Ground-Water Resources of Natrona County, Wyoming

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1897

Prepared in cooperation with the Wyoming State Engineer

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By MARVIN A. CRIST *and* MARLIN E. LOWRY

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A study of the availability and chemical quality of ground water

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GROUND-WATER RESOURCES OF NATRONA COUNTY, WYOMING

By Marvin A. Crist and Marlin E. Lowry

ABSTRACT

Natrona County covers an area of 5,369 square miles in central Wyoming. The climate is arid except in the mountainous areas. The county includes parts of the Great Plains, Middle Rocky Mountains, Wyoming Basin, and Southern Rocky Mountains physiographic provinces. There is wide variation of topography.

More than 30 geologic formations are exposed in the county, 28 of which are known to yield water to wells and springs. The formations range in age from Precambrian to Holocene. Ground water in approximately 40 percent of the county contains more than 1,000 mg/l (milligrams per liter) of dissolved solids. Water chemically suitable for livestock can be developed at depths of less than 1,000 feet throughout most of the area.

Many of the geologic formations were deposited under similar conditions and have similar water-bearing properties; also, water from these rocks deposited under similar conditions tends to have similar chemical characteristics. For this report, the stratigraphic section has been arbitrarily divided into six rock units based on similartiy of deposition.

The igneous and metamorphic rock unit includes rocks of Precambrian age and igneous intrusives and extrusives of Tertiary age. These rocks probably would not yield more than about 5 gpm (gallons per minute) to wells. The water is usually calcium bicarbonate type and contains less than 500 mg/l of dissolved solids.

The marine rock unit includes formations of Cambrian, Mississippian, and Pennsylvanian and Permian age, having a maximum total thickness of about 1,900 feet. The Madison Limestone of Mississippian age and the Tensleep Sandstone and the Casper Formation of Pennsylvanian and Permian age supply the largest yields to wells and springs in the county. In the northeastern part of the county, flow from each of three wells in the Madison reportedly is more than 4,000 gpm. Each of three wells in the Tensleep in the same area flows more than 400 gpm. Yields of springs in the Casper Formation near Casper Mountain range from about 1.0 to 17 cubic feet per second. Ground water from near the outcrop of all these formations usually contains less than 500 mg/l of dissolved solids. The dissolved-solids content increases with distance from the outcrop and in places is more than 3,200 mg/l. Several types of water were found in this unit including sodium sulfate, calcium sodium sulfate, calcium sulfate, sodium calcium sulfate, sodium chloride, and calcium bicarbonate.

The continental and marine rock unit includes formations of Permian, Triassic, Jurassic, and Cretaceous age totaling about 1,900 feet thick. The Cloverly Formation of Cretaceous age is the most productive aquifer in this unit. Several wells in the Cloverly flow, or flowed when drilled, at rates ranging from 1 to 40 gpm. Yields of as much as 250 gpm have been obtained from the continental and marine rock unit, but generally the yields range from about 5 to 20 gpm. The quality of water from the unit is quite variable. Concentration of dissolved solids ranged from 70 to 1,780 mg/l in the waters analyzed. Types of water found in this unit were sodium sulfate, sodium bicarbonate, calcium sodium sulfate, calcium bicarbonate, calcium sulfate, calcium magnesium sulfate, and magnesium calcium bicarbonate.

The marine and continental rock unit consists of shale and sandstone of Cretaceous age ranging from 7,000 to 9,000 feet in thickness. The principal aquifers are the Frontier and Mesaverde Formations and the Fox Hills Sandstone. Yields of as much as 100 gpm have been obtained from the Mesaverde, but 50 gpm generally is the maximum yield expected from any of these formations. The water quality is generally poor, and water suitable for domestic use is present only near the sandstone outcrops. Dissolved-solids content of water obtained from wells about 1,000 feet deep is estimated to average about 1,700 mg/l. Sodium sulfate was the predominant type of water found in this unit.

The consolidated continental rock unit has the greatest areal extent of aquifers that contain water with less than 1,000 mg/l of dissolved solids. The unit is divided into two subunits: the orogenic subunit, which includes formations of Late Cretaceous through early Eocene age, and the postorogenic subunit, which includes formations of middle and late Eocene, Oligocene, Miocene, and Pliocene age.

Total thickness of the orogenic subunit is as much as 20,000 feet. Most wells are less than 500 feet deep and produce less than 25 gpm for stock and domestic use. Yields of 200 gpm, or more, could probably be obtained at depths of less than 1,000 feet in the Wind River Formation at some places. Ten water samples from the orogenic subunit contained dissolved solids ranging from 276 to 1,830 mg/l. Sulfate associated with calcium, sodium, and magnesium was found to be the principal constituent in the water.

Maximum total thickness of the postorogenic subunit is in the southwestern part of the county, where it is about 4,000 feet thick. The White River Formation of Oligocene age and the Arikaree Formation of Miocene age are the principal aquifers. Yields of 50 gpm might be obtained from wells in the upper member of the White River; wells in the lower member of the White River could yield as much as 300 gpm locally. The Arikaree would probably yield 25–50 gpm to wells where there is about 100 feet of saturation. Yields of 200–300 gpm can probably be obtained from wells penetrating about 500 feet of saturation. This much saturation would require wells about 600 feet deep in the Arikaree. Generally, water from the postorogenic subunit contains less than 500 mg/l of dissolved solids except in an area near the west end of Pathfinder Reservoir, where some water contains concentrations up to 4,770 mg/l. The waters analyzed from this subunit were primarily calcium bicarbonate type.

The unconsolidated continental rock unit includes deposits of Quaternary age. Yields to wells are as much as 1,300 gpm. The highest yields are obtained from alluvium along Bates Creek and along the North Platte River. Test holes augered in the alluvium along Bates Creek show a maximum of about 75 feet of saturation; thus, wells could be developed along this creek to supplement irrigation from surface supplies.

Quaternary deposits are the most reliable source of ground water as to quantity and chemical quality in many parts of the county, especially where the underlying bedrock is any formation of the marine and continental rock unit. Chemical quality of the water may be different from place to place depending upon material in the deposits, underlying bedrock, source of recharge, and ease of movement through the aquifer. Fourteen water samples from the unconsolidated continental rock unit contained dissolved solids ranging from 246 to 8,240 mg/l.

Selenium ranging from 0.01 to 1.1 mg/l was found in some waters from Cretaceous and Quaternary rocks near Casper. Concentrations of selenium in six streams in the same area ranged from less than 0.01 mg/l in the North Platte River at Alcova to 0.94 mg/l in Oregon Trail Drain, which empties into the North Platte above Casper.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

Natrona County, in central Wyoming, is about 74 miles square and covers an area of 5,369 square miles. Figure 1 shows the area of this report and other areas in the State for which ground-water reports have been published, or of which investigations are in progress, by the U.S. Geological Survey.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this investigation was to determine the general occurrence, chemical quality, and availability of ground water in Natrona County, Wyo. Special attention was given to identifying the chemical suitability of ground water for domestic, livestock, industrial, municipal, and irrigation use. The investigation was started in August 1965 as part of the program of ground-water studies being made in Wyoming by the U.S. Geological Survey in cooperation with the Wyoming State Engineer.

PREVIOUS GROUND-WATER INVESTIGATIONS

Babcock and Morris (1953) made a study of ground-water conditions in a small area (about 49 sq mi) near Edgerton, Wyo. Whitcomb and Lowry (1968) made a reconnaissance study of the geology and ground-water resources of the Wind River Basin area, which includes nearly half of Natrona County. Two other reports (Larsen, 1951; Wilson, 1951) have been prepared on ground-water investigations in the Kendrick Project near Casper, Wyo.

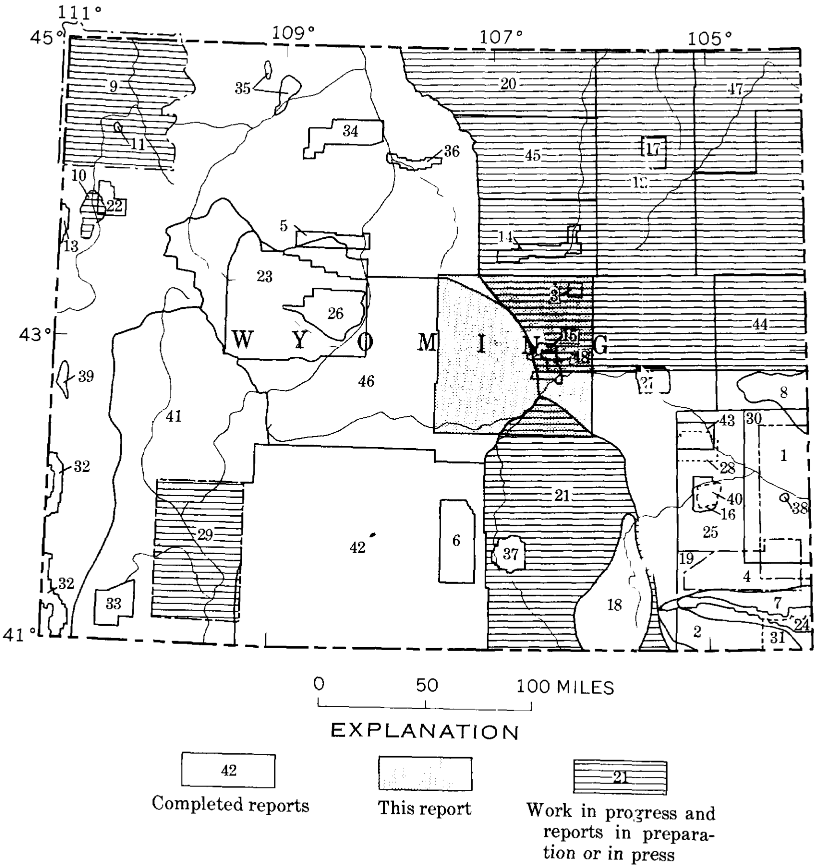

FIGURE 1.—Area described in this report and areas of ground-water reports in Wyoming. Numbers on map refer to U.S. Geological Survey reports and University of Wyoming theses listed below. Type of publication identified as follows: WSP, water-supply paper; Circ., circular; and HA, hydrologic investigations atlas.

