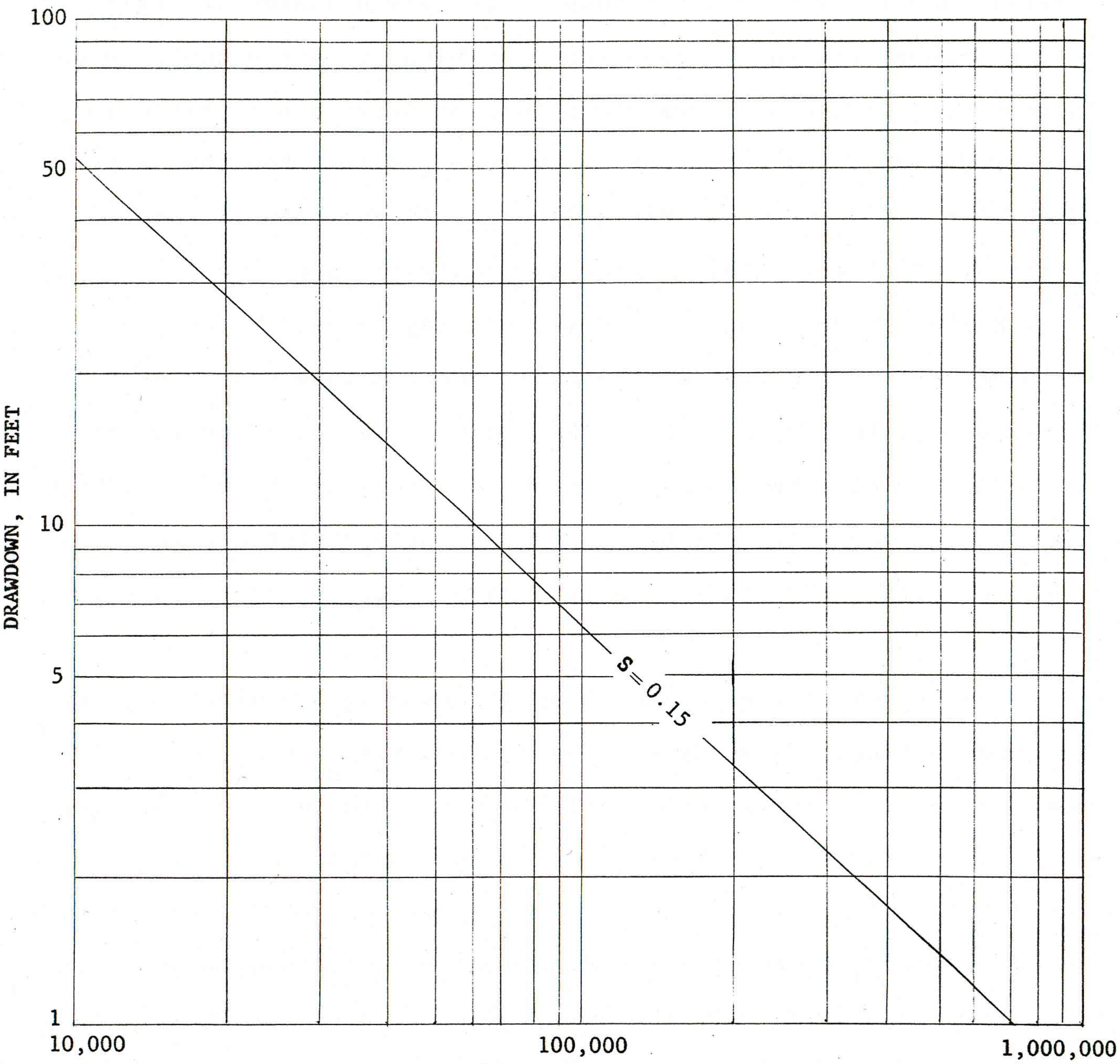

Figure 9.--Logarithmic graph showing theoretical drawdown in a well 24 inches in diameter after pumping for 12 hours at 500 gpm.

Table 4.--Aquifer-test data

[Geologic source: A, Alluvium; T, Tertiary sediments]

Well number	Geologic source	Depth of well (ft.)	Pumping rate (gpm)	Drawdown (ft.) in pumped well	Length of test (min.)	Coefficient of transmissibility (gpd/ft.)	Remarks
6-20-3bd	A	35.3	24	3.6	230	---	
6-20-6dd	A	9.2	300	1.3	300	280,000	Observation wells 42 & 95 ft. from pumped well.
6-20-8aa	A	20.5	62	.3	200	---	Observation well 50 ft. from pumped well.
6-21-11aa	A	20.0	87	6.4	200	25,000	
6-21-26db	A,T	365.0	20	9.4	91	3,800	
7-20-4aa	A	7.7	30	1.6	320	---	Two tests: 1 with no observation well, 1 with an observation well 50 ft. from pumped well.
7-20-16ab	A	9.9	220	1.1	420	---	
7-20-16ac	A	12.1	135	.9	390	---	
7-20-21ab	A	11.6	58	.8	250	150,000	Observation wells 25 & 50 ft. from pumped well.
7-20-28bc1	A	9.5	70	.6	400	130,000	Observation well 54 ft. from pumped well.
7-20-32dd	A	12.7	67	.3	300	240,000	Observation wells 37 & 164 ft. from pumped well.
8-20-14cb	A,T	29.3	30	3.5	300	18,000	
8-20-28dc1	A	7.1	53	1.4	100	230,000	Observation well 64 ft. from pumped well
9-19-5ad	A	29.0	60	3.0	287	20,000	
9-19-5ca	A	21.3	50	4.1	280	---	
9-19-6ca	A	14.7	52	1.7	200	27,000	
9-19-31aa2	T	58.5	20	11.4	200	2,400	Flowing well: static head, 5.4 ft. above land surface; drawdown, 6.0 ft. below land surface; total drawdown, 11.4 ft.
9-20-12bb	A	19.7	40	2.2	280	20,000	
9-20-26ba3	A,T	20.3	60	6.7	455	18,000	Two tests made: observation wells 82 and 140 ft. from pumped well.
9-20-26ba4	T	46.7	4	11.3	80	3,300	
9-20-28db	A	8.2	14	1.1	210	---	
9-20-34ab4	A	39.1	62	1.5	100	---	
10-19-7bd	T	160.0	153	29.4	100	11,000	
10-19-7dc2	A	64.3	220	25.0	180	40,000	Observation well at 73 ft. from pumped well.
10-20-15dc	A	16.7	82.5	5.9	220	25,000	
10-20-26ab	A	8.5	22.5	2.7	97	15,000	

storage coefficient of 0.15, helps to interpret the data presented in table 4 and to predict the drawdown that may be expected in wells under the assumed conditions. The drawdown shown would occur in a perfectly designed and constructed 24-inch well under the assumed conditions after pumping 500 gallons per minute for 12 hours. The figure shows that the drawdown increases as the coefficient of transmissibility decreases. Though not shown on the graph, the drawdown increases as the storage coefficient decreases, according to the relation

$$s = k \log \frac{1}{S}$$

where s is the drawdown, k is the constant, and S is the coefficient of storage.

