WATER RESOURCES
OF
WESTON COUNTY, WYOMING

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4079

Prepared in cooperation with the
WYOMING STATE ENGINEER

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1986

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information contact:

District Chief
U.S. Geological Survey
2120 Capitol Avenue
P.O. Box 1125
Cheyenne, Wyoming 82003
Telephone: (307) 772-2153

Copies of this report can be purchased from:

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Box 25425
Denver, Colorado 80225
Telephone: (303) 236-7476

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CONVERSION FACTORS

For the use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-foot (acre-ft)	.001233	cubic hectometer
cubic foot per second (ft^3/s)	.02832	cubic meter per second
foot (ft)	.3048	meter
foot per day (ft/d)	.3048	meter per day
foot squared per day (ft^2/d)	.09290	meter squared per day
gallon per minute (gal/min)	.06308	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

Weston County, an area of about 2,400 square miles in northeastern Wyoming, includes parts of the Black Hills and the Powder River basin. Because surface water is scarce, ground water is used extensively for municipal, agricultural, and industrial supplies.

Ground water has been developed from rocks ranging in age from Mississippian to Quaternary. Adequate supplies for domestic or stock use can be developed from wells generally less than 1,000 feet deep, except in an area underlain by a thick sequence of predominantly marine shale that extends approximately from the southeast to the northwest corners of the county. Wells completed in the shale sequence generally will yield only small quantities of very mineralized water, which is unsuitable for most uses.

In the early 1960's, decreases in artesian pressures occurred in some wells completed in the Lakota Formation of Early Cretaceous age and the Pahasapa Limestone of Early Mississippian age, equivalent to the Madison Limestone. Only the decrease of artesian pressure in the Lakota was attributed to development. Extensive development of either of these aquifers, however, may result in significant interference between nearby wells completed in the same aquifer.

The Morrison and Sundance Formations of Jurassic age are within a few hundred feet of the overlying Lakota Formation and could be developed as an alternative to the Lakota to help limit loss of pressure in the Lakota in the event additional supplies are needed. The much deeper Pahasapa Limestone generally is developed because large supplies are possible from that formation. There are no alternative, large-yield aquifers that could be developed to limit loss of pressure in the Pahasapa in the event of increased development.

The only perennial streams in Weston County originate in the Black Hills. At the only long-term gaging station in the county, Beaver Creek near Newcastle, seasonal variation of streamflow is similar to that of precipitation. The mean daily flow is greatest during June and least during late August.

INTRODUCTION

An investigation of the water resources of Weston County was started in 1974 by the U.S. Geological Survey in cooperation with the Wyoming State Engineer. The investigation was part of a continuing series of cooperative studies to improve knowledge about the water resources of the State. Weston County was selected for study because of the county's proximity to the major coal deposits to the west. Because surface water is scarce in the county, ground water is used extensively for municipal, agricultural, and industrial supplies. Ground water occurs at relatively shallow depths, compared to that in areas where the coal is being mined. An assessment of the ground-water resources was undertaken, in anticipation of increased development of ground water for activities related to coal mining.

Purpose and Scope

The purpose of this report is to describe the water resources using the information available at the time the investigation was terminated. Emphasis is on the occurrence, chemical quality, and availability of ground water. Streamflow characteristics for Beaver Creek as determined at a gaging station near Newcastle, the only long-term continuous streamflow-gaging station in the county, also are included.

Description of Area

Weston County, comprising an area of 2,408 mi^2, is located in northeastern Wyoming. It is bounded on the north by Crook County, on the west by Campbell County, on the south by Niobrara and Converse Counties, and on the east by South Dakota (fig. 1).

A small part of the Black Hills occurs in the extreme northeastern part of the county, where the maximum altitude is about 6,600 ft above sea level. Immediately bordering the Black Hills is a broad lowland cut into a series of easily eroded shales. Altitudes in this area range from about 3,600 ft in the southeast to about 4,400 ft in the northwest. The principal towns and routes of travel are located in this lowland. Westward toward the center of the Powder River basin, the altitude increases slightly. The altitude is about 5,300 ft in the southwest corner of the county.

Approximately 90 percent of the surface drainage is southward to the Cheyenne River. Most of the course of the river, however, is south of the county. Beaver Creek, draining the eastern part of the county, is the main tributary of the Cheyenne River in Weston County. Streams in the remaining 10 percent of the county (the northwestern part) drain northwest to the Belle Fourche River.

The only streams in the county with perennial flow in upstream reaches originate in the Black Hills. Stockade Beaver Creek is the only stream that has perennial flow to its mouth. Beaver Creek is perennial downstream from its confluence with Stockade Beaver Creek.

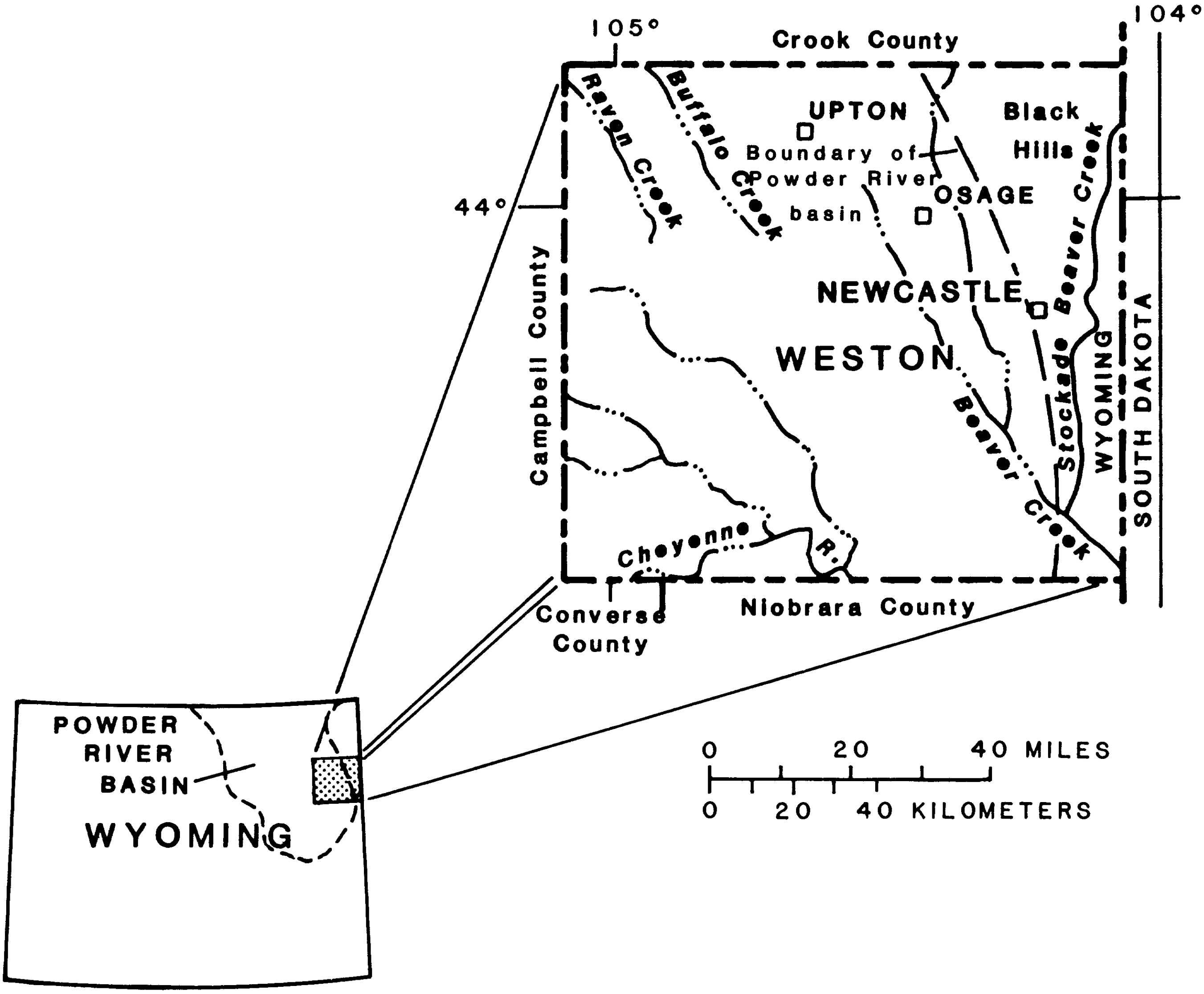

Figure 1.--Location of Weston County.

Previous Water-Resources Investigations

Hodson and others (1973) described the water resources of the Powder River basin and adjacent areas--an area that includes Weston County. Whitcomb (1960 and 1963) described artesian conditions in aquifers near Osage and Newcastle.

Description of the hydrology of the Pahasapa Limestone of Early Mississippian age, which is the lateral equivalent of part of the Madison Limestone of Mississippian age, was included in regional studies of the Madison by the Wyoming State Engineer (1974), Swenson (1974), Swenson and others (1976), and Konikow (1976).

Regional streamflow studies pertinent to the area are those of Matthai (1968), Lowham (1976), and Craig and Rankl (1978).

Well- and Spring-Numbering System

Wells and springs in this report are numbered according to the Federal system of land subdivision in Wyoming (fig. 2). The first number indicates the township and the second number the range. The letters following these numbers indicate the direction from the baseline and principal meridian. In Weston County, all townships are north of the baseline, and the ranges are west of the principal meridian. The third number is the section in which the well is located. Uppercase letters following the section number indicate the position of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10-acre tract). The subdivisions of a section are lettered A, B, C, and D in a counterclockwise direction, starting in the northeast quarter. A sequence number, beginning with 01, is assigned to distinguish wells in the same 10-acre tract.

GEOLOGIC SETTING

The Black Hills and the Powder River basin are the principal structural features in Weston County. Rocks of Paleozoic and Early Cretaceous age are exposed on or near the flanks of the Black Hills but are deeply buried a short distance away. Progressively younger formations crop out farther from the Black Hills. A summary of the stratigraphy is given in table 1.

The general geologic structure of the county, exclusive of the Black Hills, is shown by contours drawn on top of the Inyan Kara Group of Early Cretaceous age (fig. 3). The structures of all of the formations from Cambrian through Cretaceous age are similar to that of the Inyan Kara. The altitude of the different formations in the basin can be approximated by their relation to the Inyan Kara from table 1 and the altitude of the Inyan Kara from figure 3.