EXPLANATION

Map No.	*Report*	*Author*	*Year*
1	WSP 70	Adams, G. I	1902
2	WSP 1367	Babcock, H. M., and Bjorklund, L. J	1956
3	Open-file report	Babcock, H. M., and Morris, D. A	1953
4	Circ. 162	Babcock, H. M., and Rapp, J. R	1962
5	WSP 1519	Berry, D. W., and Littleton, R. T	1961
6	WSP 1458	Berry, D. W	1960
7	WSP 1483	Bjorklund, L. J	1959
8	WSP 1368	Bradley, Edward	1956
9	WSP (work in progress)	Cox, E. R.	
10	WSP (work in progress)	Cox, E. R.	
11	WSP 1475–F	Gordon, E. D., and others	1962
12	HA 465	Hodson, W. G	1972
13	WSP 1789	Kilburn, Chabot	1964
14	WSP 1360–E	Kohout, F. A	1957
15	M. S. thesis, Univ. Wyo	Larsen, J. H	1951
16	Circ. 70	Littleton, R. T	1950

EXPLANATION—*continued*

Map No.	Report	Author	Year
17	Circ. 76	Littleton, R. T	1950
18	Circ. 80	Littleton, R. T	1950
19	WSP 1834	Lowry, M. E., and Crist, M. A	1967
20	WSP 1807	Lowry, M. E., and Cummings, T. R	1966
21	HA 471	Lowry, M. E., and others	1972
22	Circ. 494	McGreevy, L. J., and Gordon, E. D	1964
23	WSP 1576–I	McGreevy, L. J., and others	1969
24	WSP 425–B	Meinzer, O. E	1919
25	WSP 1490	Morris, D. A., and Babcock, H. M	1960
26	WSP 1375	Morris, D. A., and others	1959
27	Circ. 243	Rapp, J. R	1953
28	Circ. 163	Rapp, J. R., and Babcock, H. M	1953
29	Prof. Paper (in preparation).	Rapp, J. R., and Stuart, W. T.	
30	WSP 1377	Rapp, J. R., and others	1957
31	WSP 1140	Rapp, J. R., and others	1953
32	WSP 1539–V	Robinove, C. J., and Berry, D. W	1963
33	WSP 1669–E	Robinove, C. J., and Cummings, T. R	1963
34	WSP 1596	Robinove, C. J., and Langford, R. H	1963
35	WSP 1418	Swenson, F. A	1957
36	Circ. 96	Swenson, F. A., and Bach, W. K	1951
37	Circ. 188	Visher, F. N	1952
38	Circ. 238	Visher, F. N., and Babcock, H. M	1953
39	WSP 1809–C	Walker, E. H	1965
40	WSP 1783	Weeks, E. P	1964
41	HA 290	Welder, G. E	1968
42	HA 219	Welder, G. E., and McGreevy, L. J	1966
43	WSP 1791	Welder, G. E., and Weeks, E. P	1965
44	WSP 1788	Whitcomb, H. A	1965
45	WSP 1806	Whitcomb, H. A., and others	1966
46	HA 270	Whitcomb, H. A., and Lowry, M. E	1968
47	WSP 1698	Whitcomb, H. A., and Morris, D. A	1964
48	M. S. thesis, Univ. Wyo	Wilson, R. W	1951

WELL-NUMBERING SYSTEM

Water wells, springs, and test holes cited in this report are numbered according to the Federal system of land subdivision in Wyoming (fig. 2).

The first number indicates the township, the second the range, and the third the section in which the well, spring, or test hole is located. Lowercase 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 counterclockwise direction, starting in the northeast quarter. If more than one well is listed in a 10-acre tract, consecutive numbers starting with 1 follow the last lowercase letter of the well number.

ACKNOWLEDGMENTS

The authors are indebted to the many residents of Natrona County who contributed information for this report, especially to the ranchers

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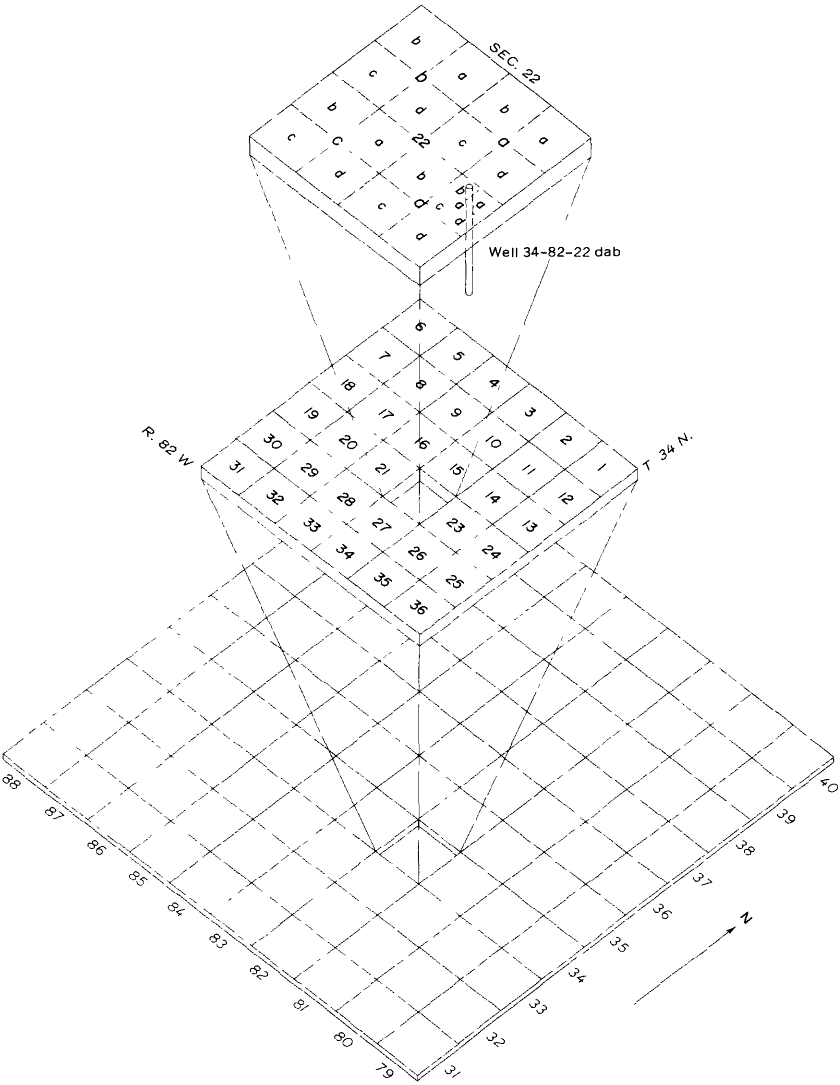


FIGURE 2.—System of numbering wells, springs, and test holes.

in the county who gave permission to conduct pumping tests and make periodic water-level measurements at their wells. Amax Petroleum Corporation, Pan American Petroleum Corporation, Forest Oil Corporation, and Amerada Petroleum Corporation supplied information about wells in the deep aquifers in the county. Robert L. Streeter, consulting engineer, and Myron D. Hubley, consulting geologist, in

Casper, contributed data about quantity and quality of water available in parts of the county. Much information was also obtained from local water-well drillers.

GEOGRAPHIC SETTING

PHYSIOGRAPHY

Natrona County includes parts of four physiographic provinces delineated by Fenneman and Johnson (1946) : Great Plains, Wyoming Basin, Middle Rocky Mountains, and Southern Rocky Mountains (fig. 3). There is wide variation of terrain and topography in the county.

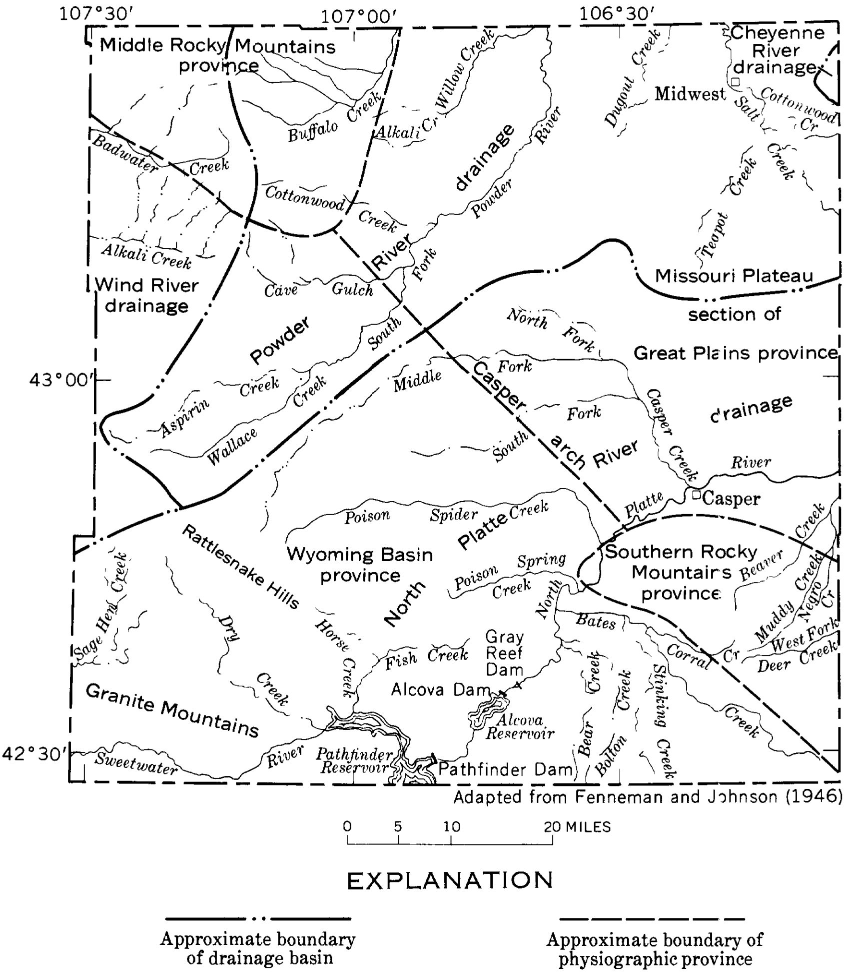


FIGURE 3.—Location of physiographic provinces and river drainage basins.

Altitudes range from about 9,100 feet in the Middle Rocky Mountain province in the northwestern part to a low of about 4,800 feet near Midwest in the Great Plains province.

Generally, the northeastern part of the county, which is in the Missouri Plateau section of the Great Plains province, is characterized by badlands, broad valleys, deeply eroded gullies, and isolated mountains. Along the east edge of the county, low ridges are formed by easterly dipping beds of sandstone; some of the sandstone beds form short escarpments. Sand dunes cover an area of about 125 square miles east of Casper and north of the North Platte River. Another area of sand dunes, consisting of about 57 square miles, extends eastward from the town of Powder River and north of the Middle Fork of Casper Creek.

Most of the southwestern part of the county lies in the Wyoming Basin province. The northwestern part of this area is characterized by rolling hills and deep gullies. Badlands have developed locally in Tertiary age rocks. A band of mountains named the Rattlesnake Hills extends from near the center of the west border southeastward about 20 miles into the county. South of these mountains, nearly flat-lying Tertiary deposits punctuated by granite knobs called the Granite Mountains dominate the topography. Southeast of the North Platte River, the topography includes deep gullies and steep-dipping beds with steep drainage slopes in the pre-Tertiary rocks. Badlands are evident in this area in the Tertiary age rocks.