Recharge and Movement

The water table does not remain stationary but rises and falls as does the water level of a surface reservoir. A rising water table indicates that the recharge (addition of water to the underground reservoir) is greater than the discharge in that area; conversely, a falling water table indicates that discharge is greater than recharge. The water table fluctuates more by the addition or discharge of a certain quantity of water than does the level of a surface reservoir, because groundwater occupies only part of the volume of a groundwater reservoir.

Recharge in the area of study occurs primarily by the infiltration of water used for irrigation, as may be seen by the hydrograph of well 9-20-34ab1 (fig. 10). The hydrograph shows that the water level in the vicinity of the well was declining through the winter and early spring, then rose rapidly through May and June. It remained at a fairly high level through the irrigation season, then declined rapidly after irrigation ended in September. Irrigation during May and June, when adequate water is available, generally fills the ground-water reservoir to capacity. However, when precipitation is unusually high in June, as it was in 1958, irrigation is curtailed and the ground-water reservoir is not filled.

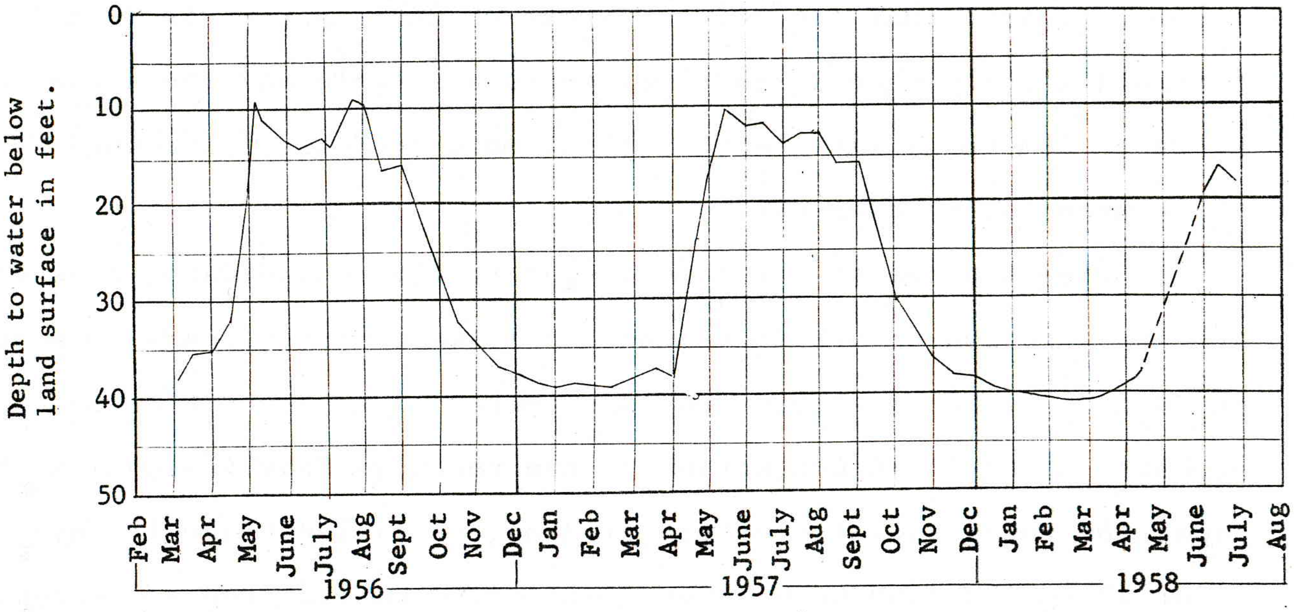

Figure 10.--Hydrograph of well 9-20-34ab1, showing effect of recharge from infiltrating irrigation water.

Large quantities of water are diverted annually from the Bitterroot River for irrigation on the flood plain of the river and on the adjacent terraces. According to the U. S. Soil Conservation Service, approximately 29,000 acres is irrigated with water diverted from the Bitterroot River. In the late summer almost the entire flow of the river is diverted before it reaches Corvallis. The downstream rights are satisfied mainly by return flow. During the irrigation period, most of the flow of the 20 major tributaries entering the area from the west and the 5 entering from the east is diverted for irrigation use. About 75,000 acres is irrigated from the tributary streams.

According to standard practice in Montana, the average diversion requirement under present conditions and irrigation practices is one Montana miners inch per acre (40 miners inches of flow = 1 cfs). One inch delivered continuously for 30 days will cover an acre to a depth of 1½ feet. Using this and a total of 104,000 irrigated acres, it is estimated that 156,000 acre-feet of water per month is diverted from all sources when adequate water is available and the water is needed. Something like half of this, more or less, is recharged to the ground-water reservoir.

Other sources of water recharged to the ground-water reservoir are infiltration of precipitation and leakage from streams that cross the area. Direct recharge from precipitation in the Bitterroot Valley probably is small in comparison to the recharge from irrigation, because the total annual precipitation on the valley floor is only about 11 or 12 inches, and only heavy rains could be expected to replenish soil moisture freely and provide a surplus for ground-water recharge. Almost one-fourth of the total precipitation occurs in May and June, which are the months of high recharge from irrigation diversions, so it is difficult to determine from hydrographs of observation wells whether, and how much, recharge occurs from precipitation in these months. Recharge from streams may be large in certain places where they cross sand and gravel, but the total recharge from streams probably is much less than that from irrigation.

The direction and velocity of movement of groundwater are governed by the shape and slope of the water table. In order to facilitate the preparation of a water-table contour map showing the shape and slope of the water table, the water levels and altitudes of about 100 wells were determined during the course of this investigation. Plate 1 shows the location of the wells that were measured; it shows also the shape and slope of the water table.

The map shows that groundwater in the area moves generally toward the Bitterroot River, but in detail the slope and direction of movement vary from one part of the area to another. The slope is greatest along the western periphery of the area where the slope of the ground surface also is the greatest; the slope is least along the valley floor in the northern part of the area. The slope of the water table along the western periphery is about 150 feet per mile; the slope along the river ranges from about 7 to 29 feet per mile and averages about 12 feet per mile. On the west side of the river the direction of the movement is eastward almost at right angles to the river. On the east side of the river the direction of movement is almost parallel to the river between Hamilton and Stevensville; northwestward toward the river along Skalkaho Creek and Burnt Fork; and westward toward the river along Three Mile and Eight Mile Creeks.

The rate of movement of groundwater, which is very slow in comparison to the rate of movement of water on the land surface, varies directly with the hydraulic gradient and the permeability of the aquifer and inversely with the porosity. Under a gradient of 10 feet to the mile, the rate of movement may range from less than one foot per year in clay to about 4 miles per year in clean, coarse gravel. Under higher gradients the rates of movement would be proportionately higher. Preliminary data indicate that the rate of ground-water movement under existing gradients in the area of study is roughly 400 feet per year through Tertiary sand, 700 feet per year through the Recent flood-plain alluvium, and 1,000 feet per year through the alluvial material on the west side of the river.

