WATER RESOURCES OF WASHAKIE COUNTY, WYOMING

By David D. Susong, Myron L. Smalley, Edward R. Banta

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.09290	meter squared per day
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
pound per square inch (lb/in^2)	6.895	kilopascal
ton (short, 2,000 lb)	0.9072	metric ton

Temperatures can be converted to degrees Fahrenheit (^oF) or degrees Celsius (^oC) by the following equations:

$$^oF = 9/5\ (^oC) + 32$$
$$^oC = 5/9\ (^oF - 32)$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Data on the surface- and ground-water resources are complied to summarize the water resources of Washakie County. This study, prepared in cooperation with the Wyoming State Engineer, is one in a series investigating the water resources of Wyoming counties. The three principal types of streams in the county are perennial, intermittent, and ephemeral. Perennial streams have continuous streamflows, and high streamflows are associated with snowmelt runoff; low streamflows usually occur in the winter months when the snowpack is frozen and ground-water discharge is at its smallest rate. Intermittent and ephemeral streams are characterized by periods of no flow, and high streamflows are associated with snowmelt or thunderstorms.

The principal aquifers are as follows: alluvium of Quaternary age, Willwood Formation of Tertiary age, Fort Union Formation of Tertiary age, and the formations of primarily Paleozoic age--Goose Egg Formation, Tensleep Sandstone, Madison Limestone, Bighorn Dolomite, and Flathead Sandstone. Reported yields from wells completed in the alluvium ranged from 10 to 40 gallons per minute, and reported yields from wells completed in the Willwood Formation ranged from 1 to 28 gallons per minute. Yields as large as 2,500 gallons per minute are reported from wells completed in the Madison Limestone, Bighorn Dolomite, and Flathead Sandstone.

Calcium magnesium sodium sulfate water and sodium sulfate water with concentrations of dissolved solids greater than 1,000 milligrams per liter are common in the alluvium, Willwood Formation and Fort Union Formation. Water samples from six of eight wells completed in the Willwood Formation have trace concentrations of herbicides. Calcium carbonate water with small dissolved-solids concentrations is common in the aquifers in Paleozoic formations.

INTRODUCTION

Washakie County in north-central Wyoming (fig. 1) has an area of 2,262 mi^2 and is 19th in size of the 23 counties in Wyoming. The Federal government administers more than 67 percent of the land in the county, with most of this land managed by the U.S. Bureau of Land Management, U.S. Department of the Interior. The State of Wyoming administers about 10 percent of the land, and the remaining 23 percent is in private ownership (State of Wyoming, 1987, p. 224). Much of the private land is along the Bighorn and Nowood Rivers.

The landforms in the county range from the high alpine terrain of the Bighorn Mountains to the badlands terraces and alluvial plains in the central and western parts of the county. Altitudes range from 3,950 ft above sea level in the central and western parts to 9,600 ft above sea level in the eastern part of the county.

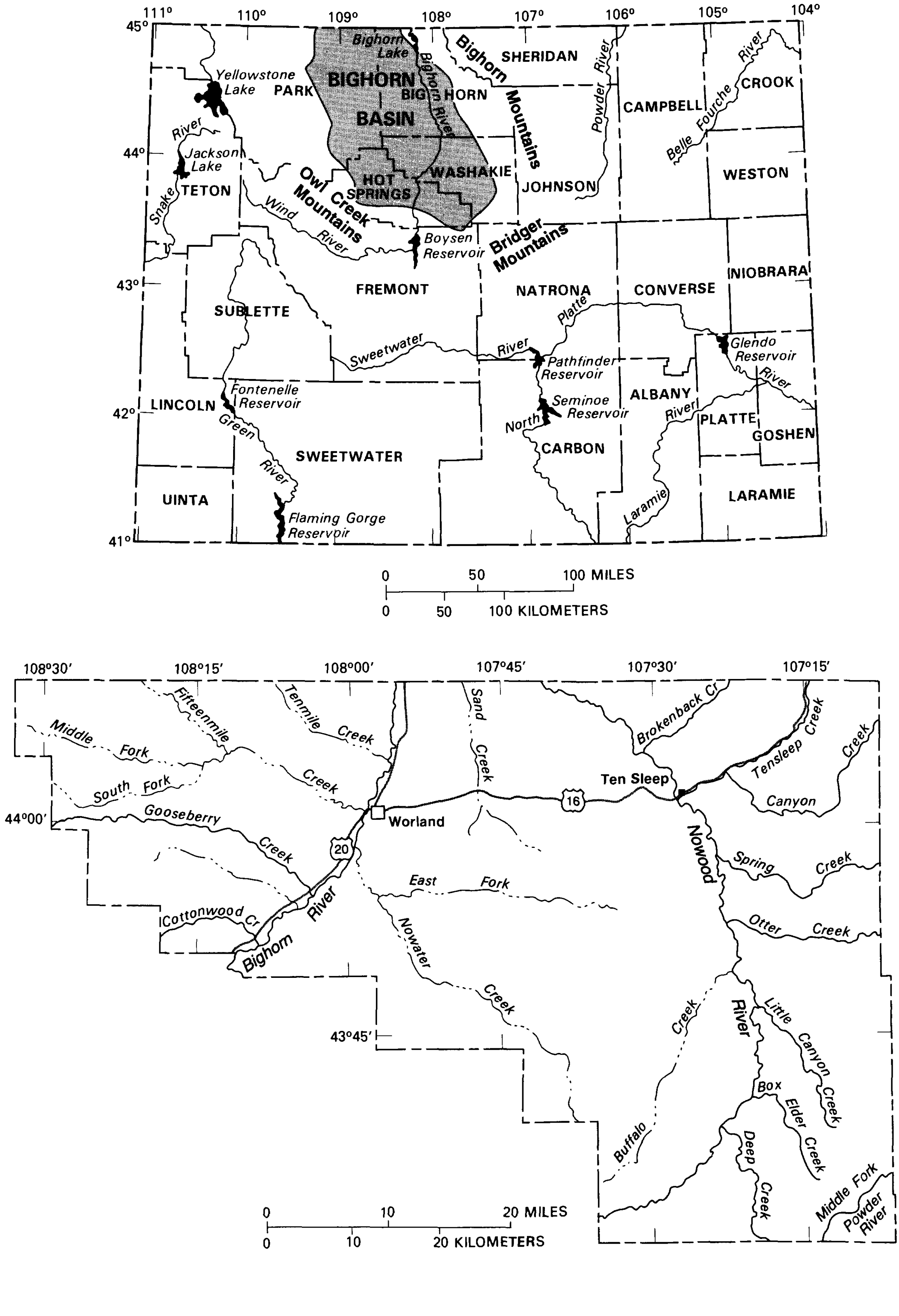


Figure 1.--Location of Washakie County and the Bighorn Basin.

About two-thirds of the 9,496 county residents (State of Wyoming, 1987, p. 224) live in Worland, the county seat. Most of the remaining population is dispersed along the major drainages in the county. Economic development in the towns of Worland and Ten Sleep has increased the demand for water suitable for domestic use. In some of the outlying areas, the availability of water suitable for domestic use is a problem for residents.

The economy of Washakie County is based primarily on the energy industry and agriculture and agriculture-related industries. The availability and quality of irrigation water are limiting factors on crop selection and arable acreage in the county.

Economic development in Worland and Ten Sleep, water-quality problems in rural areas, and the use of large quantities of water by agriculture place demands on the surface-water and ground-water resources of Washakie County. In response to these water-availability and water-quality concerns, the U.S. Geological Survey, in cooperation with the Wyoming State Engineer, conducted a study to quantify the water resources of the county.

Purpose and Scope

This report describes the water resources of Washakie County. It is one of a series of reports on the water resources of Wyoming counties.

Surface- and ground-water data were compiled from U.S. Geological Survey reports and data files. Additional wells were inventoried to improve data coverage and to evaluate water-level and water-quality changes. This report includes data on 194 wells and springs, and chemical analyses of water from 104 of these sites. Four surface-water and eight ground-water samples were collected and analyzed for herbicides.

Previous Investigations

The Wyoming Geological Association has published five guidebooks to the Bighorn Basin (Blackstone and Sternberg, 1947; Spalding and Wold, 1952; Wicker, 1959; Exum and George, 1975; Boberg, 1983). Many papers in these guidebooks specifically address aspects of the geology of Washakie County.

The results of investigations conducted by the U.S. Geological Survey (USGS) in the county are published in USGS reports. The Tensleep Sandstone has been investigated in two studies; one examined variations in permeability (Bredehoeft, 1964) and another mapped the potentiometric surface of water in the sandstone (Bredehoeft and Bennett, 1971). Chemical analyses of ground water in the county are included in the compilation by Lowry and Lines (1972). Lowry and others (1976) described the ground- and surface-water resources of the Bighorn Basin, including Washakie County, in a hydrologic atlas. Some of the sites used in a study of runoff and flood hydrographs from small, ephemeral drainage basins (Craig and Rankl, 1978) were in Washakie County. The hydrogeologic features of alluvial deposits in the Nowood River area, in the eastern part of the county, were investigated by Cooley and Head (1979). Larson (1984) compiled dissolved-solids data from 125 ground-water samples in the county, including some previously published by Lowry and Lines (1972). The hydrology of aquifers in Paleozoic formations in the eastern part of the county was described by Cooley (1986).

Site-Numbering System

Ground-water wells and springs are identified by a local site number that consists of three numbers followed by one to three lowercase letters and two additional numbers (for example, 46-093-29dcb01). The numbering system is based on the Federal system of land subdivision (fig. 2). The first number denotes the township, the second the range, and the third the section number. The letters following the section number describe the location in the section. The section is divided into quarters (160 acres), which are lettered a, b, c, and d in a counterclockwise direction, beginning in the northeast quadrant (fig. 2). Similarly, each quarter may be divided further into quarters (40 acres) and again into 10-acre tracts and lettered in the same manner. The first letter following the section number denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section, or 10-acre tract. The number following the letters is a sequential number assigned to each site in the quarter-quarter-quarter section. For example, in figure 2, well 46-093-29dcb01 is the first well assigned an identification number in the NW1/4 of the SW1/4 of the SE1/4 of section 29, T. 46 N., R. 93 W.

Acknowledgments

The authors gratefully acknowledge the generous assistance of the ranchers and landowners in Washakie County who provided access to their property and wells.

Water-Right Administration

By Richard G. Stockdale, Wyoming State Engineer's Office

According to article 8, section 1 of the Wyoming State constitution, "The water of all natural streams, springs, lakes or other collections of still water, within the boundaries of the State, are hereby declared to be property of the State." Anyone desiring to use water beneficially in Wyoming must apply for and obtain an approved permit from the State Engineer to appropriate water prior to initiating construction of water-diversion structures, such as dams, headgates, spring boxes, and wells. Once a permit to appropriate water has been obtained from the State Engineer, the permittee may proceed with construction of the water-diversion works and with beneficial use of the diverted water for the purposes specified in the permit. Such diversion and beneficial use must be made in accordance with statutory provisions. After the permittee has beneficially used the diverted water for all of the permitted uses at all of the permitted point(s) or area(s) of use, proof of beneficial use is filed, and the water right is adjudicated (finalized). The adjudication process fixes the location of the water-diversion structure, the use, quantity, and points or areas of use for the water right.

Wyoming water rights are administered using the Doctrine of Prior Appropriation, commonly referred to as the "First in time, first in right" system. Article 8, section 3 of the Wyoming constitution states: "Priority of appropriation for beneficial uses shall give the better right." The priority date of an appropriation is established as the date when the application for permit to appropriate water is received in the State Engineer's Office.

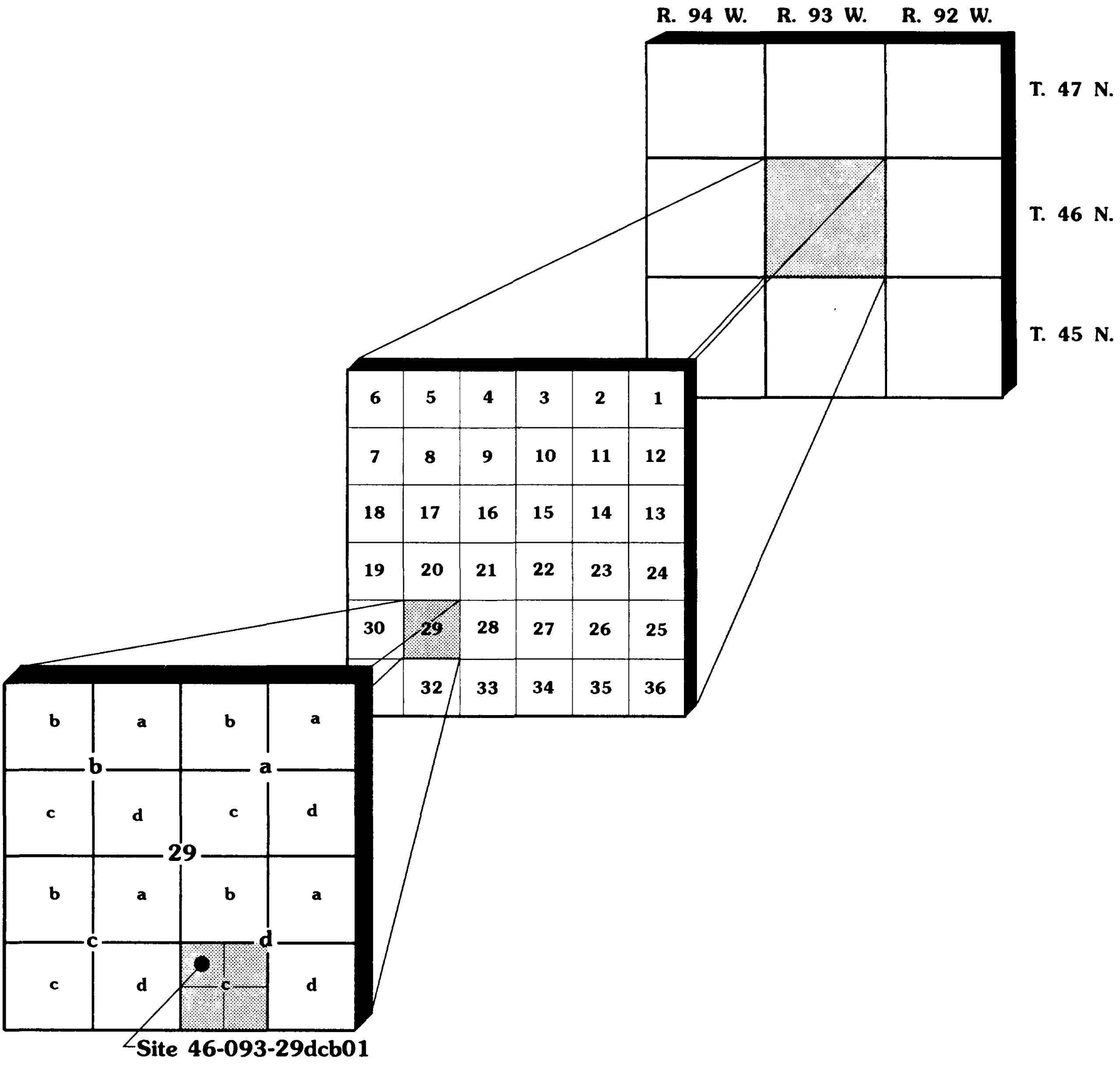


Figure 2.--Site-numbering system.

Water-right administration is conducted by the State Engineer and the Water Division Superintendents. Article 8, section 5 of the Wyoming constitution provides for the appointment of a State Engineer, and section 4 provides for the creation of four Water Divisions in the State and the appointment of a superintendent in each division. The State Engineer is Wyoming's chief water-administration official and has general supervision of all waters of the State. The superintendents, along with their staff of hydrographers and water commissioners, are responsible for the local administration of water rights and the collection of hydrologic data in their respective divisions.

Deviations from the standard water-right administrative system of "First in time, first in right" might exist. Such deviations might be caused by conditions in compacts, court decrees, and treaties or through the creation of special water-management districts. Virtually every stream exiting the State is subject to a compact, court decree, or treaty that dictates to some degree how the appropriations on that specific stream are administered. While the interstate nature of ground water and the interconnection of ground water with streams are recognized, the development of interstate agreements on use of water from aquifers is still in its infancy. The reason that few ground-water compacts exist is twofold. First, there is a lack of sound technical data on which to base appropriate administrative allocations of ground water between adjoining states, and, second, there is not sufficient competition between Wyoming and adjoining states to require binding interstate agreements or allocations of ground-water resources.

Precipitation

Average annual precipitation ranges from about 7 in. in the northwestern part of the county to about 16 in. at the higher altitudes in the Bighorn Mountains along the eastern edge of the county (fig. 3). The arid lowlands of the central and western parts of the county meet the recognized criteria for classification as desert (Martner, 1986, p. 5). Areas in the Bighorn Mountains are classified as alpine.

Most precipitation from November through April occurs as snowfall, while precipitation during the remainder of the year occurs as light showers or occasional intense thunderstorms. Fluctuations in annual precipitation are substantial. Annual precipitation for the period 1907-80 ranged from 2.27 in. (1954) to 13.57 in. (1944) at Worland (U.S. Department of Commerce, 1984).

Geology

Most of Washakie County is in the Bighorn Basin, which is a structural basin that developed about 65 million years ago. The Bighorn and Owl Creek Mountains (fig. 1) were uplifted at this time, and large quantities of pre-Tertiary sediments were eroded into the developing Bighorn Basin. Following the uplift of the mountains, a broad regional uplift raised basins and mountains thousands of feet to their present position (Blackstone and Huntoon, 1984, p. 3).

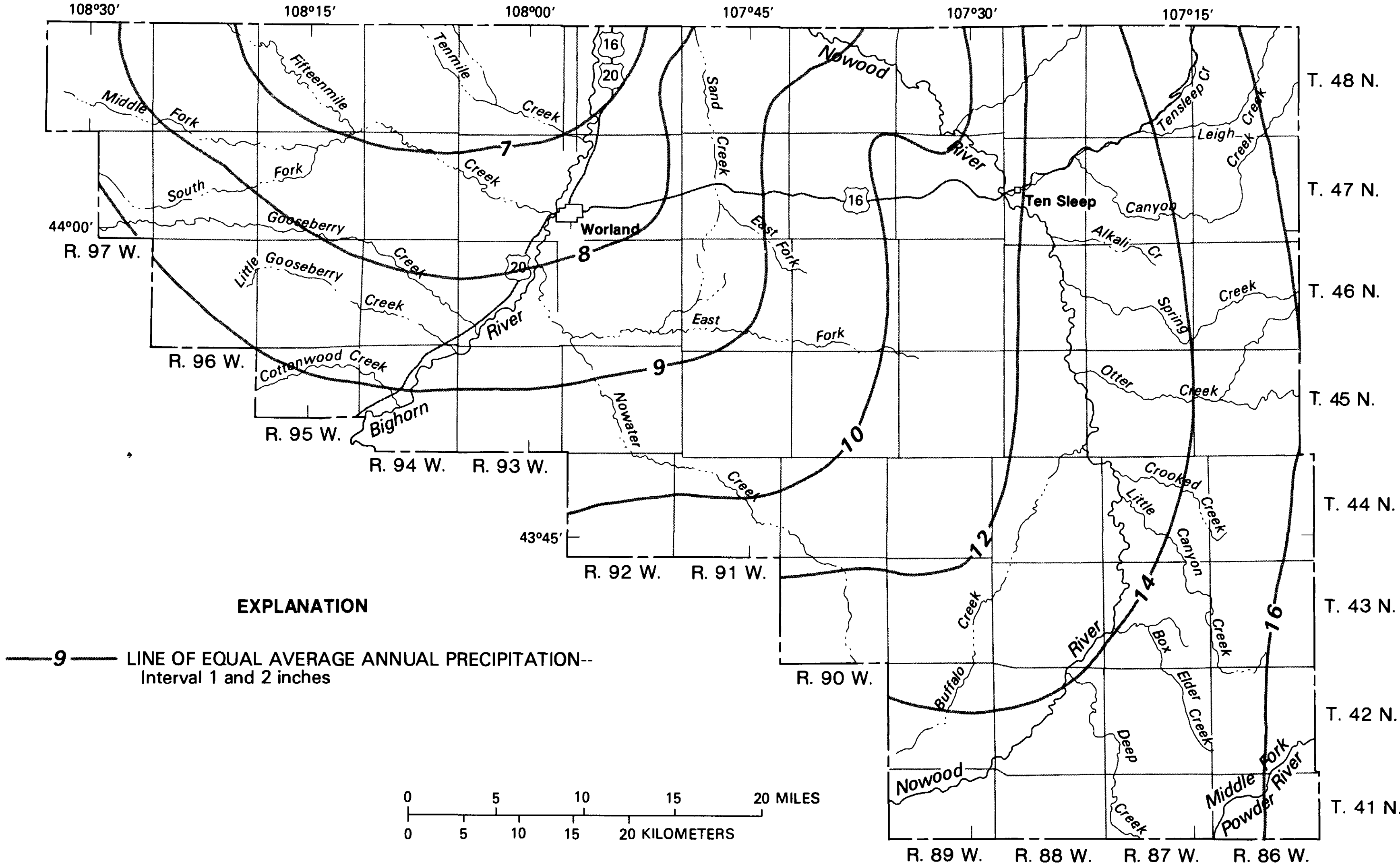


Figure 3.--Average annual precipitation through 1980 (from Lowham, 1988).

Bedrock in Washakie County consists of rocks of Precambrian through Tertiary age (plate 1). Because the Bighorn Basin is a large synclinal basin, the oldest rocks are exposed in the Bighorn Mountains in the eastern part of Washakie County, and younger rocks crop out in the western and central parts of the county. Sedimentary rocks have been eroded completely from the summit of the Bighorn Mountains, exposing Precambrian rocks. In the western and central parts of the county, the total sedimentary rock sequence is as much as 15,000 ft thick (Blackstone and Huntoon, 1984, p. 3). Faults and folds are common along the western flank of the Bighorn Mountains. Anticlines along the mountain front have been extensively tapped for oil and gas and are important structural features that partially control ground-water flow in deeper aquifers (Blackstone and Huntoon, 1984, p. 2).

SURFACE WATER

The principal stream in Washakie County and the Bighorn Basin is the Bighorn River, which flows northward through the west-central part of the county. The Nowood River, a major tributary of the Bighorn River, flows northward along the western flank of the Bighorn Mountains, draining the eastern part of the county before joining the Bighorn River in Big Horn County (fig. 1). Gooseberry and Fifteenmile Creeks drain the western part of the county, and Nowater Creek drains the central part of the county east of the Bighorn River (fig. 4).

Streamflow is characterized statistically by flow duration, high flows, low flows, and average flows. Each streamflow characteristic provides important information for surface-water users and will be discussed in further detail in following sections.

Surface-Water Data Network

Data have been collected by the U.S. Geological Survey, in cooperation with State, municipal, county, and Federal agencies, on the surface-water resources of Washakie County since 1910. The data include gage height, discharge, and water quality.

Streamflow records at a surface-water station may be continuous or partial. A recorder is used to collect continuous record of stage. Continuous records can be used for computing the average discharge for the period of record, and, if the length of the record is adequate, the streamflow characteristics.

Partial records are obtained from discrete measurements and from continuous records that are collected on a less than annual basis. Partial discharge records are collected for specific purposes, such as peak discharge or seasonal flow information, and have limited applications.

The location of surface-water stations is shown in figure 4. Drainage area, type of data collected, period of record, and stream type for each station are listed in table 1. Three stations listed in table 1 were in operation during the 1988 water year.