The northwestern part of the county is mountainous terrain making up part of the Middle Rocky Mountains province. Altitudes of more than 8,000 feet and deep canyons are common in this area.

The mountainous terrain between the southeast corner of the county and the North Platte River make up part of the Southern Rocky Mountains province. Steep drainage slopes and narrow valleys are characteristic of this area. Altitude generally ranges from about 6,000 to 8,000 feet.

DRAINAGE

Natrona County includes parts of three principal drainage basins, which are part of the Missouri River drainage. These basins, shown in figure 3, are the North Platte River drainage, the Powder River drainage, and the Wind River drainage. About 3 square miles in the extreme northeastern part of the county is part of the Cheyenne River drainage.

The North Platte River is the principal stream and drains approximately the south half of the county. From Pathfinder Reservoir, near the center of the south boundary of the county, the North Platte flows northeastward, cutting through the west tip of the Southern Rocky Mounains province, and then flows eastward to the east border of the county. Flow in the North Platte is regulated by Seminoe and Kortes Dams about 20 miles south of Natrona County in Carbon County and by Pathfinder and Alcova Dams in Natrona County. An additional small control called Gray Reef Dam is located about 3 miles downstream from Alcova Dam to regulate surges of discharge caused by changes in demand for electric power generated at Alcova Dam. Average discharge below Alcova Dam was 1,194 cfs (cubic feet per second) for 33 years of record to October 1966.

The Sweetwater River, which drains the southwestern part of the county, is the major tributary of the North Platte River in Natrona County. Average discharge of the Sweetwater River above Pathfinder Reservoir was 123 cfs for 39 years of record to October 1966.

Several small perennial creeks, of which Poison Spider Creek, Casper Creek, Bates Creek, and Poison Spring Creek are the principal ones, flow into the North Platte between Alcova Dam and the county line. Discharge into the river from the west between Alcova Dam and Casper is mostly return flow from surface-water irrigation. The water is diverted from Alcova Reservoir for irrigation of lands on the Kendrick Project shown in figure 4. A constructed ditch on the Kendrick Project, Oregon Trail Drain, also is perennial and is one of the major contributors of irrigation return flow to the North Platte River in Natrona County.

The South Fork of the Powder River drains the north-central part of the county. In Natrona County, Willow Creek is the major tributary to the South Fork of the Powder and joins the main stream just north of the county. Buffalo Creek joins the Powder River about 10 miles north of the county line; this creek is perennial, although in the summer most of the flow is diverted for irrigation.

Salt Creek drains the northeastern part of the county. The stream is perennial north of the Salt Creek oil field because water produced in the oil field is discharged into the creek. Salt Creek joins the Powder River about 13 miles north of the county line. Nearly all other creeks in the Powder River drainage in the county are intermittent.

In Natrona County, Badwater Creek is the only stream of consequence in the Wind River drainage. Several other small creeks flow north into the Bighorn River. It should be pointed out that the Bighorn River and the Wind River are the same stream. The name is changed from Wind River to Bighorn River at the point where the stream enters the Bighorn Basin. (See fig. 6.)

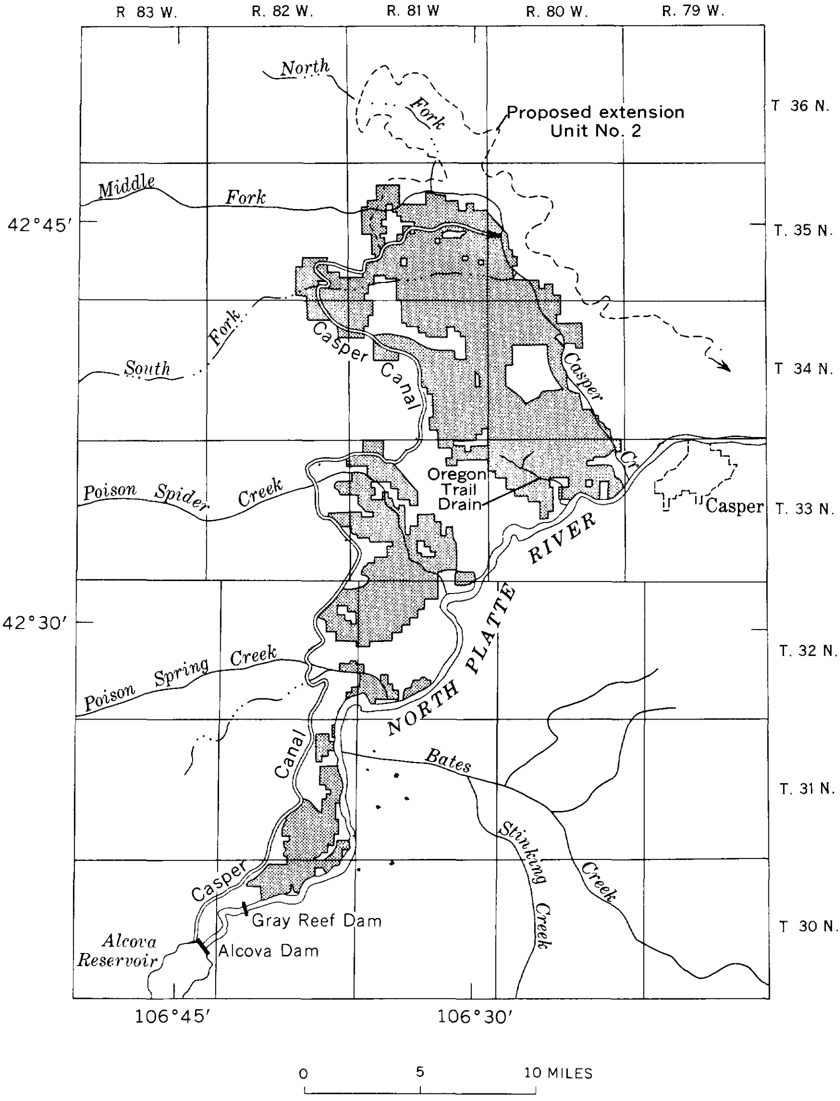


FIGURE 4.—Irrigated areas (shaded) in the Kendrick Project. The approximate boundaries of the irrigation project are North Platte River, Casper Creek, and Casper Canal. Map adapted from U.S. Bureau of Reclamation (1964), region 7, map 144–703–3229.

CLIMATE

The climate of Natrona County is arid except in the mountainous areas at altitudes above about 6,000 feet. At the lower altitudes, the average annual precipitation ranges from less than 7 inches at Arminto to about 12 inches at Casper. Precipitation is not adequate for dry-land farming in most of the area; consequently, irrigation is necessary for most agricultural crops. Snowfall is generally light during the winter months, and occasional heavy wet snows occur in the spring. Summer precipitation usually occurs from thunderstorms which have a wide range of intensity; hail sometimes accompanies the thunderstorms. Normal monthly precipitation at Casper is shown in figure 5.

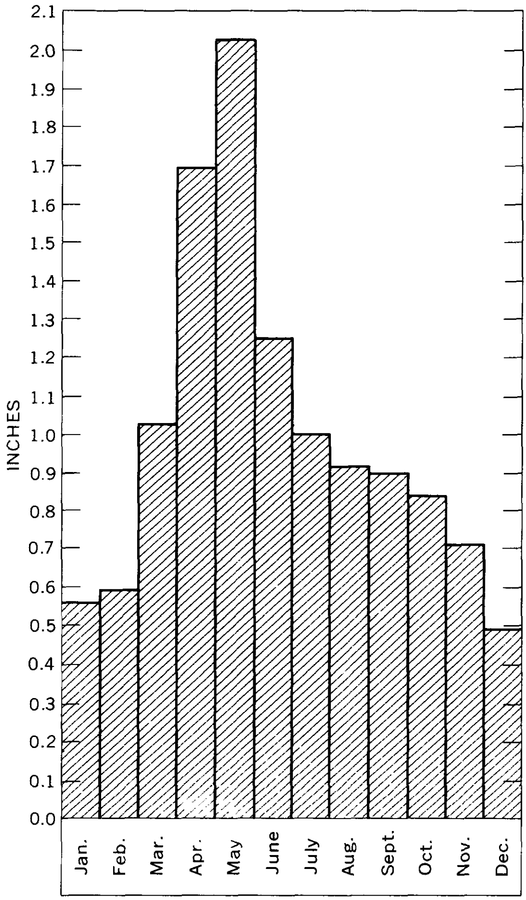
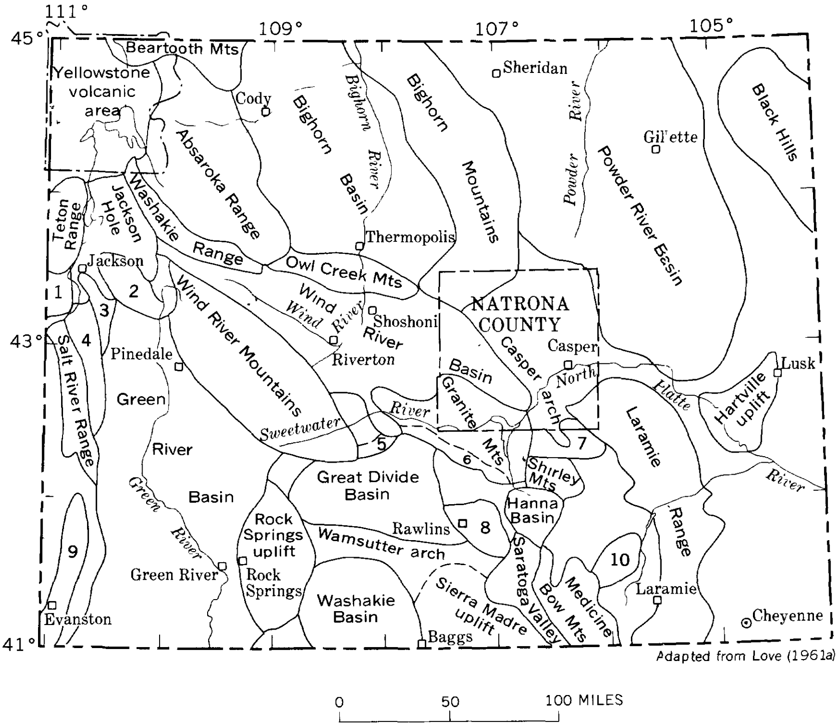


FIGURE 5.—Normal monthly precipitation at Casper, Wyo., based on the period 1931–60.

Mean annual temperature is about 46°F at the Casper airport. The average temperature in January 1966 ranged from about 18°F at Alcova to about 26°F near Casper. The average temperature for July of the same year ranged from about 70°F at Alcova to about 78°F near Casper. The growing season in the county varies between 120 and 140 days, depending upon the altitude. Windy days are characteristic of the county, and strong winds occur frequently.