Storage and Discharge

Changes of water levels in observation wells reflect changes in the amount of groundwater in storage. Fluctuations of the water table in the area were determined by measuring the depth to water in about 100 wells monthly. Records of water-level measurements are in open file at the U. S. Geological Survey office in Missoula. The product of the difference between any two successive water-level measurements and the area involved gives a measure of the volume of material saturated or drained during the period between measurements. The amount of saturated material in the study area increased by about 1,100,000 acre-feet between March 1, 1957, and July 1, 1957, and by about 1,125,000 acre-feet between March 1, 1958, and July 1, 1958. Assuming an average specific yield of only 0.15 for the area, about 165,000 acre-feet of water was added to the ground-water reservoir during the 1957 period and about 170,000 acre-feet during the 1958 period. Preliminary streamflow data of the Geological Survey show that inflow to the area of study exceeded outflow by more than 135,000 acre-feet from March 1, 1957, to July 1, 1957. Precipitation data indicate that more than 65,000 acre-feet of water fell within the area during the same period. Thus, during the 1957 period 200,000 acre-feet of water entered the area that did not leave as streamflow. This figure accords reasonably well with the previously calculated addition of about 165,000 acre-feet of water to the ground-water reservoir. The figure of 165,000 acre-feet also is in line with the estimate that half the irrigation water applied in May and June percolated to the water table from canals and irrigated fields. Inflow-outflow records are not yet available for the 1958 period.

Groundwater may be discharged from the zone of saturation by evapotranspiration or by hydraulic discharge through streams, drains, springs, seeps, or wells. Discharge by evapotranspiration is relatively great along stream courses and in poorly drained areas. Of the 200,000-acre-foot surplus mentioned above, the portion that did not recharge the ground-water reservoir was evaporated or transpired or stored in the soil. At places where the water table intersects the land surface, groundwater is discharged by effluent seepage into streams, drains, springs, or seeps. This is the primary means of ground-water discharge in the area. The amount of water discharged by wells is small in relation to the total amount of ground-water discharge.

CHEMICAL QUALITY OF THE WATER

The Mineral Content of Natural Waters

We know from our sense of taste and from common knowledge that rain water is fresh and sea water is salty. No one needs a chemical analysis to establish this fact. Laboratory tests show that falling rain and snow contain some dissolved solids, perhaps as much as 0.001 percent, or 10 parts per million (ppm). Sea water averages about 3.5 percent, or 35,000 ppm, and some natural brines contain several hundred thousand parts per million. Between the wide extremes in concentration represented by precipitation and sea water are the concentrations of natural waters of most of our springs, wells, rivers, and creeks. Tolerances to salt content and to specific constituents in water for drinking, cultivation of crops, industry, and other uses are now generally known. Chemical examination is the practical answer to measurement of the quality of a water. Table 5 lists the common constituents and their concentrations in 36 samples of water from subsurface and surface sources in the Bitterroot Valley. Measurements of certain physical characteristics, for example, water temperature and color also are tabulated.

In the Bitterroot Valley domestic and public water supplies are obtained from wells. The amounts of iron, fluoride, nitrate, dissolved solids, and hardness in the water have practical significance to the consumer. If these amounts are excessive, the water is poor in quality and its use is restricted or even prohibited. Irrigation water likewise must meet certain criteria; its boron content, dissolved-solids concentration (often measured approximately in terms of specific electrical conductance of the water), and sodium-adsorption ratio should be known.

Examination of Valley Waters

Residents of the valley generally are favored with water of good chemical quality. Some domestic supplies contain iron and nitrate in objectionable amounts, but this problem is not common. The surface waters are softer, as a rule, and contain smaller amounts of dissolved solids than the groundwaters, as shown in the following table:

Source	Number of samples	Range in concentration (ppm)	
		Dissolved solids	Hardness
Wells and springs	40	42 - 748	17 - 210
Streams	16	13 - 121	4 - 98

Table 5.--Chemical analyses of water from the Bitterroot Valley, Montana.

[Chemical constituents in parts per million]