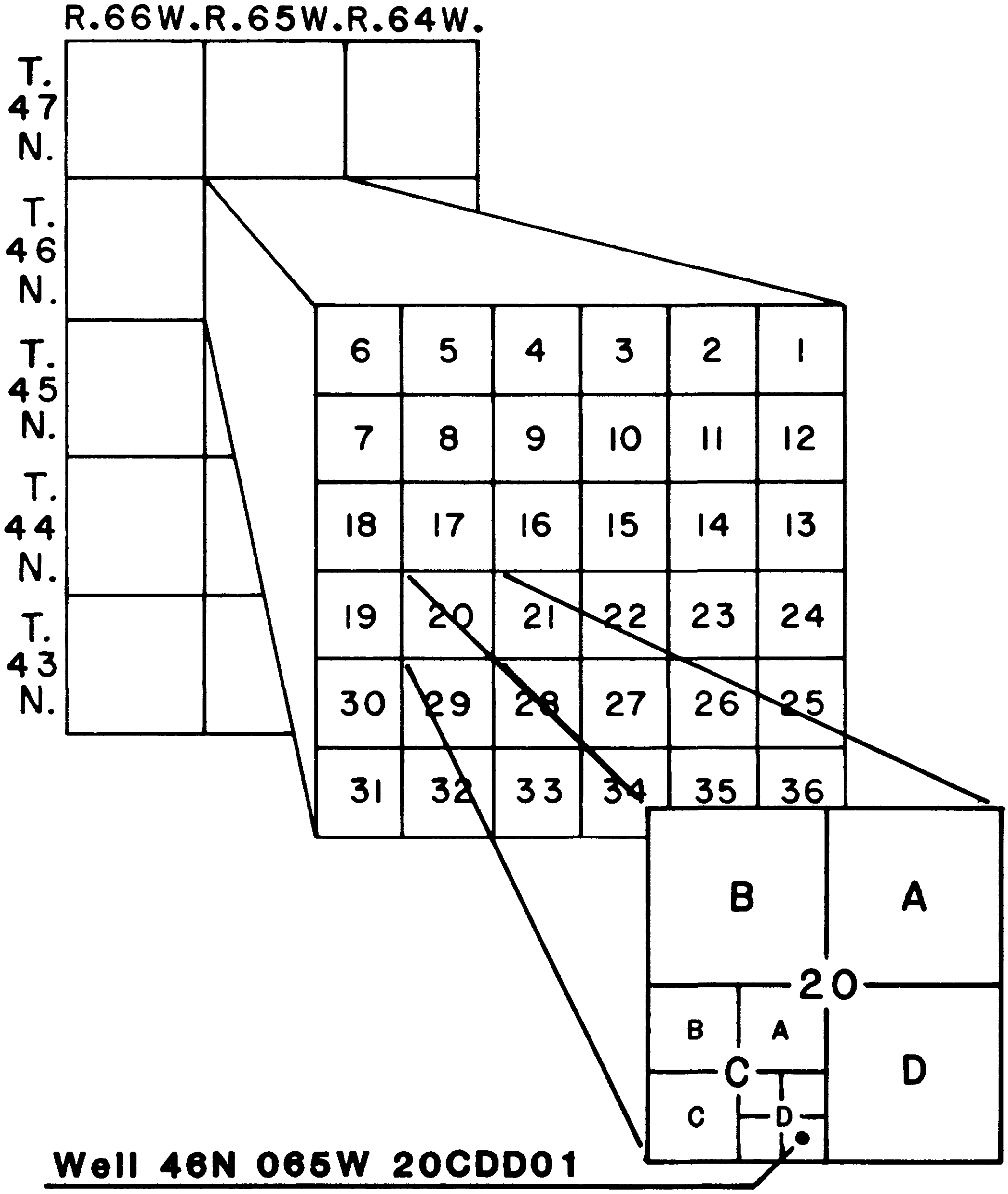

Figure 2.--Well- and spring-numbering system.

Table 1.--*Summary of stratigraphy*[1]

System and series	Geologic unit		Thickness (feet)	Lithology
Quaternary	Landslide deposits[2]		--	Commonly displaced material of Early Cretaceous and Jurassic age.
	Alluvium[2]		0-187	Mainly silt, clay, and fine-grained sand, but coarse-grained sand and gravel do occur.
Paleocene	Fort Union Formation		2,000	Fine-grained sandstone and interbedded shale, carbonaceous shale and coal; nonmarine. Includes upper part of Fort Union and underlying Tullock Member.
Upper Cretaceous	Lance Formation		900-1,400	Light-gray sandstone and dark-gray shale and sandy shale; nonmarine.
	Fox Hills Sandstone		50-200	Fine- to medium-grained, light-gray and light-yellow-gray sandstone with thin beds of dark-gray sandy shale; marine.
	Pierre Shale		2,500-2,900	Dark-gray shale, some sandy shale, siltstone, sandstone, and limestone concretions; many bentonite beds; marine.
	Niobrara Formation		200	Marl and shale; weathers light gray and yellowish orange; several thin bentonite beds; marine.
	Carlile Shale		500	Dark-gray shale; contains Turner Sandy Member that consists of shale intercalated with siltstone and fine sandstone; marine.
	Greenhorn Formation		275	Dark-gray to brown calcareous shale and thin-bedded limestone; marine.
	Belle Fourche Shale		400-750	Gray to black shale with thick bentonite beds; siderite and limestone concretions; marine.
Lower Cretaceous	Mowry Shale		200	Hard, siliceous shale, weathers light gray; many bentonite beds; marine.
	Newcastle Sandstone		10-100	Lenticular beds of light-gray sandstone, dark-gray shale and claystone, and gray bentonite; marine and nonmarine.
	Skull Creek Shale		200	Grayish-black shale with local siltstone partings; marine.
	Inyan Kara Group	Fall River Formation	125-200	Fine- to medium-grained brown weathering sandstone, light- to dark-gray siltstone, and dark-gray shale; locally carbonaceous; marginal marine.
		Lakota Formation	50-370	Light-gray sandstone and conglomerate; variegated sandy claystone; continental.
Upper Jurassic	Morrison Formation		100	Greenish-gray and grayish-red claystone and marl and grayish-white sandstone; nonmarine.
Upper Jurassic / Middle Jurassic	Sundance Formation		375	Greenish-gray shale, light-gray and light-yellowish-gray sandstone, sandstone, and glauconitic limestone; marine.
Middle Jurassic	Gypsum Spring Formation		0-20	White, massive gypsum and red claystone.

Table 1.--*Summary of stratigraphy*[1]--Continued

System and series	Geologic unit	Thickness (feet)	Lithology
Triassic	Spearfish Formation	450-650	Red siltstone, sandstone, and conglomerate; thick gypsum beds in lower half.
Permian	Minnekahta Limestone	40	Light-gray, thin-bedded limestone.
	Opeche Shale	75-100	Red, sandy siltstone and shale.
Permian / Pennsylvanian	Minnelusa Formation	700-800	Light-gray and red sandstone, gray limestone and dolomite, red shale and local gypsum and anhydrite; marine.
Lower Mississippian	Pahasapa Limestone	450-600	Light-gray limestone, locally dolomitic; marine.
Devonian	Englewood Limestone	50	Pinkish-gray limestone; marine.
Ordovician	Whitewood Dolomite	0-50	Light-gray to tan dolomite; marine.
	Winnipeg Formation	0-50	Light, yellowish-gray to greenish-gray siltstone and greenish-gray shale; marine.
Ordovician / Upper Cambrian	Deadwood Formation	200	Brown sandstone, some greenish-gray shale, and gray limestone; marine.
Precambrian	Undifferentiated	---	Igneous and metamorphic rocks.

[1]Based chiefly on data from Dobbin and others (1957), Brobst (1961), Brobst and Epstein (1963), Cuppels (1963), Mapel and Pillmore (1963 and 1964), and Robinson and others (1964).
[2]Order does not indicate age.

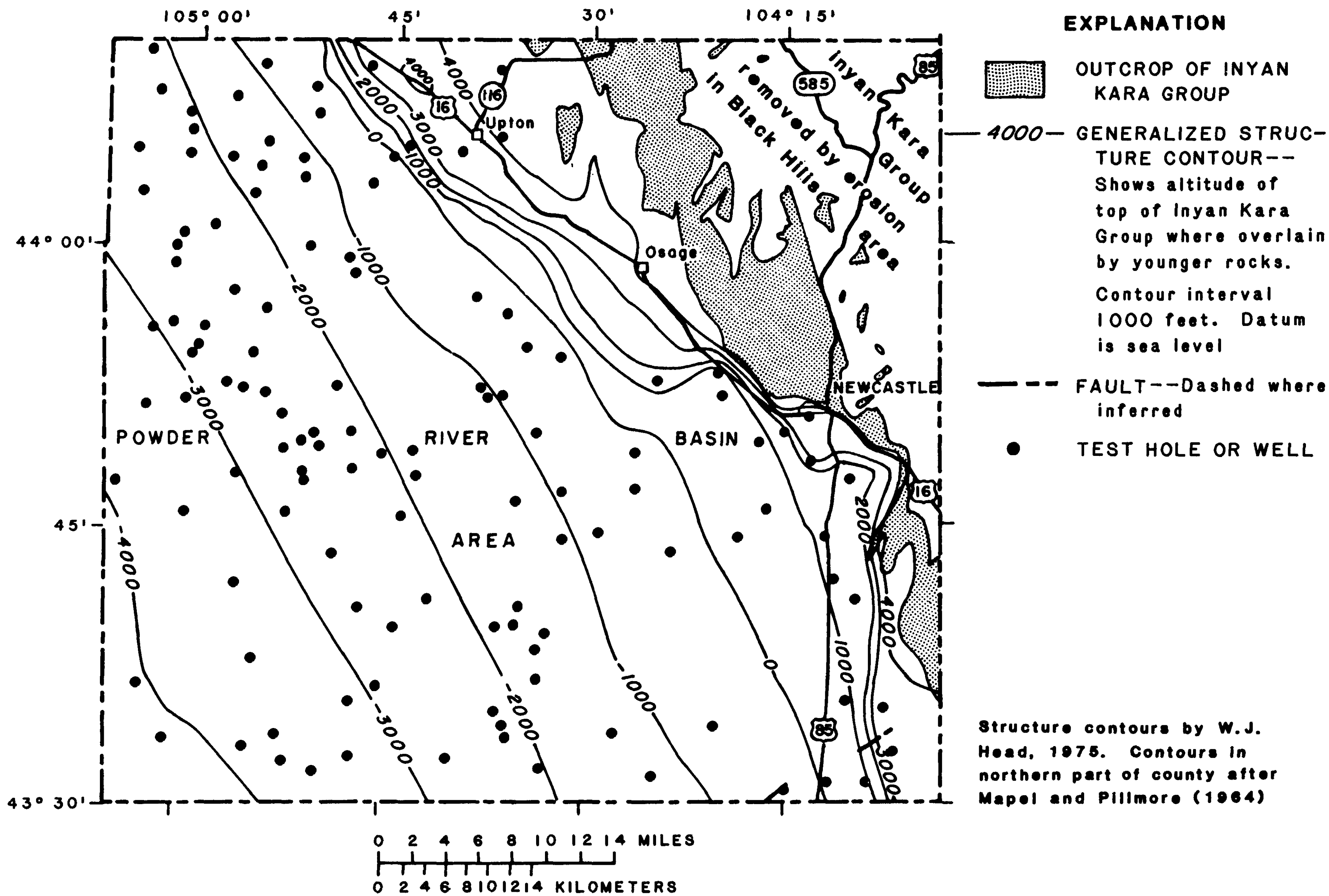

Figure 3.--Generalized structure contours on top of the Inyan Kara Group in part of Weston County.

GROUND WATER

Occurrence of Ground Water

Meinzer (1923), Wenzel (1942), and numerous others have fully discussed the principles of the occurrence and movement of ground water. Only a few definitions and principles will be discussed in this report.

Porous rocks contain interstices, which are open spaces that form the receptacles for water. The size of the interstices in a sedimentary rock depends on the size of the particles, the degree of sorting, and the degree of compaction and cementation. Interconnected interstices form the conduits through which water may move through the rocks.

Permeability is the property of a porous material that permits it to transmit water through its interconnected interstices under a hydraulic gradient. In the more permeable rocks, such as deposits of unconsolidated sand and gravel, the interstices are relatively large and will permit free movement of water. Rocks such as shale, siltstone, and fine sandstone are less permeable, so movement through them is much slower. Hard, massive formations may have secondary permeability resulting from deformation or solution that occurred after the rocks were deposited. Rocks that are capable of yielding recoverable quantities of water to wells or springs are called aquifers.

The zone of saturation is that zone in which permeable rocks generally are saturated with water under hydrostatic pressure. The water table, which is not a flat surface, has irregularities related to those of the land surface, although smoother. The water table is not stationary; instead, it fluctuates as water is added to or removed from the underground reservoir.

An artesian aquifer is one in which water will rise in a well to some level higher than the top of the aquifer. For this to occur, a relatively impermeable rock layer must overlie the aquifer and confine the water under pressure.

The potentiometric surface is an imaginary surface that everywhere coincides with the static level of the water in the aquifer. If the potentiometric surface is above the land surface, water in wells that penetrate the aquifer will flow. The potentiometric surface also is irregular, but its irregularities may not be related to those of the land surface. The water table is a particular potentiometric surface.