GEOLOGIC SETTING

The major structural features of Wyoming are shown in figure 6.



EXPLANATION

1 Snake River Range
2 Gros Ventre Mountains
3 Hoback Range
4 Wyoming Range
5 Green Mountains
6 Ferris Mountains
7 Shirley Basin
8 Rawlins uplift
9 Fossil syncline
10 Laramie Basin

FIGURE 6.—Structural features of Wyoming in relationship to the location of Natrona County.

Those features in Natrona County include parts of the Wind River Basin, Granite Mountains, Bighorn Mountains, Laramie Range, and Powder River Basin. The boundaries between the mountains and basins are arbitrary, and in this report, discussion of basins includes much of the area the structural feature map (fig. 6) does not show as basins. The boundary between the Wind River and Powder Piver Basins is taken as the Casper arch.

The Wind River Basin trends northwest in the county and is strongly asymmetric with the axis along the north and east margin. Dips of pre-Tertiary rocks on the south flank in the Rattlesnake Hills are about 30°–40°. On the north and the east margin, the dips may be vertical to overturned. Many minor structures have caused reversals of dip direction.

The Granite Mountains are knobs and masses of Precambrian rocks which make up the south border of the Wind River Basin. These mountains are part of the Precambrian core of the Sweetwater uplift as defined by Van Houten (1964, p. 11).

The Bighorn Mountains mark the south end of the middle Rocky Mountains, and the Laramie Range is the north end of the southern Rocky Mountains. A narrow uplifted area named Casper arch joins the two mountain features.

The Powder River Basin is a strongly asymmetric south-north trending structural basin and includes (fig. 6) only a small part of Natrona County. The axis of the basin is just east of the county, and therefore the beds generally dip steeply toward the east in Natrona County between the Bighorn Mountains and the Powder River Basin. Reversals of dip associated with smaller structures are common in the northeastern part of the county.

CHEMICAL QUALITY

CHEMICAL CHARACTERISTICS

The quality of water as discussed in this report refers to the chemical quality. Bacterial and radiological examinations were not made during this investigation.

All ground and surface waters contain dissolved substances, organic and inorganic; the amount and kind depend on the source, environment, and movement of the water. In this report, discussion is limited primarily to the dissolved-mineral content (inorganic) of water in Natrona County. All minerals are soluble in water to some extent, but usually only a few constituents account for most of the mineralization. The principal cations (positively charged ions) in most water are calcium, magnesium, sodium, and potassium; the principal anions (negatively charged ions) are bicarbonate, carbonate, sulfate, and chloride. Also, small amounts of iron, manganese, fluoride, boron, and nitrate are common. Silica is also a common constituent that occurs naturally, but it is not present in dissociated form as ions. Table 1 lists the common chemical constituents in water, their maximum concentration recommended by the U.S. Public Health Service (1962) for public water supplies, and some data on the water in Natrona County.

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TABLE 1.—*Common chemical constituents in water in Natrona County and their effect upon usability*

Constituent	Effect upon usability of water [1]	Recommended limits for drinking water [2] (mg/l)	Remarks
Silica (SiO_2)	In the presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat; the scale is difficult to remove. Silica may be added to soft water to inhibit corrosion of iron pipes.		Igneous and metamorphic rocks contain silicate minerals. Breakdown of these minerals, through chemical reactions, in the processes of metamorphism and weathering is probably the major source of silica in water. Mostly clay minerals are formed from these reactions. Concentrations of silica ranged from 50 to 62 mg/l in the hot waters (71°–88°C.) from rocks of Mississippian and Pennsylvanian age. Concentrations ranged from 11 to 56 mg/l in rocks of Tertiary age. High concentrations would be expected in siltstone aquifers because of the clay minerals and in aquifers close to igneous rocks as in the southwestern part of Natrona County.
Iron (Fe)	Where concentrations are more than 0.1 mg/l, precipitates will form after exposure to air. Iron causes turbidity; stains plumbing fixtures; laundry, and cooking utensils; and imparts objectionable taste and color to food and drinks.	0.3	The limit of iron concentration (0.3 mg/l) was recommended to prevent objectionable taste or laundry staining. Iron was found in water from every formation sampled in Natrona County. In most instances where iron concentrations were found to be above the recommended limit, the water was not being used for domestic supply or was rejected for domestic supply because of considerations other than iron. Exceptionally high concentrations of iron were found in waters from some Cretaceous and Tertiary rocks where concentrations were as much as 20 mg/l and 58 mg/l, respectively.
Calcium (Ca) and magnesium (Mg).	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in boilers and other heat-discharge equipment. Calcium and magnesium contribute to the hardness of water and retard sudsing of soap. High concentrations of magnesium salts in drinking water have a laxative effect, especially to those not accustomed to the water.	-----------	Calcium and magnesium concentrations vary over a wide range, but generally calcium is more abundant. Concentrations of calcium ranged from 580 mg/l in Tertiary rocks to 0 mg/l in some Cretaceous rocks. Magnesium concentrations ranged from 147 mg/l in Pennsylvanian rocks. to 0 mg/l in some rocks of Cretaceous age. Higher concentrations of magnesium were found in some Quaternary deposits, but it is believed these water samples were influenced by irrigation water.
Sodium (Na) and potassium (K).	More than 50 mg/l of sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers. More than 65 mg/l of sodium can cause problems in ice manufacture. High concentration of sodium is detrimental to plant growth and deleterious to soils.	-------------	Sodium salts readily go into solution and tend to remain in solution. Concentrations of sodium range from about 2 mg/l to 1,260 mg/l in waters from the consolidated formations in Natrona County. Rocks that contain potassium are usually resistant to weathering. If in solution potassium is easily recombined with other products of weathering. Therefore, concentration of potassium in ground water is generally less than 100 mg/l In Natrona County, potassium concentration ranged from a trace to 73 mg/l.
Bicarbonate (HCO_3) and carbonate (CO_3).	Upon heating, bicarbonate is changed into steam, carbon dioxide, and carbonate. The carbonate combines with alkali earths principally calcium and magnesium to form scale in heating vessels and pipes. Water with an excess of bicarbonate and carbonate over calcium and magnesium is deleterious to soils.	-------------	In irrigation water, the concentration of bicarbonate and carbonate by themselves is not detrimental, but these constituents aid in the precipitation of calcium and magnesium carbonate, a process which increases the relative proportion of sodium remaining in the soil.

TABLE 1.—*Common chemical constituents in water in Natrona County and their effect upon usability*—Continued

Constituent	Effect upon usability of water [1]	Recommended limits for drinking water [2] (mg/l)	Remarks
Sulfate (SO_4).	Sulfate combines with calcium to form heat-retarding scale. Water containing about 500 mg/l of sulfate tastes bitter, and water containing about 1,000 mg/l may be laxative. Glauber salt (sodium sulfate) and Epsom salt (magnesium sulfate) are both well known laxatives.	250	The principle source of sulfate in water in Natrona County is evaporites such as gypsum and anhydrite. Sulfate concentrations of more than 250 mg/l are common in water in all aquifers in the county except aquifers of Tertiary age.
Chloride (Cl).	Chloride in excess of 100 mg/l may impart a salty taste. Concentrations greatly in excess of 250 mg/l may be injurious to some people with diseases of the heart or kidneys.	250	Chloride concentrations generally are less than 250 mg/l in water in the consolidated aquifers in the county except in those of Mississippian and Pennsylvanian age. The water samples collected from these aquifers are probably influenced by oil-field brines.
Fluoride (F).	Fluoride concentration between 0.8 and 1.3 mg/l in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth.	[3] 0.8–1.3	The average maximum daily air temperature for the 5-year period 1962–66 is 58.4° F at the Casper airport weather station. Generally, fluoride concentrations were low in the waters that would be considered a potential source for domestic supply. One sample from rocks of Quaternary age contained excessive fluoride.
Nitrate (NO_3).	Large amounts of nitrate (more than 100 mg/l) is bitter tasting. Concentration of more than 45 mg/l in water used for preparing formulae has been reported to cause methemoglobinemia in infants.	[4] 45	Concentration of nitrate is usually much less than 45 mg/l in water from aquifers in Natrona County. The exceptions are shallow aquifers where inorganic nitrate fertilizers are added to the soil and where there is pollution from barnyards or similar sources.
Boron (B)	Boron in irrigation water is essential to plant growth in trace quantities, but is toxic to some plants in low concentrations. Crops such as beets, alfalfa, onions, cabbage, lettuce, and carrots can tolerate 2–4 mg/l of boron; potatoes, tomatoes, peas, wheat, corn, and oats can grow well at 1–2 mg/l. Sensitive crops such as plums, apples, cherries, and grapes cannot tolerate more than 0.5–1 mg/l of boron.		In Natrona County, concentrations of more than 1 mg/l of boron were commonly found in Water from a sandstone of Cretaceous age. Water from all other aquifers generally contained less than 1 mg/l.
Selenium (Se).	Selenium is toxic to humans and to livestock. Some plants can absorb large amounts of selenium from water without injury to themselves. Selenium is known to produce "alkali disease" in cattle. Effects of selenium poisoning may be permanent.	[4] 0.01	Selenium concentrations ranging from 0.01 to 1.1 mg/l were found in water from Cretaceous rocks and Quaternary rocks in contact with Cretaceous shale. Streams draining these areas also contained selenium with concentrations ranging from 0.06 to 0.94 mg/l.
Dissolved solids.	Less than 500 mg/l is desirable for drinking. Requirements for industry vary over a wide range according to use.	500	Water containing less than 500 mg/l of dissolved solids is not available in many parts of Natrona County, and there are several instances where water containing more than 1,000 mg/l is being used for drinking without apparent adverse effects.

[1] Adapted from Durfor and Becker (1964, table 2).
[2] Limits from U.S. Public Health Service, 1962 (changed here from parts per million to milligrams per liter).
[3] Recommended control limits depend upon annual average maximum daily air temperature range of 58.4°–63.8°F.
[4] Maximum permissible limits (U.S. Public Health Service, 1962).

Chemical-quality analyses made by the U.S. Geological Survey after October 1, 1967, are reported in the metric system of measurement. Concentration of dissolved minerals is reported as milligrams per liter, which is the weight of the constituent(s) in a liter of water. For water samples collected prior to the above date, concentration of dissolved minerals has been converted from parts per million to milligrams per liter in this report. One part per million represents the unit weight of the constituent(s) in a million weights of water. For concentrations of dissolved solids of less than 8,000 mg/l, no significant error is introduced by assuming milligrams per liter to be equivalent to parts per million.