Well number or surface source	Depth of well (feet)	Diameter of well (inches)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$		Sodium-adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Color
																		Residue on evaporation at 180°C	Sum	Calcium, magnesium	Noncarbonate				
GROUNDWATER																									
Tertiary sediments																									
7-20-22 da	79.4	6	10-24-55	--	44	0.01	47	13	32	9.9	292	0	9.0	1.5	0.7	1.5	0.05	292	303	171	0	1.1	465	8.0	5
8-20-5 cc	95	4	9-13-57	53	32	.03	20	4.4	6.1	.9	94	0	2.7	1.0	.2	.5	.00	121	114	68	0	.3	155	7.6	5
9-19-10 bb	29.8	42	10-20-55	50	57	.01	58	16	158	20	441	0	39	43	.8	131	.08	748	740	210	0	4.7	1,090	7.8	15
9-20-10 bc	170	6	9-19-57	52	41	4.0	19	6.7	28	2.2	155	0	5.8	3.5	.5	.0	.11	195	183	75	0	1.4	257	7.7	25
Pleistocene sand and gravel																									
7-21-11 bc	40.1	6	9-18-57	48	25	.33	8.9	2.8	10	.7	62	0	1.4	2.0	.3	2.2	.00	89	84	34	0	.7	113	7.0	5
10-19-30 cd	Spring	--	10-15-55	54	23	.00	25	5.0	14	1.8	112	0	8.1	3.0	.2	7.4	.02	147	143	83	0	.7	223	7.5	0
Alluvium																									
6-20-4 bc1	43.0	6	10-24-55	51	36	.00	52	13	24	4.4	257	0	12	5.0	.1	3.9	.02	278	277	183	0	.8	447	7.7	0
-30 bc	70	--	a/ 7-34	--	13	.16	37	12	14		170	0	24	3.0	--	--	--	200	--	142	3	--	--	--	--
6-21-12 db	17	3	8-22-57	57	13	4.1	6.6	2.1	5.2	.9	49	0	1.6	.8	.2	.0	.05	58	54	25	0	.5	80.9	6.8	5
-25 aa	70	--	a/ 4-54	--	--	.00	45	14	2.0		189	18	5.0	8.0	.1	1.8	--	200	--	168	0	--	--	--	--
-25 ad	70	--	a/ 11-53	--	--	.00	40	9.0	7.0		171	0	3.0	5.0	.2	19	--	200	--	136	0	--	--	--	--
-25 ad	70	--	12- 6-55	50	20	.00	38	10	8.6	2.4	181	0	5.1	2.0	.0	3.2	--	176	178	136	0	.3	295	7.5	0
7-20-16 ab	9.9	50	9-19-57	58	20	.18	45	8.0	12	3.8	195	0	6.4	2.8	.3	3.1	.01	202	197	145	0	.4	322	7.7	5
7-21-36 dd1	30	2	8-27-57	58	13	.19	8.1	1.9	3.0	2.1	44	0	2.0	1.0	.1	.4	.04	56	54	28	0	.2	78.5	6.7	5
8-20-18 dd1	12	36	9-17-57	52	16	.16	13	4.6	13		74	0	6.3	3.0	.3	7.9	.05	117	101	51	0	.2	166	7.1	25
8-21-26 dd	25	4	8-27-57	51	19	.19	39	8.5	11	1.4	174	0	2.9	2.5	.3	7.1	.06	176	178	132	0	.4	294	7.6	5
9-20-34 ac	54.1	4	10-18-55	55	17	.00	31	6.2	8.2	3.0	135	0	5.9	2.0	.0	1.7	.10	139	142	103	0	.4	238	7.1	5
Undifferentiated deposits																									
9-20-16 dc	54	6	9-20-57	48	28	.01	14	6.0	5.7	1.4	82	0	2.8	.8	.1	1.5	.02	103	100	60	0	.3	140	7.2	5
10-19-7 cd2	60	5	10-31-55	--	13	2.1	24	8.9	4.4	1.9	120	0	5.5	2.0	.0	2.4	.08	118	121	96	0	.2	208	7.5	0
10-20-14 bal	43.8	--	8-26-57	54	11	.02	4.6	1.3	2.2	1.0	25	0	3.3	.5	.0	.2	--	42	36	17	0	.2	53.5	6.4	5
SURFACE WATER																									
Bitterroot River (main stem)																									
Near Darby	--	--	10-13-55	49	11	.00	11	1.4	3.2	1.0	44	0	2.4	.5	.1	.2	.01	53	53	33	0	.2	77.5	7.1	5
	--	--	7- 6-56	59	11	.00	7.5	.3	1.4	1.2	30	0	.0	.0	.1	.1	.01	40	--	20	0	.1	54.5	7.6	--
At Florence	--	--	10-12-55	51	15	.00	20	3.7	6.6	2.0	89	0	2.1	1.5	.1	.4	.04	100	95	65	0	.4	154	7.4	5
Streams from Sapphire Mountains																									
Sleeping Child Creek near Hamilton	--	--	10-13-55	41	16	.03	7.9	1.4	5.2	1.2	38	0	4.4	.8	.4	.3	.02	60	57	25	0	.4	76.1	7.0	10
Skalkaho Creek near Hamilton	--	--	10-11-55	42	12	.00	27	7.4	2.0	1.9	117	0	4.7	.2	.0	.0	.05	113	113	98	2	.1	194	8.0	5
Willow Creek near Corvallis	--	--	10-14-55	40	20	.00	32	3.4	1.8	1.5	113	0	3.5	.2	.3	.2	.15	121	119	94	1	.1	188	7.4	0
Burnt Fork Creek near Stevensville	--	--	10-11-55	43	10	.00	22	4.4	2.3	1.5	88	0	4.0	.2	.0	.1	.04	89	88	73	1	.1	148	7.6	5
Threemile Creek near Florence	--	--	10-12-55	44	17	.03	24	3.4	3.8	2.1	92	0	4.4	.8	.3	.2	.02	104	101	74	0	.2	160	7.3	5
Eightmile Creek near Florence	--	--	10-12-55	51	15	.00	20	3.7	6.6	2.0	89	0	2.1	1.5	.1	.4	.04	100	95	65	0	.4	154	7.4	5
Streams from Bitterroot Range																									
Como Lake on Rock Creek	--	--	10-11-55	48	4.9	.00	2.0	.2	1.1	.5	9	0	.7	.2	.0	.3	.01	16	14	6	0	.2	32.3	6.4	5
Blodgett Creek near Corvallis	--	--	9-19-57	45	3.4	.04	1.4	.1	.8	.3	8	0	1.1	.2	.2	.0	.01	13	11	4	0	.2	15.1	6.5	5
Mill Creek near Corvallis	--	--	9-19-57	47	7.7	.04	2.2	.1	1.2	.3	11	0	1.0	.2	.2	.0	.00	20	18	6	0	.2	20.1	6.6	5
Bear Creek near Victor	--	--	9-19-57	45	7.2	.07	2.2	.2	1.5	.3	12	0	1.4	.2	.3	.2	.04	21	19	6	0	.3	23.0	6.7	5
Big Creek near Victor	--	--	9-17-57	53	4.1	.02	2.2	.1	1.3	.3	9	0	2.9	.2	.1	.1	.00	17	16	6	0	.2	21.3	6.7	5
Kootenai Creek near Stevensville	--	--	9-12-57	52	6.7	.00	2.6	.2	1.5	.6	10	0	4.4	.2	.1	.0	.04	22	21	7	0	.2	28.2	6.8	5
Bass Creek near Stevensville	--	--	9-17-57	50	5.9	.02	2.4	.2	1.1	.6	10	0	2.8	.2	.1	.2	.02	20	18	7	0	.2	23.3	6.9	5

a/ Analysis by Montana State Board of Health.

The success of irrigation and the steady economic development of the valley is due in part to the absence of serious water-quality problems. Even in waterlogged areas the quality of the water has not changed materially.

Chemical Character and Environment

The chemical character of a natural water reflects the environment through which the water has passed. Geologic factors as well as the influence of man play important roles in the composition and concentration of mineral constituents in waters. Supplies originating on one side of Bitterroot Valley show distinctive differences in quality from those sampled on the other side. With reference to hardness of water these results are plotted in figure 11. Streams heading in the Sapphire Mountains (east side of valley) are more mineralized than those whose sources are in the Bitterroot Mountains (west side). Ground-water reservoirs, recharged by creek waters and irrigation return flows, reflect similar differences.

Streams draining the Bitterroot Mountains flow through an area of granitic rocks and other rock materials of igneous origin which are resistant to rapid solution by water. As a result, these waters have small concentrations of dissolved solids. A sample of water from Como Lake collected on October 11, 1955, while storage was being released for late-season irrigation, contained only 16 ppm of dissolved solids. In the spring, melting of the heavy snow pack in the mountains above Como Lake releases water of even lower mineral content to the reservoir. Water is diverted from Rock Creek, siphoned across the Bitterroot River, and conveyed through a 73-mile canal to irrigate about 16,000 acres of cropland on the east side of the river.