Geologic Units and their Water Resources

There are 28 geologic units shown in table 1, 17 of which are known to yield water to wells or springs in Weston County. Water-yielding properties of the units, and the chemical quality of water contained in them, greatly differ in part because of the differences in lithology. Too few wells have been drilled into many of the units to accurately describe their water-yielding properties and the chemical quality of water contained in them. Therefore, in this report the geologic units are grouped into seven geohydrologic units. The geohydrologic units are contiguous and, insofar as possible, comprise rocks formed in similar types of environments.

The geohydrologic units, from oldest to youngest, are: (1) Igneous and metamorphic rocks; (2) marine carbonate and sandstone sequence; (3) red-bed and gypsum sequence; (4) marine, marginal marine, and continental sandstone and shale sequence; (5) marine shale sequence; (6) continental sandstone and shale sequence; and (7) unconsolidated alluvium and landslide deposits. The areas of outcrop of the geohydrologic units are shown on plate 1. Information on distribution of individual formations can be obtained from maps referenced on plate 1. The lithology and thickness of the formations are summarized in table 1. The depths, water levels, yields, and distribution of selected wells completed in the formations are given on plate 1. Chemical analyses of ground water are given in table 2 (at end of report).

Igneous and Metamorphic Rocks

Igneous and metamorphic rocks of Precambrian age are exposed in the center of the Black Hills, mainly in South Dakota, northeast of Weston County. They underlie the sedimentary rocks and are deeply buried throughout the county.

Water-yielding properties.--The ability of the igneous and metamorphic rocks in Weston County to store and transmit water depends on development of secondary permeability by weathering and fracturing. Weathering could have occurred before the overlying sediments were deposited, and fracturing may have occurred at several different times during the geologic past. No wells are developed in these rocks within the county. However, elsewhere in the State, yields adequate for stock and domestic purposes are developed where the rocks occur at the surface. Because secondary permeability decreases with increased depth of burial, yields of wells in Weston County probably would be less than those elsewhere in the State.

Chemical quality of water.--Chemical-quality data are not available for water from these rocks at the depth they occur in the county.

Future development.--The great depth at which the rocks occur, the uncertain yield and quality of water from them, and the presence of shallower aquifers make future development of water from the rocks unlikely.

Marine Carbonate and Sandstone Sequence

The marine carbonate and sandstone sequence predominantly consists of marine carbonates and sandstone, and has an aggregate thickness of about 1,500 ft in the county. From oldest to youngest, the formations included in this unit are the Deadwood Formation of Late Cambrian and Early Ordovician age, the Winnipeg Formation and the Whitewood Dolomite of Ordovician age, the Englewood Limestone of Devonian and Early Mississippian age, the Pahasapa Limestone of Early Mississippian age (equivalent to the Madison Limestone), and the Minnelusa Formation of Pennsylvanian and Early Permian age.

Water-yielding properties.--The marine carbonate and sandstone sequence yields larger quantities of water from individual wells than other sequences in the county. Some wells flow more than 1,000 gal/min. The largest yields are mostly from the Pahasapa Limestone. However, because there are large areal variations in permeability in the Pahasapa Limestone, there also are large areal variations in well yields. For example, well 45N 061W 20DCA01 yields 1,450 gal/min, whereas well 45N 061W 29CBB01 yields 119 gal/min. Both wells are completed in the Pahasapa.

The large variation in permeability is further indicated by the wide range in transmissivity determined for the Pahasapa in the area. The following tests of wells completed in the Pahasapa were made in 1972:

Well number	Transmissivity (feet squared per day)	Remarks
46N 062W 18BDC01	0.6	8-minute recovery of flowing well.
46N 063W 15BA 01	86	1,000-minute recovery.
46N 064W 12CC 01	230	65-minute recovery.
46N 065W 23BAD01	840	--
46N 066W 25DBB01	1,800	10-minute drawdown.
	4,100	recovery from 10-minute drawdown.
48N 065W 25CC 01	5,000	900-minute recovery.
48N 065W 35CCB01	250	300-minute drawdown.

The data were analyzed using the modified nonequilibrium method. The method is not strictly applicable, however, because the analysis assumes the aquifer to be homogeneous. Nonetheless, the large variability in transmissivity in the Pahasapa is evident.

The second major water-yielding formation in the marine carbonate and sandstone sequence is the Minnelusa Formation. It consists of a significant percentage of sandstone with some primary permeability. The largest yield from this formation in the county is 300 gal/min from well 47N 064W 12CCC01.

Although no wells yield water from the Deadwood Formation in Weston County, a well completed in the formation in adjacent Crook County yielded 55 gal/min during a drill-stem test of an oil test well in the interval from 4,092 to 4,355 ft. Similar yields may be possible in Weston County.

Chemical quality of water.--Water from the Pahasapa Limestone and the Minnelusa Formation generally is either a calcium bicarbonate or calcium sulfate type (table 2). The water in the Pahasapa is a bicarbonate type near the recharge area of the Black Hills, and grades to a sulfate type away from the Hills. The sulfate is from the solution of gypsum and anhydrite. The solution of these evaporites in the recharge area has resulted in a decrease in thickness of the Minnelusa Formation from 900 ft, where the formation occurs at depth, to 700 ft, where the formation is near the surface (Cuppels, 1963, p. 227).

Future development.--Yields in excess of 500 gal/min probably can be developed from the Pahasapa Limestone in all parts of the county. However, as stated earlier, large areal variations in yield can be expected. In the early 1960's, yields of flowing wells completed in the Pahasapa in the vicinity of Newcastle decreased. At that time, development was not considered as one of the factors causing the decrease (Whitcomb, 1963, p. 11-12). However, large-scale development could result in decreased pressure in the area and, therefore, in decreased flow.

Yields in excess of 100 gal/min probably can be developed in the Minnelusa only from deep wells, because large drawdowns will be required for such yields. However, where yields of 100 gal/min are possible, the chemical quality of the water may be unsuitable for most uses. Generally water in the Minnelusa is least mineralized at relatively shallow depths in the outcrop area of the formation and mineralization increases with depth of burial.

Development of wells with yields of 50 gal/min probably is possible from the Deadwood Formation in all parts of the county. However, development of the aquifers is unlikely, because better aquifers occur at shallower depths throughout the county.

Red-Bed and Gypsum Sequence

Overlying the marine carbonate and sandstone sequence is a sequence predominantly composed of red siltstone, sandstone, and claystone with subordinate quantities of evaporites. The total thickness is about 600 ft. Formations included in this sequence are the Opeche Shale and Minnekahta Limestone of Permian age, the Spearfish Formation of Triassic age, and the Gypsum Spring Formation of Jurassic age. Although the Gypsum Spring is included with this sequence because of lithologic similarities, it is included with the overlying sequence on the geohydrologic map (pl. 1) because during mapping it generally was not divided from rocks of the same age.

Water-yielding properties.--The sequence almost entirely consists of fine-grained clastics and evaporites that have little primary permeability. The principal zone where primary permeability may occur is in an arkosic sandstone at the base of the Spearfish. Some secondary permeability may be present as a result of solution of gypsum beds or fracturing in the lower part of the formation. Spring 46N 061W 09BD 01, which flows 60 gal/min (Mapel and Pillmore, 1963, p. M10), probably flows from solution openings in the Spearfish Formation.

Chemical quality of water.--Seven water samples have been collected in Weston County from this sequence. All the samples were from the Spearfish, and four of the samples reflect the presence of evaporite deposits of gypsum or halite. Two samples were a calcium sulfate type and two were a sodium chloride type. The fifth sample collected from a shallow well near the recharge area was a calcium bicarbonate type with a specific conductance of 650 μS/cm at 25 °C (microsiemens per centimeter at 25 degrees Celsius). Formation water associated with the evaporites has a large concentration of dissolved solids, hardness, sulfate, and in some areas, chloride. The maximum dissolved-solids concentration, 64,000 mg/L (milligrams per liter), was for a sodium chloride type water from spring 46N 061W 09BD 01.

Future development.--Prospects for development of water for most uses from the red-bed and gypsum sequence are limited due to the salinity of water that is prevalent. Adequate quantities of domestic and stock water of acceptable quality probably could be developed only in the outcrop area, and even there with difficulty.

Marine, Marginal Marine, and Continental Sandstone and Shale Sequence

The marine, marginal marine, and continental sandstone and shale sequence consists of the Sundance and the Morrison Formations of Late Jurassic age and the Inyan Kara Group that is comprised of the Lakota and Fall River Formations of Early Cretaceous age. The total thickness of the sequence is about 650 ft.

Water-yielding properties.--Sandstone and conglomerate in this sequence yield as much as 146 gal/min to wells. The Lakota Formation generally is a better aquifer than the Fall River Formation as evidenced by the number of wells drilled through the Fall River into the Lakota in order to obtain an adequate supply. Most of the wells completed in the Lakota flow at the surface, yielding less than 30 gal/min. Yields could be increased by pumping; however, the yield to drawdown ratio in the wells usually is less than 1 gal/min for each foot of drawdown in the well.

Yields of wells that have been completed in the Sundance Formation are similar to those from the Lakota Formation. Most wells in the Sundance are relatively shallow and are drilled near the outcrop; farther from the outcrop, shallower wells can be developed from the overlying Lakota.

Chemical quality of water.--Numerous analyses of water are available from the Inyan Kara Group, but only three analyses are available from wells completed in the Sundance (table 2). All but one of the samples from the sequence were a sulfate type water. Calcium is the dominant cation in water from the shallow wells, and sodium is dominant in water from deep wells. The dissolved-solids concentration ranged from 260 to 3,340 mg/L. The average dissolved-solids concentration of 39 analyses was 1,383 mg/L.

Local residents are of the opinion that water from the Fall River Formation is inferior in quality to that from the Lakota Formation. This is one reason most wells are drilled into the Lakota even though it is deeper (Whitcomb, 1960, p. 7). A difference in quality could be inferred from the difference in depositional environments of the two formations; the Fall River Formation is a marine deposit and, in some ways, is more similar to the overlying marine shale sequence. Well 45N 061W 29CBA01 was originally drilled to a depth of 830 ft and completed in the Fall River Formation. At this depth the water was unsuitable for most uses. The well was deepened 100 ft into the Lakota in 1946 (well 45N 061W 29CBA02), and the chemical quality of the water was much improved. For example, dissolved sulfate in water from the well decreased from 1,410 to 630 mg/L (table 2).

The chemical quality of the water in all the aquifers in the sequence probably becomes more unsuitable for most uses with increasing distance from the outcrop; however, water of quality suitable for domestic, stock, and some industrial uses can be developed in a large area where other aquifers containing water suitable for these uses do not occur at shallower depths.

Future development.--Flowing wells that yield less than 100 gal/min probably can be developed from aquifers in this sequence in much of the topographically low area that extends from the southeast corner of the county northwestward through the west-central part of the county. Yields could be increased by pumping, but the additional yield would be less than 1 gal/min for each foot of drawdown in the well. Springs are common in the outcrop area of the sequence, so the need for wells has not been great in the past. However, nonflowing wells can be developed in these areas if there is a need.

At one time, pumping from the Lakota Formation for industrial water supplies in the area of Osage caused the flow of some artesian wells to decrease or to completely stop (Whitcomb, 1960, p. 10). Subsequently, pumping decreased, and wells that had stopped flowing in 1960 were flowing again in 1975. If larger quantities of water are required from the unit in the future, interference between wells completed in the Lakota could be partly avoided by developing water from the Morrison and Sundance Formations which immediately underlie the Lakota.

Marine Shale Sequence

Overlying the Fall River Formation is a sequence consisting predominantly of marine shale that is in places more than 3,000 ft thick. From oldest to youngest, the formations are the Skull Creek Shale, Newcastle Sandstone, Mowry Shale, Belle Fourche Shale, Greenhorn Formation, Carlile Shale, Niobrara Formation, and Pierre Shale, all of Cretaceous age. The lithology of this sequence is the most homogeneous of the seven geohydrologic divisions described in this report.