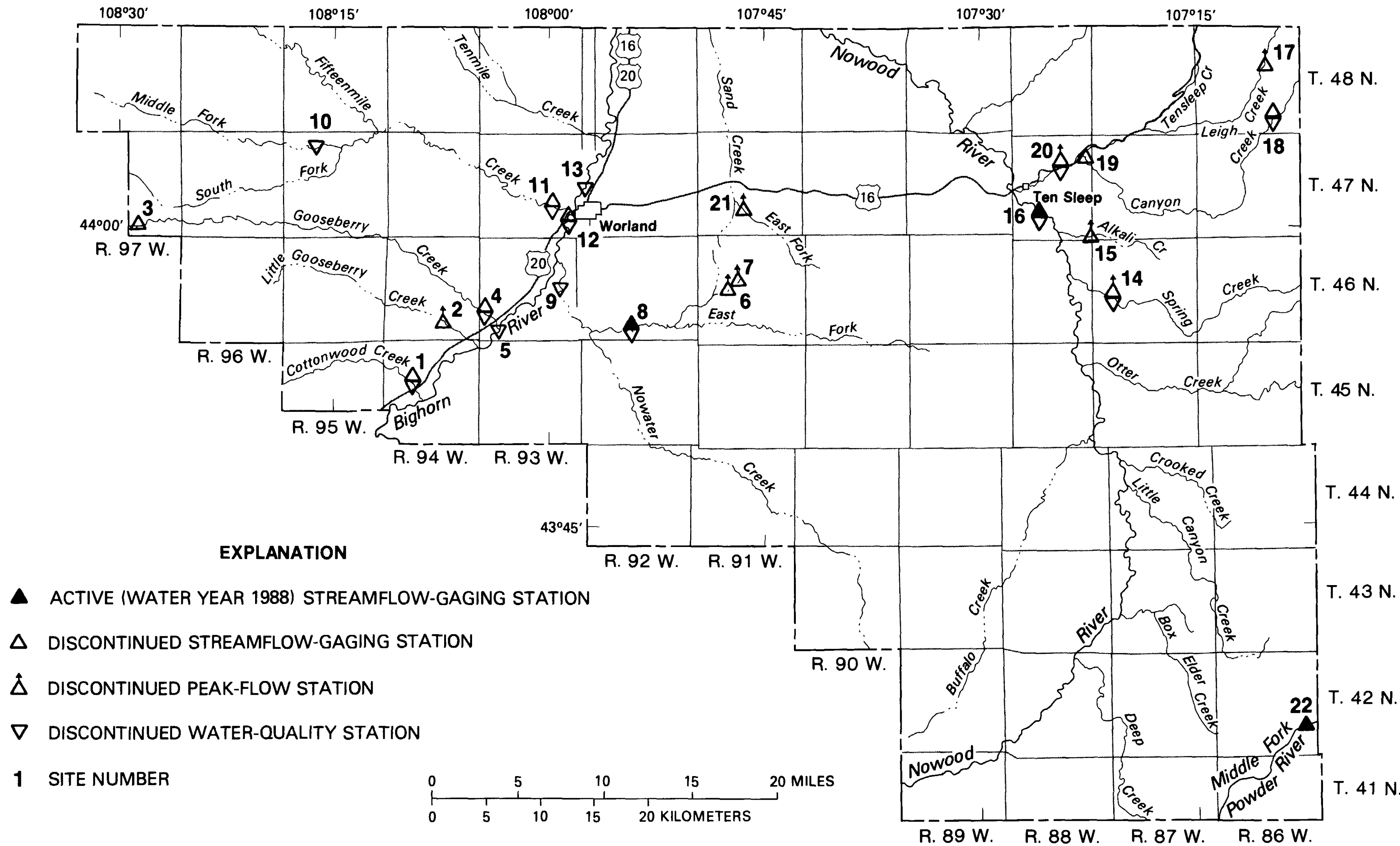


Figure 4.--Location of surface-water stations.

In addition to the data collected at continuous- and partial-record stations, nonrecurring data also are collected for special purposes at miscellaneous sites and may consist of only one measurement. Information on miscellaneous sites is published in water-data reports (U.S. Geological Survey, 1972-75; 1976-88).

The surface-water records described in table 1 are published by the U.S. Geological Survey (1972-75). The list of selected references in this report gives publication dates and document numbers of U.S. Geological Survey publications pertaining to surface-water resources in Washakie County.

Data collected by agencies other than U.S. Geological Survey also are available. The National Water Data Exchange (NAWDEX), U.S. Geological Survey, Reston, VA 22092, maintains an index of records of discharge collected by other agencies but not published by the Geological Survey. Information on records at specific sites can be obtained from that office.

Streamflow Characteristics

Streamflow characteristics can be illustrated and analyzed using hydrographs and statistical techniques. Hydrographs typically are used to show variations in streamflow, which are related to source of runoff (snowmelt, rainfall, or ground water). Flow-duration curves indicate the distribution of discharge at a continuous surface-water station for the period of record. High-flow data aid in the evaluation of floods and in the planning and design of structures. Low-flow data are used for estimating sources of base flow and are important to irrigators. Graphs or tables of average discharge illustrate the variability in discharge between streams.

Stream Types

Streams in Washakie County can be classified into three general types on the basis of when they flow. Perennial streams flow throughout the year. Intermittent (seasonal) streams only flow at certain times of the year in response to runoff from snowmelt and rainfall or inflow from springs. Ephemeral streams flow only in direct response to runoff from rainfall.

The stream type determined at the surface-water station on the basis of streamflow at the station (table 1) might not represent the total reach of the stream. The type of stream can differ along the stream; for example, a stream might be perennial in upstream reaches and intermittent or ephemeral in downstream reaches.

Streams originating in the mountains generally are perennial. Sustained streamflows result from greater precipitation, lower evapotranspiration, and greater water-storage capacity than streams in the arid to semiarid lowlands. Water is stored as ground water in aquifers and in near-permanent snowfields in the mountains and is released slowly, maintaining streamflows throughout the year. Examples of perennial streams are Nowood River near Ten Sleep (site 16) and Tensleep Creek near Ten Sleep (site 20).

Table 1.--Surface-water stations

[mi^2, square miles; --, no data]

Site number	Station number	Station name	Drainage area (mi^2)	Periods of record (water years): Discharge: Daily or monthly	Discharge: Annual peaks	Water quality: Chemical	Water quality: Sediment	Stream type
1	06265500	Cottonwood Creek at Winchester	416	1941-45 [1]1946-49	-- --	1947 1977-78	1948 1965-66 1977-78	Perennial
2	06265600	Tiedown Gulch near Worland	1.78	--	1961-84	--	--	Ephemeral
3	06266500	Gooseberry Creek near Dickie	303	1938-41	--	--	--	Perennial
4	06267000	Gooseberry Creek at Neiber	361	1941-44 1946-53	-- --	1951 --	1948 1950-53 1965-66	Perennial
5	06267050	Bighorn River at Neiber	[2]9,830	--	--	1965-69	--	Perennial
6	06267260	North Prong East Fork Nowater Creek near Worland	3.77	--	1964-84	--	--	Ephemeral
7	06267270	North Prong East Fork Nowater Creek tributary near Worland	2.11	--	1965-73	--	--	Ephemeral
8	06267400	East Fork Nowater Creek near Colter	149	[3]1972-88	--	1977-81	1977-81	Intermittent
9	06267420	Nowater Creek 4 miles south of Worland	--	--	--	--	1950-51	Intermittent
10	06267900	Middle Fork Fifteenmile Creek	--	--	--	1978-82	1978-82	Intermittent
11	06268500	Fifteenmile Creek near Worland	518	1951-72 1978-86	1973-78	1979-81	1949-72 1978-86	Intermittent
12	06268600	Bighorn River at Worland	10,810	1965-69	--	1965-86	1965-69	Perennial

Table 1.--Surface-water stations--Continued

Site number	Station number	Station name	Drainage area (mi^2)	Periods of record (water years): Discharge: Daily or monthly	Discharge: Annual peaks	Water quality: Chemical	Water quality: Sediment	Stream type
13	06268640	Slick Creek near Worland	--	--	--	1981-86	1950-51	Perennial
14	06269700	Spring Creek near Ten Sleep	57.9	--	1961-74	--	1967	Perennial
15	06269750	Nowood River tributary near Ten Sleep	.42	--	1960-81	--	--	Ephemeral
16	06270000	Nowood River near Ten Sleep	803	1938-43	--	1968-86	1950	Perennial
				1950-56	--	--	1972-82	
				[3]1973-88	--	--	--	
17	06270200	Leigh Creek near Ten Sleep	2.54	--	1961-74	--	--	Perennial
18	06270450	Canyon Creek below Cooks Canyon, near Ten Sleep	72	1969-71	--	1969-71	1969-71	Perennial
19	06270500	Canyon Creek near Ten Sleep	86.1	1939-44	--	--	--	Perennial
20	06271000	Tensleep Creek near Ten Sleep	247	1910-13	--	1967	--	Perennial
				1915-25	--	--	--	
				1944-72	--	--	--	
21	06274100	East Fork Sand Creek near Worland	19.1	--	1960-71	--	--	Intermittent
22	06309200	Middle Fork Powder River near Barnum	45.2	[3]1961-88	--	--	--	Perennial

1 Gage heights or gage heights and discharge measurements only.
2 Approximate area.
3 Currently in operation (water year 1988).

Perennial streams in the county can be altered by human activity. Dams, diversions, and land use can alter the duration of streamflow, and can change the magnitude of high, low, and average flows. For example, the Bighorn River at Worland (site 12), a perennial stream, is regulated for irrigation supply and flood control at Boysen Dam, 19 miles upstream from the county line. Regulated streamflow has a more constant average annual discharge, and the magnitude and number of high discharges are decreased. On small streams, diversions may cause the stream to cease flowing.

Most of the streams originating near the center of the county are intermittent or ephemeral and have long periods of no flow interrupted by flows with magnitudes and durations dependent on precipitation and the drainage-basin area. Maximum streamflows occur when snow melts during a winter or spring thaw, or as the result of runoff from thunderstorms. The East Fork Nowater Creek near Colter (site 8) and Fifteenmile Creek near Worland (site 11) are examples of intermittent streams (fig. 4).

The hydrographs in figure 5 show the differences in streamflow characteristics for the stream types in Washakie County. The 1967 water year was chosen because there were concurrent records at the three sites. The hydrograph of Tensleep Creek near Ten Sleep (site 20) illustrates the streamflow of a perennial mountain stream (fig. 5). In this case, the streamflow responds to individual rainfall events, but differs from the intermittent stream by having a longer period of snowmelt runoff and flow throughout the year. The hydrograph of the Bighorn River at Worland (site 12) (fig. 5), a regulated perennial stream, shows the natural effects of lowland snowmelt and rainfall runoff, and also shows streamflow variations attributed to reservoir regulation. Streamflow increases in mid-October when the irrigation season ends and as a result of fall storms. A comparison between streamflow and data for reservoir releases at Boysen Reservoir indicted that streamflow increases in early February and late March, and in mid-June to late July were caused by releases from Boysen Reservoir. Streamflow decreases in April were caused by streamflow diversions to upstream irrigation canals. The hydrograph of Fifteenmile Creek near Worland (site 11) shows extended periods of no flow. Streamflow occurs in sporadic pulses (fig. 5) as the result of snowmelt runoff or rainfall. This is characteristic of flow in intermittent streams.

Flow Duration

Streamflow distribution is dependent on the following basin characteristics: climate, physiography, geology, and water use. Basins where these conditions are similar may have similar streamflow distributions. The distribution of high flows is controlled largely by climate, physiography, and water use of the basin. The distribution of low flows is controlled mainly by basin geology. Streamflow distribution is the result of variability in precipitation as modified by the basin characteristics previously mentioned. The variability of streamflows is reduced by storage, either on the surface or in the ground (Searcy, 1959).

Flow-duration curves were developed for streams at selected streamflow-gaging stations to illustrate the variability of streamflow in Washakie County (fig. 6). The flow-duration curve is a cumulative frequency curve of daily mean discharges that shows the percentage of time specified discharges were equaled or exceeded. This curve does not account for the chronological sequence of hydrologic events, but combines the flow characteristics of a

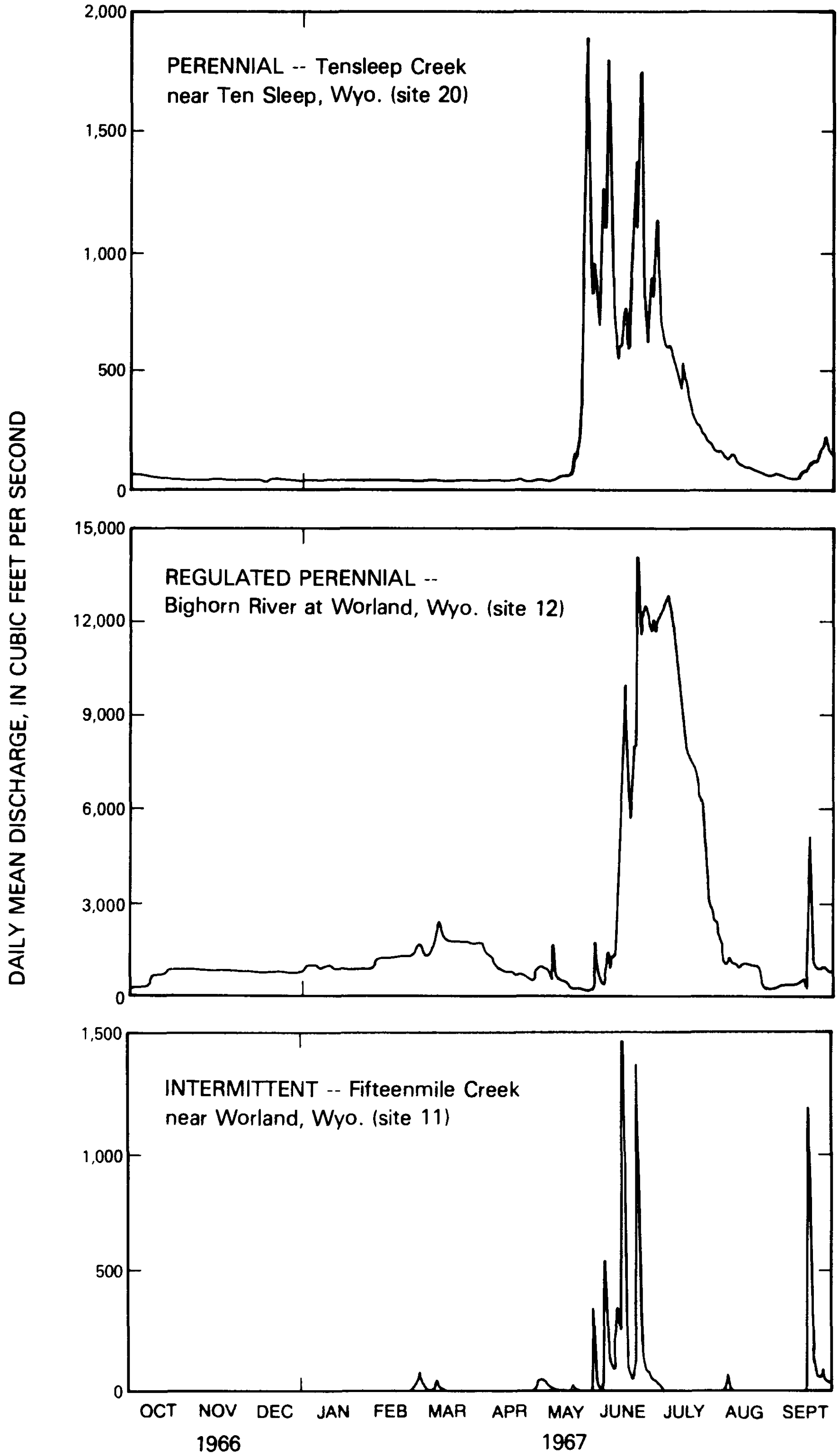


Figure 5.--Daily mean discharge for selected perennial, regulated perennial, and intermittent streams, water year 1967.

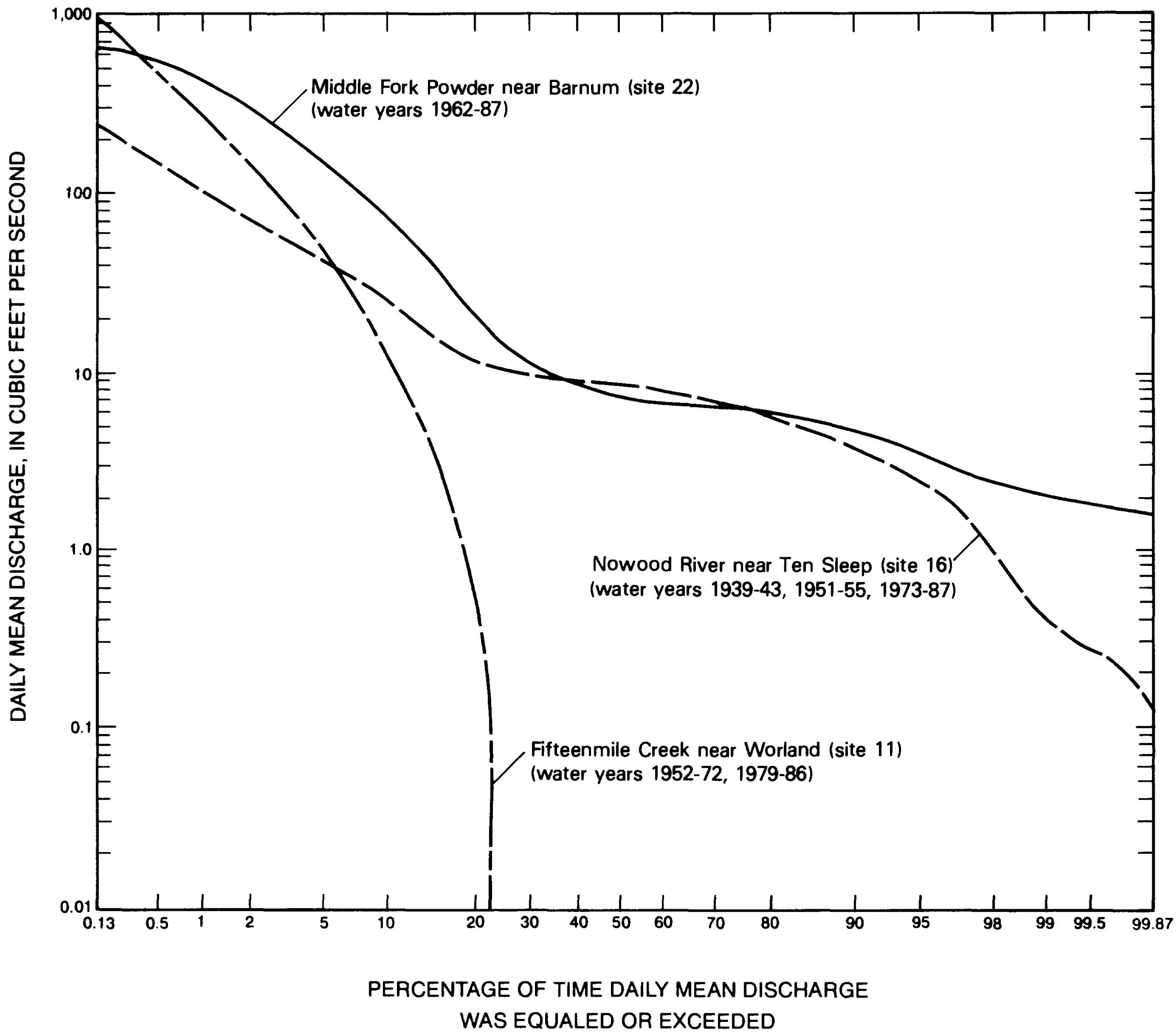


Figure 6.--Flow-duration curves for selected surface-water stations. Period of record for each curve is indicated in water years. Sites 16 and 22 are perennial streams; site 11 is an intermittent stream.

stream throughout its range of discharge. The method outlined by Searcy (1959) was used to develop the flow-duration curves. The flow-duration curve applies only to the period of record for which it was developed. However, it may be considered a probability curve, and used for estimates of other periods if streamflow, during the period on which the curve is based, represents the long-term flow of the stream. Streamflow data for complete years of record are used for the flow-duration curves; although the years need not be consecutive, the records used represent periods when human influences such as reservoir storage and irrigation diversions have been constant.

Hydrologic and geologic characteristics of a drainage basin are the major factors that determine the shape of the flow-duration curve. The flow-duration curves in figure 6 were plotted to show differences between streamflow characteristics. The flow-duration curves for the perennial Middle Fork Powder River near Barnum (site 22) and Nowood River near Ten Sleep (site 16) have moderate slopes at high flows. This can be attributed to high flows from snowmelt. The flatter slope in the middle flow range (8-12 ft^3/s) of the flow-duration curve for these sites indicates that there is storage in the basin, probably in seasonal snowpack and alluvial aquifers. The subsequent steeper slope at the low flows of the flow-duration curve for the Nowood River near Ten Sleep indicates that alluvial aquifers or snowfields have been depleted. Very steep slopes indicate highly variable streamflows dependent on direct runoff, as shown by the curve for the intermittent Fifteenmile Creek near Worland (site 11). The flow-duration curve for an ephemeral stream would be similar to that shown for Fifteenmile Creek.

High Flows

High-flow characteristics of streams vary with stream type. Perennial streams generally have a period of high flow in May and June as snowpacks melt. Diurnal fluctuations in flow are typical during snowmelt periods with successive daily flows increasing as daylight hours lengthen and temperatures warm. This pattern, if uninterrupted by changing weather conditions, will continue until peak flows occur. However, weather conditions have a substantial effect on snowmelt runoff, making it difficult to predict peak flows.

High flows in regulated streams or streams with diversions are affected by a variety of factors. Maximum flows may be the result of snowmelt runoff, rainfall runoff, reservoir releases, or a combination of these factors. Diversions can reduce flows during the irrigation season, thereby reducing peak discharges.

High flows in intermittent streams are the result of lowland runoff during a winter or spring thaw or from summer thunderstorms; high flows in ephemeral streams are the result of runoff from only rainfall. Snowmelt runoff usually is smaller in magnitude and longer in duration than rainfall runoff. Runoff from intense thunderstorms can have extremely large magnitudes and be of short duration. Magnitudes and durations of storm runoff depend on drainage-basin characteristics and on the distribution of precipitation. Peak flows in most intermittent or ephemeral streams are reached quickly from rainfall runoff, and are followed by an equally rapid recession from the peak stages with gradual return to no flow.

A clarification of terminology is necessary in describing high-flow characteristics. The term "flood" has many definitions that generally refer to magnitude of flow and commonly is synonymous with "high," "extreme," or "peak" flow. A distinction should be made between flood as a discharge, and flood as a stage or depth of water. A common occurrence on larger low-gradient streams, in climates similar to that of Washakie County, is the accumulation of slush and anchor ice during periods of severe winter temperatures. Ice jams accumulating in channel constrictions can obstruct natural flow and often cause flood stage to be reached upstream from the ice jams even though discharge is small. Winter floods can be more devastating than their summer counterparts because they carry the potential for severe damage from ice and usually occur with below zero temperatures. Backwater from ice has caused flood stages to be reached in recent years along the Bighorn River at Worland (site 12).

The peak discharges recorded at surface-water stations in Washakie County are listed in table 2. The table also lists drainage area upstream from the station and period of record. For stations currently in operation (water year 1988), the peak discharge included in the table is based on records in publication (U.S. Geological Survey, 1976-88), which are complete through water year 1987, ending September 30, 1987.

Flood or high-flow statistics can be developed using streamflow data (indexed in table 2) for daily mean discharge. Individual annual maximum discharges are needed for flood-frequency studies. These values are available in the records, but no statistical data on floods are included in this report. The interested reader is referred to Lowham (1988) and Peterson (1988).

Low flows

Low-flow characteristics of streams in Washakie County differ with stream type. The hydrographs in figure 5 illustrate the differences in low flow between stream types. Low flows in perennial streams occur in the winter months (fig. 5) and are predominantly from ground-water discharge. Low flows in regulated perennial streams are a function of reservoir releases and diversions. Intermittent and ephemeral streams have extended periods of no flow.

The frequency of occurrence and magnitude of low flows in perennial and some intermittent streams is a useful statistic for water-resources planning. The frequency and magnitude of low flows usually are compiled as 7-day low-flow statistics (table 3) and show the 7-day daily mean discharges and the corresponding recurrence intervals. For example, Nowood River near Ten Sleep (site 16) will have 7 consecutive days with daily mean discharge of 15.6 ft^3/s or less once in 2 years, on the average, and 7 consecutive days with daily mean discharge of 3.52 ft^3/s or less once in 10 years, on the average. There is a 50-percent chance that the 2-year, 7-day low flow will occur in any given year, and a 10-percent chance that the 10-year, 7-day low flow will occur in any given year.