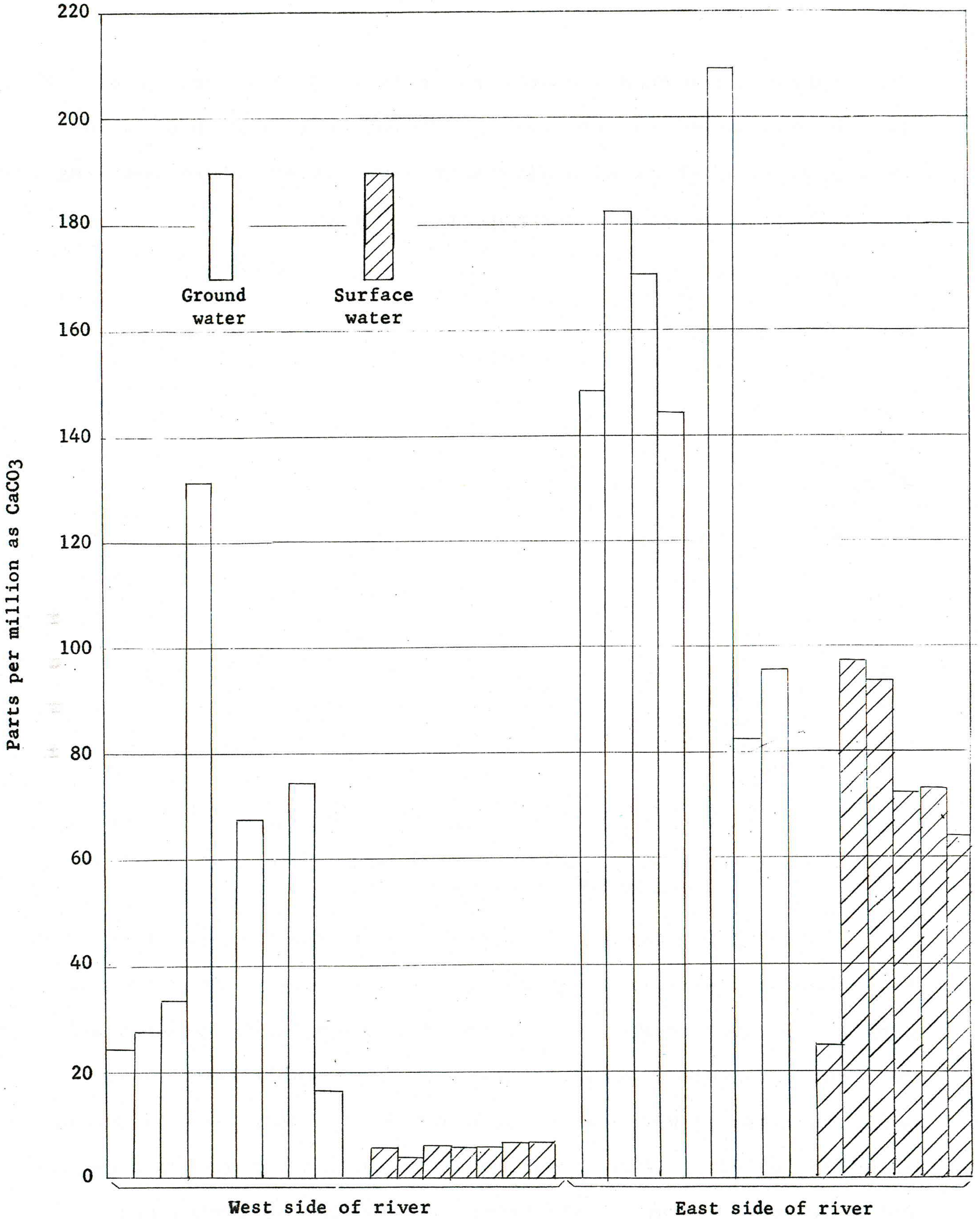

Figure 11.--Hardness of waters from Darby to Florence. Diagrams represent sampling locations in downstream order and read from left to right

Como Lake has reported a usable capacity of 34,800 acre-feet, but in the 1956 water year the maximum storage exceeded this amount. (See fig. 12.) Chemical analyses of seven creek waters draining the Bitterroot Mountains are reported in table 5.

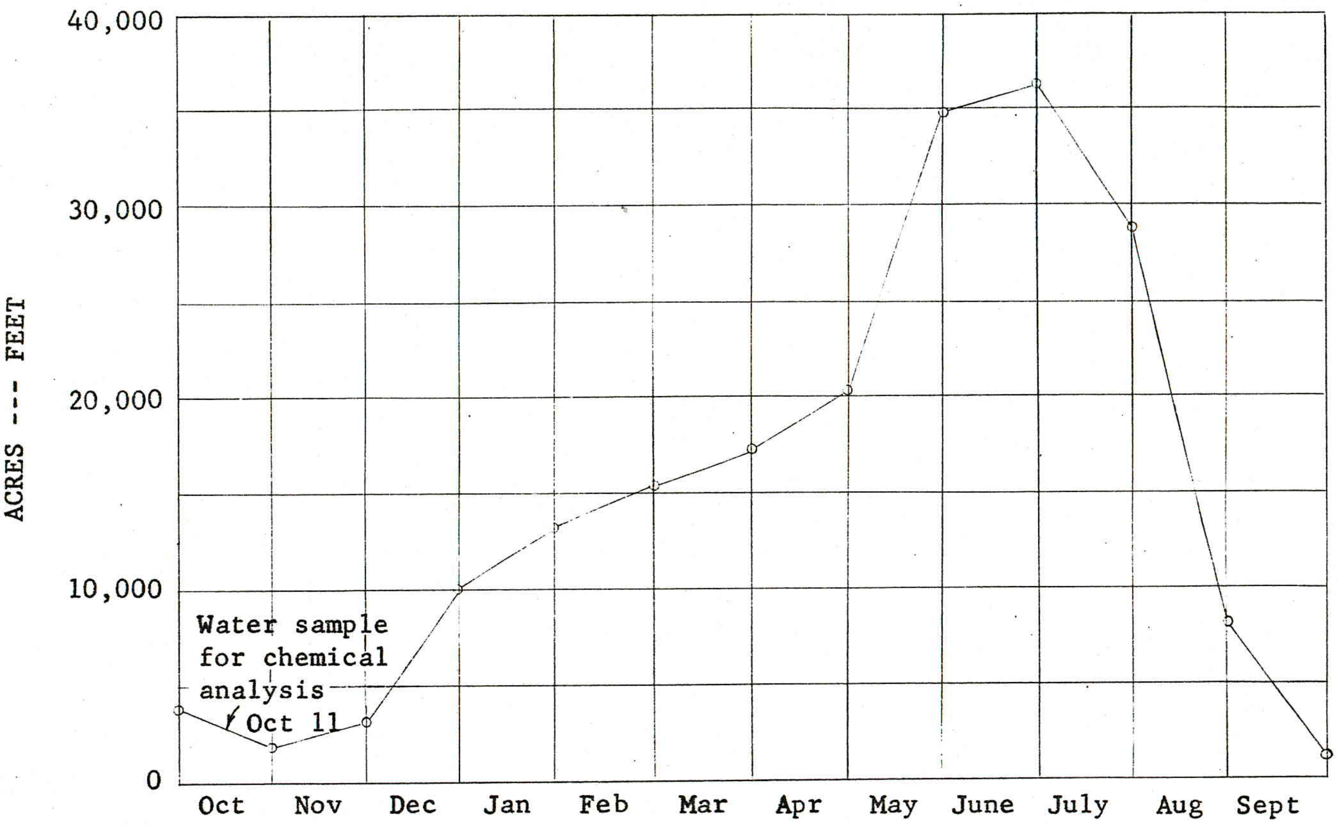

Figure 12.--Monthly contents, in acre feet, of Como Lake on Rock Creek, October 1955 to September 1956.