Water-yielding properties.--The rocks in this sequence have the smallest yields of any aquifers in the county. Well yields may be too small and water too mineralized for stock supplies. The sandstones that occur in the sequence are silty, fine grained, and discontinuous. The Mowry Shale is brittle and siliceous. In other parts of the State it is known to have secondary permeability and to yield water suitable in quantity and quality for domestic and stock use. In the study area, well 47N 064W 7CA 01 is believed to yield small quantities of water from the Mowry.

Chemical quality of water.--The only water sample from a well completed in this sequence in the county was a sodium sulfate type and contained 1,510 mg/L of dissolved solids. The water in this sequence in other parts of the State generally is a sodium sulfate type and has large concentrations of dissolved solids. The well sampled may have been completed in sandstone in the transition zone between the Pierre Shale and the overlying Fox Hills Sandstone of Cretaceous age, which would account for the better-than-normal quality of water.

Future development.--The marine shale sequence has little potential for future development of ground water because of expected small yields and very mineralized water. This is illustrated on plate 1 by the number of wells drilled in the outcrop of this sequence that are completed in deeper aquifers. The few wells that do obtain suitable supplies from the marine shale sequence probably result when wells are drilled into the transition zone between the Pierre Shale and the overlying Fox Hills Sandstone or into fractured Mowry Shale.

Continental Sandstone and Shale Sequence

This sequence, with the exception of the Fox Hills Sandstone of Late Cretaceous age, is composed of continental deposits of sandstone, shale, carbonaceous shale, and thin coal. The Fox Hills, the lowermost formation in the sequence, is a marine-regressive sandstone. It is included with the continental formations because the water-yielding characteristics are more similar to this sequence than to the underlying marine shale. Overlying the Fox Hills, in ascending order, are the Lance Formation of Late Cretaceous age and the Fort Union Formation of Paleocene age.

Water-yielding properties.--Most wells in the sequence are completed in sandstone. The hydraulic conductivity of individual sandstone beds in the Lance and Fort Union Formations in other parts of the Powder River basin in Wyoming range from 0.07 to 4.7 ft/d and average 1.5 ft/d, as determined in 13 aquifer tests. The deepest of the 13 wells tested was 600 ft. Sandstone of this sequence at depths of 600 ft or less should have a hydraulic conductivity in this range.

Chemical quality of water.--The dominant cation in water from aquifers in this sequence is sodium. This is the result of cation exchange where calcium and magnesium in solution are replaced by sodium from clay or other solid material. The principal anions in the water are sulfate and bicarbonate. Large bicarbonate concentrations are the product of sulfate reduction reaction. This reaction and cation exchange that occur in water in this sequence have been described in more detail by Riffenburg (1925). An example of the extent these two processes can control the chemistry of the water is shown by the analysis of water from well 42N 067W 14ACB01 in table 2.

Future development.--Yields suitable in quantity and quality for domestic and stock use can be developed in this sequence throughout the area. Because of the large thickness that occurs in some areas, yields of 200 to 500 gal/min might be obtainable from wells completed in a large number of sandstone beds. However, the quality of water from deep wells probably is not suitable for sustained irrigation use because of the large sodium content.

Alluvium and Landslide Deposits

The sediment deposits, of Quaternary age, that occur in most of the alluvial valleys of Weston County consist of silt, clay, and fine-grained sand. The streams of the western part of the county drain large areas underlain by formations that contribute little gravel-size detritus. However, local occurrences of sand and gravel are known throughout the county with the most notable deposits present along the Cheyenne River.

Most stream valleys generally are less than 0.25 mi wide, and alluvial deposits are less than 100 ft thick. The alluvium commonly is less than 50 ft thick. Auger holes were drilled in alluvium at Buffalo Creek (sec. 5, T. 48 N., R. 67 W.), at Stockade Beaver Creek (secs. 20 and 30, T. 46 N., R. 60 W.), and at the Cheyenne River (sec. 26, T. 41 N., R. 67 W.). The maximum thicknesses of alluvium penetrated were 70 ft at Buffalo Creek, 50 ft at Stockade Beaver Creek, and 35 ft at the Cheyenne River. Three resistivity soundings were made in the flood plain of Beaver Creek in sec. 21, T. 42 N., R. 61 W. Depths to bedrock, a consolidated shale, as determined by the soundings, were 63 ft in the youngest terrace, 36 ft in an older terrace to the south, and 187 ft in the oldest terrace to the north.

Landslide deposits of limited extent are known to occur in parts of northeastern Weston County. The deposits are poorly sorted mixtures of rock material, silt, and clay. The deposits usually are small in area.

Water-yielding properties.--Because the alluvium generally has little permeability, yields are small. Reported yields of wells completed in alluvium along Buffalo Creek are less than 10 gal/min. Wells completed in the alluvium along Beaver Creek reportedly yield as much as 60 gal/min, but the average expected yield is less than 10 gal/min. Wells completed in alluvium along Stockade Beaver Creek reportedly yield from 4 to 75 gal/min. The largest yields of wells from alluvium occur along the Cheyenne River, where yields of 200 to 900 gal/min are reported.

Landslide or talus deposits in northeastern Weston County are reported to yield small quantities of water to wells. A spring (46N 062W 13) is reported in a talus deposit. Because the deposits are of small areal extent, the water supply probably varies seasonally.

Chemical quality of water.--The quality of the water from alluvium ranges from fresh to saline. Measured specific conductance ranges from 1,600 to 4,400 µS/cm. Water from wells completed in alluvial deposits in the basin can be expected to have alkaline characteristics and large dissolved-solids concentrations that preclude their development except for watering of stock. The generally better quality alluvial water in the Black Hills may have a larger dissolved-solids concentration than is desirable for domestic use. Water in gravel deposits of the Cheyenne River varies greatly in dissolved solids; however, water of suitable quality for irrigation has been developed.

Future development.--The Cheyenne River alluvium has greater potential for development of water than other alluvial deposits in the county. Also, some deposits in the northern part of the county may yield water of sufficient quantity and quality for domestic and stock uses. Even though there are withdrawals for irrigation from alluvium along the Cheyenne River and the Oil Creek drainage near Newcastle, the prospects for extensive water withdrawals are small.

SURFACE WATER

The downstream reach of Beaver Creek and the entire length of its tributary, Stockade Beaver Creek, are perennial streams. Tributaries to Stockade Beaver Creek that drain the west and south slopes of the Black Hills also are perennial. Most other streams in the county are ephemeral.

Only one streamflow-gaging station in the county, Beaver Creek near Newcastle (06394000), has sufficient length of record to analyze streamflow characteristics (pl. 1). Records for Beaver Creek (water years 1944-74) were analyzed statistically and graphically for flow distribution, high flows, low flows, flow volumes, and storage analysis. Three additional streamflow stations were installed during the 1973 and 1974 water years, but records are too short to determine statistical trends. Two crest-stage gages have been in operation since about 1960 to provide peak-flow data for regional flood-frequency analysis.

Flow Distribution

As a preliminary to a discussion of flow distribution, limited discussion of precipitation in the study area is necessary because of the direct relation between precipitation and streamflow.

Precipitation at Newcastle, Wyo. is assumed to be the average for the entire drainage basin. This is a reasonable assumption because precipitation at Newcastle is less than precipitation in the Black Hills area but greater than precipitation in the southern and western parts of the basin.

Mean annual precipitation at Newcastle is 14.1 in. Mean monthly precipitation is greatest in June and least in January (fig. 4). During November through April, when 28 percent of the mean annual precipitation occurs, precipitation is primarily in the form of snow. Seventy-two percent of the mean annual precipitation occurs during May through October, primarily as rain from convective-type storms.

The seasonal variation of streamflow in Beaver Creek near Newcastle is similar to the seasonal variation of precipitation (fig. 4). However, 45 percent of the annual runoff occurs from November through April and 55 percent from May through October. Lesser evapotranspiration and infiltration rates are the major reason for the greater precipitation-runoff ratio during winter months.

Hydrographs of the maximum, mean, and minimum daily flows for the period of record (water years 1944-74) were prepared (fig. 5) to show seasonal streamflow characteristics of Beaver Creek. During February, March, and April, when snowmelt occurs, minimum daily flow is large relative to the rest of the year. During May through September, when convective storms occur, runoff has the greatest variability. The mean daily flow is greatest in June and decreases to about 4 ft^3/s in late August and September. The mean daily flow increases to about 8 ft^3/s during October through December. This increase in mean daily flow is associated with the end of the growing season and is an approximation of the mean evapotranspiration draft of the stream.

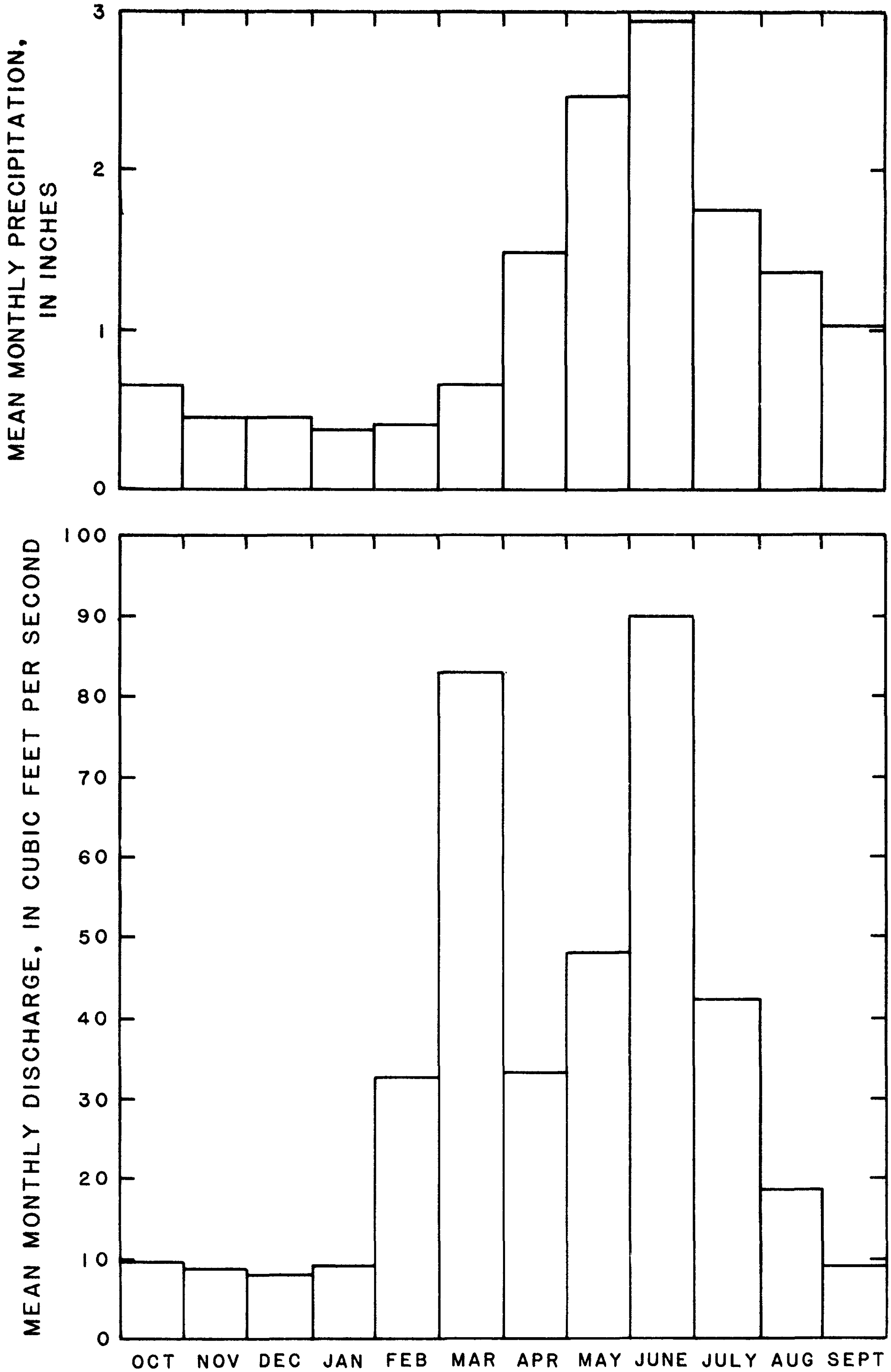

Figure 4.--Mean monthly precipitation (water years 1941-70) at Newcastle and mean monthly discharge (water years 1944-74) for Beaver Creek near Newcastle (06394000).