Table 2.--Peak discharge of record and average discharge at selected surface-water stations, through water year 1988

[mi^2, square miles; ft^3/s, cubic feet per second; --, no data]

Site number	Station name	Drainage area (mi^2)	Period of record (water years): Daily or monthly discharge	Period of record (water years): Annual peak discharge	Peak discharge: Date	Peak discharge: Discharge (ft^3/s)	Average discharge (ft^3/s)	Stream type
1	Cottonwood Creek at Winchester	416	1941-45	--	07-27-41	4,120	28.5	Perennial
			[1]1946-49	--	--	--	--	
2	Tiedown Gulch near Worland	1.78	--	1961-84	08-10-83	420	--	Ephemeral
4	Gooseberry Creek at Neiber	361	1941-44	--	05-18-44	1,650	12.5	Perennial
			1946-53	--	--	--	--	
6	North Prong East Fork Nowater Creek near Worland	3.77	--	1964-84	09-18-67	394	--	Ephemeral
7	North Prong East Fork Nowater Creek tributary near Worland	2.11	--	1965-73	06-06-67	158	--	Ephemeral
8	East Fork Nowater Creek near Colter	149	[3]1972-88	--	[2]05-18-78	3,040	4.51	Intermittent
11	Fifteenmile Creek near Worland	518	1951-72	1973-78	05-18-78	4,270	9.92	Intermittent
			1978-86	--	--	--	--	
12	Bighorn River at Worland	10,810	1965-69	--	06-23-67	15,900	--	Perennial
14	Spring Creek near Ten Sleep	57.9	--	1961-74	06-16-65	265	--	Perennial
15	Nowood River tributary near Ten Sleep	.42	--	1960-81	08-17-60	126	--	Ephemeral

Table 2.--Peak discharge of record and average discharge at selected surface-water stations --Continued

Site number	Station name	Drainage area (mi^2)	Period of record (water years): Daily or monthly discharge	Period of record (water years): Annual peak discharge	Peak discharge: Date	Peak discharge: Discharge (ft^3/s)	Average discharge (ft^3/s)	Stream type
16	Nowood River near Ten Sleep	803	1938-43	--	[2]05-19-78	3,380	116	Perennial
			1950-56	--	--	--	--	
			[3]1973-88	--	--	--	--	
17	Leigh Creek near Ten Sleep	2.54	--	1961-74	06-25-65	250	--	Perennial
18	Canyon Creek below Cooks Canyon, near Ten Sleep	72	1969-71	--	05-19-70	478	--	Perennial
19	Canyon Creek near Ten Sleep	86.1	1939-44	--	05-18-44	248	32.1	Perennial
20	Tensleep Creek near Ten Sleep	247	1910-13	--	06-15-24	2,890	146	Perennial
			1915-25	--	--	--	--	
			1944-72	--	--	--	--	
21	East Fork Sand Creek near Worland	19.1	--	1960-71	09-08-63	5,500	--	Intermittent
22	Middle Fork Powder River near Barnum	45.2	[3]1961-88	--	[2]06-15-63	7,110	70.8	Perennial

[1] Gage heights or gage heights and discharge measurements only.
[2] Based on records through Sept. 30, 1987.
[3] Currently in operation (water year 1988).

Table 3.--Seven-day low-flow statistics for selected surface-water stations

Site number	Station name	Drainage area (square miles)	Length of record (years)	Seven-day low flow, in cubic feet per second, for indicated recurrence intervals (years)							
				1.01	1.25	2	5	10	20	50	100
12	Bighorn River at Worland	10,810	4	506	186	126	95.4	85.9	80.2	75.5	73.2
16	Nowood River near Ten Sleep	803	25	56.7	29.8	15.6	6.31	3.52	2.04	1.04	0.63
20	Tensleep Creek near Ten Sleep	247	40	57.8	42.8	37.2	33.0	31.2	29.9	28.6	27.8
22	Middle Fork Powder River near Barnum	45.2	26	6.43	5.08	3.93	2.71	2.13	1.69	1.27	1.03

Average Discharge

Average discharge is the arithmetic average of the annual mean discharges for a stream for the period of record and can be used to compare differences in flow between streams. The average annual discharges for eight streams are given in table 2. Peterson (1988, p. 110-119) tabulated average discharges for each month (mean monthly discharge) at sites 4, 8, 11, 16, and 20. Average discharge usually is not computed for reservoir-regulated streams because the average discharge is dependent on reservoir releases and does not reflect normal streamflows.

The average discharge of perennial streams depends on the physical characteristics of the drainage basins (area, altitude, aspect) and climatic factors such as precipitation, temperature, wind, evaporation, and solar radiation. The average discharge of intermittent streams is dependent on amount and intensity of precipitation, drainage area, evapotranspiration, permeability of the surface material, and ground-water discharge. Because ephemeral streams are dry most of the time, average annual discharge and mean monthly discharges are not useful flow characteristics for such streams.

GROUND WATER

Ground water in geologic units in Washakie County is under water-table (unconfined) or artesian (confined) conditions. The quantity and quality of water differs within and between geologic units and is related to the lithology and the physical and geochemical properties of the rocks. The porosity, a measure of the void space in a rock, and the permeability, a measure of the ability of a porous medium to transmit fluids, affect the ability of a geologic unit to store water and to yield water to wells.

Ground Water as Related to Geology

The lithology and water-yielding characteristics of geologic units in Washakie County are summarized in table 4, and the distribution of these geologic units is shown on plate 1. Included in table 4 are ranges of thicknesses and reported yields. Reported well yields do not necessarily reflect potential yields from an aquifer. Well yields are a function of the diameter of the hole, pump capacity and efficiency, saturated interval penetrated, and the permeability of that interval.

The following geologic units, in descending order, are the principal aquifers in the county: alluvium of Quaternary age, Willwood Formation of Tertiary age, Fort Union Formation of Tertiary age, and the formations of primarily Paleozoic age--Goose Egg Formation, Tensleep Sandstone, Madison Limestone, Bighorn Dolomite, and Flathead Sandstone (table 4). Many geologic units in table 4 are used infrequently as sources of ground water in Washakie County or are used only for stock water in remote areas of the county. The lithology and the water-yielding characteristics of these infrequently used units are listed in table 4. The principal aquifers, listed above, are discussed in more detail in this section. Records of selected wells and springs completed in various geologic units are listed in table 5 and the location of the selected wells and springs are shown on plate 2.

Table 4.--Summary of lithology and water-yielding characteristics of geologic units (modified from Lowry and others, 1976)

[ft, feet; gal/min, gallons per minute; mg/L, milligrams per liter; --, no data]

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Cenozoic	Quaternary	Order does not indicate age	Alluvium	Unconsolidated clay, silt, sand, gravel, and cobbles. Deposits associated with mountain streams generally coarser.	May yield large quantities of water to wells; permeability dependent upon sorting and size of grains and clasts.	0-80	10-40
Cenozoic	Quaternary	Order does not indicate age	Gravel, pediment, and fan deposits	Unconsolidated clay, silt, sand, gravel, cobbles, and boulders. Well sorted to poorly sorted, stratified to unstratified, may be mantled with slope wash where adjacent topography is steep.	May yield large quantities of water to wells when recharge is predominantly from diverted surface water and irrigation-return flows.	0-100	5-25
Cenozoic	Quaternary	Order does not indicate age	Glacial deposits	Unconsolidated deposits of poorly sorted silt, clay, sand, gravel, and boulders. Lithology variable depending upon geologic source. Deposits limited to mountainous areas.	Generally a perched aquifer with springs near base or edges of deposits. Yields dependent upon saturated thickness.	--	--
Cenozoic	Tertiary	Oligocene	White River Formation	Sand, volcanic ash, gravel, and boulders. Occurs as erosional remnants in the Bighorn Mountains.	Not known to yield water to wells.	--	--

Table 4.--Summary of lithology and water-yielding characteristics of geologic units--Continued

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Cenozoic	Tertiary	Eocene	Wagon Bed Formation	Interbedded green and gray tuffaceous claystone, sandstone, and conglomerate with some uranium-phosphate marlstone and variegated bentonitic claystone.	Not known to yield water to wells.	--	--
Cenozoic	Tertiary	Eocene	Tatman Formation	Interbedded claystone, shale mudstone, marl, sandstone, and minor coal. Marly brown kerogenic shale common (Rohrer and Smith, 1969).	Not known to yield water to wells.	50-980	--
Cenozoic	Tertiary	Eocene	Willwood Formation	Variegated, interbedded claystone, mudstone, and discontinuous channel sandstones. Sandstone locally conglomeratic. Averages 25 percent sandstone.	Widely developed in center of basin. Yields usually from discontinuous sandstones. The depth of drilling required for desired yields will vary substantially. Greater yields reported in Bighorn County.	As much as 2,500 in western part of county	1-28
Cenozoic	Tertiary	Paleocene	Fort Union Formation	Interbedded sandstone, siltstone, claystone, carbonaceous shale, and thin coal. Crossbedding and channel sandstones common but highly discontinuous (Moore, 1961; Jepsen and Van Houten, 1947, p. 142-149).	May yield enough water from discontinuous sandstones for domestic or stock use. Depth of drilling for penetrating sufficient thickness of sandstone for desired yields differs from place to place.	1,000-8,000 Thickens toward western part of county	4-10

Table 4.--Summary of lithology and water-yielding characteristics of geologic units--Continued

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Mesozoic	Cretaceous	Upper Cretaceous	Lance Formation	Light-yellowish-brown, poorly indurated concretionary sandstone interbedded with claystone, shale, and thin beds of carbonaceous shale. Massive sandstone near base (Downs, 1952).	Yields usually from discontinuous sandstones.	50-950 Thickens to west	6-15
Mesozoic	Cretaceous	Upper Cretaceous	Meeteetse Formation	Interbedded discontinuous claystone, shale, and siltstone. Shaly lenticular coals and poorly indurated sandstones (Downs, 1952).	May yield enough water from thin sandstones for domestic and stock use. Yields dependent upon number of sandstones open to the well.	450-1,000 Thickens to northwest	--
Mesozoic	Cretaceous	Upper Cretaceous	Mesaverde Formation	Massive cross-bedded sandstones, thin-bedded sandstones, sandy shales and coals. Most prominant coals occur above lowermost sandstone (Stevern, 1961).	May yield enough water from sandstones for domestic or stock use. Yields dependent upon number of sandstones open to the well.	650-1,300 Thickens to west	--
Mesozoic	Cretaceous	Upper Cretaceous	Cody Shale	Predominantly black shale, shaly sandstone (upper part), calcareous shale, and thin beds of bentonite.	Thin sandstones locally may yield small quantities of water.	2,600-3,000 Thickens to west	--

Table 4.--Summary of lithology and water-yielding characteristics of geologic units--Continued

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Mesozoic	Cretaceous	Upper Cretaceous	Frontier Formation	Conglomeratic sandstone, sandstone, siltstone, and some bentonitic and carbonaceous shales. Sandstones are lenticular and thinly bedded. Percentage of sandstones decreases from southwest to northeast (Van Houten, 1962; Merewether and others, 1975).	Sandstones may yield sufficient quantities of water for domestic or stock use.	600-800 Thickens to east	8-29
Mesozoic	Cretaceous	Lower Cretaceous	Mowry Shale	Black siliceous resistant shale with thin sandstones and bentonite near top. Fish scales are common.	Siliceous shales generally brittle and may yield water to wells through fractures.	300-500	--
Mesozoic	Cretaceous	Lower Cretaceous	Thermopolis Shale	Black soft shale. Muddy Sandstone Member ranges from 40 to 80 ft thick; occurs 150 to 200 ft above the base and thins to north (Downs, 1952; Paull, 1962).	Shales are relatively impermeable. Wells developed in Muddy Sandstone Member may yield enough water for domestic or stock use, and are the most dependable source of water in a thick shale section.	400-600	20
Mesozoic	Cretaceous	Lower Cretaceous	Cloverly Formation	Variegated bentonitic mudstone with local conglomerates in lower part. Middle is shaly with lenticular sandstones. Upper part is limonitic silty sandstone interbedded with black shales (Moberly, 1962).	Sandstones may yield sufficient quantities of water for domestic or stock use.	85-400 Thins to south	4

Table 4.--Summary of lithology and water-yielding characteristics of geologic units--Continued

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Mesozoic	Jurassic	Upper Jurassic	Morrison Formation	Variegated mudstone, claystone, silty sandstone, and lenticular freshwater limestones.	Sandstones may yield enough water for domestic and stock use.	175-280 Thickens to west	--
Mesozoic	Jurassic	Middle Jurassic	Sundance Formation	Greenish-gray, glauconitic, calcareous sandstone, siltstone, shale, and limestone.	Sandstones may yield enough water for stock and domestic use.	215-320	--
Mesozoic	Jurassic	Middle Jurassic	Gypsum Spring Formation	Reddish-brown claystone and siltstone with thin limestones and massive gypsum beds in lower part.	Solution cavities in gypsum may yield large quantities of water to wells.	100-230	--
Mesozoic	Triassic	Upper and Lower Triassic	Chugwater Formation	Very fine-grained red sandstones, siltstones, shales, and thin limestone (Alcova Limestone Member).	May yield sufficient quantities of water to wells for domestic and stock use.	700-800 Thins to north	11
Paleozoic	Triassic and Permian	Lower Triassic and Upper and Lower Permian	Goose Egg Formation	Upper 15-100 ft consists of tan and red siltstones, shales, and gypsum. Cherty limestone in upper part and red siltstone, gypsum, shales, and dolomitic limestone in lower part (Mills, 1956; Peterson, 1984). Phosphoria Formation is equivalent to the Goose Egg Formation.	May yield water to wells from solution cavities in gypsum. Can be confining unit for underlying Tensleep Sandstone depending upon the presence of shales in lower part.	160-300	5-50

Table 4.--Summary of lithology and water-yielding characteristics of geologic units--Continued

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Paleozoic	Pennsylvanian	Upper and Middle Pennsylvanian	Tensleep Sandstone	White and tan massive, cross-bedded sandstone with cherty dolomite in upper part. Lower part is interbedded sandstone, limestone, dolomite, and shales (Zapp, 1956; Moore, 1984).	Flowing wells along the western flank of the Bighorn mountains yield large dependable supplies of water.	130-400 Thickens to south	1-250
Paleozoic	Pennsylvanian and Mississippian	Middle and Lower Pennsylvanian and Upper Mississippian	Amsden Formation	Upper part cherty limestone, lower part red and green shales with Darwin Sandstone Member present locally.	Lower sandstone may yield enough water for domestic or stock use.	140-300	--
Paleozoic	Mississippian	Lower Mississippian	Madison Limestone	Blue-gray massive limestone and dolomite with chert nodules. Upper half generally thick bedded and contains solution features.	Flowing wells along Bighorn Mountain front yield large dependable supplies of water. Unit in hydraulic connection with underlying Bighorn Dolomite forming the Madison-Bighorn aquifer. Yield of 14,000 gal/min reported from well completed in Madison-Bighorn aquifer in Big Horn County.	500-800 Thickens to northwest	15-2,500
Paleozoic	Mississippian	Upper Devonian	Darby Formation	Present in subsurface only in northwestern corner.	Considered part of the Madison-Bighorn aquifer.	--	--

Table 4.--Summary of lithology and water-yielding characteristics of geologic units--Continued

Erathem	System	Series	Geologic unit	Lithology	Water-yielding characteristics	Approximate thickness (ft)	Reported yield (gal/min)
Paleozoic	Ordovician	Upper Ordovician	Bighorn Dolomite	Gray massive dolomite and dolomitic limestone. Thin shales present near base. Solution features visible in outcrops.	In hydraulic connection with Madison Limestone yields large dependable supplies of water.	325-425	15-2,500
Paleozoic	Cambrian	Upper Cambrian	Gallatin Limestone	Gray-green glauconitic calcareous shale and flat-pebble conglomerate. Massive limestone near base in some areas.	Not known to yield water to wells.	400-600	--
Paleozoic	Cambrian	Upper and Middle Cambrian	Gros Ventre Formation	Green-gray glauconitic limestone and sandy limestone with interbedded grayish green shale and infrequent limey sandstones (Mills, 1956).	Not known to yield water to wells.	400-500	--
Paleozoic	Cambrian	Middle Cambrian	Flathead Sandstone	Tan and pink coarse arkosic sandstone with interbedded shale in upper part (Mills, 1956).	Flowing wells in eastern part of county yield large dependable supplies of water under great artesian pressures.	100-200 Thickens to south	500-2,300
Precambrian			Igneous and metamorphic rocks	Tan and pink granite gneiss and metasedimentary rocks.	May yield small quantity of water from fractures or weathered zone at the top of the unit.	--	--

Table 5.--Records of selected wells and springs

[Primary water-yielding unit: Qa, alluvium; Qt, gravel, pediment, and fan deposits; Twl, Willwood Formation; Tfu, Fort Union Formation; Kl, Lance Formation; Kmv, Mesaverde Formation; Kf, Frontier Formation; Km, Mowry Shale; Ktm, Muddy Sandstone Member of the Thermopolis Shale; Kcv, Cloverly Formation; Jg, Gypsum Spring Formation; TRc, Chugwater Formation; TRPg, Goose Egg Formation; IPt, Tensleep Sandstone; Mm, Madison Limestone; Ꞓf, Flathead Sandstone. Use of Water: D, domestic; I, irrigation; N, industrial; P, public supply; Q, aquiculture; S, stock; T, institutional; U, unused. Altitude of land surface, in feet above sea level. Hydraulic head: Calculated by multiplying the wellhead pressure in pounds per square inch times 2.31. ft, feet; gal/min, gallons per minute; NA, not applicable; --, no data]

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Water level below or hydraulic head above (+) land surface	Date	Discharge Gal/min	Discharge Date
41-089-09ad01	NA	Spring	Jg	I	5,980	NA	NA	--	--
42-088-03adc01	1968	400	IPt	D	5,100	--	--	5.0	--
42-088-21bbd01	1952	590	IPt	D	5,363	--	--	1.0	08-19-52
42-088-21bcb01	1965	595	IPt	S	5,410	--	--	20	--
42-088-30ad01	NA	Spring	TRPg	--	5,440	NA	NA	--	--
42-088-31bcc01	1942	397	IPt	D	5,720	105	01-07-75	--	--
43-087-11bdb01	--	443	IPt	D	5,320	+13.9	11-12-53	17	--
43-087-20ccc01	1943	--	IPt	D	4,960	+143	11-12-53	--	--
						+155	05-14-62	--	--
43-087-20ccc02	--	740	IPt	D	4,950	+115	05-02-89	20	09-28-87
43-087-21bcb01	1950	500	IPt	U	5,050	+58	10-07-75	--	--
						+59	05-04-76	--	--
43-087-21bcb02	1987	490	IPt	D	5,050	+80	05-02-89	35	--
43-089-23add01	1941	215	Kcv	S	5,050	--	--	4.0	--
43-089-31baa01	--	1,290	Kf	--	5,465	15.98	07-20-70	--	--
						72.9	07-14-88	--	--
43-090-06baa01	--	4,005	Ktm	S	4,700	--	--	20	--
43-090-25dab01	1961	2,900	Kf	S	5,300	--	--	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Water level below or hydraulic head above (+) land surface	Date	Discharge Gal/min	Discharge Date
44-087-08dcd01	1974	--	ℙt	I	4,830	+164	05-13-76	--	--
						+160	04-26-77	--	--
						+167	05-15-78	--	--
44-087-08ddc01	1952	1,040	Mm	I	4,795	+166	11-11-53	462	1953
						+137.5	05-02-89	--	--
44-087-09bbc01	1961	1,820	Mm	S	4,860	+266	05-09-62	260	1962
44-087-17dad01	1976	--	Mm	I	4,790	--	--	--	--
44-087-17ddc01	1942	575	ℙt	D	4,810	+58.0	11-12-53	--	--
						+55	05-06-75	250	1942
						+56	05-04-76	--	--
						+49.6	04-26-77	--	--
						+51.9	05-15-78	--	--
						+49.7	05-02-89	--	--
44-087-21dbb01	NA	Spring	℞c	--	4,875	NA	NA	--	--
						13.52	07-21-70	--	--
44-088-06abc01	1966	66	Kmv	S	4,738	8.31	10-27-87	--	--
						8.25	07-18-88	--	--
44-088-24dc01	--	200	Kf	U	4,955	11.38	07-23-80	--	--
44-088-35cab01	1966	2,030	Kf	--	5,000	+1	07-21-70	--	--
44-089-10dc01	1975	340	Kf	S	4,880	68.89	06-23-80	--	--
						63.53	10-27-87	--	--
44-089-21ddb01	--	68	Kl	U	4,905	49.97	10-28-87	--	--
						49	07-30-70	--	--
44-089-23bbb01	1955	200	Kmv	S	4,875	48.47	07-23-80	--	--
						48.47	07-30-87	--	--
44-090-27ada01	--	218	Kl	U	4,910	151.49	10-28-87	--	--
44-090-29abd01	1942	152	Kmv	S	4,665	80.00	08-04-42	--	--
44-091-35add01	1959	4,197	Ktm	S	4,710	--	--	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Water level below or hydraulic head above (+) land surface	Date	Discharge Gal/min	Discharge Date
44-092-07dba01	1956	261	Kmv	S	4,540	110.6	06-29-88	--	--
45-087-07add01	--	20	Qa	D	4,645	--	--	--	--
45-088-04cca01	1954	530	Kf	--	4,880	148.50	08-01-70	--	--
45-090-09aac01	1968	250	Tfu	S	4,560	9.92	09-20-68	--	--
45-091-09bad01	1945	220	Twl	S	4,440	41.97	07-28-80	6.0	--
45-091-21aad01	1941	225	Tfu	S	4,520	146.00	10-15-41	10	--
45-091-25bad01	1945	280	Twl	--	4,580	+51.37	07-23-80	--	--
45-091-30bbb01	--	604	Tfu	U	4,585	330	06-29-88	--	--
45-092-13aad01	1945	600	--	--	4,450	156.96	06-25-80	--	--
45-092-19bad01	1946	620	Tfu	S	4,450	178.00	12-01-70	--	--
45-093-14dca01	--	630	Tfu	S	4,560	220.00	06-01-66	--	--
45-094-11bca01	1978	48	Qa	S	4,180	18.51	05-12-87	--	--
45-094-17ac01	1965	21	Qa	S	4,230	14.57	06-27-88	--	--
45-094-20aab01	1981	95	Tfu	D	4,215	11.87	05-12-87	--	--
45-094-21abc01	1985	80	Tfu	D	4,185	7.42	05-02-85	--	--
45-095-08cb01	--	165	Tfu	D	4,530	45	06-28-88	--	--
45-095-09bdb01	1978	100	Tfu	D	4,490	22.8	06-28-88	--	--
46-087-10acb01	--	1,410	Mm	I	5,100	+393	05-09-62	450	10-14-58
46-087-21acd01	1953	1,100	IPt	S	4,790	+176	05-22-75	9.7	1953
						+150.2	05-04-89	--	--
46-088-14aac01	--	40	Qa	--	4,460	--	--	--	--
46-088-24bbc01	--	60	Km	--	4,990	--	--	--	--
46-090-20dda01	--	138	Twl	S	4,600	61.28	12-04-70	10	--
46-090-34ddd01	--	500	--	S	4,700	16.68	12-04-70	--	--
46-091-02dba01	1948	1,402	Kl	--	4,562	200	07-22-70	--	--
46-091-26abd01	1948	1,355	--	U	4,625	--	--	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Water level below or hydraulic head above (+) land surface	Date	Discharge Gal/min	Discharge Date
46-091-35bb 01	--	--	Tfu	S	4,330	--	--	--	--
46-092-06aa01	--	320	Twl	D	4,150	--	--	--	--
46-092-06ca01	--	320	Twl	D	4,140	--	--	--	--
46-092-06ccb01	1949	90	Twl	D	4,140	19.7	04-22-87	--	--
46-092-07bc01	1953	425	Twl	P	4,173	90.00	09-22-54	--	--
46-092-24dd01	1946	1,390	Twl	S	4,360	--	--	28	10-06-46
46-093-01cb01	--	70	Twl	S	4,160	--	--	--	--
46-093-03cca01	1981	100	Twl	D	4,160	28.97	04-22-87	--	--
46-093-03cdb01	1956	67	Twl	D	4,158	22.38	05-13-87	--	--
46-093-11aa01	--	90	Twl	--	4,260	--	--	--	--
46-093-11dbb01	1973	25	Qa	S	4,085	4.06	05-14-87	--	--
46-093-12dab01	1980	35	Qa	D	4,154	3.91	05-14-87	--	--
46-093-13ccb01	1981	18	Qt	S	4,160	9.91	05-13-87	--	--
46-093-15acb01	1982	40	Qa	D	4,110	9.94	05-16-87	--	--
46-093-15adc01	1969	287	Twl	S	4,100	--	--	3.0	--
46-093-15bcc01	--	385	Twl	T	4,126	--	--	23	11-10-71
46-093-15bdd01	--	65	Twl	T	4,124	12.5	04-24-85	25	04-24-85
46-093-15cab01	1975	300	Twl	D	4,115	--	--	8.2	07-14-75
46-093-15dda01	1979	35	Qa	D	4,153	19.14	05-13-87	--	--
46-093-15dda02	1978	100	Twl	D	4,153	19.79	05-13-87	--	--
46-093-27bbc01	1970	30	Qa	D	4,122	11.21	05-13-87	--	--
46-093-29dcb01	1980	25	Qa	D	4,122	6.38	05-15-87	--	--
46-093-30dba01	1973	205	Twl	D	4,170	103	06-28-88	--	--
46-094-06aab01	--	79	Twl	D	4,450	29.61	10-29-87	--	--
46-094-09acc01	--	80	Twl	U	4,375	15.84	10-29-87	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Water level below or hydraulic head above (+) land surface	Date	Discharge Gal/min	Discharge Date
46-094-09bdd01	1987	170	Twl	D	4,380	30	10-29-87	--	--
46-094-35db01	--	180	Tfu	D	4,222	--	--	--	--
46-095-15ab01	1958	190	Tfu	S	4,560	--	--	--	--
46-096-08caa01	1968	271	Tfu	--	5,185	232	07-08-77	--	--
						188.48	06-27-88	--	--
46-096-10bb01	1971	236	Tfu	S	5,000	160.74	08-06-79	--	--
						164	06-27-88	--	--
46-096-27cba01	--	380	Tfu	S	5,379	--	--	4.0	--
46-096-32bdc01	--	399	Tfu	S	5,154	--	--	--	--
47-087-06dab02	1951	20	Qa	--	4,967	16	06-28-51	25	--
47-087-28bbc01	--	--	₮Pg	D	4,980	--	--	--	--
47-087-33bdb01	1959	2,708	€f	I	4,980	+767	05-14-75	1,800	--
						+684.1	05-05-89	--	--
47-087-33bdb02	--	--	IPt	D	4,990	+89	05-14-75	--	--
						+89	05-04-76	--	--
						+52.0	05-05-89	--	--
47-088-01cda01	1965	1,070	Mm	Q	4,780	+12	05-06-66	700	05-15-75
47-088-01cdb01	NA	Spring	Mm	Q	4,745	NA	NA	--	--
47-088-01dbc01	NA	Spring	Mm	Q	4,780	NA	NA	--	--
47-088-02bc01	1943	176	IPt	S	4,865	--	--	--	--
47-088-02bcd01	1941	540	IPt	D	4,755	28	1968	--	--
47-088-05baa01	1970	1,680	Mm	I	4,470	+366	05-04-76	1,500	1966
47-088-08dab01	1970	2,960	€f	I	4,470	+457	05-14-74	--	--
						+457	05-03-76	--	--
						+437	04-27-77	--	--
						+403.3	05-05-89	--	--
47-088-10dbd01	1950	500	₮Pg	S	4,590	--	--	--	--
47-088-11cdb01	--	20	Qa	--	4,585	--	--	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Water level below or hydraulic head above (+) land surface	Date	Discharge Gal/min	Discharge Date
47-088-12bca01	1972	597	Mm	D	4,725	--	--	--	--
47-088-15cbc01	--	--	Qa	--	4,485	--	--	--	--
47-088-16aba01	1970	2,700	€f	I	4,550	+1,058	05-15-75	--	--
						+1,041	05-10-76	--	--
						+1,048	04-26-77	--	--
						+693.0	05-03-89	--	--
47-088-16cca01	1955	1,050	Mm	P	4,460	+194.1	07-24-85	--	--
						+196.4	08-21-85	--	--
						+203.4	05-12-86	--	--
						+201.1	05- -88	--	--
						+196.4	05- -89		
47-088-16cdb01	1953	--	₱Pg	S	4,436	--	--	--	--
47-088-16cdc01	--	238	₱Pg	U	4,420	--	--	--	--
47-088-16cdc02	1953	505	₱Pg	I	4,430	+55	05-06-70	--	--
						+54	05-07-75	--	--
						+51	05-04-76	--	--
						+51	05-11-76	--	--
						+49	04-26-77	--	--
						+51	05-15-78	--	--
						+37	05-06-89	--	--
47-088-16daa01	1969	260	₱Pg	I	4,420	+18.5	05-06-75	--	--
						+20	10-08-75	--	--
						+19	06-22-76	--	--
						+15.4	05-15-78	--	--
						+69.3	05-03-89	--	--
47-088-16dba01	1945	300	₱Pg	U	4,450	--	--	--	--
47-088-17dad01	1978	1,100	Mm	P	4,465	+296	09-01-78	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Static water level or hydraulic head: Feet above (+) or below land surface	Static water level or hydraulic head: Date	Discharge: Gal/min	Discharge: Date
47-088-21aba01	1969	280	₹Pg	D	4,460	--	--	5.0	--
47-089-01cac01	1957	755	ℙt	S	4,410	--	--	100	--
47-089-03aad01	--	20	Qa	--	4,310	--	--	--	--
47-089-03ba01	1976	340	₹c	D	4,505	180	- -76	--	--
47-089-06abd01	1958	2,835	Mm	S	4,673	+85.0	07-23-62	--	--
47-089-12bdc01	--	40	Qa	--	4,350	--	--	--	--
47-089-12db01	--	901	ℙt	I	4,360	+330.0	10-30-53	181	--
47-089-13aab01	1940	901	ℙt	D	4,405	+344	05-22-75	--	--
47-090-06cba01	1959	3,734	Kf	I	4,600	--	--	29	--
47-090-08dbc01	--	6,660	Mm	U	4,490	--	--	500	--
47-090-19bbb01	1941	195	Kl	S	4,650	63.77	05-30-80	15	--
47-090-23cab01	1963	1,945	Kf	U	4,518	222.28	09-20-80	--	--
47-092-05bbd01	1975	27	Qa	D	4,022	12.5	04-18-87	20	1975
47-092-08daa01	1985	81	Qt	D	4,084	25.96	04-21-87	5.0	04-20-85
47-092-09bcc01	--	--	Twl	D	4,080	--	--	--	--
47-092-17cdc01	--	40	Twl	D	4,080	--	--	--	--
47-092-17daa01	1979	25	Qa	D	4,096	8.24	04-18-87	10	05-08-79
47-092-18acc01	1984	120	Twl	D	4,037	27.84	04-21-87	3.0	10-25-84
47-092-18cbd01	1965	120	Twl	D	4,035	--	--	--	--
47-092-19dad01	1978	80	Twl	D	4,105	24.18	04-21-87	5.0	04-03-78
47-092-20bbc01	1985	40	Qt	D	4,095	9.85	05-15-87	--	--
47-092-24aac01	1968	110	Twl	S	4,550	--	--	--	--
47-092-26bab01	1978	272	Twl	D	4,310	180	05-06-78	10	05-06-78
47-092-28bbc01	1949	36	Qt	U	4,125	14.60	05-15-87	--	--
47-092-30aac01	1982	20	Qt	D	4,110	10.68	04-20-87	20	12-15-82