Specific conductance of water is a measure of the ability of water to conduct an electric current. The specific conductance is related to the amount of dissolved solids. Chemically pure water has a very low conductance. Natural water contains dissolved salts, thus dissociated ions in solution; therefore, it is more conductive. Usually the ratio of dissolved solids in parts per million (milligrams per liter) to specific conductance in micromhos per centimeter at 25°C ranges from 0.55 to 0.75 (Hem, 1959, p. 40). Where no other data are available, an estimate of total dissolved solids can be obtained by multiplying the specific conductance, reported as micromhos per centimeter at 25°C, by 0.65.

Hardness is that property of water that is usually associated with problems of scale in steam generation plants and with problems of soap consumption in the household. Presence of calcium and magnesium is the principal cause of hardness. If only soap consumption is considered, then other alkaline earths, free acid, and heavy metals (iron, manganese, aluminum, and zinc) also contribute to the formation of insoluble compounds. Values used by the U.S. Geological Survey to classify water hardness follow:

Concentration of hardness (mg/l)	*Classification*
60 or less	Soft.
61–120	Moderately hard.
121–180	Hard.
181 or more	Very hard.

Two kinds of hardness are listed in tables 2 and 3: calcium and magnesium hardness and noncarbonate hardness. Both types of hardness are reported as an equivalent amount of calcium carbonate ($CaCO_3$). Calcium and magnesium hardness represents the hardness computed from the concentration of only these two constituents, but is generally equivalent to the hardness caused by all the alkaline earth metals. The hardness remaining, if any, is called noncarbonate hardness. The principal anions associated with noncarbonate hardness are sulfate, nitrate, and chloride.

The best quality of water expressed in milligrams per liter of dissolved solids that can be expected within a depth of 1,000 feet in Natrona County is shown on the hydrologic map (pl. 1). Quality-of-water data for the map were obtained from existing wells and springs. The water quality may differ locally from that shown on the map because the immediate environment may influence the water.

RELATION OF WATER QUALITY TO USE

DOMESTIC USE

Water used for domestic supply should not have objectionable taste, smell, or color. In this report, determination of the suitability of water for domestic use is based on standards recommended by the U.S. Public Health Service (1962) for public water supplies. (See table 1.) In parts of Natrona County, water used for domestic supplies contains concentrations of several chemical constituents greater than those recommended in the U.S. Public Health Service drinking-water standards because supplies that meet those standards are not available; however, the water is used by local residents without ill effects after physiological adjustments. In general, most of the common constituents in drinking water are objectionable only when they are present in such concentrations to be noticeable to the taste or smell. It should be stressed that for most constituents the U.S. Public Health Service has *recommended* maximum concentrations, but for constituents that are toxic or which have adverse effects upon humans, such as selenium, nitrate, and fluoride, the U.S. Public Health Service also lists maximum *permissible* concentrations. Water containing concentrations of these latter constituents above the permissible limit is grounds for rejection of the supply.

LIVESTOCK USE

Classification of water quality for livestock is not as rigid as for domestic use. Beath and others (1953) suggested the following guide, based on total dissolved solids, for classification of water for livestock:

Total dissolved solids (mg/l)	*Classification*
<1,000	Good.
1,000–3,000	Fair.
3,000–5,000	Poor (usable).
5,000–7,000	Very poor (questionable).
>7,000	Not advisable to use.

TABLE 2.—*Chemical*

[Analyt'cal results in milligrams

Location	Depth of well (ft)	Production interval (ft)	Date of collection	Temperature (° C)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
												Madison
33-77-15bcb	7,615	7,304–7,615	4-18-67	----	40	4.8	338	55	452	58	124	0
39-78-26cdc	7,180	6,931–7,180	8-11-67	88	62	.20	307	40	738	73	133	0
40-79-26caa	4,889	4,675–4,889	11-18-66	84	47	.58	366	28	492	36	112	0
40-79-35ccc [1]	----------	----------	10-26-62	----	------	------	328	60	469	------	98	----
												Tensleep Sandstone
30-83-18dcd [2]	1,590	1,245–1,590	1-18-66	14	12	0.11	502	147	300	7.2	70	0
32-81-15bad [3]	Spring	----------	2-1-67	16	13	.05	88	20	28	2.8	236	0
39-83-18cad [4]	1,540	865–1,540	10-19-65	16	14	.05	124	24	16	2.7	122	0
40-79-25caa [5]	4,400	4,070–4,388	11-18-66	71	42	.29	315	67	561	41	125	0
40-83-19cca [4]	Spring	----------	9-9-66	14	11	.02	62	28	5.5	1.6	182	0
												Chugwater
39-83-7aab	Spring	----------	8-21-66	8	11	0.06	188	67	108	4.3	210	0
												Sundance
39-83-5aad	Spring	----------	9-9-66	7	13	0.07	55	36	40	2.5	236	0
												Cloverly and
29-81-5bbb	1,014	----------	9-14-66	24	12	0.06	1.4	0.1	184	0.2	350	4
31-79-8ccd	Spring	----------	8-10-67	7	19	.74	10	1.0	2.3	.3	34	0
33-79-24acc	5,101	5,005–5,055 (?)	3-23-67	31	27	.05	1.0	.0	149	.3	278	0
33-89-15acd	537	343–537	7-16-64	14	12	.04	23	6.9	120	7.0	288	0
34-80-21cad	3,100	----------	12-21-66	35	20	.07	.0	.2	112	.2	253	8
37-82-36ddd	1,275	----------	2-2-67	11	19	.12	9.8	1.3	600	1.3	351	0
39-84-3bbc	Spring	----------	9-9-66	9	12	.06	205	73	173	4.3	342	0
												Muddy Sandstone
33-87-16cca [6]	3,501	3,183–3,193	1-23-61	----	------	------	10	3	693	------	1,400	180
37-86-13dd	1,657	1,611–1,657	11-9-65	24	12	0.00	.4	3.5	1,000	9.5	1,960	94
												Mowry
39-83-13bdd	117	----------	2-2-67	9	22	0.62	36	9.7	196	1.7	141	0

See footnotes at end of table.

analyses of ground water

per liter except as indicated]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180° C	Dissolved solids: Sum	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium-adsorption-ratio (SAR)	Residual sodium carbonate (RSC) (meq/l)	Specific conductance (micromhos per cm at 25° C)	pH	Arsenic (As), selenium (Se)
Limestone													
1,560	322	5.0	1.1	0.71	3,040	2,900	1,070	968	6.0	0	3,660	7.4	
900	1,050	5.0	[illegible]	.65	[illegible]	3,240	932	823	[illegible]	0	4,940	7.5	
1,120	619	3.2	[illegible]	.51	2,860	2,770	1,030	938	6.7	0	3,980	7.5	
1,060	640	-----	-----	-----	2,770	2,600	-----	-----	6.3	0	-----	7.3	
and Casper Formation													
2,350	48	3.6	0.1	0.49	3,620	3,400	1,860	1,800	3.1	0	3,740	7.7	
92	47	.1	.9	.04	422	408	300	106	.7	0	684	7.8	
311	7.2	.6	2.3	.04	603	562	407	307	.3	0	809	7.9	
1,130	698	5.5	.1	.46	3,040	2,920	1,060	950	7.5	0	4,280	7.6	
126	2.0	.2	2.0	.03	338	-----	268	119	.1	0	520	7.7	
Formation													
789	5.7	0.3	4.2	0.21	1,320	-----	744	572	1.7	0	1,570	7.9	
Formation													
156	4.7	0.3	8.9	0.06	416	-----	283	89	1.0	0	671	8.1	
Morrison Formations													
98	11	1.6	0.0	0.34	484	-----	4	0	40	5.79	779	8.3	
6.0	.7	.1	3.2	.01	70	60	30	2	.2	0	88	6.6	
74	6.7	.7	.0	.07	402	396	2	0	41	4.50	538	8.0	
111	6.0	1.2	1.0	.42	445	430	86	0	5.6	3.00	694	7.6	0.01 (Se).
12	3.2	2.5	.0	1.4	278	284	1	0	49	4.40	453	8.5	
958	18	.7	.2	.28	1,770	1,780	30	0	48	5.15	2,540	8.2	
879	5.7	.4	.1	.19	1,610	-----	810	530	2.6	0	1,920	7.9	
Member of Thermopolis Shale													
56	25	-----	-----	-----	1,690	1,660	-----	-----	49	28.2	-----	8.4	
.0	270	4.3	0.0	1.2	2,380	2,360	16	0	110	34.9	3,640	8.5	
Shale													
424	1.9	1.3	0.5	0.37	780	763	120	14	7.5	0	1,140	7.3	

TABLE 2.—*Chemical analyses*

Location	Depth of well (ft)	Production interval (ft)	Date of collection	Temperature (°C)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
Frontier												
33-80-6cbc	204	37-204	12- 6-66	23	8.8	1.9	42	21	963	2.4	688	8
33-80-8aad [7]	147	----------	6-1[illegible]-67	18	9.0	.03	4.4	1.0	984	2.8	1,750	9
34-80-[illegible]2cbc	735	250-735	5-25-67	10	6.4	.36	.4	.6	752	1.3	1,440	28
34-83-9cab	80	35-80	7-12-67	18	14	.07	141	20	98	2.6	251	0
35-82-33dca [8]	60	----------	5-19-66	13	10	1.9	135	68	153	3.5	279	0
36-85-23daa [9]	----------	ca 950	3- 1-67	----	------	.0	Tr.	------	443	Tr.	695	72
37-82-36bbb	925	----------	2- 2-67	11	19	.48	2.9	.7	461	1.2	442	12
39-79-11dd	2,069	1,905-2,081	3-22-67	----	16	.47	2.0	1.8	1,040	2.4	2,220	0
39-82-9cbc	1,030	868-1,025	2- 2-67	13	9.8	.21	2.7	1.3	766	1.2	350	20
40-80-27ba	1,150	1,120-1,150	7-13-67	22	19	.08	1.2	.0	852	.6	391	90
40-81-20cad	1,029	949-1,029	2- 2-67	13	11	.38	14	11	703	1.7	728	19
Cody												
33-79-33bba	100	40-100	9-19-67	11	11	0.43	145	80	800	3.3	481	0
34-79-17dba	405	385-405	6-12-67	13	8.1	.08	14	3.8	1,260	54	509	0
Mesaverde												
33-86-34adc	64	----------	6-27-66	11	11	0.35	44	29	270	4.6	449	0
37-78-7dcd	1,796	860-1,715	8-24-67	22	10	.11	15	1.2	712	2.3	419	3
37-79-19dda	210	----------	8-15-66	12	22	20	82	48	310	7.4	40	0
37-79-30dcd	511	----------	8-16-66	13	1.8	2.0	.2	2.3	141	.8	235	17
38-79-34bda [11]	100	----------	4-26-66	12	1.0	.35	146	46	1,100	9.2	662	0
Fox Hills and Lance												
40-78-11acb [12]	950	64-950	9- 9-65	14	------	1	14	15	360	4	387	0
40-78-11dba [12]	1,005	114-1,005	10-15-65	14	------	.26	8	3	420	5	402	12
40-78-26cba [13]	90(?)	----------	7-13-67	16	7.9	.05	20	1.0	655	2.0	466	0
Lance												
34-77-9bcc	90	30-90	11-10-65	10	15	0.00	174	97	78	9.2	305	0
36-77-5bbb [14]	496	452-496	----------	12	------	------	------	------	576		575	59
40-78-11dba [16]	1,005	114-240	8-12-65	----	------	------	17	3	374	3	464	Tr.
Fort Union												
36-86-36acc [9]	435	160-167	3-20-67	----	------	2.7	56	39	12	Tr.	61	0
36-86-36acc [9]	435	310-340	3-20-67	----	------	19.5	118	54	5	Tr.	134	0
36-86-36acc [9]	435	340-430	3-23-67	----	------	32.0	184	85	37	10	195	----
36-86-36dbc	600	485-585	4-25-66	21	7.2	58+	236	95	175	15	116	0
Wind River												
33-85-3dbb	128	----------	6-23-66	9	9.1	0.00	4.5	1.7	305	1.3	487	0
36-87-23ccc	8.3	3-8	11- 8-65	10	10	.10	.8	2.7	190	4.0	372	4
36-89-25abb	----------	----------	11- 9-65	9	16	.02	36	22	18	5.5	73	0