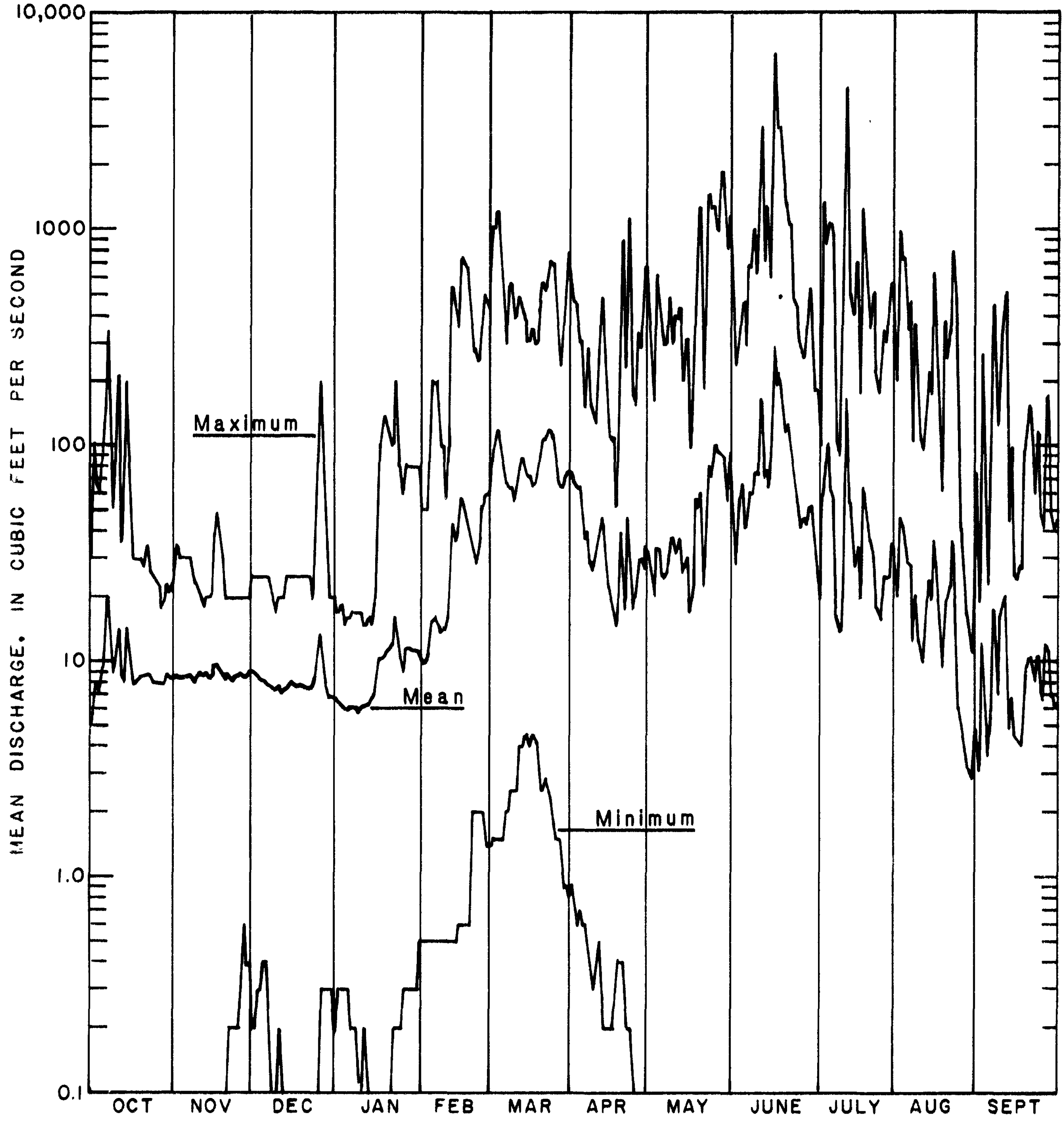

Figure 5.--Maximum, mean, and minimum daily flows (water years 1944-74) for Beaver Creek near Newcastle (06394000).

Analysis of Low Flows

The adequacy of streamflow to supply requirements for waste disposal, industrial and municipal supplies, and suitable conditions for fish can be evaluated using low-flow frequency curves. For example, in any given year the chance of the flow in Beaver Creek not exceeding 1 ft^3/s for 14 consecutive days is approximately 70 percent (fig. 6). The convex shape of low-flow frequency curves for Beaver Creek reflects the ephemeral nature of flow from a large part of the drainage basin. The record low-flow period occurred in 1961 when 170 days of zero flow occurred.

The low-flow frequency curves for Beaver Creek (fig. 6) represent observed minimum flows at the gaging station. If sustained flows greater than those indicated by the curves are needed, the use of storage needs to be considered.

Storage Analysis

Because of the significant variability and the small quantity of streamflow in Beaver Creek, it is necessary to consider storage to control floods or provide a sustained supply of water for irrigation, industrial, or other uses. Storage analysis is a statistical technique for assessing the availability of specified quantities of streamflow; it does not consider availability of reservoir sites, feasibility of constructing reservoirs, reservoir designs, or adjudication of waters. Both within-year and carryover storage are assessed in storage analysis.

Within-year storage is the water available in any given year that will provide a continuous discharge of a specified quantity of water without depleting the supply. Streamflow data for Beaver Creek were analyzed for within-year storage using methods described by Riggs and Hardison (1973). The analysis showed that a continuous supply of water of 1 ft^3/s could be maintained without the reservoir going dry, but a continuous flow of 2 ft^3/s would be deficient about 13 percent of the time for the year with the minimum measured flow. In order to provide larger continuous flows, carryover storage between years would need to be considered.

An analysis of carryover storage for Beaver Creek was made using probability-routing methods described by Riggs and Hardison (1973). Within-year storage was a factor in the analysis. The results are a set of draft-storage curves (fig. 7) for selected deficiencies (percent chance of insufficient storage). The use of the curves is illustrated by the following example:

1. Desired flow rate (draft) is 25 ft^3/s.
2. It is acceptable to have insufficient storage to maintain a flow of 25 ft^3/s during 1 year out of 10 (10-percent chance).
3. From figure 8, a storage of 33,000 acre-ft is needed.

The techniques described by Riggs and Hardison (1973) used for Beaver Creek apply only to perennial streams. A technique for storage analysis for ephemeral streams also is available (Glover, 1983). Storage analyses for ephemeral streams in Weston County have not been done.

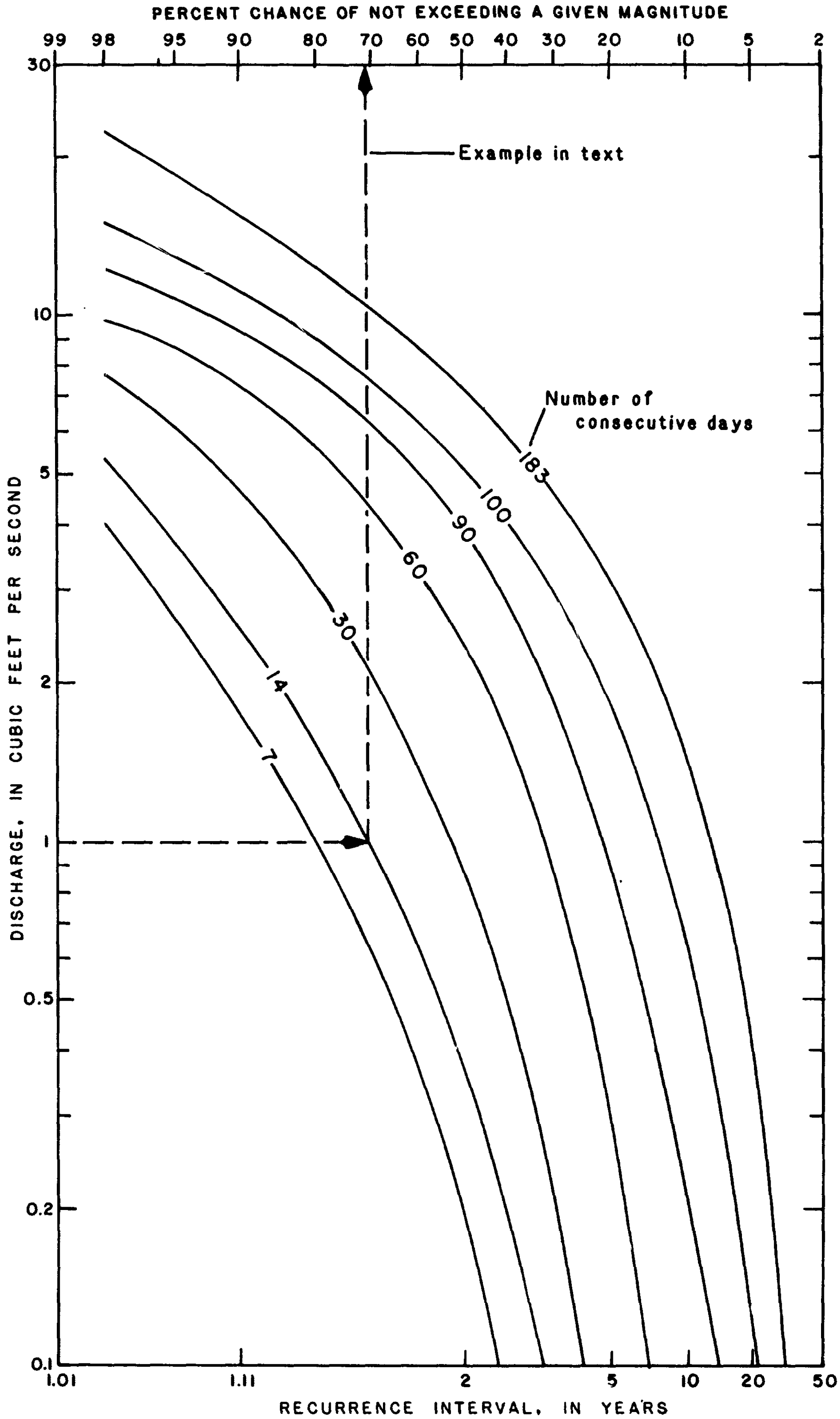

Figure 6.--Frequency curves of annual minimum mean discharge for indicated number of consecutive days, Beaver Creek near Newcastle (06394000).