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Static water level or hydraulic head: Feet above (+) or below land surface	Static water level or hydraulic head: Date	Discharge: Gal/min	Discharge: Date
47-092-30ccc01	--	42	Qa	--	4,085	--	--	--	--
47-092-30ccc02	1977	60	Twl	D	4,085	19.53	04-20-87	--	--
47-092-30cdd01	--	268	Twl	D	4,085	--	--	--	--
47-092-30dbb01	1964	225	Twl	D	4,100	--	--	8.0	--
47-092-30dbc01	1958	87	Twl	D	4,100	--	--	--	--
47-092-30dc01	--	240	Twl	--	4,100	--	--	--	--
47-092-31aca01	1980	50	Qt	D	4,121	23.18	05-16-87	--	--
47-092.5-01cdd01	1984	40	Qt	S	4,080	12.84	05-16-87	25	01-15-84
47-092.5-12cac01	--	--	Twl	D	4,080	--	--	--	--
47-092.5-24aad01	1980	160	Twl	D	4,042	33.2	04-20-87	2.0	05-30-88
47-092.5-24aad02	1972	21	Qa	D	4,042	7.55	04-20-87	25	04-25-72
47-092.5-24ada01	--	90	Twl	D	4,045	--	--	--	--
47-092.5-24add01	1974	100	Twl	D	4,045	42	04-20-87	--	--
47-092.5-25aba01	--	20	Qa	I	4,058	--	--	--	--
47-092.5-25caa01	1973	20	Qa	D	4,058	9.96	04-23-87	--	--
47-093-24caa01	1974	35	Qt	U	4,095	23.04	05-16-87	--	--
47-093-24caa02	1969	35	Qt	D	4,095	--	--	--	--
47-093-25ddc01	1982	16	Qa	D	4,059	4.88	05-16-87	15	05-05-82
47-093-35dbc01	1981	160	Twl	S	4,102	18.54	05-14-87	--	--
47-093-35dbc02	1987	30	Qa	D	4,102	13.1	05-15-87	--	--
47-093-36d01	--	237	Twl	--	4,070	--	--	--	--
47-093-36dcb01	1985	14	Qa	D	4,070	4.39	05-17-87	12	05-20-85
47-094-04ddb01	--	25	Qa	U	4,240	7.2	05-24-88	--	--
47-095-09ccc01	1966	250	Twl	S	4,460	--	--	1.0	--
47-095-32bcb02	--	25	Qa	S	4,655	15.07	10-29-87	--	--

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Static water level or hydraulic head: Feet above (+) or below land surface	Static water level or hydraulic head: Date	Discharge: Gal/min	Discharge: Date
47-095-33bb01	--	44	Qa	S	4,630	--	--	--	--
47-096-26ddd01	1955	256	Twl	D	4,760	0	06-28-88	--	--
47-096-29ccc01	--	100	Qa	U	4,900	24.37	06-27-88	--	--
48-087-33ddb01	1985	45	Qa	P	5,360	27.12	05-03-89	--	--
48-088-28ccb01	1969	--	Mm	S	4,725	--	--	250	1969
48-088-28ccc02	--	1,200	Mm	I	4,510	--	--	250	1972
48-088-29baa01	1953	450	Mm	S	4,800	--	--	15	1974
48-089-04abb01	1950	470	₮Pg	S	4,610	--	--	50	1953
48-089-04acd01	1959	1,362	Mm	I	4,550	+384	05-14-75	2,500	1959
						+377	05-05-76		
						+373	04-27-77		
48-089-06dcb01	1974	3,933	€f	I	4,430	+577	05-23-75	2,300	1974
48-089-08dcb01	1971	3,987	€f	I	4,490	+504	05-15-75	2,200	1971
48-089-10acc01	1953	460	IPt	U	4,550	10	11-03-53	20	1953
48-089-25acb01	1953	400	IPt	D	4,540	+88	06-10-75	--	--
						+74	05-14-62		
						+87	05-22-75		
						+83	05-11-76		
48-089-25ada01	1965	2,287	€f	I	4,575	+1,155	- -65	2,000	1965
						+832	05-22-75		
						+783	05-06-76	--	--
						+612	04-13-88		
48-089-28db01	1983	120	₮c	D	4,320	57	06-30-88	11	04-15-83

Table 5.--Records of selected wells and springs--Continued

Local site number	Year drilled	Depth of well (ft)	Primary water-yielding unit	Primary use of water	Altitude of land surface (ft)	Static water level or hydraulic head: Feet above (+) or below land surface	Static water level or hydraulic head: Date	Discharge: Gal/min	Discharge: Date
48-090-11dba01	--	32	Qa	--	4,980	--	--	--	--
48-090-20acd01	--	350	Kf	U	4,310	26.32	08-14-80	--	--
						20	06-29-88		
48-090-20dbb01	--	563	Kf	S	4,300	42.46	07-23-70	--	--
						19.95	05-06-89		
48-090-27bcd01	1942	120	Kf	--	4,400	44.06	06-03-70	8.0	--
						20.15	05-06-89		
48-091-20bcd01	1951	150	Tfu	S	4,225	52.4	06-29-88	--	--
						50.55	07-23-70		
						51.56	06-03-80		
48-091-32caa01	1940	--	Tfu	S	4,265	49.62	06-29-88	10	1940
						48.68	06-02-80		
48-092-04ab01	--	107	Twl	--	3,980	--	--	9.0	--
48-092-04bda01	--	125	Twl	--	3,970	--	--	--	--
48-092-04ddc01	1958	135	Twl	I	4,003	31.9	04-16-87	4.0	09-20-58
48-092-06cad01	1967	210	Twl	D	4,040	86.00	04-11-70	--	--
48-092-07cdc01	1978	185	Twl	U	4,060	29.97	04-16-87	--	--
48-092-08bab01	1985	200	Twl	D	3,691	17.60	04-16-87	8.0	12-31-85
48-092-10ccc01	1970	390	Tfu	D	4,034	48.47	04-17-87	4.0	12-31-70
48-092-16ccb01	--	2,360	Kl	N	3,985	--	--	--	--
48-092-18ca 01	--	192	Twl	--	4,060	--	--	--	--
48-092-22ccc01	1961	2,220	Kl	N	4,046	--	--	6.0	--
48-092-27ccd01	1974	250	Twl	D	4,110	--	--	7.0	11-15-74
48-093-16da01	1971	378	--	U	4,405	247	06-28-88	5.5	10-23-71
48-093-28bdd01	--	80	Twl	S	4,160	--	--	--	--

Alluvium

The alluvium along major streams in Washakie County, the Bighorn and Nowood Rivers, consists of unconsolidated clay, silt, sand, gravel, and boulders of Quaternary age. The alluvium along the Bighorn River is about 3/4 mi wide in the southern part of the county and widens to about 3 mi in the northern part. The thickness of alluvium, as compiled from drillers logs, is typically 20 to 40 ft, with local extremes of 10 and 80 ft (fig. 7). The alluvial aquifer of the Nowood River was mapped and described by Cooley and Head (1979, p. 37-50). This aquifer is narrower than the Bighorn River alluvium with widths less than 1 mi and thicknesses of alluvial deposits from 10 to 50 ft.

The depth to water was measured in wells completed in the alluvium along the Bighorn River in April and May 1987, early in the irrigation season. Water-table altitudes and altitudes of the Bighorn River are shown on the water-table map (fig. 8) of the alluvium along the Bighorn River. The water-table contours indicate that water in the alluvium is flowing toward the Bighorn River. Much of this flow probably is irrigation-return flow from canals and irrigated fields on the Bighorn River floodplain, which is mapped as part of the alluvium (fig. 7).

Reported yields for wells completed in the alluvium along the Bighorn River ranged from 10 to 40 gal/min in Washakie County. Much greater yields, as large as 600 gal/min, have been reported from wells in Bighorn County from alluvial deposits (E.W. Cassidy, U.S. Geological Survey, oral commun., 1989).

Willwood Formation

The Willwood Formation is widely distributed in the central and western parts of Washakie County (pl. 1) where its maximum thickness is about 2,500 ft. The Willwood Formation consists of variegated, interbedded mudstone and claystone, and discontinuous channel sandstone that is locally conglomeratic.

The channel sandstones in the Willwood Formation yield sufficient quantities of water to wells for domestic and stock use. However, these channel sandstones are discontinuous and vary substantially in thickness. The Willwood Formation is composed of 3- to 88-percent sandstone with the average about 25 percent (Lowry and others, 1976). The sandstones thicken and are more continuous in the western part of the county. Reported yields from wells completed in the Willwood Formation ranged from 1 to 28 gal/min with typical yields ranging from 1 to 10 gal/min.

Fort Union Formation

The Fort Union Formation is exposed in the western and central parts of the county (pl. 1) and is as thick as 8,000 ft. It consists of fluvial sandstone, siltstone, and claystone. The water-bearing sandstone is a highly discontinuous, cross-bedded channel sandstone.

The sandstones in the Fort Union Formation yield sufficient water for stock and domestic uses. Reported yields are from 4 to 10 gal/min.

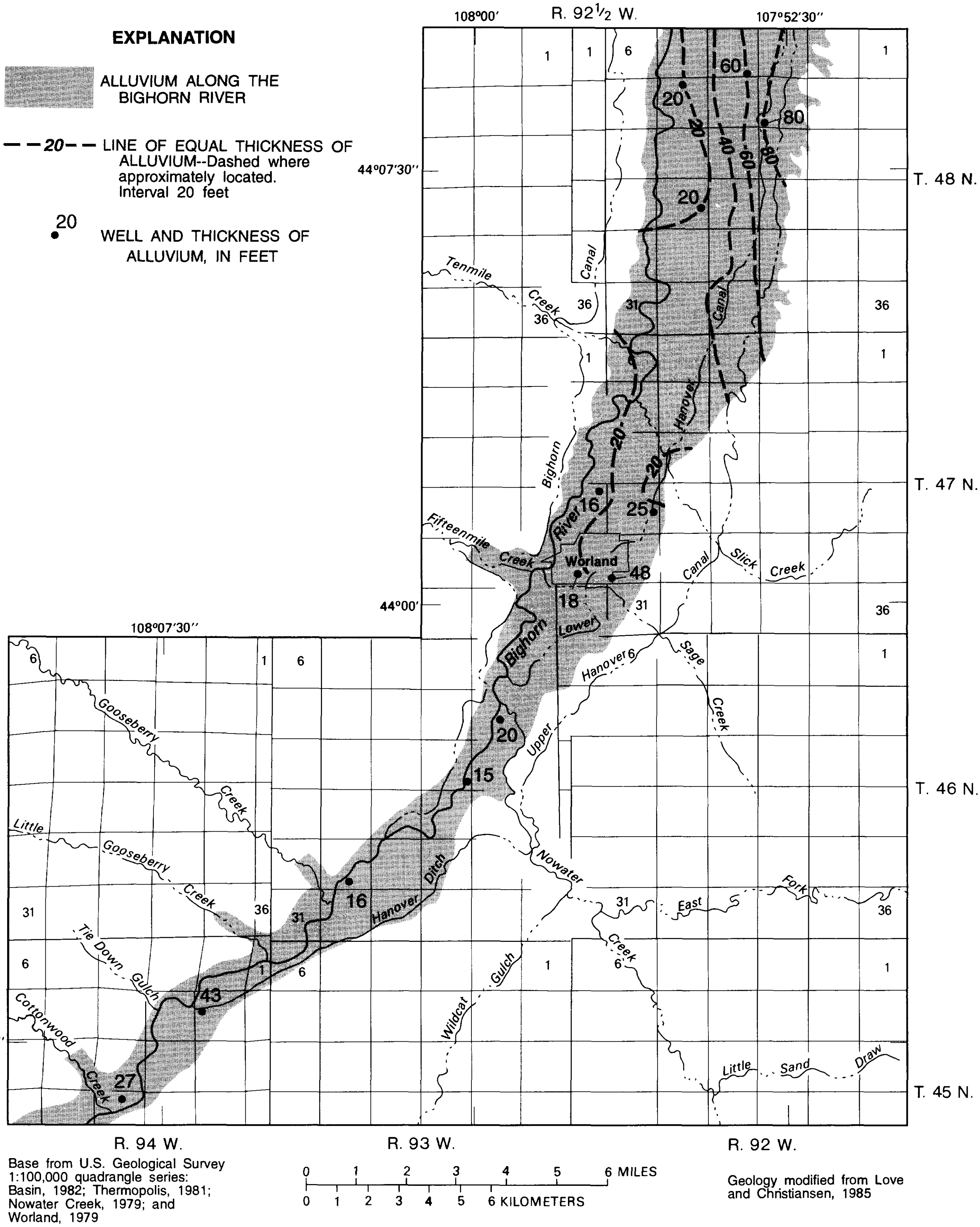


Figure 7.--Thickness of alluvium along the Bighorn River.

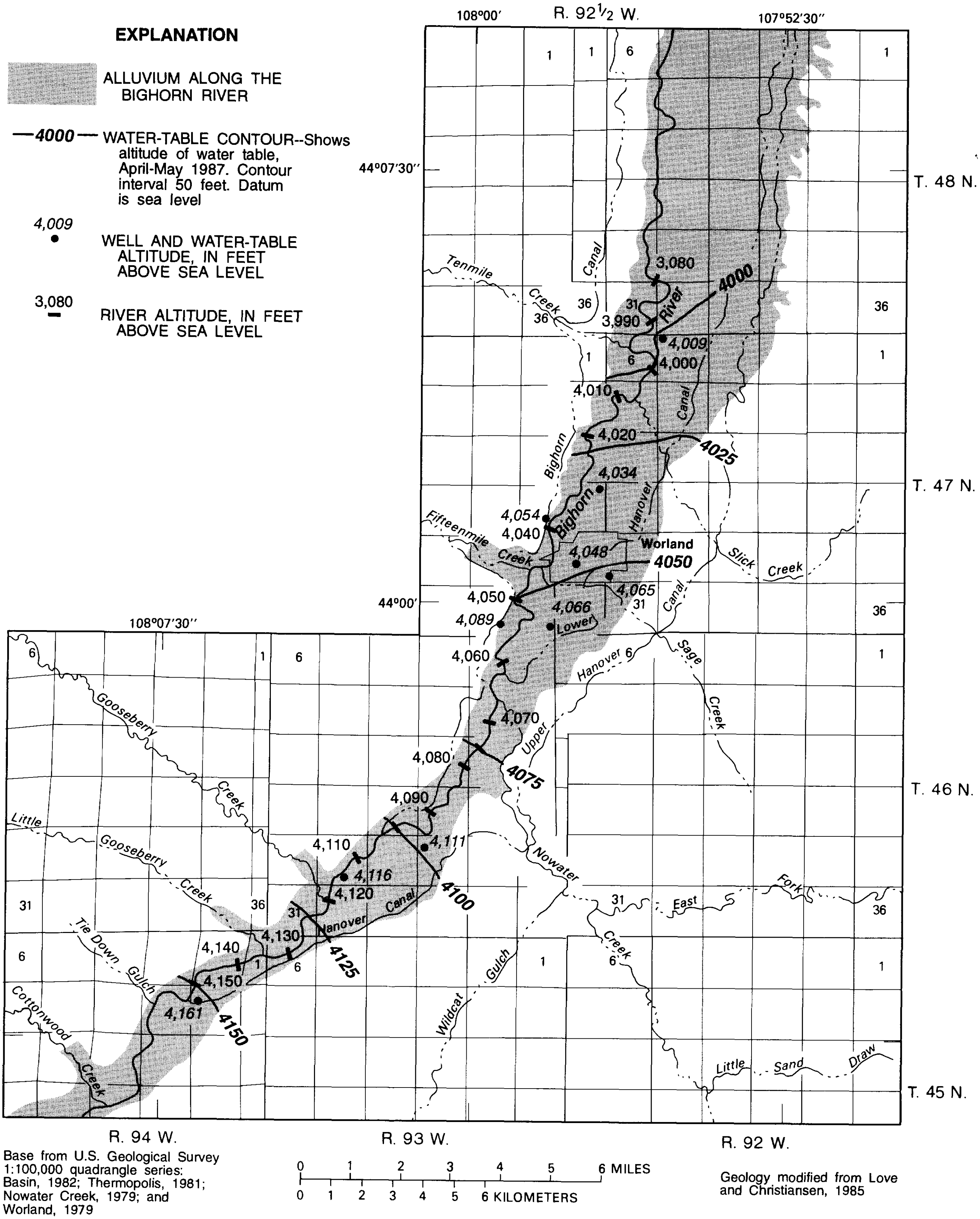


Figure 8.--Altitude of water table in alluvium along the Bighorn River.

Paleozoic Formations

Paleozoic formations crop out along the western flank of the Bighorn Mountains in eastern Washakie County. These formations dip to the west, and, along the mountain flank, are used for ground-water supplies. In the center of the county, the Paleozoic formations are buried to depths of 15,000 ft and are economically inaccessible for ground-water supplies. The aquifers in Paleozoic rocks have been the subject of studies by Cooley (1986), Bredehoeft and Bennett (1971), Blackstone and Huntoon (1984), and Huntoon (1985a; 1985b; 1985c).

The locations of selected wells completed in Paleozoic formations are shown in figure 9. Ground water from Paleozoic formations is widely used for domestic, stock, irrigation, municipal, and agricultural purposes in this area. Wells completed in Paleozoic formations are under artesian conditions and generally flow at land surface. The hydraulic heads above land surface listed in table 5 are calculated from measured wellhead pressures. To convert hydraulic heads in feet above land surface to pressure in pounds per square inch (lb/in^2), divide the hydraulic head by 2.31.