of ground water—Continued

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180° C	Dissolved solids: Sum	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium-adsorption-ratio (SAR)	Residual sodium carbonate (RSC) (meq/l)	Specific conductance (micromhos per cm at 25° C)	pH	Arsenic (As), selenium (Se)
F[illegible]rmation													
1,620	12	0.7	0.2	1.1	3,0[illegible]0	3,020	192	0	30	7.71	4,110	8.3	
425	149	12	.0	3.1	2,[illegible]0	2,460	15	0	111	28.6	3,670	8.3	0.02 (Se).
64	208	7.3	.0	1.9	1,790	1,780	4	0	175	24.6	2,[illegible]30	8.5	0.02 (Se).
199	65	.4	154	.00	862	817	4[illegible]5	227	2.0	0	1,250	7.4	
648	9.3	.6	.0	.27	------	1,170	617	388	2.7	0	1,560	8.0	
5	190	------	------	------	1,050	------	------	------	------	------	------	8.8	
487	73	2.0	1.2	1.1	1,[illegible]10	1,280	10	0	63	7.44	2,000	8.6	
.0	243	13	.6	1.8	2,360	2,410	12	0	128	36.2	3,5[illegible]0	8.1	
1,280	12	.9	.2	.37	2,290	2,270	12	0	96	6.17	3,230	8.7	
286	4.6	1.0	3.3	.27	940	950	3	0	88	9.34	1,460	8.9	
884	21	3.5	.6	1.5	2,040	2,0[illegible]0	82	0	34	10.9	2,930	8.6	
[illegible]hale													
1,470	75	4.0	6.6	0.93	2,720	2,6[illegible]0	690	296	9.9	0	[10] 3,470	7.8	
2,1[illegible]0	46	1.0	.3	.42	[illegible],590	3,720	50	0	77	7.33	4,840	7.8	0.01 (Se).
F[illegible]rmation													
414	10	0.5	0.8	0.34	1,0[illegible]0	1,010	229	0	7.7	2.78	1,500	7.9	
1,150	15	.9	.1	.18	2,180	2,120	44	0	47	6.09	3,080	8.3	
995	5.5	.2	.1	.08	1,480	------	400	367	6.7	0	1,950	6.7	
89	3.7	.3	.1	.15	[illegible]70	------	10	0	19	4.22	625	8.9	
2,040	73	2.5	153	.42	3,980	3,910	554	11	20	0	5,000	7.5	
F[illegible]rmations combined													
517	20	------	0.0	0.2	1,180	------	95	------	16	4.45	1,700	7.7	
513	13	0.92	.55	.18	1,170	------	------	------	33	6.[illegible]6	1,790	8.4	
1,070	12	.8	.9	.32	1,980	2,000	54	0	39	6.56	2,850	7.9	
F[illegible]rmation													
712	37	0.7	0.0	0.04	1,[illegible]80	1,270	834	584	1.2	0	1,710	7.8	
6[illegible]5	16	------	------	------	1,5[illegible]0	1,570	------	------	------	------	[15] 2,600	8.2	
456	12	------	------	------	1,090	------	55	------	22	6.51	[15] 1,650	8.5	
F[illegible]rmation													
255	8	------	------	------	400	------	300	------	0.3	0	------	6.6	
390	8	------	------	------	641	------	517	------	.1	0	------	6.6	
700	10	------	------	------	1,120	------	809	------	.6	0	------	7.2	
1,220	12	0.9	0.7	0.25	1,940	1,8[illegible]0	980	885	2.4	0	2,210	7.2	
F[illegible]rmation													
264	3.2	1.2	0.2	0.31	863	830	18	0	31	7.62	1,300	8.2	
110	7.1	.5	.0	.00	526	510	13	0	23	5.95	812	8.3	
143	11	.8	.0	.03	276	288	181	121	.6	0	413	7.6	

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TABLE 2.—*Chemical analyses*

Location	Depth of well (ft)	Production interval (ft)	Date of collection	Temperature (°C)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
												White River
29-77-32b	Seep	----------	9- 9-60	18	25	0.16	64	15	11	9.0	278	0
29-77-32ca	Springs	----------	9- 9-60	18	23	.33	32	7.3	6.6	4.2	130	0
29-79-34b [17]	Spring	----------	10- 3-61	6	46	.01	33	5.4	20	5.8	162	0
29-82-28ca	Spring	----------	6-27-61	----	23	.03	49	9.0	4.4	2.4	194	0
29-83-26bbc	Spring	----------	12- 3-62	----	22	.00	46	9.3	20	4.9	219	0
												Arikaree
29-86-9dda	23	----------	8-12-66	6	36	0.44	122	34	191	10	233	7
29-86-31cb	250	220-250	10- 5-65	10	56	.02	38	8.5	13	5.6	165	0
30-85-27abc1	300	----------	5-20-66	11	14	.02	33	6.2	167	1.3	151	0
30-85-27abc2	90	----------	5-20-66	10	11	1.37	580	122	758	6.1	197	0
30-86-18cdb	120	----------	4-28-66	9	28	.19	43	7.8	80	1.2	255	0
30-86-35caa	90	60-90	6-16-67	9	35	.06	56	13	27	5.7	228	0
31-89-27ddd	Spring	----------	7-10-67	8	27	.07	36	8.0	14	4.0	171	0
												Alluvial terraces near
34-80-29add	Spring	----------	6-13-67	12	15	0.04	223	196	411	7.1	389	0
34-80-30add	11	6-11	6-13-67	12	26	.06	139	82	151	11	426	0
34-81-23ddd	48	6-48	5-24-67	11	19	.07	469	197	1,330	20	597	0
												Flood-plain
29-87-25caa [18]	35	----------	8-12-66	16	28	0.81	39	8.9	31	4.4	163	0
30-80-30abd [19]	Test hole, 64	22-62	6-15-67	9	29	.15	228	65	180	18	299	0
31-81-7abb [20]	35	31-35	8-10-66	18	33	------	141	68	215	4.3	308	0
31-82-12acb [20]	66	34-66	8-19-66	14	29	3.5	238	82	113	14	365	0
33-77-3bdc [21]	20	6-20	8-25-67	12	14	.20	140	44	250	3.7	328	0
33-79-18bab1 [21]	38	14-38	8-10-67	12	13	------	82	21	57	4.6	210	0
33-79-18bdd [21]	----------	----------	10-17-67	8	------	------	------	------	------	------	------	----
33-81-7caa [22]	16	14-16	12- 6-66	----	12	.44	137	27	229	4.1	276	0
33-81-33dda [23]	42	----------	6-14-66	14	13	.10	412	735	1,140	13	563	0
34-79-36dbb [21]	37	10-37	7-18-61	----	------	0	97	29	77	------	244	----
35-83-5dac [24]	61	15-35	7-12-67	16	13	.91	178	56	510	4.7	324	0
35-85-2[illegible]dd [2]	40	37-40	2- 8-66	----	12	.03	165	54	410	8.5	274	7

[1] Analysis by Chemical and Geological Laboratories (by permission of Pan American Petroleum Corp.).
[2] Tensleep Sandstone; may be influenced by Goose Egg Formation.
[3] Casper Formation.
[4] Tensleep Sandstone.
[5] Tensleep Sandstone; may be influenced by Madison water.
[6] Analysis by Chemical and Geological Laboratories (by permission of Forest Oil Corp.).
[7] H_2S odor.
[8] Sampled close to outcrop.
[9] Analysis by Chemical and Geological Laboratories (by permission of M. D. Hubley).
[10] Specific conductance measured 3,600 in the field.
[11] Possibly contaminated from sheep pens.
[12] Analysis by Wyoming Dept. Agr. Location 40-78-11dba; sampled after well completed.
[13] This is probably predominantly Fox Hills water.