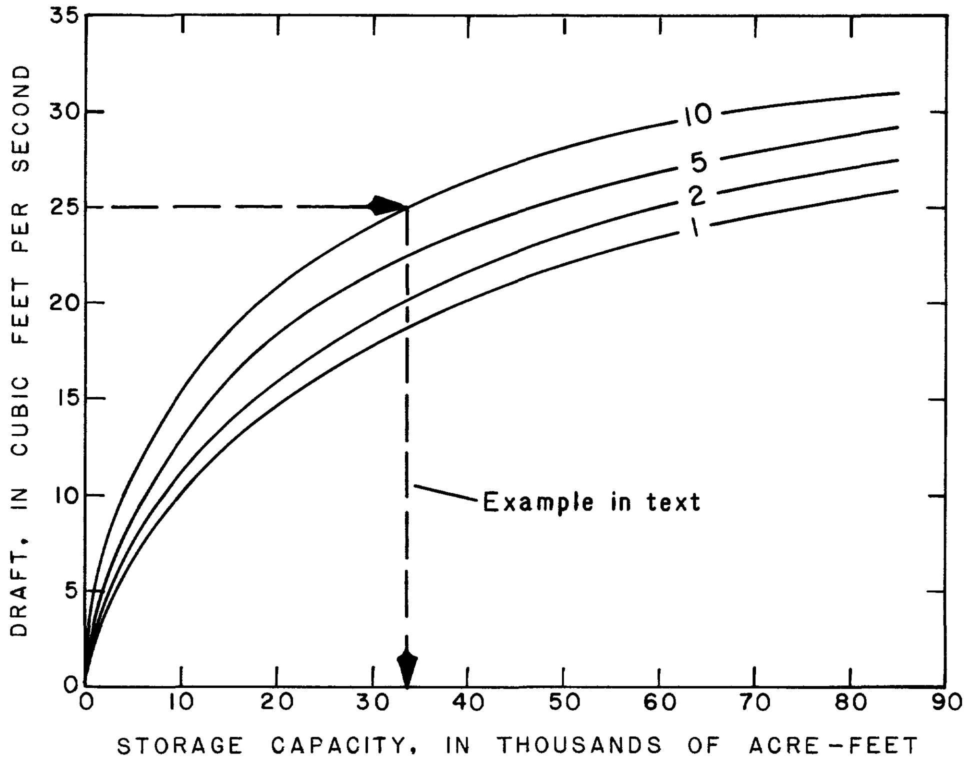

Figure 7.--Draft-storage relations for Beaver Creek near Newcastle (06394000). Numbers on curves indicate the percent chance of insufficient storage to maintain the required draft rate.

Analysis of High Flows

High flows from streams in Weston County primarily are the result of runoff from convective storms in the summer. Seldom has an annual maximum flow occurred during winter snowmelt.

The magnitude and frequency of floods are not discussed in this report. However, values of peak discharges for selected frequencies may be estimated for Weston County by using methods outlined in reports by Lowham (1976) and Craig and Rankl (1978).

Flood-volume frequency curves were prepared for Beaver Creek for a selected number of consecutive days (fig. 8). For example, the flow with a 20-percent chance of being equalled or exceeded for 15 consecutive days in any given year is 375 ft^3/s. The storage required to contain the entire flow would be 5,625 ft^3/s-days (375 ft^3/s x 15 days), or 11,200 acre-ft.

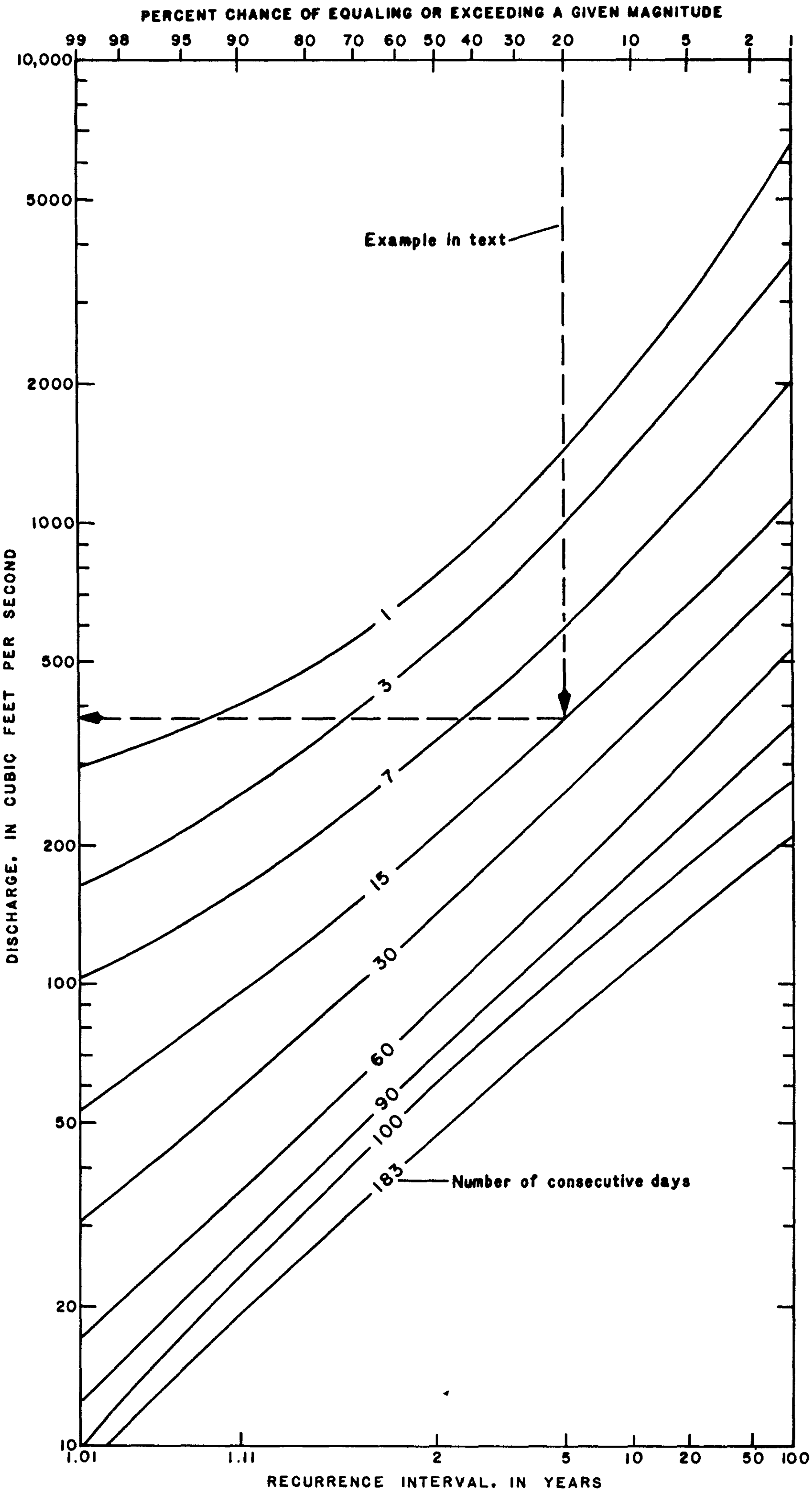

Figure 8.--Frequency curves of annual maximum mean discharge for indicated number of consecutive days, Beaver Creek near Newcastle (06394000).

SUMMARY

Surface water is scarce in Weston County. Ground water is used extensively for municipal, agricultural, and industrial supplies.

Igneous and metamorphic rocks of Precambrian age occur only at great depth in the county. Water has not been developed from these rocks, and future development is unlikely because of the uncertainties of yield, chemical quality and the depth of drilling necessary, and because better aquifers overlie the rocks.

Overlying the igneous and metamorphic rocks is a sequence of principally marine carbonate and sandstone rocks of Late Cambrian to Permian age that yields the largest quantities of water to individual wells; some wells flow more than 1,000 gal/min. The large yields are obtained from zones of secondary permeability. Aquifers in the sequence are attractive because of the large yields possible; in places, wells have been drilled through overlying units to obtain larger yields. However, large-scale development may result in interference between nearby wells.

A thick sequence of red siltstone, sandstone, and claystone with subordinate quantities of evaporites, of Permian to Jurassic age, overlies the marine carbonate and sandstone sequence. Prospects for future development are small because the water is very mineralized and is unsuitable for most uses.

The marine and continental sandstone and shale sequence, of Late Jurassic to Early Cretaceous age, overlies the red beds and evaporites and yields as much as 75 gal/min to wells. Deep wells usually are drilled in order to penetrate the aquifers in this sequence because suitable supplies are not available in the overlying marine shale sequence. Development of water from this sequence was great enough in the area of Osage to cause some wells to stop flowing in the early 1960's, but enough pressure had recovered by 1975 for the wells to flow. If development of water in this sequence increases, interference between wells in the future could be lessened by using more of the aquifers. In the past, the Lakota Formation was the principal aquifer developed.

The rocks in the marine shale sequence of Cretaceous age, which overlies the marine and continental sandstone and shale sequence, yield the least water of any aquifers in the county. There is little potential for future development of ground water from this sequence.

Sandstone aquifers in the continental sandstone and shale sequence of Late Cretaceous to Paleocene age, which overlies the marine shales, have been developed throughout the area. Yields of 200 to 500 gal/min might be available from wells completed in sandstone beds in this sequence.

Alluvium (Quaternary age) in the study area commonly is less than 50 ft thick and has little permeability. Reported yields of wells completed in the alluvium are small.

The only perennial streams in Weston County originate in the Black Hills. Stockade Beaver Creek is the principal perennial tributary to Beaver Creek. The seasonal variation of streamflow in Beaver Creek at the gaging station near Newcastle, the only long-term gaging station in the county, is similar to the seasonal variation of precipitation at Newcastle. During February, March, and April, when snowmelt occurs, minimum daily flow in Beaver Creek is large relative to the rest of the year. The mean daily flow is greatest in June and least in late August.

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SUPPLEMENTAL DATA

Table 2.--*Chemical*

[Analyses by U.S. Geological Survey. Local identifier: see well-numbering system in text.
microsiemens per centimeter at 25 degrees Celsius; °C, degrees

Local identifier	Date of sample	Specific conductance (µS/cm at 25 °C)	pH	Temper-ature (°C)	Hardness ($CaCO_3$) (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved sodium + potassium (Na + K) (mg/L)
									Allu
41N 067W 26AA 01	74-09-18	4,020	7.1	11.0	1,100	240	120	610	-----
48N 067W 05DB 01	74-05-22	1,600	7.9	8.1	170	40	17	310	-----
									Fort Union
42N 067W 14ACB01	69-09-08	1,510	8.3	12.0	30	4.8	4.4	385	-----
42N 068W 08DB 01	74-10-22	570	8.5	11.0	17	4.2	1.6	140	-----
42N 068W 26DD 01	74-09-18	810	7.7	12.5	360	87	35	290	-----
	74-10-23	2,050	---	12.0	420	96	43	320	-----
43N 066W 29CA 02	69-09-09	3,100	7.9	14.0	90	25	6.7	720	-----
43N 067W 16DA 01	74-10-24	2,550	---	10.5	70	18	6.1	560	-----
43N 068W 23AC 01	74-10-24	1,220	---	10.5	41	11	3.2	280	-----
45N 067W 08CC 01	74-09-18	2,750	---	11.0	580	100	80	450	-----
45N 067W 14DC 01	74-09-18	2,200	7.4	11.0	180	39	21	440	-----
46N 067W 09AD 01	74-06-26	1,560	7.2	10.3	920	210	97	18	-----
46N 067W 29BBC01	74-06-26	1,870	7.5	11.0	950	200	110	98	-----
									Lance
41N 063W 15AA 01	69-09-12	2,800	8.4	----	31	11	.8	712	-----
42N 064W 09CAD01	69-09-10	972	8.2	12.0	482	106	53	38	-----
42N 065W 30BCA01	69-09-09	1,010	8.3	12.0	292	70	28	132	-----
45N 064W 21BB 01	74-10-23	2,500	8.6	10.2	24	6.2	2.1	490	-----
45N 065W 26CB 01	74-10-22	810	7.4	10.0	230	50	25	110	-----
46N 065W 03DD 01	74-10-01	1,300	7.6	10.5	14	3.6	1.3	310	-----
47N 066W 02CCB01	69-07-15	951	8.5	12.0	37	7.1	4.7	227	-----
47N 066W 22C 01	74-06-05	1,230	8.0	10.5	47	12	4.1	270	-----
47N 066W 30DA 01	74-06-05	-----	7.6	10.5	370	87	38	150	-----
	74-06-28	1,280	7.6	10.4	370	87	38	150	-----
47N 067W 02BAA01	69-07-15	2,020	8.2	11.0	57	13	6.0	445	-----
	74-06-05	2,060	8.6	10.0	56	14	5.2	450	-----
47N 067W 03CA 01	74-06-05	2,120	8.9	10.0	130	13	24	430	-----
48N 067W 25DB 01	74-05-21	1,010	8.1	10.0	85	21	7.9	210	-----
									Fox Hills
42N 062W 30AA 01	69-09-12	1,730	8.2	12.0	277	50	37	315	-----
42N 065W 06CAA01	69-07-12	1,490	8.1	25.0	12	3.8	.0	350	-----
43N 065W 11AC 01	69-07-14	1,310	7.4	21.0	5	.0	.0	325	-----
44N 063W 18DC 01	74-11-15	1,500	8.3	10.5	160	37	16	200	-----
46N 064W 20BB 01	68-10-23	875	8.0	----	316	67	36	82	-----
47N 065W 17CB 01	74-06-04	2,270	7.6	9.0	310	69	34	410	-----
48N 068W 26BAB01	69-07-17	1,400	9.0	25.0	7	1.5	.0	330	-----
									Pierre
46N 064W 33AD 01	74-10-03	2,200	7.4	10.2	16	3.9	1.5	560	-----
									Inyan Kara
41N 060W 07BDA01	72-07-11	1,810	7.9	14.0	50	15	3.1	391	-----
41N 060W 07DBB01	69-05-14	1,920	8.4	14.0	98	21	11	365	-----
41N 060W 17AAD01	69-05-14	1,630	8.6	15.0	86	22	7.5	330	-----
41N 061W 01ACC01	69-05-14	1,480	8.7	9.0	19	3.1	2.8	330	-----
42N 060W 07CB 01	69-05-14	2,540	8.1	26.0	855	234	66	150	-----
43N 060W 30DC 01	74-09-19	2,800	8.3	12.0	99	24	9.4	600	-----
44N 063W 09CAD01	69-07-12	1,750	7.9	52.0	6	2.1	.2	400	-----
44N 064W 27ACC01	69-07-15	1,700	8.2	50.0	7	.8	1.2	405	-----
45N 061W 29CBA02	47-12-10	2,080	5.5	16.1	1,200	286	118	59	-----
	74-10-24	1,360	6.7	15.0	610	150	57	31	-----
45N 062W 22CCC01	69-05-19	1,780	7.7	32.0	923	243	77	83	-----