Goose Egg Formation

The Goose Egg Formation is exposed along the Nowood River and its tributaries and on the lower slopes of the Bighorn Mountains (pl. 1). The formation consists of red shale, siltstone, and fine-grained sandstone. The upper part may contain a cherty limestone, and the lower section commonly has abundant gypsum. Collapse features caused by the dissolution of gypsum are found in lowlands along the Bighorn Mountain front (Cooley, 1986, p. 5). The dissolution of gypsum generally occurs along fractures that also hydraulically connect the Goose Egg Formation with the underlying Tensleep Sandstone. Cooley (1986, p. 5) notes, "Much of the spring flow that discharges from the Goose Egg Formation is probably derived from the Tensleep Sandstone."

The Goose Egg Formation has a maximum thickness of 300 ft in the eastern part of Washakie County. Wells completed in the Goose Egg Formation in the county are artesian and have hydraulic heads less than 69.3 ft above land surface and reported yields of 5 to 50 gal/min. Yields of less than 10 gal/min are most commonly reported.

Tensleep Sandstone

The Tensleep Sandstone is a white to tan, massive, cross-bedded sandstone. It consists of fine- to medium-sized sand cemented with siliceous and calcareous cement. The lower part of the unit is interbedded sandstone, limestone, dolomite, and shale.

The Tensleep Sandstone is a major source for domestic and stock water in eastern Washakie County. It is 130 to 400 ft thick with the top of the unit less than 600 ft below land surface in many areas. Most of the small domestic and stock wells completed in the Tensleep Sandstone have hydraulic heads from 10 to 344 ft above land surface and yields of less than 50 gal/min (Cooley,

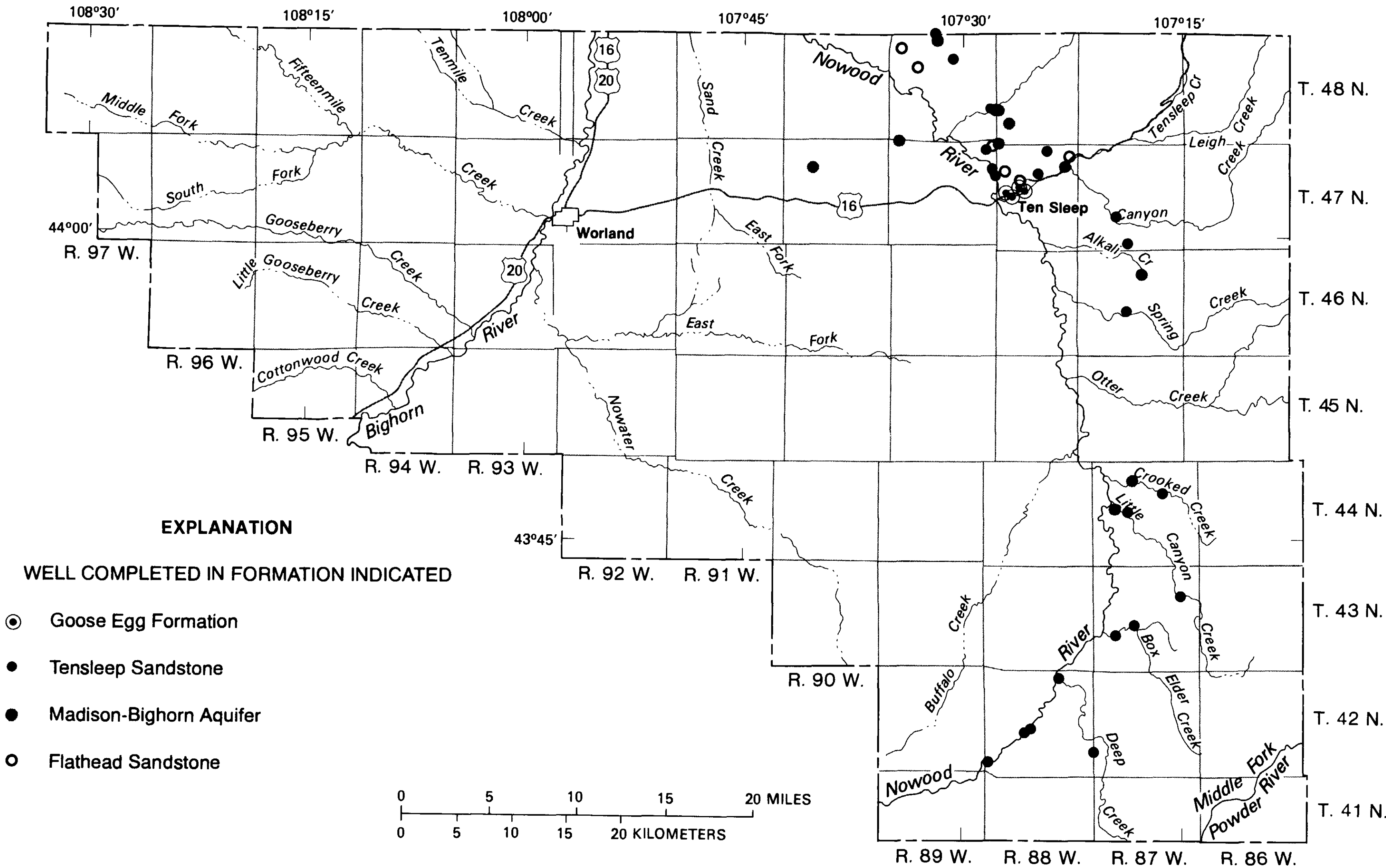


Figure 9.--Locations of selected wells completed in Paleozoic formations.

1986). A representative transmissivity of 150 ft²/d is reported for the Tensleep Sandstone (Cooley, 1986, p. 13). The Tensleep Sandstone has the potential for future development by wells that could yield as much as 250 gal/min when properly developed.

Madison-Bighorn aquifer

The Madison-Bighorn aquifer provides water for irrigation, agriculture, and municipal supplies for the towns of Ten Sleep and Worland. The Madison Limestone and the Bighorn Dolomite are hydraulically connected and are grouped into a single aquifer, the Madison-Bighorn aquifer (Cooley, 1986, p. 4). These massive to thick-bedded carbonates contain abundant chert nodules but few detrital materials. Fractures penetrate both formations, and dissolution occurs along the fractures, creating secondary permeability, cavities, and caverns. Extensive cave systems have been investigated in the Medicine Lodge Creek drainage in Bighorn County (Huntoon, 1985b), and the upper 300 ft of the Madison Limestone contains paleokarst features. The Madison-Bighorn aquifer is about 600 to 1,000 ft thick along the west flank of the Bighorn Mountains. The depth to the top of the Madison Limestone ranges from 500 to 2,000 ft (Cooley, 1986, p. 4). The Madison-Bighorn aquifer has the potential for future development with well yields as large as 2,500 gal/min when properly developed.

Wells completed in the Madison-Bighorn aquifer are artesian and have hydraulic heads 12 to 393 ft above land surface and yields as large as 2,500 gal/min. Yields generally are dependent on the fracture-dissolution secondary permeability of the aquifer. For example, well 47-088-16aba01 was drilled to the Madison-Bighorn aquifer and then completed in the underlying Flathead Sandstone when water could not be obtained from the Madison-Bighorn aquifer (Cooley, 1986, p. 4). In contrast, the Worland municipal well in Big Horn County has the largest reported flow for any well in Wyoming--14,000 gal/min. This well is completed in a highly fractured area of a large anticline. Transmissivity in the Madison-Bighorn aquifer ranges from 300 to 1,900 ft²/d because of the fracture-dissolution secondary permeability of the aquifer (Cooley, 1986, p. 11).

Flathead Sandstone

The Flathead Sandstone is a tannish pink, coarse arkosic sandstone with interbedded shale in the upper part. It is well cemented with silica where it is exposed high in the Bighorn Mountains and in Tensleep Canyon. However, Cooley (1986, p. 4) notes that drillers, in a few instances, have reported that the Flathead Sandstone was "soft and easy to drill." These reports indicate that the Flathead may be poorly cemented or is fractured at these sites.

The Flathead Sandstone is deeply buried at depths from 2,000 to 3,000 ft in the Ten Sleep area and ranges from 100 to 200 ft thick. Hydraulic heads range from 403 to 1,155 ft above land surface, and water temperatures commonly exceed 70°F. Yields from the Flathead Sandstone range from 500 to 2,300 gal/min (Cooley, 1986, p. 27). The Flathead Sandstone has the potential for future development with well yields as large as 2,300 gal/min when properly developed.

Recharge, Movement, and Discharge

Aquifers are recharged by precipitation, streamflow leakage, irrigation, and subsurface inflow from other aquifers. Alluvium in Washakie County generally is recharged by leakage from streams and by precipitation, and, more importantly, in agricultural areas by infiltration of irrigation water. Water-level fluctuations in wells completed in alluvium in agricultural areas show close correlation with the irrigation season (E.W. Cassidy, U.S. Geological Survey, oral commun., 1989). The Willwood and Fort Union Formations are recharged primarily by precipitation and by leakage from streams. The Willwood Formation and the alluvium in some areas are hydraulically connected and may be either recharging or discharging into the adjacent formations, depending on the hydraulic gradient.

Paleozoic formations are recharged by infiltration of precipitation, mainly from snowmelt, where Paleozoic rocks are exposed. Water infiltrates directly into the formations and through fractures and dissolution cavities. Streams also contribute water by leakage where they flow over formation outcrops (Huntoon, 1985c).

Ground-water movement is controlled by the location of recharge and discharge areas and by thickness and permeability of the aquifer. Primary permeability is a function of the grain size, sorting, and cementation between grains. Secondary permeability, fracturing, and dissolution also are factors that control ground-water flow because fractures can provide conduits for vertical and horizontal ground-water flow. For example, the Goose Egg Formation is recharged through fractures in the underlying Tensleep Sandstone (Cooley, 1986, p. 5). Fractures associated with anticlines and faults can provide conduits for both vertical and horizontal movement, producing exceptional yields to wells (Blackstone and Huntoon, 1984, p. 3).

Ground-water flow in alluvium usually is toward local streams. Conditions that can affect flow directions include losing streams that recharge alluvium, pumping wells, and topographic variations in the bedrock. Water in the Willwood Formation, Fort Union Formation, and the Paleozoic formations generally flows toward the axis of the Bighorn Basin, which is oriented approximately southeast-northwest. Thus, ground-water flow in these formations is from the southeast to the northwest across the county (Bredehoeft and Bennett, 1971).

Ground water is naturally discharged by springs and seeps, by evapotranspiration, and by discharge to streams and other aquifers. Springs and seeps occur when the water table intersects the land surface. This commonly is the result of changes in lithology, faults and fractures, and topography. Evaporation from soils and transpiration by plants are processes that remove water from aquifers. Discharges to streams and aquifers result from differences in hydraulic head. Ground water is discharged by evaporation and transpiration when the water table is close to the land surface, which is most likely to occur in the alluvium near streams. The alluvium also commonly discharges water to the streams. Generally water discharges from a small number of widely scattered springs and seeps in the Willwood and Fort Union Formations. Water is discharged from the remaining principal aquifers by numerous springs and seeps commonly associated with fractures, and from contacts between the geologic units.

The relation between recharge and discharge is complex and dependent on a number of factors, including transmissivity, hydraulic gradient, fracturing and solution cavities, and geologic structures. For example, much of the water that recharges the Madison-Bighorn aquifer does not flow into the center of the basin in the aquifer. The water is discharged through fractures to springs along the flanks of the mountains because of basinward decreases in transmissivity in the aquifer (Huntoon, 1985a). Another example of this relation was described by Lowry and others (1976), the Gooseberry Creek alluvial aquifer recharges the underlying sandstones of the Willwood Formation. These sandstones crop out nearby in the headwaters of the South Fork of Fifteenmile Creek at a lower elevation and therefore have a lower hydraulic head than the Gooseberry Creek alluvial aquifer. Thus, the Willwood Formation transmits water from Gooseberry Creek to Fifteenmile Creek because of the hydraulic gradient between the two drainages.

Changes in Water Levels and Hydraulic Heads

The relation between the water level in the well and the top of the aquifer indicates if an aquifer is an unconfined or confined aquifer. In an unconfined aquifer, the water level in a well will be at the level of the water in the aquifer. In a confined aquifer, the water in the aquifer is under pressure, and the water in a well, referred to as an artesian well, is at a level above the top of the aquifer but not necessarily above land surface. If the water level is above land surface, then the well is a flowing artesian well. The pressure of a flowing well is measured at the wellhead in pounds per square inch. For ease of discussion in this report, the wellhead pressures were converted to a hydraulic head above land surface at each well by multiplying the pressure times 2.31. In the following discussion, water levels below land surface are used for nonflowing wells and hydraulic heads above land surface for flowing wells.

Ground-water levels or hydraulic heads fluctuate in response to changes in aquifer recharge and discharge. For example, droughts can decrease ground-water recharge, resulting in ground-water-level and hydraulic-head declines. Human activities also can substantially affect ground-water levels and hydraulic heads. For example, pumped wells and flowing wells, which are used for irrigation and may have large yields, can dramatically change hydraulic heads. A graph of the maximum daily hydraulic head calculated from wellhead pressure measured in an artesian irrigation well is shown in figure 10 and illustrates how the hydraulic head fluctuates throughout the year. The irrigation season began in mid-April and lasted through late October. Spikes in the graph during the summer months represent rapid recovery of pressure in the well after the irrigation systems were shut off. Following the irrigation season, the hydraulic head recovers until the beginning of the next irrigation season. Because of the seasonal hydraulic-head fluctuation in wells in irrigated areas, as indicated by the hydrograph in figure 10, the wellhead pressure of flowing wells or water levels in nonflowing wells need to be measured either continuously or at the same time annually, preferably in the spring prior to the irrigation season, to determine long-term trends.

Water levels in wells completed in alluvium in areas irrigated with surface water rise in late spring and peak in mid- to late summer as irrigation water recharges the alluvium. In the fall, water levels decline after the irrigation season.

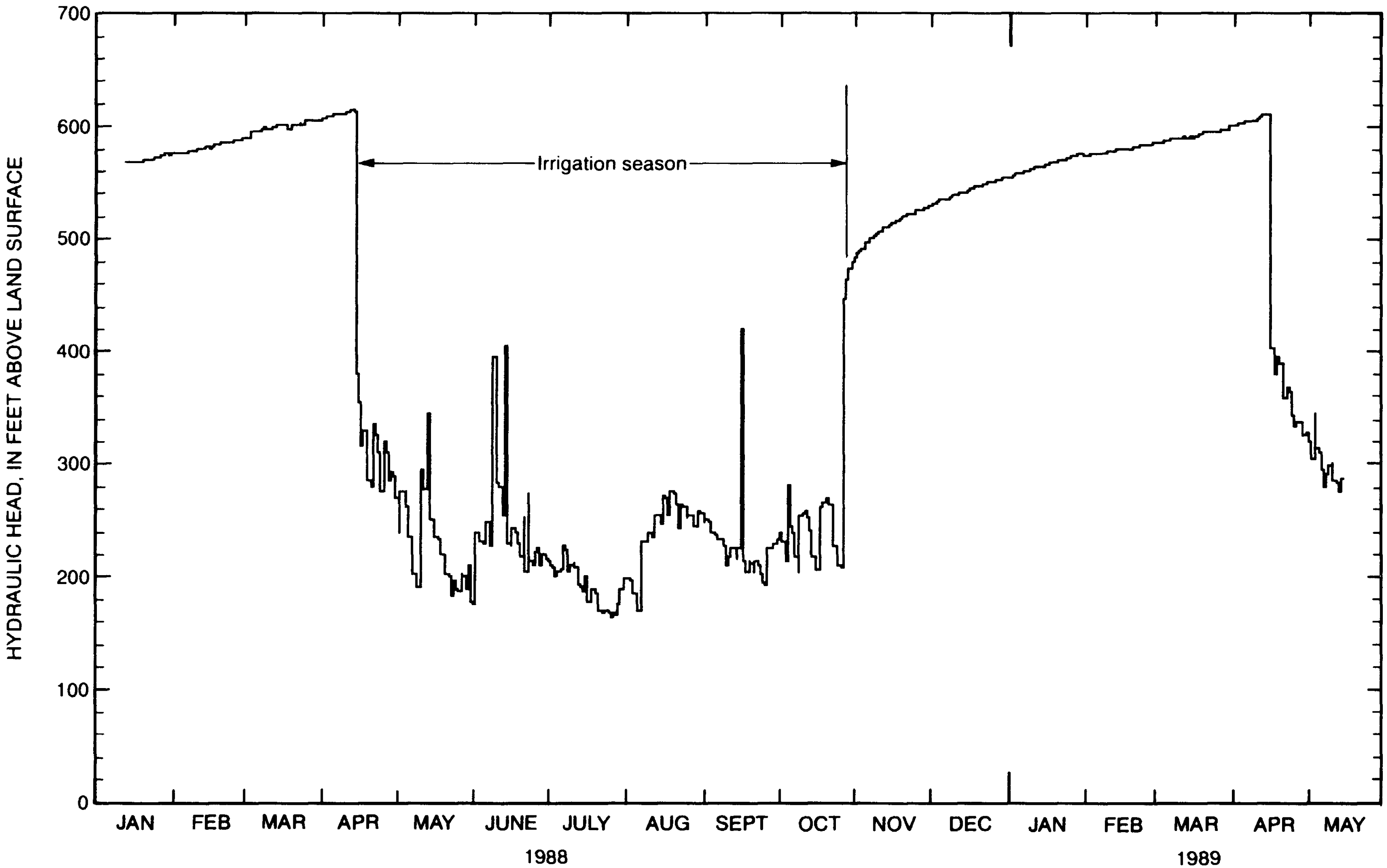


Figure 10.--Maximum daily hydraulic head calculated from the wellhead pressure measured at well 48-089-25ada01.

Changes in pressure and hydraulic head have occurred in two wells, 48-090-20dbb01 and 48-090-27bcd01, completed in the Frontier Formation. Hydraulic heads have risen more that 20 ft from 1970 to 1989 (table 5). Both wells are near the Hidden Dome oil field, and the changes in hydraulic heads may be the result of decreased production and recovery in the adjacent oil field.

Decreases of artesian pressure in Paleozoic formations have become a concern along the western flank of the Bighorn Mountains. Cooley (1986, p. 15) studied this problem and concluded that there had been long-term decreases of artesian pressure, and thus hydraulic-head declines, in wells completed in several of the Paleozoic formations in localized areas. Two wells completed in the Goose Egg Formation, well 47-088-16cdc02 and well 47-088-16daa01, for which Cooley (1986, p. 15) determined decreases of wellhead pressure, were remeasured in 1989. The hydraulic head, calculated from the wellhead pressure, of well 47-088-16cdc02 declined 14 ft from 1978 to 1989 (table 6). This decline might represent an actual decrease in the artesian pressure of the aquifer or, more likely, the result of pressure leakage because of well deterioration as evidenced by the wellhead fittings and valves leaking considerably. The hydraulic head of well 47-088-16daa01 was substantially higher in 1989 than in 1975. In May 1975 the hydraulic head was 18 ft above land surface, and in May 1989 the hydraulic head was 69 ft above land surface. This large increase of 51 feet is difficult to explain. Possible explanations include that in 1975 the wellhead pressure, as indicated by hydraulic head, was decreased and had not recovered when the measurement was made, or that nearby wells may have been interfering with this well. From the 1989 wellhead-pressure measurements, it is difficult to evaluate changes in hydraulic head in the Goose Egg Formation.

Cooley (1986, p. 16) did not measure decreases of artesian pressure, and thus, did not determine any hydraulic-head declines in wells completed in the Tensleep Sandstone and Madison-Bighorn aquifer, with the exception of wells 47-088-05baa01 and 48-089-04acd01 completed in the Madison-Bighorn aquifer near Ten Sleep (table 6). Wellhead-pressure measurements in 1989 also indicated that there had not been any hydraulic-head declines with the exception of the Madison-Bighorn aquifer in the Ten Sleep area.

Decreases in the pressure of flowing artesian wells usually are accompanied by decreases in yield from the wells. Cooley (1986, p. 16) found that for the Ten Sleep town well (well 47-088-16cca01) completed in the Madison-Bighorn aquifer, a decrease in pressure from 135 to 123 lb/in^2 was accompanied by a decrease in the combined yield from 750 to 500 gal/min of well 47-088cda01 and East Spring at Wigwam Fish Rearing Station. Thus, changes in yields from artesian wells can be used to indicate changes in hydraulic head in wells completed in the confined aquifers. A graph of the combined yield of well 47-088-01cda01 and the East Spring (47-088-01dbc01) at the Wigwam Fish Rearing Station is shown in figure 11. The annual peaks and troughs in the curve represent seasonal fluctuations, whereas the overall curve indicates a trend of decreasing yields. The slight increase in yields in 1984 may correspond to greater-than-average precipitation.

Table 6.--Selected hydraulic heads in wells completed in Paleozoic formations

[Water-yielding unit: ₮Pg, Goose Egg Formation; ℙt, Tensleep Sandstone; MD-Ob, Madison-Bighorn aquifer; Ꞓf, Flathead Sandstone. Hydraulic head: Calculated by multiplying the wellhead pressure in pounds per square inch times 2.31]

Local well number	Water-yielding unit	Date of measure-ment	Hydraulic head above land surface (feet)
47-088-16cdc02	₮Pg	05-06-70	55
		05-04-76	51
		05-11-76	51
		04-26-77	49
		05-15-78	51
		05-06-89	37
47-088-16daa01	₮Pg	05-06-75	18
		10-08-75	20
		06-22-76	19
		05-03-89	69
43-087-20ccc01	ℙt	11-12-53	143
		05-14-62	155
43-087-20ccc02	ℙt	05-07-62	24
		05-02-89	115
43-087-21bcb01	ℙt	05-06-75	54
		10-07-75	58
		05-04-76	59
43-087-21bcb02	ℙt	05-02-89	80
44-087-08dcd01	ℙt	05-13-76	164
		04-26-77	160
		05-15-78	167
44-087-17ddc01	ℙt	11-12-53	58
		05-06-75	55
		05-04-76	56
		04-26-77	50
		05-15-78	52
		05-02-89	50
46-087-21acd01	ℙt	05-22-75	176
		05-04-89	150
47-087-33dbd02	ℙt	05-14-75	89
		05-04-76	89
		05-05-89	52
47-089-13aab01	ℙt	05-22-75	344
48-089-25acb01	ℙt	05-14-62	74
		05-22-75	87
		05-11-76	83
47-088-05baa01	MD-Ob	05-14-75	368
		05-04-76	366
47-088-16cca01	MD-Ob	07-24-85	194
		08-21-85	196
		04-15-86	205
		08-18-86	182
		04- -87	205
		08- -87	198

Table 6.--Selected hydraulic heads in wells completed in Paleozoic formations--Continued

Local well number	Water-yielding unit	Date of measure-ment	Hydraulic head above land surface (feet)
48-089-04acd01	MD-Ob	05-14-75	384
		05-05-76	377
		04-27-77	373
47-088-08dab01	€f	05-14-75	457
		05-03-76	457
		04-27-77	437
		05-05-89	403
47-088-16aba01	€f	05-15-75	1,058
		05-10-76	1,041
		04-26-77	1,048
		05-03-89	693
48-089-06dcb01	€f	05-23-75	577
48-089-25ada01	€f	- -65	1,155
		05-22-75	832
		05-06-76	783
		04-13-89	612

Cooley (1986, p. 16) reported that the artesian pressures of wells completed mostly in the Flathead Sandstone but also in the Madison-Bighorn aquifer decreased from the time of completion through 1978. To further document pressure trends for wells chiefly completed in the Flathead Sandstone, the wellhead pressure for two wells inventoried by Cooley (1986, p. 26) were remeasured in 1989. Pressure and hydraulic head of the wells 47-088-08dab01 and 48-089-25ada01 continued to decline (table 6). Cooley (1986, p. 16) reported that the reason for the decreasing pressure trend for these wells is because they generally discharge continuously. If the wells are shut in, then the water in the Flathead Sandstone potentially could continue to move through the well casing into the Madison-Bighorn aquifer, which has lower hydraulic heads than heads in the Flathead.