c^f ground water—Continued

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180° C	Dissolved solids: Sum	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium-adsorption-ratio (SAR)	Residual sodium carbonate (RSC) (meq/l)	Specific conductance (micromhos per cm at 25° C)	pH	Arsenic (As), selenium (Se)
ormation													
14	1	0.5	4.5	0.57	262	281	221	0	0.3	0.14	461	7.4	0.00 (As, Se).
7.4	7.4	.1	2.2	.56	182	154	110	3	.3	0	226	7.6	0.00 (As, Se).
17	4.0	.3	1.9	.00	206	213	105	0	.9	.57	295	7.5	0.00 (Se).
6.0	.9	.1	1.3	-----	196	191	159	0	.1	0	315	7.0	0.00 (As, Se).
13	3.9	.3	.2	-----	217	227	153	0	.7	.53	373	7.9	0.00 (As, Se).
ormation													
412	168	0.5	0.1	0.02	1,120	------	444	242	4	0	1,650	8.4	
27	5.3	.4	.3	.20	248	235	130	0	.5	.10	316	8.7	
340	3.4	1.3	.1	.15	682	640	108	0	7.0	.31	970	8.0	
3,010	183	.4	.2	.27	5,080	4,770	1,950	1,790	7.5	0	5,380	8.2	
85	9.9	2.0	.7	.00	422	383	140	0	2.9	1.37	588	7.8	
48	11	.8	3.1	.03	310	312	192	5	.8	0	480	7.8	
13	2.1	.3	.0	.02	186	187	122	0	.5	.37	306	7.4	
North Platte River													
1,510	295	1.0	8.1	0.74	3,010	2,860	1,360	1,040	4.9	0	3,590	7.7	0.10 (Se).
596	44	2.8	31	.51	1,330	1,290	682	333	2.5	0	1,740	7.6	0.03 (Se).
4,050	200	4.3	24	1.23	6,750	6,610	1,980	1,490	13	0	7,180	7.4	1.1 (Se).
lluvium													
56	12	0.4	0.0	0.03	246	------	134	0	1.2	0	400	8.1	
950	25	.9	.0	.28	1,690	1,640	835	590	2.7	0	2,050	7.7	
774	31	1.0	.1	.49	1,470	------	632	379	3.7	0	1,820	7.9	
863	9.0	.4	1.7	.27	1,580	------	932	633	1.6	0	1,850	8.2	
738	32	.7	.0	.10	1,430	1,380	530	261	4.7	0	1,900	7.7	
206	16	.5	10	.07	506	513	290	118	1.4	0	786	7.6	
													0.02 (Se).
663	16	.4	.0	.17	1,240	1,230	454	228	4.7	0	1,670	8.1	
5,320	119	1.1	207	.70	9,300	8,240	4,050	3,590	7.8	0	8,280	7.8	
273	32	-----	-----	-----	634	628	362	-----	1.8	0	------	7.5	
1,490	29	1.0	.0	.13	2,440	2,440	675	409	8.5	0	3,160	7.6	
1,100	99	.8	73	.29	2,110	2,060	634	398	7.1	0	2,750	8.3	

[14] Analysis obtained from Amerada Petroleum Corp.
[15] Specific conductance measured by U.S. Geological Survey in the field.
[16] Analysis by Chemical and Geological Laboratories.
[17] Includes some Arikaree water.
[18] Alluvium along Sweetwater River.
[19] Alluvium along Stinking Creek.
[20] Alluvium along Bates Creek.
[21] Alluvium along North Platte River. Location 33–79–18bdd; sample collected from alluvium recharged by water from North Platte River.
[22] Aluvium along Poison Spider Creek.
[23] Alluvium along Iron Creek.
[24] Alluvium along Middle Fork of Casper Creek.
[25] Water source is sand dunes, but water is obviously influenced by minerals in Cody Shale.

TABLE 3.—*Chemical*

[Estimated discharges are marked by an asterisk.

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
6-3130.90 Salt										
[Lat 43°25′40″, long 106°17′30″; at U.S.										
Aug. 11, 1967	*6	29	------	117	33	1,730	24	792	0	1,070
6-6394.80 Horse Creek at										
[Lat 42°34′11″, long 106°59′55″; upstream side										
June 16, 1966	*3	34	------	100	35	28	13	212	0	280
6-6410.00 North Platte River										
[Lat 42°27′54″, long 106°50′47″;										
July 18, 1963	*1	10	0.00	29	13	35	2.6	104	0	99
6-6420.00 North Platte										
[Lat 42°33′02″, long 106°4?′58″; at bridge on county										
July 18, 1963	1,480	12	0.00	44	13	28	2.6	145	0	95
Nov. 27, 1967	1,200	--------	------	--------	--------	--------	--------	--------	--------	--------
6-6420.60 Lone Tree										
[Lat 42°36′40″, long 106°38′14″; upstream										
Oct. 16, 1967	*1	--------	------	--------	--------	--------	--------	--------	--------	--------
Nov. 27, 1967	.5	--------	------	--------	--------	--------	--------	--------	--------	--------
6-6425.00 Bates Creek										
[Lat 42°32′31″, long 106°20′04″; upstream side of bridge										
July 18, 1963	----------	24	0.00	39	7.2	11	2.6	168	0	12
6-6425.60 Corral Creek										
[Lat 42°36′35″, long 106°21′17″; upstream of bridge										
July 18, 1963	----------	10	0.00	57	11	3.7	1.4	158	9	49
6-6431.00 Poison Spring										
[Lat 42°42′55″, long 106°34′43″; upstream of bridge on										
Oct. 16, 1967	*0.5	--------	------	--------	--------	--------	--------	--------	--------	--------
Nov. 27, 1967	.5	--------	------	--------	--------	--------	--------	--------	--------	--------

analyses of surface water

‾Results in milligrams per liter except as indicated]

Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue at 180° C, milligrams per liter	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Temperature (°C)	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos per cm at 25°C)	pH	Remarks
'reek below Midwest												
‾Iighway 87 bridge north of Midwest]												
1,670	3.8	0.3	1.2	5,070	5,090	426	0	24	36	7,720	7.6	
‾tate Highway 220												
of highway bridge approximately 15 miles west of Alcova]												
3.9	1.3	0.2	0.12	600	634	392	218	16	0.6	873	7.7	
' elow Pathfinder Reservoir												
¼ mile below Pathfinder Dam]												
8.0	0.2	1.2	0.21	249	252	126	41	----	1.3	395	8.1	
‾iver at Alcova												
road at Alcova, 0.2 mile downstream from Alcova Dam]												
8.2	0.4	1.1	------	276	267	164	44	----	0.9	430	7.6	
--------	------	------	------	--------	--------	------	--------	----	------	--------	------	Selenium, <0.01.
'ulch near Alcova												
‾ide of culvert under State Highway 220]												
--------	------	------	------	--------	--------	------	--------	14	------	3,000	------	Selenium, 0.08.
--------	------	------	------	--------	--------	------	--------	----	------	--------	------	Selenium, 0.05.
near Freeland												
on old Medicine Bow Road near entrance to Steinle Ranch]												
2.3	0.1	0.9	------	182	180	127	0	----	0.4	273	8.2	
near Milne Ranch												
on old Medicine Bow Road near entrance to Milne Ranch]												
0.9	0.2	0.1	------	220	231	187	43	----	0.1	364	8.5	
'reek near Alcova												
road approximately 0.75 mile upstream from mouth]												
--------	------	------	------	--------	--------	------	--------	11	------	6,000	------	Selenium, 0.18.
--------	------	------	------	--------	--------	------	--------	----	------	--------	------	Selenium, 0.22.

TABLE 3.—*Chemical analyses*

[Estimated discharges are marked by an asterisk.

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
6-6439.00 Poison Spider [Lat 42°49′25″, long 106°40′45″; upstream side of culvert on Poison										
July 21, 1967	*1	9.7	------	91	40	248	7.6	282	0	654
6-6440.00 Poison Spider [Lat 42°46′44″, long 106°31′46″;										
July 21, 1967	11	3.1	------	145	66	316	7.5	293	0	990
Nov. 27, 1967	4	--------	------	--------	--------	--------	--------	--------	--------	--------
6-6440.40 Oregon Trail [Lat 42°49′41″, long 106°24′51″;										
Oct. 17, 1967	*1	--------	------	--------	--------	--------	--------	--------	--------	--------
Nov. 27, 1967	2	--------	------	--------	--------	--------	--------	--------	--------	--------
6-6441.20 Middle Fork of [Lat 43°04′35″, long 106°34′40″; approximately										
Aug. 23, 1967	*0.01	0.2	------	129	145	938	11	382	0	2,520
6-6445.00 Casper [Lat 45°50′51″, long 106°21′49″;										
Aug. 23, 1967	12	7.9	------	183	107	445	8.4	304	0	1,500
Nov. 27, 1967	4	--------	------	--------	--------	--------	--------	--------	--------	--------
6-6452.00 Muddy [Lat 42°44′03″, long 106°07′02″; at bridge on Hat Six Road										
July 19, 1963	----------	8.8	0.00	132	47	35	2.0	274	0	368
6-6457.00 Deer [Lat 42°29′22″, long 106°04′37″; above										
July 18, 1963	----------	18	0.10	20	3.0	4.8	0.4	86	0	1.0

of surface water—Continued

Results in milligrams per liter except as indicated]

Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue at 180° C, milligrams per liter	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Temperature (°C)	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos per cm at 25°C)	pH	Remarks

Creek near Mills

pider Road approximately 2.5 miles east of Poison Spider Oil Field]

22	0.8	0.5	0.21	1,210	1,250	394	163	24	5.4	1,720	7.8	Upstream of irrigation.

Creek near Goose Egg

at Bureau of Reclamation gage at the mouth].

31	0.9	30	0.25	1,730	1,820	634	394	24	5.5	2,340	7.8	Downstream of irrigation; selenium, 0.06.
----	----	----	----	----	----	----	----	----	----	----	----	Selenium, 0.16.

Drain near Goose Egg

at Bureau of Reclamation gage]

----	----	----	----	----	----	----	----	----	----	----	----	Selenium, 0.54.
----	----	----	----	----	----	----	----	----	----	----	----	Selenium, 0.94.

Casper Creek near Bucknum

100 yards downstream from Bucknum Road bridge]

42	2.2	0.3	0.64	3,980	4,130	917	604	17	14	4,950	8.1	Upstream of irrigation.

Creek at Casper

at Bureau of Reclamation gage]

68	1.0	21	0.36	2,490	2,630	894	645	14	6.1	3,210	7.5	Downstream of irrigation; selenium, 0.20.
----	----	----	----	----	----	----	----	----	----	----	----	Selenium, 0.24.

Creek near Casper

(formerly Blackmore Road) approximately 11 miles southeast of Casper]

4.0	0.1	0.8	----	733	767	524	299	----	0.7	1,010	7.8	

Creek near Casper

ford, approximately 25 miles southeast of Casper]

0.7	0.1	0.7	----	91	104	25	0	----	0.8	151	7.4	

Livestock can drink water unfit for domestic use, but water containing some minerals such as selenium, fluoride, and nitrate is also toxic to animals. Water containing 0.4–0.5 mg/l of selenium is believed to be nontoxic to cattle (McKee and Wolf, 1963, p. 254). No maximum concentration of selenium in water has been established for livestock, but water containing more than 0.5 mg/l of selenium should be used with caution.

The effects of fluoride in drinking water for animals is similar to those for humans. McKee and Wolfe (1963, p. 191) reported there are indications that 1.0 mg/l is the threshold value below which no harm results.

Nitrate poisoning (methemoglobenemia) also occurs in animals, but animals can tolerate higher concentration of nitrate in water than humans. Water with nitrate concentrations exceeding 570–1,000 mg/l should be used with caution for stock water (McKee and Wolf, 1963, p. 225).

INDUSTRIAL USE

Water-quality requirements for industry range widely. Generally, the criteria considered are (1) effect of the dissolved constituent on the product, (2) corrosive properties, and (3) scale-forming properties. Water temperature may be considered for some industries. Water that is suitable for domestic use is suitable for most industries or can be economically treated so that it is within the specified standards for the particular industry.