The Sapphire Mountains, lying east of the Bitterroot River in an area of diversified geology, contain rocks of both sedimentary and igneous origin. These rocks contain higher proportions of readily soluble mineral constituents. Skalkaho Creek near Hamilton contains water which on October 11, 1955, had 113 ppm of dissolved solids. This stream heads in an area of granitic gneiss and sedimentary rocks. Daly Creek, a tributary entering from the northeast above the sampling site, flows through outcrops of argillaceous and dolomitic limestone. This tributary then cuts through an area of quartz monzonite, granodiorite, granitic gneiss, and sedimentary rocks before joining Skalkaho Creek. The water from Skalkaho Creek near Hamilton is of the calcium magnesium bicarbonate type. Analyses of waters from six streams that drain the Sapphire Mountains are listed in table 5.

Bitterroot River water in October 1955 was about twice as mineralized at Florence, near the north end of the valley, as it was near Darby. This increase in salt concentration, which is not significant in relation to the usefulness of the water, is the net effect of inflow from 20 tributaries from the west and 5 from the east and of circulation of water through the soil and alluvium after it has been used for irrigation.

Stream sand and gravel in the alluvial deposits of the valley floor produce waters of variable but generally acceptable quality. (See table 5 for 11 analyses.) The chemical character of these groundwaters is influenced by many factors. The source of recharge water, permeability, texture, and chemical character of the water-bearing materials, soil cover, and rate of ground-water movement through the aquifer all have a bearing on the water quality.

SUMMARY AND CONCLUSIONS

The waters available in the Bitterroot Valley, with very few exceptions, are acceptable for general use. Further development of water supplies in the project area, under conditions now existing or likely to exist in the next few decades, would seem to be more dependent on quantity and access to sources than on water-quality factors.

Each spring and summer, in amounts greatly exceeding the discharge by natural and artificial means, water infiltrates to the ground-water reservoir underlying the Bitterroot Valley. During the fall and winter the surplus water is released from storage. In the spring of 1957 the amount of water in storage in the underground reservoir was increased by an amount estimated at 165,000 acre-feet; the increase in the spring of 1958 was roughly 5,000 acre-feet more.

Use of the water stored in the underground reservoir is limited by the type of material in which the water is stored. Relatively large amounts of water are readily available for development on the floodplain of the Bitterroot River and some of the adjacent low terraces, expecially those east of the river. Wells capable of yielding more than 250 gallons per minute can be developed in these areas. In the vicinity of Corvallis, on a low terrace, wells capable of yielding 1,000 gallons per minute or more can be developed. Wells capable of yielding 50 to 250 gallons per minute can be developed on many of the alluvial fans of the tributary streams. In the remaining area wells will yield only enough water for domestic and stock use. (See plate 1.) The water generally is of good chemical quality.

Table 6.--Records of typical wells and springs

Well number: See explanation of well-numbering system in text.
Type of well: Dn, driven; Dr, drilled; Du, dug.
Depth of well: Reported depths are shown in whole feet below land surface; measured depths are shown in feet and tenths below measuring point.
Type of casing: C, concrete; P, pipe; R, rock; T, tile; W, wood.
Type of pump: C, centrifugal; Cy, cylinder; J, jet; N, none; P, pitcher; T, turbine.
Type of power: E, electric; G, gasoline; H, hand; N, none.
Use of water: D, domestic; F, firefighting; I, irrigation; N, none; O, observation; PS, public supply; S, stock.
Measuring point: Tca, top of casing; Tco, top of cover.
Altitudes determined by spirit level, unless otherwise indicated in remarks column.
Remarks: *Alt, altimeter; CA, chemical analysis; Spr, spring.

Well number	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Type of pump	Type of power	Use of water	Measuring point			Depth of water level below measuring point (feet)	Date of measurement	Remarks
										Description	Distance above or below (-) land surface (feet)	Altitude (feet)			
5-20-7bc	Dan Hoagland		Dr	32.8	5	P	J	E	S,O	Tco	2.5	3630.8	14.77	4- 9-56	
5-20-7ca	J. A. Le Clair		Du	21.5	8	T	Cy	H	D,O	Tco	.5	3664.5	19.68	4- 6-56	
5-20-18bb	Jack Stewart		Dr	26.5	5	P	C	E	S,O	Tco	0	3643.0	17.51	5-16-56	
6-20-3bd	M. Holloran		Du	35.3	30	R	C	E	D,S,O	Tco	0	3578.7	28.35	5-10-56	
6-20-4bc1	Emmet Smyth		Dr	43.0	6	P	J	E	D,O	Tco	0	3480.8	2.67	9-19-55	
6-20-4cc	George Talbot		Du	22.1	28	R	N	N	O	Tco	.3	3495.3	10.80	9-20-55	
6-20-6dd	John Hawker		Du	9.2	40	C	C	E	I,O	Tca	0	3481.0	1.98	8-30-56	
6-20-8aa	John Hawker		Du	20.5	30	R	C	E	S,O	Tca	-3.5	3489.3	11.24	4-16-56	
6-20-10cb	Levi Davis		Dr	80.8	4	P	N	N	O	Tca	-3.5	---	58.72	9-20-55	
6-20-19cc	Ravalli Co.Fairgrounds		Du	14.8	48x48	W	C	E	I,O	Tco	0.6	3558.9	11.66	5- 7-56	
6-20-30bc	Valley Water Co.		Dr	70	12	P	T	E	PS						CA
6-21-1ca	F. O. Burrell		Dr	64.1	4	P	Cy	H	O	Tco	.5	3548.0	39.35	12-31-56	
6-21-2ba	Jane Hauf		Dr	83.9	4	P	N	N	O	Tca	0	---	57.70	3-22-57	
6-21-2dd	J. C. Rummell		Du	27.8	36	P	N	N	I,O	Tca	0	3642.9	23.86	2-18-57	
6-21-11aa	J. C. Rummell		Du	20.0	48	C	N	N	O	Tco	.5	3626.4	17.05	3-11-57	

Table 6.--Records of typical wells and springs, cont'd.

Well number: See explanation of well-numbering system in text.
Type of well: Dn, driven; Dr, drilled; Du, dug.
Depth of well: Reported depths are shown in whole feet below land surface; measured depths are shown in feet and tenths below measuring point.
Type of casing: C, concrete; P, pipe; R, rock; T, tile; W, wood.
Type of pump: C, centrifugal; Cy, cylinder; J, jet; N, none; P, pitcher; T, turbine.
Type of power: E, electric; G, gasoline; H, hand; N, none.
Use of water: D, domestic; F, firefighting; I, irrigation; N, none; O, observation; PS, public supply; S, stock.
Measuring point: Tca, top of casing; Tco, top of cover.
Altitudes determined by spirit level, unless otherwise indicated in remarks column.
Remarks: *Alt, altimeter; CA, chemical analysis; Spr, spring.