The remaining wells completed in the Flathead Sandstone inventoried by Cooley (1986, p. 26) have wellheads that deteriorated during the last decade, making accurate measurement of wellhead pressures impossible and comparison to earlier measurements questionable. Wells completed in the Tensleep Sandstone and Madison-Bighorn aquifer also have deteriorated. Several wells completed in the Tensleep Sandstone have been abandoned, and new wells were drilled by the owners.

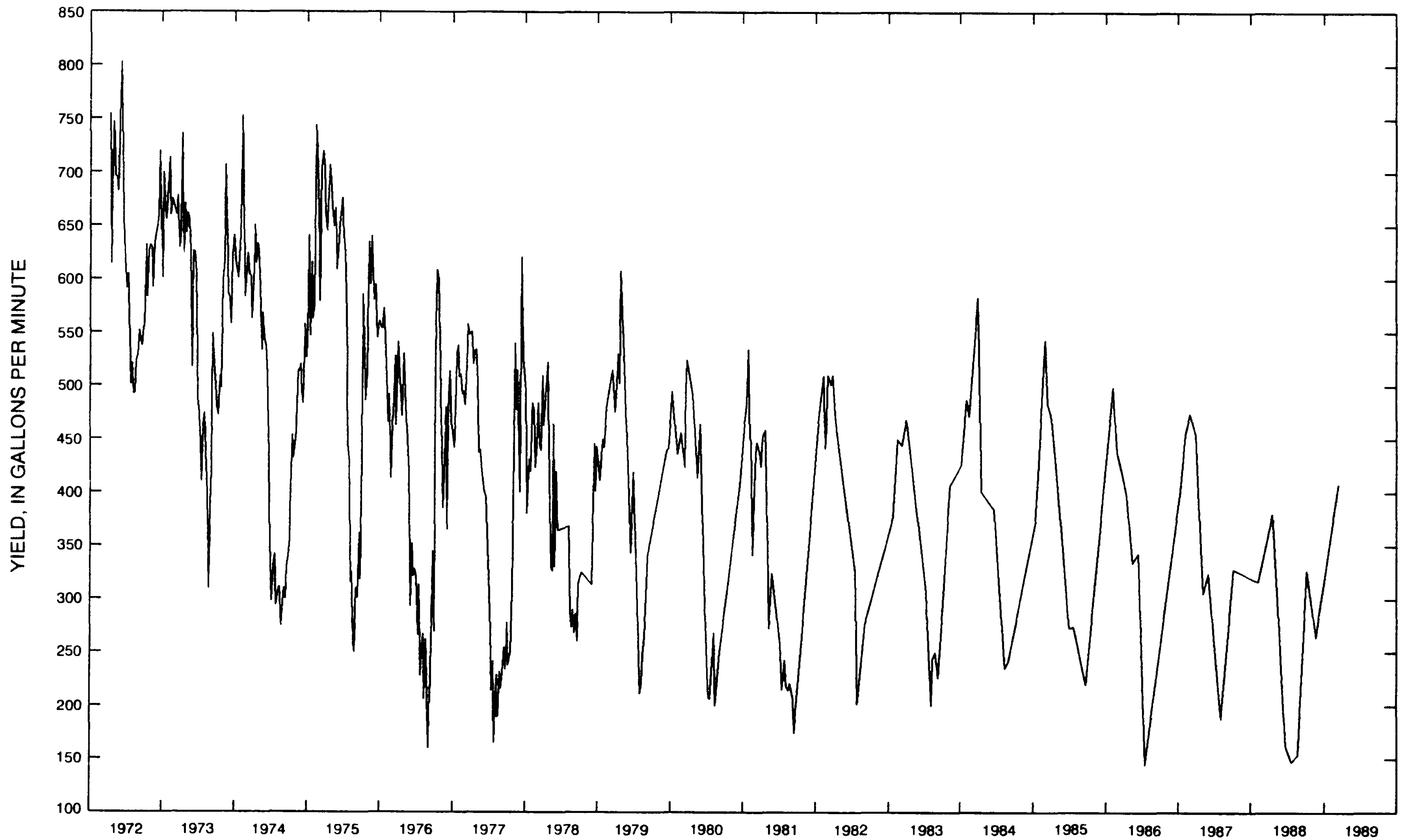


Figure 11.--Combined yield of well 47-088-01cda01 and East Spring (47-088-01dbc01) at Wyoming Game and Fish Wigwam Fish Rearing Station, 1972-89. Data collected by Wyoming Game and Fish Department.

WATER QUALITY

Water quality refers to organic and inorganic material dissolved and suspended in water in a variety of forms and to the physical properties of water. Generally, the presence of any foreign substance in water is thought to reduce water quality; however, not all materials in water are detrimental. Water quality is divided into three catagories--biological, chemical, and physical. Biological quality includes organisms, both plant and animal, living in water and is generally restricted to surface water. Little biological water-quality data have been collected from streams in Washakie County; therefore, biological water quality is not evaluated in this report. A general discussion of the chemical quality and physical properties of surface and ground water follows.

Inorganic material in water is classified by the size of the particles. Dissolved material, the smallest particles, usually is ionized and is associated with the chemical quality of water. Larger particles of insoluble suspended materials are classified as sediment and considered a physical property. Sediments can be filtered from water; chemical substances require more sophisticated techniques for removal. Substances that will pass through a 0.45-micrometer membrane filter are classified as dissolved materials, and particles that will not pass through such a filter are classified as particulate materials (Hem, 1985, p. 60).

Physical properties of water commonly measured in water-quality studies include water temperature, specific conductance, and pH. Temperature controls many physical, chemical, and biological processes. For example, the solubility of ions, the saturation levels of gases, and biological activity are affected by water temperature.

Surface-water temperature is affected by the local climatic and physical conditions. Common climatic factors are solar radiation, wind, air temperature, and vapor pressure. Physical factors include shading, stream width, depth, and velocity, ground-water inflow, and proximity to reservoirs. Ground-water temperatures generally are a function of the depth of the aquifer below the surface of the earth. Deeper aquifers generally have higher water temperatures.

Specific conductance is a measure of the ability of water to conduct electrical current. It is expressed in microsiemens per centimeter ($\mu S/cm$) at 25 degrees Celsius, and is a function of the type and concentration of dissolved solids in the water. The concentration of dissolved solids is about 65 percent of the specific conductance. This relation varies slightly with the composition of dissolved solids.

A measure of the acidity of water is pH. The pH is defined as the negative logarithm of the hydrogen-ion concentration. This parameter is dimensionless and has a range from 0 to 14. A pH greater than 7 indicates the water is alkaline, whereas a pH less than 7 indicates an acidic water.

Chemical quality of water is related to the chemical composition of rocks and sediment with which the water has been in contact and to materials introduced into the hydrologic environment by human activities. Surface-water quality depends on the water source and the exposure of the water to soluble material between the source and the sampling site. Ground-water quality closely reflects the chemical composition of the rocks. Water temperature, the duration of contact with the rocks, and the rate of movement of the water also will affect the chemical quality of ground water. The source and significance of common dissolved-mineral constituents and physical properties of ground water and surface water are summarized in table 7.

Water is classified into ionic types by the dominant dissolved cation (positive ion) and anion (negative ion). The dominant ion must be more than 50 percent of the total. For example, a sodium sulfate water contains more than 50 percent sodium cations and more than 50 percent sulfate anions. If a water does not contain a dominant cation and anion, then the water is classified as a mixed type.

Surface-Water Quality

Specific conductances of water samples from intermittent and perennial streams in Washakie County range between 300 and 1,200 μS/cm. Specific conductance tends to increase downstream in each drainage basin, indicating an increase in dissolved-solids concentration downstream. The concentration of dissolved solids in the water increases as the distance from the headwaters increases. Specific-conductance data at several sites on one stream have not been collected in this county; however, data collected in adjacent Big Horn County (E.W. Cassidy, U.S. Geological Survey, oral commun., 1989) supports this trend.

Fluctuations in discharge account for much of the variability in the chemical quality of surface water. Specific conductance usually varies inversely with stream discharges, and consequently a range of specific conductance would be expected at a surface-water station having a broad range of discharges. Daily values of specific conductance and the daily mean discharge at the Bighorn River at Worland (site 12) for 1967 water year are shown in figure 12. The specific conductance values are large during low flows, whereas during high flows, specific conductance values are smaller.

The chemical quality of water in streams in Washakie County varies by type of stream as well as with discharge. The principal dissolved constituents in county streams are calcium or sodium, and bicarbonate or sulfate. Water samples have been collected at 11 surface-water stations in Washakie County, beginning in the 1947 water year (table 1). Records at most of the stations are short (1 to 6 years). Long-term records are available for two perennial streams: Bighorn River at Worland (site 12) and Nowood River near Ten Sleep (site 16). Water in the Bighorn River at Worland is sodium sulfate type, whereas water in the Nowood River near Ten Sleep is calcium sulfate type. No long-term records are available for intermittent and perennial mountain streams.

Human activities also affect chemical quality of surface waters. Dissolved-solids concentrations in streams may be increased by upstream diversion of water containing smaller concentrations or by discharge of used water containing larger concentrations. Dissolved trace metals, herbicides, and other contaminants may enter surface waters as a result of municipal, domestic, agricultural, industrial, or other uses of water. In Washakie County, serious contamination problems have not been documented. However, because of concern about effects of using agricultural chemicals, a sampling program was initiated to monitor surface water and ground water for the presence of herbicides. The results are discussed later in this report.

Table 7.--Source or cause and significance of dissolved-mineral constituents and physical properties of water (modified from Popkin, 1973)

[mg/L, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Constituent or property	Source or cause	Significance
Specific conductance (μS/cm)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
pH	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Hardness as calcium carbonate ($CaCO_3$)	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form and deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness of 60 mg/L or less are considered soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L, hard; more than 180 mg/L, very hard.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are detected in large quantities in some brines. Magnesium is present in large quantities in seawater.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.

Table 7.--Source or cause and significance of dissolved-mineral constituents and physical properties of water--Continued

Constituent or property	Source or cause	Significance
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils; also in ancient brines, seawater, industrial brines, and sewage.	Large concentrations, in combination with chloride, give a salty taste. Moderate concentrations have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers. Large sodium concentration may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large concentrations, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large concentrations in ancient brines, seawater, and industrial brines.	In large concentrations in combination with sodium, gives salty taste to drinking water. In large concentrations increases the corrosiveness of water.
Fluoride (F)	Dissolved in minute to small concentrations from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, quantity of drinking water consumed, and susceptibility of the individual.

Table 7.--Source or cause and significance of dissolved-mineral constituents and physical properties of water--Continued

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/L. Large concentrations, as much as 100 mg/L, generally occur in alkaline waters.	Forms hard scale in pipes and boilers. Transported in steam of high-pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. Also may be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/L of iron in surface water generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/L stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	Waters containing more than 1,000 mg/L dissolved solids are unsuitable for many purposes.
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may indicate contamination. Waters with large nitrate concentration have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms that produce undesirable tastes and odors.

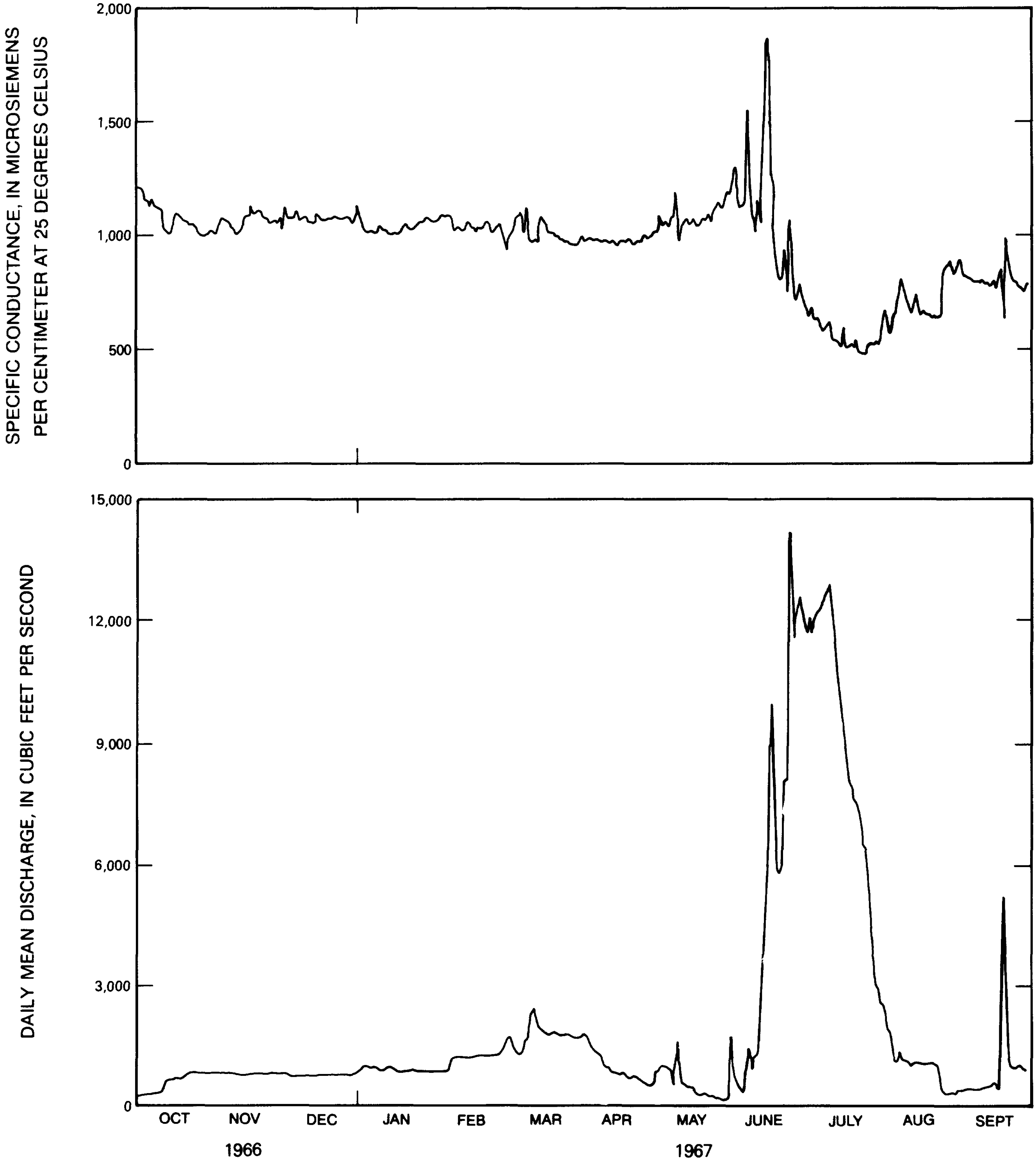


Figure 12.--Daily specific conductance and daily mean discharge of the Bighorn River at Worland (site 12), water year 1967.

Sediment

Unlike chemical constituents, which usually are dissolved in water, sediment particles are suspended in flowing water, and even small concentrations of suspended sediment are noticeable. Suspended-sediment loads result from erosion. These loads are deposited in stream channels and reservoirs, are in water supplies, cause excessive wear on mechanical systems, and are detrimental to aquatic and wildlife habitat. Sediment loads are considered to be aesthetically displeasing and environmentally degrading even though they occur naturally.

Human activities can increase or decrease suspended-sediment loads. For example, overgrazing, deforestation, and agriculture can greatly increase suspended-sediment loads. Reservoirs and other sediment-control structures can reduce suspended-sediment loads in streams. Fifteenmile Creek near Worland (site 11), the subject of long-term collection and analysis of sediment data, illustrates the effects of human activities on suspended-sediment loads.

In 1958 the U.S. Bureau of Land Management constructed a series of spreader-dike systems on the Fifteenmile Creek floodplain. These spreader-dike systems were designed to cause suspended sediments to be deposited rather than transported downstream. For an annual total discharge of 10,000 acre-ft, the annual total suspended-sediment load decreased from about 1,200,000 to about 620,000 tons after the installation of the spreader-dike systems in 1958 (fig. 13).

Ground-Water Quality

Chemical analyses of water samples from selected wells and springs in Washakie County are listed in table 8. The physical properties and chemical constituents in table 8 include specific conductance, pH, cations, sodium-adsorption ratio, alkalinity, anions, and nutrients. The physical properties and chemical characteristics of the water aid in evaluating the suitability of water for various uses. Chemical constituents for evaluating water quality for domestic use, livestock watering, and irrigation are listed in table 9.

The concentrations of the principal chemical constituents in ground-water samples from wells completed in selected formations are shown in figure 14. The bar graphs show the difference between selected water samples representative of Cenozoic, Mesozoic, and Paleozoic formations. In Cenozoic formations, the dominant cation is sodium, and the dominant anion is sulfate (fig. 14), except in the alluvium, where the cations are mixed (calcium magnesium sodium, and potassium) and sulfate is the dominant anion. Sodium generally is more common than potassium in "sodium plus potassium" analytical result. Thus, water in the Cenozoic formations is classified as a sodium sulfate type. Water in the Mesozoic formations also is classified as a sodium sulfate type. In the Paleozoic aquifers, the dominant ions are calcium and bicarbonate (expressed by alkalinity), so the water is classified as a calcium carbonate type.

The concentrations of dissolved solids in water samples from aquifers are shown in figure 15, which is used to evaluate the suitability of water for various uses. Water from many of the aquifers in Washakie County have large concentrations of dissolved solids, which exceed the secondary maximum

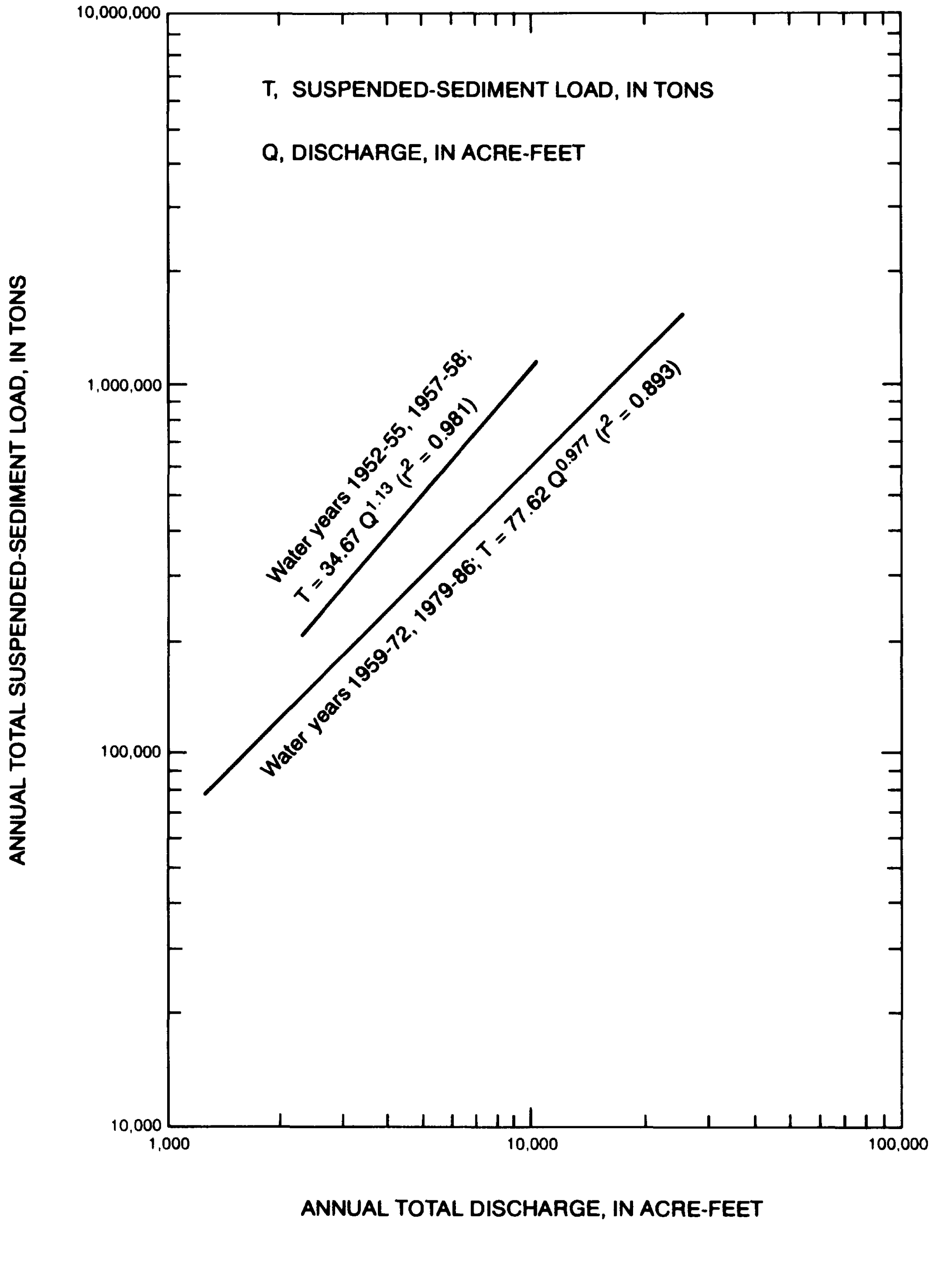


Figure 13.--Annual total discharge in relation to annual total suspended-sediment load by water years at streamflow-gaging station Fifteenmile Creek near Worland (site 11).