analyses of ground water

Date of sample: year, month, and day of collection of sample. Abbreviations: µS/cm at 25 °C, Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Dissolved potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)	Carbonate (CO_3) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved fluoride (F) (mg/L)	Dissolved silica (SiO_2) (mg/L)	Dissolved solids (residue at 180 °C) (mg/L)	Dissolved solids (sum of constituents) (mg/L)	Dissolved boron (B) (µg/L)	Iron, total recoverable (Fe) (µg/L)
vium										
24	767	--	1,700	32	0.7	22	-----	3,130	130	-----
3.6	532	--	420	4.9	.4	8.5	-----	1,070	140	-----
Formation										
1.9	937	9	33	30	2.2	7.0	936	942	70	-----
2.9	327	0	40	5.3	.7	8.3	-----	369	70	-----
9.6	574	--	510	13	.6	7.4	-----	1,240	40	-----
7.8	568	--	580	12	.7	7.5	-----	1,360	40	-----
2.8	376	0	1,240	27	1.3	6.5	2,210	2,210	80	-----
4.4	509	--	790	18	.7	7.1	-----	1,660	80	-----
3.1	572	--	170	11	1.7	7.4	-----	774	40	-----
9.4	565	--	990	13	.3	8.7	-----	1,940	110	-----
6.6	774	--	510	7.7	.1	8.1	-----	1,410	90	-----
5.4	787	--	290	1.7	.2	15	-----	1,030	100	-----
8.7	586	--	630	3.9	.1	18	-----	1,360	230	-----
Formation										
2.0	994	11	705	9.0	.6	12	1,910	1,960	210	-----
2.3	384	0	210	5.0	.2	11	662	629	40	-----
1.9	436	4	.0	13	.4	9.0	660	670	70	-----
2.7	651	44	480	9.1	.5	5.8	-----	1,360	600	-----
3.4	425	--	80	12	.1	8.7	-----	618	50	-----
1.6	635	0	170	2.7	.7	7.4	-----	813	---	-----
1.9	487	9	92	1.7	.0	7.6	580	592	230	40
3.0	636	--	130	3.6	.0	11	-----	748	100	-----
5.4	439	--	300	17	.1	12	-----	834	130	-----
5.4	439	--	300	17	.1	12	-----	834	130	-----
2.3	454	0	635	4.0	.0	8.3	1,350	1,340	150	60
2.3	453	1	650	4.2	.0	7.9	-----	1,360	180	-----
4.8	473	3	650	4.2	.0	2.1	-----	1,370	170	-----
2.5	487	--	140	2.4	.3	9.2	-----	635	150	-----
Sandstone										
3.7	556	0	460	11	.4	14	1,170	1,160	0	-----
1.0	559	0	288	11	2.5	11	952	943	210	30
.0	525	0	238	8.0	2.0	11	842	844	240	40
3.3	369	--	260	10	.5	6.0	-----	730	70	-----
4.2	371	0	182	8.5	.2	12	582	579	110	-----
4.8	446	--	810	8.6	.1	12	-----	1,570	480	-----
1.0	419	26	310	11	.0	12	928	900	380	60
Shale										
2.6	943	--	460	5.9	.7	6.9	-----	1,510	---	-----
Group										
2.3	209	0	693	13	.5	8.4	-----	1,230	70	-----
3.3	200	8	660	13	.3	8.1	1,220	1,190	90	-----
4.1	183	12	570	10	.3	8.1	1,080	1,050	60	-----
2.1	251	10	454	22	.5	8.6	980	956	70	-----
9.4	153	0	985	18	.4	11	1,690	1,570	70	-----
6.8	350	--	1,100	17	.7	8.7	-----	1,940	1,600	-----
1.7	194	0	655	14	.7	32	1,190	1,200	70	-----
2.1	472	0	382	58	2.8	39	1,100	1,120	560	-----
14	24	0	1,250	14	1.8	3.0	1,940	1,760	---	-----
6.8	20	--	630	8.2	1.0	7.2	-----	901	40	-----
19	144	0	970	3.6	.2	20	1,540	1,490	10	-----

Local identifier	Date of sample	Specific conductance (μS/cm at 25 °C)	pH	Temper-ature (°C)	Hardness ($CaCO_3$) (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved sodium + potassium (Na + K) (mg/L)
									Inyan Kara Group
45N 063W 04CAC01	69-05-22	1,360	7.8	24.0	12	2.5	1.5	304	-----
	74-10-24	1,360	7.7	24.8	10	4.2	.0	290	-----
46N 062W 12BA 01	74-09-17	1,740	7.5	9.0	790	150	100	87	-----
47N 063W 31CDA01	69-05-22	3,360	7.7	18.0	198	47	20	740	-----
47N 064W 31BB 01	68-10-23	1,780	8.1	19.0	7	2.4	.0	400	-----
	74-06-04	1,870	8.4	21.0	5	1.7	.3	400	-----
47N 065W 13DD 01	74-06-04	1,450	8.9	13.0	4	1.4	.1	330	-----
48N 063W 30BD 01	69-09-10	1,780	7.7	32.0	923	243	77	83	-----
									Fall River
45N 061W 29CBA01	41-08-15	-----	---	----	1,340	308	138	-----	128
46N 063W 31B 01	46-01-22	-----	---	----	-----	-----	-----	-----	652
48N 066W 01CCC01	69-07-11	1,090	8.2	15.0	3	.0	.0	244	-----
48N 066W 02DD 01	74-08-08	1,030	8.5	14.0	5	.5	.8	240	-----
									Lakota
44N 062W 02DCA01	69-05-19	3,290	8.1	32.0	2,070	603	138	150	-----
44N 062W 11CC 01	74-11-14	4,000	7.1	41.0	1,600	410	130	300	-----
44N 062W 22CCC01	69-07-14	1,660	8.0	53.0	269	77	19	270	-----
46N 061W 10BA 01	74-06-27	309	8.6	6.0	150	42	12	2.6	-----
46N 062W 27DC 01	69-09-09	3,350	7.8	11.0	2,080	424	248	172	-----
	74-08-15	3,380	7.2	10.5	2,000	410	240	130	-----
46N 063W 05DD 01	46-02-11	-----	---	16.0	-----	-----	-----	415	-----
46N 063W 18ADD01	58-03-14	-----	7.9	----	17	5.0	1.0	-----	486
	67-06-05	2,130	7.4	----	24	7.6	1.2	475	-----
46N 063W 18ADD02	60-08-19	-----	7.6	----	-----	3.0	-----	-----	281
46N 063W 19BD 01	46-01-22	-----	---	----	-----	-----	-----	-----	810
46N 063W 20BD 01	46-02-11	-----	---	----	-----	-----	-----	-----	336
46N 063W 21AA 01	46-02-11	-----	---	----	-----	-----	-----	-----	488
46N 064W 11DB 01	60-08-19	-----	8.1	----	-----	8.0	-----	688	-----
46N 064W 13CCA01	60-08-19	-----	7.7	----	-----	3.0	-----	-----	225
	75-05-14	432	7.3	40.0	250	56	27	1.8	-----
46N 064W 24ADA01	46-01-22	-----	---	----	-----	-----	-----	-----	263
	67-06-05	1,130	7.7	----	0	.0	.0	250	-----
46N 064W 26BBB01	46-01-22	-----	---	----	-----	-----	-----	-----	279
47N 062W 24AD 01	74-09-17	413	7.3	14.0	200	45	22	6.8	-----
47N 063W 25CB 01	74-08-15	1,210	4.2	11.0	290	68	28	61	-----
									Sundance
48N 062W 19DC 01	69-09-10	1,560	7.7	8.0	928	187	112	29	-----
48N 062W 20AD 01	74-08-14	2,110	7.3	11.5	1,300	390	88	17	-----
48N 062W 20DDD01	69-07-09	2,040	7.5	11.0	1,340	393	87	19	-----
									Spearfish
46N 060W 30AD 01	74-08-13	1,580	6.9	10.0	900	240	73	14	-----
	75-08-29	700	7.9	15.0	430	100	44	12	-----
46N 061W 09BD 01	62-05-05	86,300	8.2	----	4,800	1,440	297	22,900	-----
	69-05-14	41,800	8.1	----	3,000	910	168	10,100	-----
47N 062W 11AA 01	69-09-09	2,760	7.7	----	1,720	533	95	111	-----
									Minnekahta
48N 061W 07AD 01	74-08-14	476	7.9	11.0	240	63	21	3.5	-----
	75-08-30	400	7.7	17.0	230	59	21	3.2	-----
									Minnelusa
44N 060W 05BB 01	47-12-10	2,230	7.2	----	1,530	474	84	9.7	-----
45N 061W 02BC 01	47-12-10	2,680	7.5	----	1,840	504	14	29	-----
	68-06-18	2,700	8.0	15.0	1,860	685	37	35	-----
	74-09-17	2,740	---	14.5	1,900	500	150	31	-----
	75-07-18	2,400	7.3	15.0	-----	---	-----	-----	-----
	75-08-29	2,100	7.5	14.9	1,900	510	160	30	-----