Well number	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Type of pump	Type of power	Use of water	Measuring point			Depth of water level below measuring point (feet)	Date of measurement	Remarks
										Description	Distance above or below (-) land surface (feet)	Altitude (feet)			
6-21-12db	Wesley Cook		Dr	17	3	P	C	E							CA
6-21-24cb	Lyle Cleveland		Du	25.6	200	C	C	E	I,O	Tco	1.0	3619.6	6.09	5- 7-57	
6-21-25aa	Valley Water Co.		Dr	70	12	P	T	E	PS						CA
6-21-25ad	Valley Water Co.		Dr	70	12	P	T	E	PS						CA
6-21-26db	Hamilton Cemetery	1956	Dr	365.0	8	P	N	N	I,O	Tca	1.4	3621.7	19.20	3-28-57	
6-21-36dd	Ben Rowe		Dn	27.0	1¼	P	N	N	O	Tca	3.0	3589.3	18.67	4-10-56	
7-20-3ba1	Sacks Brothers		Du	14.0	36	R	C	E	D,S,O	Tco	.2	3383.8	8.68	9-12-55	
7-20-4aa	Neil Overturf		Du	7.7	40	R	Cy	H	O	Tco	0	3378.4	4.82	9-14-55	
7-20-7ba	Unknown		Du	18.2	30	W	Cy	H	O	Tco	.3	3448.8	6.17	6-24-47	
7-20-16ab	Homer Bailey		Du	9.9	50	C	C	E	I,O	Tco	.5	3403.8	5.73	3- 5-56	
7-20-16ac	Homer Bailey		Dn	12.1	60x60	W	C	E	I,O	Tco	.5	3411.7	7.16	3- 5-56	
7-20-17aa	U. S. Geol. Survey	1956	Dn	10.5	3/4	P	N	N	O	Tca	2.5	3403.9	6.63	10- 8-56	
7-20-18bb	Albert Sestak		Du	11.7	48	R	N	N	O	Tco	.5	3488.4	6.14	6- 5-57	
7-20-19ba	U. S. Geol. Survey		Dn	10.0	3/4	P	N	N	O	Tca	.5	3437.4	7.95	4-25-57	
7-20-20dd	U. S. Geol. Survey	1957	Dn	10.1	3/4	P	N	N	O	Tca	1.1	3432.8	6.62	4-25-57	

Table 6.--Records of typical wells and springs, cont'd.

7-20-21ba1	O. N. McClure	1955	Du	8.4	24	T	C	E	I,O	Tca	0	3422.0	3.88	9-20-55	
7-20-21cd	M. J. Holloron		Du	13.7	30	R	Cy	H	O	Tco	0	3432.6	6.02	7- 6-56	
7-20-22cb	Clarence Popham		Dr	25	5	P	C	E	D,O	Tca	-4.6	---	15.04	3- 5-56	
7-20-22da	Ralph Erickson		Dr	79.4	6	P	Cy	H	D,O	Tco	1.0	---	35.59	9-22-55	
7-20-28bc1	Lee Lear		Du	9.5	48	R	Cy	H	O	Tco	.5	3442.5	3.95	9-19-55	
7-20-30bb	Allen Nelson	1956	Du	11.8	48	W	C	E	I,O	Tco	.3	3452.3	7.34	9-10-56	
7-20-31bb	Douglas Johnson		Dr	37.5	4	P	Cy	H	S,O	Tca	1.0	3468.9	14.43	4-15-57	
7-20-32dd	Corvallis Rural Fire Dept.		Du	12.7	48	C	C	G,E	F,O	Tco	0	3470.7	5.94	6-29-56	
7-21-11bd	Carl Larson		Dr	40.1	6	P	J	E	D,S,O	Tca	.5	3652.1	12.39	1- 4-57	
7-21-36dd1	C. W. Park		Dn	30	2	P	C	E	D						CA
7-21-36dd3	C. W. Park		Dr	31.5	5	P	Cy	E	O	Tca	.5	3486.8	17.64	12- 5-57	
8-19-6cc	Carl Rasmussen		Du	25.4	20x48	C	Cy	H	O	Tca	1.0	3863 *	2.47	10-25-55	*Alt
8-19-7cb	William Wax		Du	116.5	48	C	J	E	D,S,O	Tco	1.4	3893 *	93.16	4-18-56	*Alt
8-20-2bb	John Wenger		Du	21.5	36	C	J	E	D,S,O	Tca	.5	3436.4	18.72	4-18-56	
8-20-3bda	Anna Rebberg		Du	38.5	40	C	J	E	D,O	Tco	.9	3338.6	15.37	9- 7-55	
8-20-5ba	U. S. Geol. Survey	1956	Dn	9.8	3/4	P	N	N	O	Tca	1.2	3297.9	8.26	11- 1-56	
8-20-5cc	J. O. Cote		Dr	9.5	4	P	C	E	D						
8-20-5dc1	William Allozier		Du	5.3	6	W	N	N	O	Tca	.7	3303.9	3.66	4-16-57	
8-20-7ab	Curlew School		Dr,Du	62.1	2	P	N	N	O	Tca	0	3439.3	30.55	4-29-57	
8-20-10bb	Clarence Hagen		Du	8.7	30	P	Cy	H	O	Tco	0	3311.4	5.40	9- 7-55	
8-20-14cb	David Metelman		Du	29.3	40	C	Cy	H	O	Tco	0	3389.4	8.17	9-13-55	
8-20-15ba	U. S. Geol. Survey	1957	Dn	18.7	3/4	P	N	N	O	Tca	.5	3332.5	17.16	4-30-57	
8-20-18dd1	Wilbur Robinson		Du	12.0	36	R	J	E	S,O	Tco	1.0	3374.8	3.04	6-10-57	
8-20-21ba	U. S. Geol. Survey	1956	Dn	10.3	3/4	P	N	N	O	Tca	.7	3330.6	5.53	10- 5-56	
8-20-22aa1	David Metelman		Du	26.9	40	C	Cy	H	S,O	Tco	.9	3366.5	17.06	9-13-55	
8-20-28ad1	George Pfau		Du	10.2	36	T	N	N	O	Tco	2.3	3353.0	4.74	9-14-55	
8-20-28cc	U. S. Geol. Survey	1956	Dn	10.3	3/4	P	N	N	O	Tca	2.1	3360.1	6.11	10- 8-56	
8-20-28dc1	W. J. Raymond		Dn	7.1	24	R	N	N	O	Tca	1.0	3359.6	4.51	9-14-55	
8-20-30ca	Ernest Buker		Du	10.3	6-12	T	N	N	I,O	Tca	0	3308.8	8.99	10-27-56	
8-20-30dc	Fred Garrod		Du	13.4	48x60	C	C	E	I,O	Tco	.5	3397.7	8.69	5- 8-56	
8-21-26dd	L. Williamson	1947	Dr	25	4	P	C	E	D,S						CA
9-19-5ad	Richard Whittle		Du	29.0	60	R	Cy	H	O	Tco	1.0	3470.5	9.14	9-29-55	

Table 6.--Records of typical wells and springs, cont'd.

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Type of casing; C, concrete; P, pipe; R, rock; T, tile; W, wood.
Type of pump: C, centrifugal; Cy, cylinder; J, jet; N, none; P, pitcher; T, turbine.
Type of power: E, electric; G, gasoline; H, hand; N, none.
Use of water: D, domestic; F, firefighting; I, irrigation; N, none; O, observation; PS, public supply; S, stock.
Measuring point: Tca, top of casing; Tco, top of cover.
Altitudes determined by spirit level, unless otherwise indicated in remarks column.
Remarks: *Alt, altimeter; CA, chemical analysis; Spr, spring.