Table 8.--Chemical analyses of water

[Analytical results in milligrams per liter (mg/L) except as indicated; ft, feet;
no data; <, less than. Primary water-yeilding unit: Qa, alluvium; Twl, Willwood Formation;
Frontier Formation; Km, Mowry Shale; Ktm, Muddy Sandstone Member of the Thermopolis Shale; Kcv,
TRPg, Goose Egg Formation; IPt, Tensleep Sandstone; PMa, Amsden

Local site number	Primary water-yielding unit	Date	Depth of well (ft)	Specific conductance (μS/cm)	pH	Water temperature (°C)	Hardness ($CaCO_3$)	Calcium, dissolved (Ca)	Magnesium, dissolved (Mg)
41-089-09ad01	Jg	06-25-65	Spring	531	8.2	9.5	200	37	25
42-088-21bbd01	IPt	06-21-65	590	381	7.7	12.0	210	43	24
	IPt	05-13-75	590	391	7.9	--	200	44	23
42-088-30ad01	TRPg	06-25-65	Spring	2,380	7.8	10.5	1,600	510	77
43-087-11bdb01	IPt	11-12-53	443	365	7.5	10.0	200	43	22
	IPt	05-23-75	443	352	7.8	--	190	36	24
43-087-20ccc01	IPt	05-22-75	--	618	7.9	--	330	80	31
43-087-21bcb01	IPt	11-12-53	500	470	7.4	--	260	59	27
	IPt	06-10-75	500	430	8.0	--	240	50	27
	IPt	09-08-75	500	--	--	11.5	230	54	24
43-089-23add01	Kcv	08-01-70	215	3,500	9.0	15.0	57	11	7.2
43-090-06baa01	Ktm	07-17-70	4,005	1,610	8.9	40.0	4	1.2	.2
43-090-25dab01	Kf	06-20-67	2,900	2,030	8.7	16.5	18	2.4	2.8
44-087-08dcd01	IPt	07-15-75	--	--	--	--	170	42	16
44-087-08ddc01	IPt	11-11-53	1,040	329	7.5	14.5	170	43	16
44-087-09bbc01	Ꞓf	05-13-75	1,820	400	7.9	15.5	210	46	23
44-087-17dad01	Mm	07-23-84	--	--	--	--	--	--	--
44-087-17ddc01	IPt	11-12-53	575	414	7.5	13.5	200	45	21
	IPt	09-08-75	575	--	--	15.0	210	50	20
44-087-21dbb01	TRc	11-07-76	Spring	--	--	--	230	53	24
44-091-35add01	Ktm	06-20-67	4,197	1,720	8.6	35.0	0	0	0
45-087-07add01	Qa	09-10-76	20	--	--	--	440	120	34
45-092-19bad01	Tfu	12-07-70	620	1,910	8.2	12.0	39	12	2.3
45-093-14dca01	Tfu	12-07-70	630	2,250	8.3	10.0	43	12	3.1
45-095-09bdb01	Tfu	08-18-88	100	5,600	--	11.0	1,300	270	150
	Tfu	08-20-88	100	1,600	--	13.0	--	--	--
46-087-10acb01	Mm	06-11-75	1,410	390	8.2	--	210	44	24
	Mm	09-08-75	1,410	--	--	14.0	210	46	23
	Mm	07-23-84	1,410	--	--	15.0	--	--	--
46-087-21acd01	IPt	10-31-53	1,100	474	7.6	14.5	260	58	28
	IPt	07-28-59	1,100	467	7.7	14.5	250	53	29
	IPt	05-13-75	1,100	444	7.8	--	240	54	26
46-088-14aac01	Qa	09-10-76	40	--	--	--	100	26	8.8
46-088-24bbc01	Km	09-10-76	60	--	--	--	28	8.8	1.4
46-091-35bb 01	Tfu	12-04-70	--	3,480	8.1	10.0	140	33	13

from selected wells and springs

°C, degrees Celsius; μS/cm, microsiemems per centimeter at 25 degrees Celsius; --,
Tfu, Fort Union Formation; Kl, Lance Formation; Kmv, Mesaverde Formation; Kc, Cody Shale; Kf,
Cloverly Formation; Jm, Morrison Formation; Jg, Gypsum Spring Formation; TRc, Chugwater Formation;
Formation; Mm, Madison Limestone; €f, Flathead Sandstone]

Sodium, dis- solved (Na)	Sodium- adsorp- tion ratio	Potas- sium, dis- solved (K)	Alka- linity, total (as $CaCO_3$)	Sulfate, dis- solved (SO_4)	Chlo- ride, dis- solved (Cl)	Fluo- ride, dis- solved (F)	Silica, dis- solved (SiO_2)	Dissolved solids (sum of con- stituents)	Nitro- gen, $NO_2 + NO_3$ dis- solved	Phos- phorous, total (P)
46	1	4.1	--	100	2.0	0.6	21	349	--	--
3.5	.1	1.4	--	32	1.2	.4	11	221	--	--
4.3	.1	1.2	180	27	1.8	.3	10	222	--	<0.01
75	.9	4.9	--	1,400	6.5	.7	26	2,230	--	--
1.4	0	1.8	--	9.0	1.0	.2	11	202	--	--
1.6	0	1.2	180	6.6	<.1	.2	1	188	--	.01
6.4	.2	2.1	213	130	1.8	.3	9.3	389	--	<.01
2.6	.1	1.0	--	44	1.0	.3	9.4	271	--	--
2.1	.1	2.8	205	33	1.8	.3	8.4	248	--	.01
2.3	.1	1.4	205	32	1.4	.3	9.7	249	--	<.01
820	48	1.7	--	1,400	38	1.6	12	2,520	--	--
380	88	.9	--	430	5.2	.6	25	1,080	--	--
480	51	1.4	440	590	19	.7	17	1,410	--	--
2.9	.1	1.2	139	35	1.8	.3	9.2	192	--	<.01
1.3	0	1.2	--	34	1.0	.6	8.0	187	--	--
3.2	.1	1.2	189	34	1.8	.3	9.5	232	--	<.01
--	--	--	--	--	--	--	--	--	--	--
12	.4	1.2	--	60	2.0	.2	9.6	246	--	--
2.3	.1	1.4	164	49	1.8	.2	10	234	--	<.01
2.9	.1	1.4	172	48	10	.4	9.1	254	--	.04
430	0	1.8	432	430	14	.8	26	1,180	--	--
16	.3	1.9	303	180	1.0	.4	19	560	--	.01
430	31	2.9	--	600	33	2.2	7.9	1,290	--	--
500	35	3.1	--	770	47	2.1	7.2	1,530	--	--
870	11	7.0	--	2,100	360	.5	16	4,070	0.36	<.01
--	--	--	--	--	--	--	--	--	--	--
1.1	0	2.3	189	23	1.8	.2	9.2	219	--	.01
1.2	0	.7	189	19	<.1	.2	9.8	214	--	<.01
--	--	--	--	--	--	--	--	--	--	--
3.0	.1	1.4	--	24	2.0	.2	9.6	268	--	--
2.8	.1	1.3	--	21	1.2	.3	9.9	261	--	--
2.7	.1	.9	230	21	1.8	.2	10	255	--	<.01
350	16	1.4	361	490	1.8	.8	9.2	1,110	--	.01
1,000	86	2.1	525	1,500	71	4.1	7.6	2,920	--	.07
770	30	4.5	--	1,500	56	1.2	7.1	2,510	--	--

Table 8.--Chemical analyses of water

Local site number	Primary water-yielding unit	Date	Depth of well (ft)	Specific conductance (μS/cm)	pH	Water temperature (°C)	Hardness ($CaCO_3$)	Calcium, dissolved (Ca)	Magnesium, dissolved (Mg)
46-092-06aa01	Twl	04-15-70	160	4,100	7.7	--	200	58	14
46-092-06ca01	Twl	02-17-65	320	1,950	7.5	--	44	12	3.4
46-092-07bc01	Twl	06-00-68	320	2,990	8.1	--	120	36	6.6
46-092-24dd01	Twl	09-22-54	425	3,290	7.9	--	140	41	9.9
46-092-24dd01	Twl	12-04-70	1,390	2,250	8.3	10.0	47	13	3.6
46-093-01cb01	Twl	10-19-66	70	1,740	7.7	--	340	--	--
46-093-11aa01	Twl	10-17-66	90	1,470	8.4	--	34	--	--
46-093-15adc01	Twl	06-30-69	287	2,610	8.7	11.0	13	4.7	.4
46-093-15bdd01	Twl	08-17-87	52	--	--	--	310	79	28
	Twl	08-18-88	52	2,450	--	13.5	360	97	29
46-093-15cab01	Twl	08-17-87	300	--	--	--	80	24	4.9
	Twl	08-18-88	300	990	--	12.0	13	3.7	.9
46-093-30dba01	Twl	08-20-88	205	1,600	--	13.0	17	4.6	1.3
46-094-06aab01	Twl	08-20-88	79	6,200	--	14.0	830	200	80
46-094-35db01	Tfu	05-12-70	180	2,800	7.7	--	520	130	44
46-095-15ab01	Tfu	07-28-70	190	1,440	8.7	11.5	12	3.5	.9
46-096-27cba01	Tfu	07-28-70	380	1,350	8.0	10.0	80	21	6.7
47-087-28bbc01	TRPg	09-09-76	--	--	--	--	340	68	42
47-087-33bdb01	€f	05-14-75	2,708	518	8.0	--	280	62	31
	€f	09-08-75	2,708	--	--	25.0	290	66	31
47-087-33dbd02	IPt	05-14-75	--	957	8.2	14.0	200	54	15
	IPt	09-08-75	--	--	--	15.5	200	54	17
47-088-01cda01	Mm	05-06-75	1,070	345	7.9	10.5	190	40	22
	Mm	09-08-75	1,070	--	--	10.5	180	38	20
47-088-01cdb01	Mm	09-15-76	--	--	--	--	160	33	19
47-088-02bcd01	IPt	07-19-68	540	395	8.1	--	220	47	24
	IPt	06-11-75	540	--	--	--	230	49	26
47-088-05baa01	Mm	05-14-75	1,680	406	7.7	--	220	43	27
	Mm	09-09-75	1,682	--	--	14.5	220	47	26
47-088-08dab01	€f	05-14-75	2,960	295	8.1	--	120	20	16
	€f	09-09-75	2,960	--	--	23.5	110	20	14
47-088-10dbd	TRPg	05-22-75	--	381	7.6	--	200	50	18
47-088-11cdb01	Qa	09-15-76	20	--	--	--	210	47	23

from selected wells and springs--Continued

Sodium, dis- solved (Na)	Sodium- adsorp- tion ratio	Potas- sium, dis- solved (K)	Alka- linity, total (as $CaCO_3$)	Sulfate, dis- solved (SO_4)	Chlo- ride, dis- solved (Cl)	Fluo- ride, dis- solved (F)	Silica, dis- solved (SiO_2)	Dissolved solids (sum of con- stituents)	Nitro- gen, $NO_2 + NO_3$ dis- solved	Phos- phorous, total (P)
870	28	4.6	--	1,700	160	5.4	13	2,960	--	--
430	29	2.3	281	600	57	1.8	10	1,280	--	--
690	29	4.5	--	1,200	88	1.6	7.2	2,190	--	--
710	27	5.3	--	1,300	100	1.0	7.0	2,270	--	--
500	33	3.5	--	730	30	2.4	8.3	1,520	--	--
--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--
660	82	55.3	--	.6	350	2.2	11	1,660	--	--
420	11	5.9	--	720	73	.8	26	1,600	6.2	.02
470	11	7.0	--	910	51	.8	11	1,810	4.9	<.03
470	24	2.9	--	770	76	1.7	6.3	1,500	1.2	.01
240	30	1.3	--	50	86	3.6	6.4	602	.10	<.03
330	36	2.2	--	.9	250	2.0	6.7	870	<.10	<.01
1,300	20	7.9	--	3,200	81	1.0	7.6	5,040	<.10	<.01
470	9.0	5.3	--	1,000	52	2.7	8.1	2,040	--	--
320	41	1.6	--	380	24	1.4	7.7	930	--	--
280	14	3.1	--	410	12	1.3	9.4	899	--	--
2.9	.1	1.4	312	16	.8	.2	18	348	--	2.2
4.8	.1	1.6	246	41	1.8	.2	9.8	300	--	<.01
3.5	.1	1.6	238	64	2.5	.2	10	322	--	<.01
110	4.0	12	123	220	84	1.7	9.0	579	--	<.01
120	4.0	12	123	230	84	2.2	11	604	--	<.01
2.7	.1	.5	189	8.2	1.8	.2	11	202	--	.01
1.8	.1	.9	180	5.8	<.1	.2	10	185	--	.01
2.3	.1	.7	156	4.9	3.6	.2	9.4	169	--	.01
2.4	.1	1.1	--	7.7	.4	.2	9.6	218	--	--
1.6	0	3.0	213	6.7	16	.2	9.5	242	--	.01
1.6	0	.7	221	2.5	<.1	.3	9.5	217	--	<.01
1.2	0	.9	213	3.3	<.1	.2	10	220	--	<.01
16	.7	5.6	131	18	<.1	.4	10	165	--	<.01
15	.6	5.4	115	19	2.2	.4	11	156	--	<.01
1.6	.0	.9	189	9.1	1.8	.2	9.6	205	--	.01
4.1	.1	.5	189	25	.6	.1	10	223	--	.10

Table 8.--Chemical analyses of water

Local site number	Primary water-yielding unit	Date	Depth of well (ft)	Specific conductance (μS/cm)	pH	Water temperature (°C)	Hardness ($CaCO_3$)	Calcium, dissolved (Ca)	Magnesium, dissolved (Mg)
47-088-12bca01	Mm	09-08-75	597	--	--	11.5	170	37	19
47-088-15cbc01	Qa	06-11-75	--	1,610	7.3	--	990	280	71
47-088-16aba01	€f	05-07-75	2,700	272	8.0	20.5	110	21	15
	€f	09-08-75	2,700	--	--	23.0	120	25	15
47-088-16cca01	Mm	05-10-62	1,050	445	7.5	--	230	44	28
	Mm	06-13-75	1,050	411	7.6	--	220	49	24
	Mm	07-23-84	1,050	--	--	--	--	--	--
47-088-16cdb	ꞦPg	05-06-75	--	696	7.7	--	380	96	33
47-088-16cdc01	ꞦPg	05-07-75	238	515	7.8	9.0	270	64	26
47-088-16cdc02	ꞦPg	09-08-75	505	--	--	15.5	210	48	22
47-088-16daa01	ꞦPg	05-07-75	260	640	7.8	13.0	360	88	35
	ꞦPg	09-08-75	250	--	--	14.5	340	85	32
47-088-16dba01	ꞦPg	05-07-75	300	392	8.0	13.5	200	43	23
47-088-17dad01	Mm	07-23-84	1,100	--	--	--	--	--	--
47-088-21aba01	ꞦPg	11-06-75	280	--	--	--	260	61	27
47-089-01cac01	ℙt	06-11-75	755	640	7.8	--	350	93	29
47-089-03aad01	Qa	09-15-76	20	--	--	--	780	200	68
47-089-06abd01	Mm	07-23-70	2,835	395	8.1	16.0	220	45	25
	Mm	06-11-75	2,835	394	7.7	--	220	45	25
47-089-12bdc01	Qa	09-15-76	40	--	--	--	1,100	300	76
47-089-12db01	ℙt	10-30-53	901	421	7.3	13.5	230	49	25
	ℙt	09-21-54	901	421	7.7	--	230	46	27
47-089-13aab01	ℙt	05-22-75	901	460	7.8	--	240	49	28
	ℙt	09-08-75	901	--	--	13.0	230	49	26
47-090-08dbc01	Mm	07-22-70	6,660	398	8.2	25.0	220	46	25
47-092-09bcc01	Twl	08-09-87	--	--	--	--	350	61	47
	Twl	08-17-88	--	1,900	--	17.0	450	120	36
47-092-17cdc01	Twl	03-24-70	40	3,470	7.9	--	480	130	38
47-092-18cbd01	Twl	10-17-66	120	1,610	8.0	--	26	--	--
47-092-24aac01	Twl	02-04-69	110	2,740	7.6	--	140	46	5.8
47-092-26bab01	Twl	08-17-88	272	3,500	--	13.0	220	40	30
47-092-30ccc01	Qa	06-10-66	42	2,690	8.2	12.0	540	130	50
47-092-30cdd01	Twl	10-11-63	268	1,190	8.1	--	21	2.7	3.5
47-092-30dbb01	Twl	04-05-66	225	1,580	8.8	--	32	8.9	2.4
	Twl	04-16-70	225	1,420	8.2	--	29	8.5	2.0
47-092-30dbc01	Twl	11-05-68	87	1,280	--	--	--	--	--
47-092-30dc01	Twl	07-18-68	240	2,130	8.3	--	150	42	10
47-092.5-24ada01	Twl	07-30-70	90	2,600	8.3	--	250	76	14
47-092.5-25aba01	Qa	06-10-66	20	2,260	8.2	10.5	540	130	49

from selected wells and springs--Continued

Sodium, dis-solved (Na)	Sodium-adsorp-tion ratio	Potas-sium, dis-solved (K)	Alka-linity, total (as $CaCO_3$)	Sulfate, dis-solved (SO_4)	Chlo-ride, dis-solved (Cl)	Fluo-ride, dis-solved (F)	Silica, dis-solved (SiO_2)	Dissolved solids (sum of con-stituents)	Nitro-gen, $NO_2 + NO_3$ dis-solved	Phos-phorous, total (P)
1.8	.1	.7	172	4.9	<.1	.2	9.8	176	--	.01
43	.6	4.9	230	820	3.6	.5	19	1,380	--	.01
8.0	.3	4.7	131	8.2	1.8	.3	11	149	--	<.01
9.9	.4	5.1	131	14	1.8	.3	11	161	--	<.01
2.9	.1	2.0	--	17	1.0	.4	11	229	--	--
3.2	.1	4.2	213	19	1.8	.3	8.9	239	--	.01
--	--	--	--	--	--	--	--	--	--	--
3.2	.1	1.4	180	190	1.8	.4	11	446	--	<.01
4.8	.1	3.5	180	90	<.1	.6	7.4	306	--	.01
6.4	.2	3.7	189	32	2.2	.4	8.2	236	--	.01
4.3	.1	1.6	164	200	<.1	.3	11	440	--	<.01
2.3	.1	1.2	164	180	.7	.3	11	412	--	<.01
2.7	.1	1.6	180	25	1.8	.3	12	218	--	.01
--	--	--	--	--	--	--	--	--	--	--
3.5	.1	1.2	180	97	1.8	.4	9.7	310	--	<.01
5.4	.1	4.0	205	150	1.8	1.0	6.4	414	--	.01
31	.5	3.0	279	540	2.2	.7	13	1,030	--	.02
2.0	.1	1.2	--	9.6	.8	.3	9.4	216	--	--
1.6	0	3.0	205	19	1.8	.3	8.1	228	--	.01
46	.6	2.6	303	820	1.8	.8	27	1,460	--	.02
2.4	.1	2.1	--	15	2.0	.4	8.3	230	--	--
3.2	.1	3.2	--	18	1.0	.3	8.7	235	--	--
7.0	.2	2.1	221	29	3.6	.5	8.7	263	--	.01
2.9	.1	1.9	213	16	1.1	.4	9.2	235	--	<.01
2.0	.1	1.1	--	10	1.0	.3	9.4	218	--	--
370	9.0	6.2	--	870	35	.7	27	1,570	12	.01
280	6.0	5.4	--	600	26	.7	22	1,320	3.8	.03
660	14	7.8	--	1,500	85	3.2	7.8	2,560	--	--
--	--	--	--	--	--	--	--	--	--	--
590	23	4.3	--	1,200	52	1.2	7.5	1,970	--	--
1,200	36	6.7	--	2,500	160	.5	7.1	4,030	1.9	<.01
440	8.0	5.6	--	1,000	33	.8	29	1,990	--	--
230	22	1.5	--	40	66	2.6	7.4	651	--	--
350	28	1.9	--	300	87	2.6	4.2	1,010	--	--
320	27	2.1	--	210	90	3.0	7.1	873	--	--
--	--	--	--	--	--	--	--	--	--	--
440	17	4.0	--	570	77	2.2	6.4	1,420	--	--
510	15	4.0	--	1,000	98	1.1	6.8	1,820	--	--
320	6.0	6.2	--	750	65	.6	24	1,530	--	--

Local site number	Primary water-yielding unit	Date	Depth of well (ft)	Specific conductance (μS/cm)	pH	Water temperature (°C)	Hardness ($CaCO_3$)	Calcium, dissolved (Ca)	Magnesium, dissolved (Mg)
47-093-36d01	Twl	10-19-66	237	2,140	8.2	--	6	--	--
47-095-09ccc01	Twl	08-03-70	250	1,570	8.6	12.0	14	4.1	1.0
47-095-33bb01	Qa	10-18-67	44	6,800	8.1	11.0	1,700	260	260
48-088-28ccb01	Mm	06-22-75	--	403	7.9	12.0	220	45	25
48-088-28ccc02	Mm	06-12-75	1,200	411	7.6	15.0	230	48	26
48-088-29baa01	Mm	05-23-75	450	685	7.8	11.0	380	83	41
48-089-04abb01	TRPg	05-15-75	470	1,150	7.7	13.0	660	200	40
48-089-04acd01	Mm	05-14-75	1,362	367	7.8	--	220	47	24
	Mm	09-09-75	1,362	--	--	13.5	200	44	23
	Mm	08-30-88	1,362	362	7.7	14.0	200	40	25
48-089-06dcb01	€f	05-23-75	3,933	321	8.1	--	120	29	12
48-089-08dcb01	€f	05-15-75	3,987	301	8.0	27.5	110	24	12
48-089-25acb01	IPt	05-22-75	400	503	7.7	11.5	260	49	33
48-089-25acb01	IPt	09-09-75	400	--	--	11.5	280	56	34
48-089-25ada01	€f	05-22-75	2,287	295	8.0	--	140	23	20
	€f	09-09-75	2,287	--	--	--	130	26	16
48-089-28db01	TRc	08-20-88	120	1,900	--	14.0	950	230	92
48-090-11dba01	Qa	09-15-76	32	--	--	--	840	200	82
48-092-04ab01	Twl	10-17-66	107	2,080	8.1	--	130	--	--
48-092-04bda01	Twl	10-17-66	125	817	9.4	--	11	--	--
48-092-04ddc01	Twl	08-10-87	135	--	--	--	680	160	67
	Twl	08-17-88	135	4,000	--	22.0	610	150	58
48-092-06cad01	Twl	05-03-67	210	2,620	7.6	--	180	49	14
	Twl	04-11-70	210	2,230	8.0	--	140	39	10
48-092-16ccb01	Kl	08-04-70	2,360	1,140	9.0	--	7	2.3	.4
48-092-18ca 01	Twl	02-27-69	192	1,400	8.1	--	29	6.7	3.0
48-092-22ccc01	Kl	07-30-70	2,220	1,160	8.6	17.5	12	3.5	.8
48-092-27ccd01	Twl	08-17-88	250	1,360	--	17.0	30	8.1	2.4
48-093-28bdd01	Twl	04-24-70	80	1,280	8.4	--	19	5.7	1.1

from selected wells and springs--Continued

Sodium, dis- solved (Na)	Sodium- adsorp- tion ratio	Potas- sium, dis- solved (K)	Alka- linity, total (as $CaCO_3$)	Sulfate, dis- solved (SO_4)	Chlo- ride, dis- solved (Cl)	Fluo- ride, dis- solved (F)	Silica, dis- solved (SiO_2)	Dissolved solids (sum of con- stituents)	Nitro- gen, $NO_2 + NO_3$ dis- solved	Phos- phorous, total (P)
--	--	--	--	--	--	--	--	--	--	--
380	45	1.4	--	290	34	3.4	7.1	1,010	--	--
1,300	14	34	--	3,600	65	1.5	20	6,040	--	--
1.6	0	2.6	221	5.8	<.1	.2	9.2	223	--	.01
1.6	0	3.0	221	6.6	1.8	.3	8.9	231	--	.01
9.1	.2	2.8	238	130	5.5	.7	8.6	427	--	<.01
19	.3	4.4	189	490	5.5	.8	8.6	884	--	.04
.5	0	.9	197	9.9	1.8	.3	8.6	213	--	<.01
2.3	.1	.9	197	5.8	1.4	.2	9.4	207	--	<.01
1.7	0	.9	--	6.9	.6	.3	9.2	203	.43	--
12	.5	8.6	131	25	1.8	.4	11	178	--	<.01
13	.6	7.0	123	18	<.1	.4	11	161	--	<.01
7.0	.2	3.0	197	74	1.8	1.1	8.0	297	--	<.01
8.2	.2	3.3	189	100	1.8	1.1	8.5	328	--	<.01
8.6	.3	4.9	148	19	1.8	.4	9.2	176	--	<.01
9.9	.4	5.4	136	12	1.8	.3	9.4	166	--	<.01
58	.8	3.3	--	940	4.6	.4	17	1,450	1.4	<.01
120	2.0	2.3	427	670	9.1	.6	13	1,360	--	.01
--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--
740	13	6.7	--	1,900	140	.5	4.7	3,160	.10	.02
790	14	7.4	--	1,800	160	.5	4.3	3,080	.10	.02
580	19	3.8	348	950	59	2.6	8.5	1,870	--	--
480	18	3.4	--	750	69	3.2	7.7	1,560	--	--
280	47	2.3	--	2.8	42	4.4	2.3	720	--	--
300	25	2.5	--	100	150	2.2	6.2	814	--	--
280	36	2.0	--	30	82	4.0	11	706	--	--
290	24	2.8	--	140	75	2.0	6.7	773	.10	.01
290	31	2.0	--	160	100	2.8	7.4	784	--	--

Table 9.--Drinking-water regulations and criteria for selected chemical constituents used to evaluate water quality (modified from Larson, 1984)

[μg/L, micrograms per liter; mg/L, milligrams per liter]

Primary drinking-water regulation		Secondary drinking-water regulation	
Constituent	Maximum contaminant level[1]	Constituent	Secondary maximum contaminant level[2]
Arsenic	50 μg/L	Chloride	250 mg/L
Barium	1,000 μg/L	Copper	1,000 μg/L
Cadmium	10 μg/L	Dissolved solids	500 mg/L
Chromium	50 μg/L	Fluoride	2.0 mg/L
Fluoride	4.0 mg/L	Iron	300 μg/L
Lead	50 μg/L	Manganese	50 μg/L
Mercury	2 μg/L	Sulfate	250 mg/L
Nitrate (as nitrogen)	10 mg/L	Zinc	5,000 μg/L
Selenium	10 μg/L		

Livestock[3]	
Dissolved-solids concentration (mg/L)	Remarks
Less than 1,000	Relatively low level of salinity, generally considered freshwater. Excellent for all classes of livestock and poultry.
1,000 - 2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to the water or may cause watery droppings in poultry.
3,000 - 4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to the water. Poor water for poultry, commonly causing watery feces, increased mortality, and decreased growth, especially in turkeys.
5,000 - 6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.

Table 9.--Drinking-water regulations and criteria for selected chemical constituents used to evaluate water quality--Continued

Livestock[3]--Continued	
Dissolved-solids concentration (mg/L)	Remarks
7,000 - 10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although may be tolerable for older ruminants, horses, poultry, and swine under certain conditions.
More than 10,000	Risks with this highly saline water are so great that it cannot be recommended for use under any conditions.