of ground water--Continued

Dissolved potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)	Carbonate (CO_3) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved fluoride (F) (mg/L)	Dissolved silica (SiO_2) (mg/L)	Dissolved solids (residue at 180 °C) (mg/L)	Dissolved solids (sum of constituents) (mg/L)	Dissolved boron (B) (µg/L)	Iron, total recoverable (Fe) (µg/L)
--Continued										
1.4	197	0	456	8.8	.1	12	898	884	30	-----
2.0	201	--	430	9.5	.3	12	-----	847	60	-----
14	280	--	730	15	.3	6.7	-----	1,240	390	-----
3.8	144	0	1,610	11	.0	10	2,470	2,510	170	2,200
1.2	251	0	615	17	.0	13	1,200	1,170	40	960
1.4	240	0	640	16	.2	14	-----	1,190	60	-----
.9	379	21	330	39	.7	8.9	-----	923	220	-----
19	144	0	970	3.6	.2	20	1,540	1,490	10	5,100
Formation										
----	140	--	1,410	21	---	----	2,080	-----	---	-----
----	205	--	1,160	29	---	----	-----	1,920	---	-----
.0	262	0	279	16	.0	8.2	686	678	60	60
.8	436	5	120	39	1.4	10	-----	634	230	-----
Formation										
36	160	0	2,100	58	1.6	25	3,340	3,200	1,200	-----
23	134	--	830	840	.2	21	-----	2,620	20	-----
14	162	0	690	13	.6	26	1,190	1,190	60	-----
2.8	167	0	20	1.7	.2	15	-----	180	30	-----
18	376	0	2,000	26	.3	9.8	3,300	3,090	420	-----
20	392	--	1,800	26	.2	10	-----	2,840	460	-----
----	255	--	631	26	---	----	-----	1,240	-----	-----
----	194	--	861	13	---	----	1,560	-----	-----	-----
1.0	171	0	890	12	.8	9.3	1,480	1,480	70	-----
----	220	--	403	14	---	----	832	-----	-----	-----
----	185	--	1,510	25	---	----	-----	2,380	-----	-----
----	220	--	508	19	---	----	986	-----	-----	-----
----	205	--	703	114	---	----	-----	1,210	-----	-----
----	183	--	1,270	32	---	----	2,100	-----	-----	-----
----	195	--	307	12	---	----	653	-----	-----	-----
1.7	278	0	28	.8	.2	14	260	267	7	-----
----	220	--	362	10	---	----	734	-----	-----	-----
.5	207	0	361	7.1	.6	11	742	734	60	-----
----	205	--	401	15	---	----	787	-----	-----	-----
5.5	172	--	63	2.7	.1	14	-----	251	50	-----
9.0	0	--	560	5.5	.4	6.6	-----	757	110	-----
Formation										
12	463	0	580	14	.0	8.8	1,220	1,180	310	310
8.9	354	--	1,000	4.5	.2	9.7	-----	1,690	160	-----
7.7	296	0	1,080	6.8	.0	8.8	1,870	1,750	120	1,400
Formation										
2.1	209	--	650	55	.3	17	-----	1,200	170	-----
1.7	---	--	230	2.2	.3	15	-----	-----	210	-----
38	214	0	3,780	35,500	1.8	18	-----	64,100	---	-----
14	272	0	3,190	15,600	---	20	-----	30,100	2,000	-----
5.8	188	0	1,680	9.0	.0	12	2,760	2,540	400	20
Limestone										
1.4	265	--	22	1.6	.2	8.6	-----	272	10	-----
1.3	255	0	24	1.5	.2	8.3	-----	245	0	0
Formation										
14	222	0	1,310	11	1.8	5.0	2,190	2,020	---	-----
8.4	136	0	1,720	3.8	2.4	6.0	2,760	2,480	---	-----
4.8	141	0	1,680	9.5	1.2	9.2	2,810	2,530	280	-----
5.9	141	--	1,700	11	1.1	9.5	-----	2,480	300	-----
----	135	0	1,900	12	---	---	-----	-----	300	0
4.7	---	--	1,900	15	1.1	9.3	-----	-----	300	-----

Local identifier	Date of sample	Specific Conductance (µS/cm at 25 °C)	pH	Temper-ature (°C)	Hardness ($CaCO_3$) (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved sodium + potassium (Na + K) (mg/L)
								Minnelusa Forma	
45N 061W 28AB 01	62-03-14	3,010	7.4	----	2,170	604	161	29	-----
47N 060W 30AAA01	69-06-03	463	7.9	16.0	269	68	24	1.1	-----
	75-08-30	460	7.6	10.0	260	66	24	1.9	-----
47N 061W 01CBC01	69-06-03	495	7.8	9.0	257	83	12	8.4	-----
47N 061W 11CBB01	69-06-03	432	8.0	10.0	235	70	15	1.6	-----
	69-09-10	408	7.9	----	224	76	8.4	.0	-----
47N 064W 12CCC01	74-06-27	2,010	8.1	12.0	39	11	2.8	410	-----
48N 060W 08CC 01	69-09-10	408	7.9	----	224	76	8.4	.8	-----
	74-09-16	422	---	5.5	220	76	8.0	1.0	-----
48N 061W 30AA 01	69-06-05	955	8.0	12.0	559	150	45	2.8	-----
									Pahasapa
44N 060W 05BB 02	47-12-10	504	7.2	----	191	55	13	37	-----
44N 063W 26CAC01	75-05-13	550	7.5	35.0	270	73	22	11	-----
45N 061W 20DCA01	50-01-07	-----	---	----	335	54	33	-----	6.9
	57-04-01	504	7.4	----	274	64	28	2.8	-----
	62-03-15	507	7.7	----	274	63	28	2.5	-----
	69-01-28	519	7.3	----	270	68	25	6.9	-----
	75-05-13	460	7.5	25.0	280	63	29	2.6	-----
45N 061W 21CBD01	69-01-28	578	7.4	----	310	76	29	3.2	-----
45N 061W 28AB 02	62-03-15	504	7.4	----	273	62	29	2.9	-----
	75-05-12	550	7.3	25.0	280	63	29	2.6	-----
45N 061W 29CBB01	62-03-15	642	7.4	----	327	76	33	6.1	-----
	75-05-13	610	7.6	30.0	340	78	35	4.7	-----
45N 061W 30ADB01	62-03-15	601	7.4	----	322	76	32	4.4	-----
	68-06-18	603	8.3	31.0	324	75	33	5.2	-----
	69-01-28	602	7.3	----	320	77	31	3.6	-----
	75-07-17	590	7.7	32.0	-----	---	-----	-----	-----
	75-08-29	560	7.9	32.0	320	74	34	4.6	-----
45N 061W 33AB 01	69-06-04	534	7.9	22.0	298	76	26	2.9	-----
	75-08-29	520	7.7	28.0	280	64	28	2.9	-----
	76-07-13	---	7.3	29.8	310	73	31	2.5	-----
46N 060W 31BA 01	47-12-09	492	7.1	----	185	58	9.8	36	-----
	68-10-24	473	8.2	16.0	260	65	24	2.8	-----
	74-08-15	472	7.6	15.5	260	59	28	3.1	-----
46N 062W 18BDC02	69-06-05	480	7.8	16.0	270	62	28	1.9	-----
	74-08-15	488	7.5	14.0	270	60	28	1.1	-----
	76-07-13	---	7.3	13.0	280	66	27	1.3	-----
46N 063W 10DCA01	41-05-02	---	---	----	290	76	23	-----	7.0
	47-12-09	529	7.1	----	252	70	19	18	-----
	58-04-08	563	7.5	----	306	80	26	2.6	-----
46N 063W 15BD 01	72-07-11	496	7.7	----	270	64	27	2.2	-----
46N 063W 17CBC01	75-05-13	480	7.6	26.5	270	62	27	1.6	-----
46N 064W 13CCA02	69-05-22	484	7.8	37.0	258	61	26	1.8	-----
46N 065W 20CDD01	63-11-20	---	6.9	70.5	380	104	29	-----	22
	67-09-08	---	6.6	69.0	360	101	27	-----	32
46N 065W 23BAD01	63-11-20	---	7.0	63.5	320	70	34	-----	6.0
	67-09-08	---	6.6	64.5	310	72	32	-----	3.0
	75-05-14	670	7.5	65.5	310	71	32	2.7	-----
46N 066W 25DBB01	63-11-19	---	6.8	76.5	600	176	39	-----	1.0
	67-09-08	---	6.4	74.5	600	181	37	-----	63
47N 060W 04ADA01	69-06-03	435	7.9	10.0	250	62	23	1.0	-----
	72-07-12	444	8.0	7.5	240	58	24	2.2	-----
	74-08-14	446	7.8	8.0	250	59	24	.4	-----
	75-08-30	420	8.1	8.0	240	57	24	1.3	-----
48N 065W 35CCB01	69-07-11	724	7.7	2.8	374	93	34	20	-----

Dissolved potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)	Carbonate (CO_3) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved fluoride (F) (mg/L)	Dissolved silica (SiO_2) (mg/L)	Dissolved solids (residue at 180 °C) (mg/L)	Dissolved solids (sum of constituents) (mg/L)	Dissolved boron (B) (µg/L)	Iron, total recoverable (Fe) (µg/L)
tion--Continued										
6.7	127	0	1,980	19	.9	10	3,220	2,870	150	-----
1.1	305	0	12	.0	.0	12	266	272	0	20
1.2	307	0	15	1.7	.2	11	-----	273	0	50
1.3	304	0	13	1.9	.0	11	294	297	0	100
1.4	254	0	19	1.5	.0	9.7	258	250	0	20
.0	272	0	6.2	.0	.0	9.2	218	236	0	30
2.7	166	--	760	5.5	.1	8.6	-----	1,280	110	-----
.5	272	0	6.2	.6	.1	9.2	218	236	0	30
.5	272	--	4.4	2.0	.1	8.5	-----	236	20	-----
2.0	23	0	335	1.8	.0	10	708	676	60	20
Limestone										
7.6	300	0	27	2.8	.7	7.6	298	300	140	-----
4.8	101	0	200	7.6	1.4	4.5	398	374	40	-----
----	---	--	34	5.0	---	9.0	290	-----	---	-----
2.2	290	0	38	2.0	.2	14	297	296	---	-----
1.6	291	0	38	1.2	.3	13	291	292	30	-----
91	287	0	45	1.1	---	----	315	-----	0	-----
2.1	326	0	51	1.5	.2	12	296	323	9	-----
2.2	276	0	87	1.4	---	----	385	-----	30	-----
1.8	289	0	37	1.4	.3	13	288	290	10	-----
2.2	312	0	43	1.7	.3	12	291	309	9	-----
2.6	257	0	117	2.5	.4	14	405	379	20	-----
3.3	283	0	130	1.9	.4	13	412	407	10	-----
2.8	268	0	105	1.8	.4	14	386	369	10	-----
2.3	266	2	108	1.6	.5	13	382	372	10	-----
2.5	268	0	114	1.1	---	----	490	-----	0	-----
----	264	0	110	1.9	---	----	-----	-----	20	0
2.3	---	--	100	1.5	.5	13	-----	-----	2	-----
2.3	276	0	74	1.2	.6	13	336	332	0	-----
1.9	288	0	48	1.4	.5	12	-----	301	0	170
2.1	284	--	86	2.1	.6	13	308	351	10	-----
6.8	306	0	16	1.8	.5	11	290	292	100	-----
1.5	318	0	12	.4	.3	13	270	276	0	-----
1.8	306	--	13	1.4	.3	13	-----	272	20	-----
1.4	296	0	27	.8	.3	12	268	279	0	-----
1.1	299	--	23	1.5	.3	12	-----	276	20	-----
1.2	299	--	17	.8	.3	12	259	273	6	-----
----	307	--	43	5.0	---	----	348	307	---	-----
2.4	296	0	47	1.2	.6	5.6	346	311	70	-----
.6	298	0	69	1.0	.2	15	311	342	---	-----
1.4	293	0	24	1.7	.5	13	-----	283	10	-----
1.6	329	0	27	1.6	.3	11	262	295	10	-----
1.4	273	0	29	.7	.4	14	266	269	10	-----
----	207	0	220	4.0	---	----	-----	602	---	150
----	199	0	250	2.0	---	----	-----	617	---	200
----	232	0	110	3.0	---	----	-----	465	---	50
----	228	0	125	1.0	---	----	-----	460	---	1,200
2.3	232	0	120	1.3	1.0	23	389	369	9	-----
----	179	0	420	4.0	---	----	-----	824	---	100
----	203	0	540	4.0	---	----	-----	1,030	---	400
.0	291	0	5.2	1.0	.0	12	248	249	0	40
1.4	298	0	2.5	1.7	.2	12	-----	252	0	-----
.7	297	--	3.5	1.7	.1	12	-----	249	20	-----
.7	299	0	1.8	1.0	.1	12	-----	245	0	420
1.5	267	0	174	1.5	1.2	12	482	469	20	40

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