Well number	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Type of pump	Type of power	Use of water	Measuring point			Depth of water level below measuring point (feet)	Date of measurement	Remarks
										Description	Distance above or below (-) land surface (feet)	Altitude (feet)			
9-19-5ca	George Mace		Du	21.3	30	C	N	N	D,O	Tco	2.6	3430.2	9.62	10-20-55	
9-19-6ca	J. P. Moore		Du	14.7	36	C	C	E	D,O	Tco	0	3351.9	8.67	9-29-55	
9-19-10bb	Earl W. Bjork		Du	29.8	42	C	J	E	D,S,O	Tca	0	---	10.69	10-20-55	
9-19-29cc	Farmers' Union		Du	9.9	14	T	Cy	H	O	Tco	.2	3652.9	8.43	10- 7-55	
9-19-30cc	Ralph Wood		Dn	18.2	1½	P	P	H	O	Tca	4.8	3576.4	9.27	9- 9-55	
9-20-1ac	Lyle Regester	1910	Du	47.0	60x60 36x36	C	N	N	O	Tca	1.0	3315.9	22.53	9- 1-55	
9-20-1da	Raymond H. Bell		Du	35.7	40	C	Cy	H	O	Tco	1.7	3321.6	24.41	9-29-55	
9-20-4ab	Mario Feronato		Dn	16.4	36x36	C	N	N	O	Tco	.5	3470 *	5.38	4-17-57	*Alt
9-20-10ad2	U. S. Geol. Survey	1956	Dn	10.8	3/4	P	N	N	O	Tca	1.0	3249.5	4.97	6-27-56	
9-20-10bc	Unknown	1946	Dr	170	6	P	T	E	D,S						
9-20-12bb	Raymond H. Bell		Du	19.7	42	C	J	E	O	Tco	0	3278.7	8.21	9-29-55	
9-20-12cb	Glenn Akers		Du	8.2	36	R	N	N	O	Tco	0	3273.5	2.14	9- 5-55	
9-20-15ca2	Walter Matusick		Du	12.9	40	R	Cy	H	O	Tca	0	3274.0	2.69	5-15-55	
9-20-16dc	Henry Kares		Dr	54	6	P	J	E	D,S						CA
9-20-15dd	U. S. Geol. Survey	1956	Dn	10.5	3/4	P	N	N	O	Tca	2.7	3279.7	5.38	6-26-56	

Table 6.--Records of typical wells and springs, cont'd.

9-20-21adl	Dan Shea		Dr	32.2	4	P	N	N	O	Tca	0	3307.9	10.13	9-28-55	
9-20-23ad	Joe Harington		Du	17.6	30	R	N	N	D,S,O	Tco	.5	3397.6	3.54	9- 6-55	
9-20-25bb	Murray Campbell		Du	9.4	18	T	N	N	D,O	Tca	0	3433.3	5.09	9- 6-55	
9-20-26bal	Andrew Polson, etc.		Du	22.7	60	P	Cy	E	I,O	Tco	2.0	3361.5	5.46	9- 6-55	
9-20-27cd	George Chillicott		Du	20.2	36	C	Cy	H	O	Tco	.5	3300.0	19.27	4-16-57	
9-20-28bd	U. S. Geol. Survey	1956	Dn	10.6	3/4	P	N	N	O	Tca	.2	3276.2	4.44	12-16-56	
9-20-28db	George Chillicot		Du	8.2	36	T	N	N	O	Tca	0	3283.2	6.37	12-27-56	
9-20-34abl	R. E. Frazer		Dr	42.6	4	P	N	N	O	Tca	1.2	3327.9	15.65	9- 8-55	
9-20-34ab4	Earl Lee		Du	56.5	30-4	C	J	E	D,O	Tco	.3	3326.9	12.50	9-13-55	
9-20-34ac	Adolf Lippens		Dr	54.1	4	P	J	E	O	Tco	.5	3330.3	18.71	9- 8-55	
10-19-7bd	Stanley Antrin	1952	Dr	375.0	14-10	P	N	N	I,O	Tca	1.0	---	32.02	8-10-56	
10-19-7cdl	Stanley Antrin		Dr	60.0	5	P	J	E	D,O	Tco	0	---	5-18	8-31-55	
10-19-7cd2	Stanley Antrin	1955	Dr	60.0	6	P	J	E	S						CA
10-12-7dc2	Stanley Antrin	1957	Dr	64.3	12	P	N	N	I	Tca	1.5	---	32.86	4- 1-57	
10-19-29cc	James Mason		Du	5.0	36x36	W	N	N	O	Tca	.4		.27	8-30-55	
10-19-30cd	James Mason														Spr
10-20-12cc	U. S. Geol. Survey	1957	Dr	10.2	3/4	P	N	N	O	Tca	2.8	3206.8	5.79	3-26-57	
10-20-13cc	U. S. Geol. Survey	1957	Dr	10.2	3/4	P	N	N	O	Tca	2.0	3215.6	7.35	3-27-57	
10-20-14bal	Lloyd Heggen		Du	43.8	48	C	Cy	E	O	Tco	-6.0	3260.2	31.98	10-24-56	
10-20-15dc	L. L. Simpson		Du	16.7	36	R	Cy	E	O	Tca	.5	3288.4	11.01	10- 9-56	
10-20-22bc	Dean Hoffman		Dr	46.4	8	P	Cy	E	D,I,O	Tca	-2.5	3354.1	1.65	5-24-56	
10-20-22ccl	Julius R. Zander		Du	9.0	48-24	R	Cy	H	S,O	Tco	0.6	3393.4	2-8	4-23-57	
10-20-23cb	Toivo Mattson		Du	8.3	8	T	P	H	O	Tca	0	3246.8	6.39	10-24-56	
10-20-26ab	Allen T. Hoblitt		Du	8.5	36	R	Cy	H	O	Tco	.4	3222.8	4.30	4-22-57	
10-20-27adl	Allen T. Hoblitt		Dr	31.9	4	P	Cy	H	O	Tca	2.0	3249.3	9.30	10-18-55	
10-20-34cd	Mario Feronato		Du	24.6	30	R	Cy	H	O	Tco	.0	3316 *	20.40	4-17-57	*Alt
10-20-35bb	U. S. Geol. Survey		Dn	10.4	3/4	P	N	N	O	Tca	2.7	3235.1	7.15	3-28-57	

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ERRATA

On page 9, line 7, after as 1898, insert (Lindgren, 1904).

On page 9, line 9, after of the valley, insert (Langton, 1935, p.32).

On page 10, line 12, after bedrock, insert (Vine and Erdmann, 1952, p. 32).

On page 12, line 18, after Lake Missoulas, insert (Bretz and others, 1956).

(Note) Please insert this sheet in your copy of Bulletin 9, "Preliminary Report on the Geology and Water Resources of the Bitterroot Valley, Montana."