Irrigation[4]	
Dissolved-solids concentration (mg/L)	Classification
500 or less	Water for which no detrimental effects usually are noticed.
500 - 1,000	Water that can have detrimental effects on sensitive crops.
1,000 - 2,000	Water that can have adverse effects on many crops; requires careful management practices.
2,000 - 5,000	Water that can be used for salt-tolerant plants on permeable soils with careful management practices.

[1] Maximum contaminant level is an enforceable, health-based maximum level for contaminants in public drinking-water supplies as defined in the Primary Drinking-Water Regulations established by the U.S. Environmental Protection Agency (1989a).

[2] Secondary maximum contaminant level is a nonenforceable, aesthetically based maximum level for contaminants in public drinking-water supplies as defined in the Secondary Drinking-Water Regulations established by the U.S. Environmental Protection Agency (1989b).

[3] Data from National Academy of Sciences and National Academy of Engineering, 1973, p. 308.

[4] Data from National Academy of Sciences and National Academy of Engineering, 1973, p. 335.

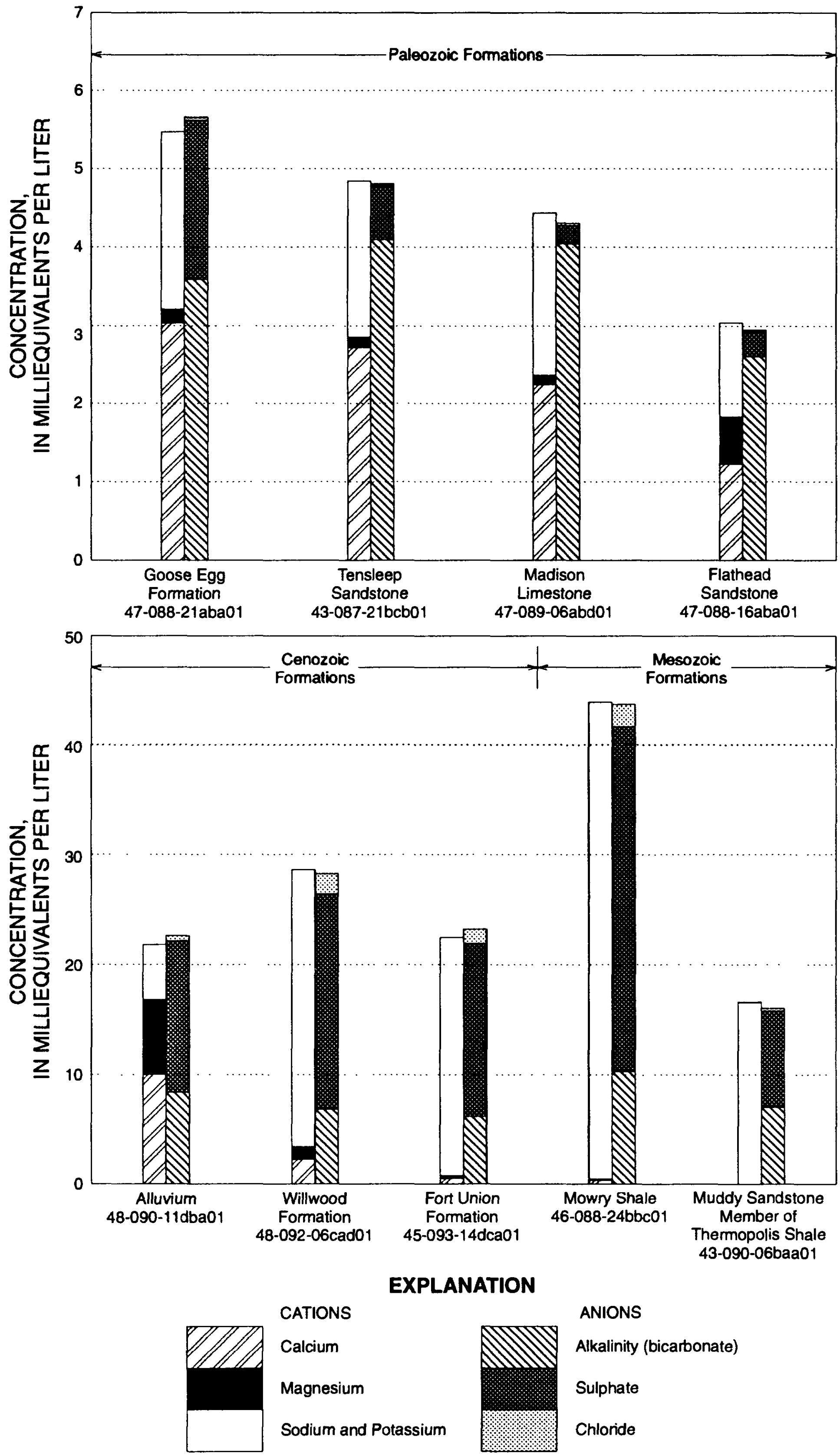


Figure 14.--Principal chemical constituents in ground-water samples from wells completed in selected formations.

contaminant level of 500 milligrams per liter (mg/L) as established by U.S. Environmental Protection Agency (1989b) for public drinking-water supplies. Livestock can tolerate concentrations of dissolved solids as great as 3,000 mg/L without serious health effects (table 9). Many crops require irrigation water with concentrations of dissolved solids less than 1,000 mg/L (table 9). Thus, water from many aquifers in Washakie County is suitable for livestock watering, but is unsuitable for irrigation water and domestic use.

The sodium-adsorption ratio (SAR) is a method of evaluating the suitability of water for irrigation. The SAR indicates the potential for sodium to replace adsorbed calcium and magnesium in soils. A large SAR indicates a high hazard of sodium replacing calcium and magnesium. This replacement process can be damaging to the soil and soil structure, causing deflocculation, and causing the soil to become impermeable to water (Hem, 1985, p. 216).

A graph of the classification of ground water for irrigation suitability is shown in figure 16 (U.S. Salinity Laboratory Staff, 1954). The sodium hazard is classified S1 to S4 with increasing SAR, and the salinity hazard is classified C1 to C4 with increasing specific conductance. The median specific conductance and SAR are plotted for water from each geologic unit. Cenozoic and Mesozoic formations with water samples having large specific conductances and large SAR both have high to very high salinity and sodium hazards. Paleozoic formations and one Mesozoic formation (Gypsum Spring Formation) have a medium salinity hazard and a low sodium hazard.

Agricultural Chemicals in Surface and Ground Water

The contamination of surface and ground water by agricultural chemicals is a growing State and national concern. The contamination of surface and ground water by herbicides is dependent on the mobility and persistence of chemicals in the environment (Jury and others, 1987). The structure and nature of the chemicals and environmental factors, such as precipitation, applied irrigation water, soil temperature, microbe populations, and topography, affect how a chemical will be transported in water or sediment, and how long the compound will exist before degrading to other forms.

The Wyoming Department of Agriculture and the U.S. Geological Survey began a cooperative program to sample surface and ground water throughout the State. The Nowood River near Ten Sleep was sampled for herbicides during the summer and fall in 1983 and 1984. Both samples collected in 1983 contained Picloram and one sample in 1984 contained Picloram (table 10). During 1987, five wells were sampled in Washakie County for a suite of commonly used herbicides. All five samples contained small concentrations of Picloram (Tordon), one sample contained 2,4-D, and one sample contained Dicamba (table 10). Four of these wells and three additional wells were sampled in 1988. Small concentrations of herbicides were detected in five of the seven samples (table 10). Picloram was found in two samples, and Dicamba was present in four samples. The wells sampled during 1987 and 1988 are completed in the Willwood Formation. Herbicides in the water samples from these wells might indicate that the alluvium is recharging the underlying Willwood Formation or that water from the alluvium may be leaking into the wells and contaminating them.

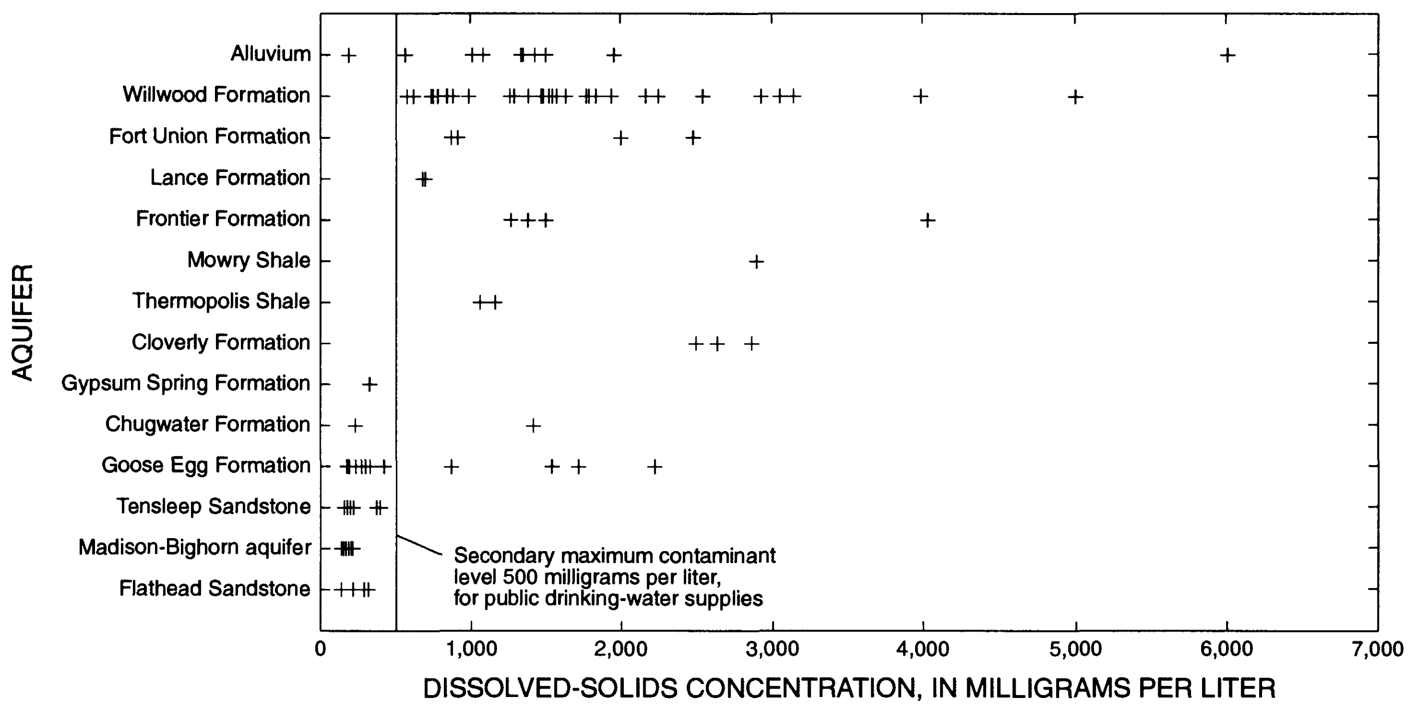
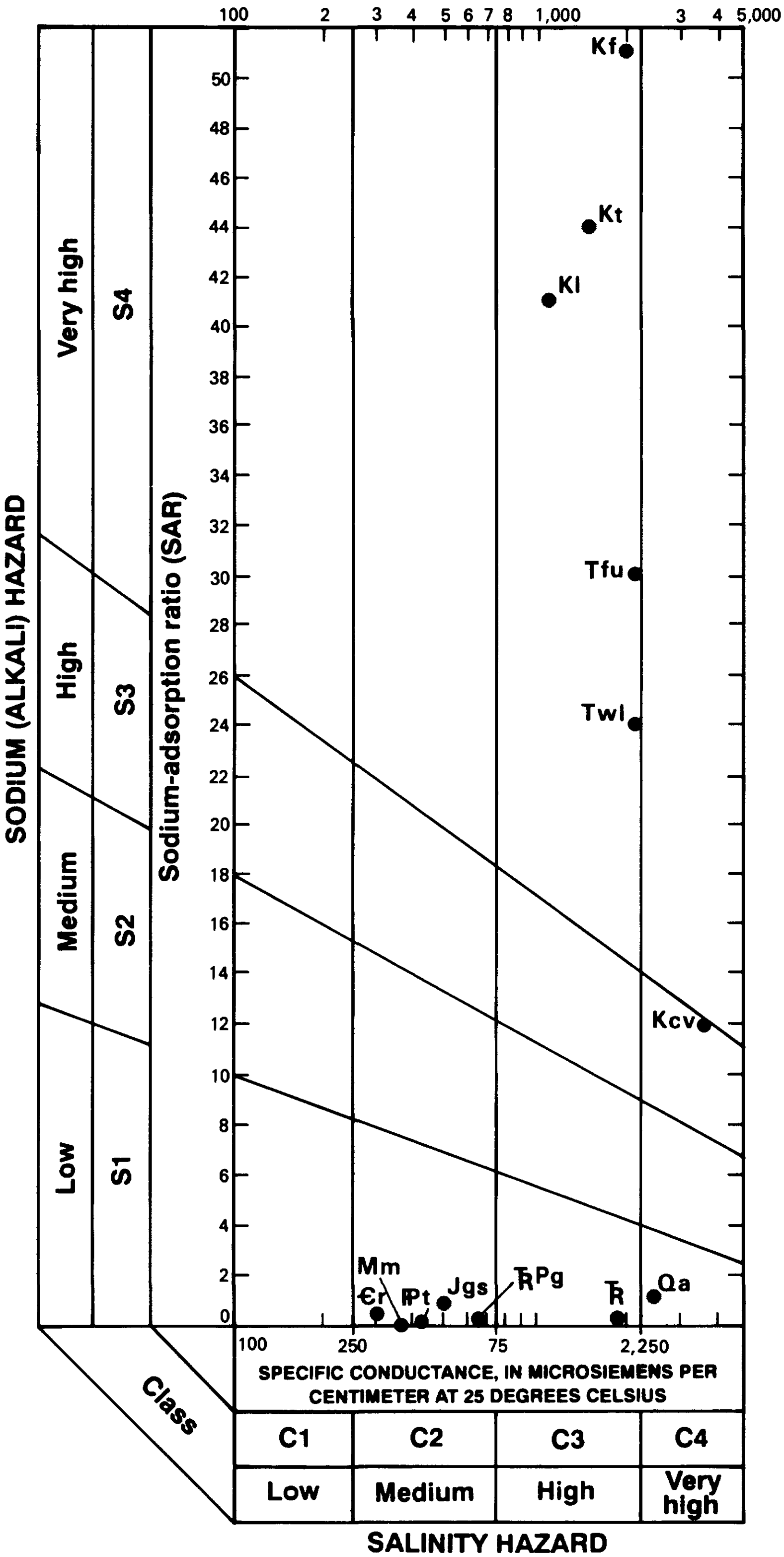


Figure 15.--Concentrations of dissolved solids in water samples, by aquifer.



EXPLANATION

CENOZOIC FORMATIONS

Qa	Alluvium
Twl	Willwood Formation
Tfu	Fort Union Formation

MESOZOIC FORMATIONS

Kl	Lance Formation
Kf	Frontier Formation
Kt	Thermopolis Shale
Kcv	Cloverly Formation
Jgs	Gypsum Spring Formation
TR	Chugwater Formation
TRPg	Goose Egg Formation

PALEOZOIC FORMATIONS

IPt	Tensleep Sandstone
Mm	Madison Limestone
€r	Flathead Sandstone

Figure 16.--Classification of ground water for irrigation suitability. Median values of specific conductance and sodium-adsorption ratio plotted for each geologic unit.

Table 10.--Chemical analyses of surface and ground water for herbicides

[Site type: SW, surface water; GW, ground water. Water-yielding unit: Twl, Willwood Formation. μg/L, micrograms per liter; <, less than.]

Surface-water station or local well number	Water-yielding unit	Site	Date	Picloram (Tordon, Amdon), total (μg/L)	2,4-D, total (μg/L)	2,4,5-T, total (μg/L)	Silvex, total (μg/L)	Dicamba, (Mediben, Banvel D), total (μg/L)	2,4-DP, total (μg/L)
Nowood River near Ten Sleep (06270000)		SW	07-08-83	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			09-09-83	.01	< .01	< .01	< .01	< .01	< .01
			06-29-84	< .01	< .01	< .01	< .01	< .01	< .01
			09-06-84	.01	< .01	< .01	< .01	< .01	< .01
46-093-15bdd01	Twl	GW	08-17-87	.01	< .01	< .01	< .01	< .01	< .01
	Twl		08-18-88	.11	< .01	< .01	< .01	.01	< .01
46-093-15cab01	Twl	GW	08-17-87	.04	< .01	< .01	< .01	< .01	< .01
	Twl		08-18-88	< .01	< .01	< .01	< .01	.01	< .01
46-093-30dba01	Twl	GW	08-20-88	< .01	< .01	< .01	< .01	< .01	< .01
47-092-09bcc01	Twl	GW	08-09-87	.02	< .01	< .01	< .01	< .01	< .01
	Twl		08-17-88	.01	< .01	< .01	< .01	< .01	< .01
47-092-26bab01	Twl	GW	08-17-88	< .01	< .01	< .01	< .01	< .01	< .01
47-092-04dcd01		GW	08-09-87	.16	< .01	< .01	< .01	.03	< .01
48-092-04ddc01	Twl	GW	08-10-87	.02	.13	< .01	< .01	< .01	< .01
	Twl		08-17-88	< .01	< .01	< .01	< .01	.01	< .01
48-092-27ccd01	Twl	GW	08-17-88	< .01	< .01	< .01	< .01	.02	< .01

The herbicides detected in the surface and ground water in Washakie County are broad-spectrum herbicides that are widely used on crops, rangeland, pasture, and lawns. The U.S. Environmental Protection Agency (EPA) issues lifetime health advisories that contain information on public-health risks, treatment technologies, and specific concentrations that are acceptable in drinking water (U.S. Environmental Protection Agency, 1989c).

The EPA lifetime health-advisory levels for herbicides detected in Washakie County are as follows:

Picloram (Tordon) 500 μg/L
2,4-D 70 μg/L
Dicamba 200 μg/L

EPA lifetime health-advisory levels are considered to be acceptable for drinking everyday over the course of a person's lifetime.

The concentrations of herbicides detected in water samples collected in Washakie County (table 10) are substantially less than the EPA lifetime health-advisory levels for these compounds and should not pose any health risks to humans according to EPA regulations. However, continued monitoring would identify any potential changes in the concentrations of herbicides in surface and ground water in Washakie County.

WATER USE

Most of the water used in Washakie County is from surface water (Solley and others, 1988). The two principal centers of population are along the Bighorn and the Nowood Rivers. Similarly, most of the irrigated lands are near large streams, indicating the importance of surface-water resources to residents of the county.

The most recent water-use estimates for Wyoming were compiled for 1985 by the U.S. Geological Survey in cooperation with State and local agencies. Estimates of total offstream water use are presented in table 11. Seven categories of offstream use are listed and the amount of water used in each category is separated into surface- and ground-water sources. Offstream use is defined as water diverted or withdrawn from a ground- or surface-water source for conveyance to the place of use. Consumptive use refers to water that is removed from the water supply by evaporation, transpiration, incorporation into products or crops, or consumption by humans or livestock.

Water for public supply is withdrawn by public and private suppliers, and delivered to groups of users. Most of the water in this category is used for domestic purposes, with small quantities delivered to commercial and industrial users. Commercial use includes water for motels, hotels, restaurants, office buildings, other commercial facilities, and institutions.

Water for domestic use includes household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, and watering lawns and gardens. This category only includes individual self-supplied withdrawals and does not include water from public suppliers.

Water for industrial use includes water used for fabrication, processing, washing, cooling, petroleum refining, and processing of agricultural products. Mining use includes water for extraction of coal and minerals, as well as petroleum and natural gas. Also included in mineral uses is water used in quarrying, milling, and mine operations.

Table 11.--Estimated total offstream water use for water year 1985
[from Solley and others, 1988]

Offstream use	Units in million gallons per day: Surface water	Ground water	Total	Consumptive use
Public supply	0.00	1.45	1.45	0.36
Commercial	.08	.10	.18	.04
Domestic	.02	.22	.34	.10
Industrial	.05	.27	.32	.06
Mining	1.35	6.44	7.79	1.08
Agriculture (nonirrigation)	.47	.12	.59	.59
Agriculture (irrigation)	216	4.23	220	169
Totals	218	12.8	231	[1]171

[1] Includes estimated 80.8 million gallons per day conveyance losses.

Nonirrigation agricultural uses include water for livestock, feedlots, dairy operations, and other farm needs whereas agricultural irrigation uses include water for crops and pastures, and recreational lands such as parks and golf courses. Agricultural water use includes conveyance losses, which is water that is lost in transit from a pipe, canal, conduit, or ditch by leakage or evaporation.

Surface water supplies about 94 percent of water for off-stream use in Washakie County. Irrigation accounts for about 99 percent of the surface water, 33 percent of the ground-water offstream use, and about 99 percent of the consumptive water use. (This includes 47 percent conveyance loss and 52 percent irrigation consumption.) Nearly 83 percent of the water used for mining is withdrawn from ground-water sources. Mining uses about 50 percent of the total ground water withdrawn in the county.

SUMMARY

Data on the surface- and ground-water resources are compiled to summarize the water resources in Washakie County. Streamflow characteristics are described for three types of streams--perennial, intermittent, and ephemeral. Perennial streams have continuous streamflows sustained by water stored in snowpack and ground-water discharge. High streamflows are caused by spring snowmelt, and low streamflows occur in the winter months when the snowpack is frozen and ground-water discharge is at its smallest rate. Regulated perennial streams have streamflow variations attributable to diversions, withdrawals, and reservoir regulation. Low streamflows generally occur during the irrigation season with higher streamflows in the winter and spring, depending on storage needs. Intermittent and ephemeral streams generally have their headwaters near the center of the county and are characterized by periods of no flow. High streamflows in intermittent streams usually are associated with snowmelt or thunderstorms; high streamflows in ephemeral streams are only associated with thunderstorms.

The principal ground-water aquifers in Washakie County, in descending order, are as follows: alluvium, Willwood Formation, Fort Union Formation, Goose Egg Formation, Tensleep Sandstone, Madison-Bighorn aquifer, and the Flathead Sandstone. The alluvium is distributed along the major streams. The Willwood Formation is exposed in the central and western parts of the county, and the Fort Union Formation is exposed in the center of the county. The remaining principal aquifers crop out along the flank of the Bighorn Mountains in the eastern part of the county. The range in yields from wells completed in the principal aquifers, in gallons per minute, is as follows: alluvium, 10 to 40; Willwood Formation, 1 to 28; Fort Union Formation, 4 to 10; Goose Egg Formation, 5 to 50; Tensleep Sandstone, 1 to 250; Madison-Bighorn aquifer, 15 to 2,500; and Flathead Sandstone, 500 to 2,300.

The Tensleep Sandstone, Madison-Bighorn aquifer, and the Flathead Sandstone probably have the greatest potential for further development in eastern Washakie County. Wells, when properly developed, could yield as much as 250 gal/min from the Tensleep Sandstone, as much as 2,500 from the Madison-Bighorn aquifer, and as much as 2,300 from the Flathead Sandstone. These aquifers could yield the quantities of water of a quality suitable for domestic, irrigation, and livestock use.

Declines in yield from the Madison-Bighorn aquifer have been documented at the well (47-088-01cda01) and East Spring (47-088-01dbc01) at the Wigwam Fish Rearing Station for the period 1972 to 1988. Two wells completed chiefly in the Flathead Sandstone and in the Madison-Bighorn aquifer have shown moderate to substantial declines in hydraulic head. These declines are because of continuous discharge from the wells or leakage in the well casing from the Flathead Sandstone to the Madison-Bighorn aquifer.

Surface-water quality varies with discharge and with stream type. Generally, dissolved-solids concentrations vary inversely with discharge and increase with distance from the headwaters. Sediment loads in the Fifteenmile Creek drainage decreased after the construction of erosion-control structures.

Water in the Cenozoic formations is predominantly sodium sulfate type, with the exception of water in the alluvium, which in some areas is calcium magnesium sodium sulfate type. Water in the Mesozoic formations also is classified as sodium sulfate type. Water in the Paleozoic formations is calcium carbonate type. Herbicides have been detected in small concentrations in six wells completed in the Willwood Formation.

Surface water supplies about 94 percent of the water for offstream use in the county. Irrigation accounts for 99 percent of the surface water and 33 percent of the ground water used offstream. The largest use of ground water is mining--about 50 percent of the total ground-water withdrawals.

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