IRRIGATION USE

The success with which irrigation water can be used depends on the effect of the dissolved salts on the soil and on the plants. The U.S. Salinity Laboratory Staff (1954) stated, "The characteristics of an irrigation water that appear to be most important in determining its quality are: 1) Total concentration of soluble salts; 2) relative proportion of sodium to other cations; 3) concentration of boron or other elements that may be toxic; and 4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium."

No specific limits have been established for permissible salt concentration in irrigation water because of so many variables. The U.S. Salinity Laboratory Staff (1954) classified the suitability of water according to the salinity (or specific conductance) and sodium hazards.

Low-salinity water can be used for irrigation of most crops on most soils. Medium-salinity water can be used where a moderate amount of leaching occurs. Use of high-salinity water should be limited to soils with good drainage. Even then care must be exercised for salinity control, and only crops of high tolerance to salt should be grown. Very high salinity water is not suitable for irrigation under ordinary conditions.

The sodium hazard is indicated by the sodium-adsorption-ratio (SAR), which is an index of the suitability of water for irrigation use. Low-sodium water can be used for irrigation on almost all soils with little danger of accumulation of an excess amount of exchangeable sodium. Medium-sodium water should be used only on coarse-textured or organic soil with good drainage. High-sodium water will cause accumulation of excess exchangeable sodium in most soils. Good drainage, proper leaching, and additions of organic matter are part of the requirements of special soil management to use high-sodium water. An exception not requiring special management is gypsiferous soils, which may not develop harmful levels of exchangeable sodium because of relatively large amounts of calcium available from the gypsum. Very high sodium water is generally unsatisfactory for irrigation except at low or medium salinity. For Natrona County, the classification of waters for irrigation are given in the section on "Geologic Units and Their Water Resources."

Bicarbonate in water increases the sodium hazard by causing precipitation of calcium and magnesium as carbonate, which increases the relative proportion of sodium. This bicarbonate effect is expressed as residual sodium carbonate (RSC) concentration and is given in table 2. Water with an RSC of less than 1.25 meq/l (milliequivalents per liter) is probably in the safe range; water with an RSC of 1.25–2.5 meq/l is marginal; and water with an RSC above 2.5 meq/l is considered not suitable for irrigation (U.S. Salinity Laboratory Staff, 1954, p. 81).

Boron in trace amounts is necessary for plant growth, but it is toxic in larger amounts. It is believed that 0.4–0.5 mg/l of boron in irrigation water is the critical concentration before injury to plants with low tolerance to boron such as apple trees. For the most tolerant crops such as beets, alfalfa, and some vegetables, the maximum concentration that is safe for irrigation is about 4.0 mg/l (McKee and Wolf, 1963, p. 111–112). Chemical analyses of ground water from Natrona County indicate that most of the ground water is low in boron and is probably safe for irrigation on the basis of this constituent.

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The minimum concentration of selenium in irrigation water that will make crops toxic is not known. Miller (1956, p. 6) credited Beath with the following tentative limits for selenium:

Selenium (mg/l)	*Remarks*
0.00–0.10	No plant toxicity anticipated.
0.11–0.20	Usable; possible long-term accumulation under particular conditions and thus should be watched.
0.21–0.50	Doubtful; probable toxic accumulation in plants except under especially favorable conditions.
Over 0.50	Not usable under any conditions.

Beath (1964, p. 30) also stated that as little as 0.2 mg/l of selenium in irrigation water is capable of making some crops toxic.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The materials that make up the earth's crust contain numerous openings or interstices which can store water underground and release a part to wells and springs. Interconnections between openings provide avenues for the movement of water in the rock. The size of the openings and the degree of interconnection between them determine the ability of a rock to store and transmit water. That part of a rock formation saturated with water and capable of yielding water to wells in usable quantities is called an aquifer.

Ground water may be recovered by drilling into the zone of saturation, if the zone is permeable. In the zone of saturation, the rock voids are filled with water under hydrostatic pressure. The upper surface of the zone of saturation is called the water table where that surface is not formed by an impermeable layer. The water table is not a plane surface, but has irregularities. Ground water in the unconsolidated formations is usually under water-table conditions; that is, the water level in a well does not rise above the upper level of the water-saturated rock in the aquifer. If the upper surface of the zone of saturation in an aquifer is formed by an impermeable layer of rock, artesian conditions can exist. Artesian water is ground water that is under sufficient hydrostatic pressure to rise above the stratum from which it is derived. If the hydrostatic pressure is great enough to raise the water level in a well above the land surface, the well will flow.

The potentiometric surface is an imaginary surface that everywhere coincides with the static level of the water in an aquifer. It is the surface to which the water from a given aquifer will rise under its full head. Therefore, the potentiometric surface may be the result of water table or artesian conditions. A potentiometric surface map can be constructed by drawing lines through points of equal water-level altitude. These lines called potentiometric surface contours can be used to determine the direction of ground-water movement. Ground water moves from higher to lower altitude following a path perpendicular to the contours. A more detailed discussion of the principles of occurrence and movement of ground water has been given by Meinzer (1923).

Permeability is a measure of the capacity of a formation to transmit fluids. The original permeability remaining in a formation after compaction and cementation is termed "primary permeability." If the primary permeability is altered, it is termed "secondary permeability." Most nonclastic rock, such as igneous rocks and chemical precipitates, generally are not permeable at the time of formation (primary permeability), but may become permeable either by fracturing or solution activity (secondary permeability). Limestone and dolomite may be porous, but there may be little interconnection between the voids. Solution openings may occur at any place in a formation which has soluble minerals; however, they are prevalent in fractured zones, which serve as initial conduits for water. In some instances, the permeability may be reduced in these zones because of greater-than-normal cementation.

WATER-LEVEL FLUCTUATIONS

Ground-water levels do not remain stationary, but rise and fall in response to recharge to and discharge from the ground-water reservoir. Ground water is discharged through wells, springs, and drains, and directly to the atmosphere by evapotranspiration. Precipitation is the principal source of recharge to the consolidated aquifers in Natrona County, and the water levels probably change only a fraction of a foot per year in response to changes in recharge. The largest fluctuations are in local areas where streamflow and irrigation seepage recharge some of the unconsolidated aquifers such as alluvium and terrace deposits of Quaternary age.

GEOLOGIC UNITS AND THEIR WATER RESOURCES

More than 30 geologic formations are exposed in Natrona County, 28 of which are known to yield water to wells or springs. Pertinent data about wells and springs in the county are given in table 4. The water-bearing properties and quality of water from the formations differ greatly, and even aquifers having low-yield potential are locally important. The geologic formations, their water-bearing properties, and quality of water are summarized on plate 2.

TABLE 4.—*Records of selected wells and springs*

Location: See text under section on "Well-numbering system."
Depth of well: Depths are given in feet below land-surface datum.
Geologic source: p€r, Precambrian rocks; Mm, Madison Limestone; PPt, Tensleep Sandstone; PPc, Casper Formation; ₮Pge, Goose Egg Formation; ₮Pcg, Chugwater Group and Goose Egg Formation; ₮c, Chugwater Group; Jsd, Sundance Formation; KJcm, Cloverly and Morrison Formations; Kmt, Mowry and Thermopolis Shales; Kf, Frontier Formation; Kn, Niobrara Formation; Kc, Cody Shale; Kmv, Mesaverde Formation; Kle, Lewis Shale; Kfh, Fox Hills Sandstone; Kl, Lance Formation; Tfu, Fort Union Formation; Twdr, Wind River Formation; Twr, White River Formation; Ta, Arikaree Formation; To, Ogallala Formation; Qt, alluvial terraces; Qls, landslide deposits; Qs, windblown deposits; Qal, flood-plain alluvium; Qc, colluvium.
Use of water: D, domestic; I, irrigation; In, industrial; N, none; P, public; S, stock.
Depth to water: Measured depths to water level are given in feet and hundredths; reported depths are given in feet.
Remarks: T, temperature in degrees Fahrenheit; D, discharge in gallons per minute (R, reported; est., estimated; no suffix, measured); Ca, chemical analysis given in table 1.

Location	Owner or tenant	Year drilled	Depth of well (ft)	Diameter of well (in.)	Geologic source	Use of water	Altitude of land surface above mean sea level (ft)	Distance to water below land surface (ft)	Specific conductance (micromhos per cm at 25° C)	Date of measurement	Remarks
29-77-32b			Seep		Twr	S	7,510	Flowing	461	9- 9-60	T65, D1 est., Ca.
32ca			Spring		Twr	S	7,410	Flowing	226	9- 9-60	T65, D1 est., Ca.
29-78-11dba	Miles L. and L. Co		Spring		Twr	S	7,420	Flowing	145	8-22-66	T58, D25.
29-79-1bbc	do		Spring		Twr	S	6,920	Flowing	315	8-19-66	T48, D300 est.
6cbc	Steinle Ranch	1961	631	6	Twr	N	6,930	250		2-21-66	
34b			Spring		Twr	S	7,210	Flowing	295	10- 3-61	T43, D200 est., Ca.
29-80-11cb	Bureau of Land Management		Spring		Twr	S	6,575	Flowing	380	9-13-66	T53, D11.
12aba	do	1965	535	5	Twdr	S	6,840	100	460	8-23-66	T54, D15.
12cbd	do	1963	422	5	Twdr	S	6,790	400	820	6- 3-65	D10.
29-80-20bdc	R. A. Body	1963	31	6	Qal	D	6,170	20	1,100	9-13-66	T58.5.
21add	Bureau of Land Management		Spring		Qls	N	6,460	Flowing		9-13-66	D2.
29-81-4ddd	Anderson Oil Co	1921(?)	1,163	8	KJcm	N	5,907	Flowing	1,600	9-14-66	T91,D20.
5bbb	do	1959	1,014	9	KJcm	S	5,940	Flowing	779	9-14-66	T75, D1½, Ca.
9aaa	do	1920	3,030	5	KJcm	N	5,943	Flowing	1,050	9-14-66	T54, D1.
10bbb	do	1949	2,300	7	Jsd	N	5,900	Flowing	2,670	9-14-66	T67, D1.
22baa	Harold Josendal		65	10	Qal	D	6,370	54		9-13-66	
29-82-2dcc	Miles L. and L. Co			6	Kn(?)	N	5,880		2,050	9-14-66	T52.
28ca			Spring		Twr	S	6,900	Flowing	315	6-27-61	T50, D30 est., Ca.
29-83-26bbc			Spring		Twr	S	6,220	Flowing	373	12- 3-62	T42, Ca.
29-85-20adc				8	Ta	S	6,095	176.10	240	11-12-64	T54.
29-86-9dda	State of Wyoming		23	5	Ta	P	5,900	10.30	1,650	8-12-66	T42, Ca.
19ccc	Dumbell Ranch		20	6	Qal	N	5,925	5.27		6-21-67	
31cb	Tom Sun	1930(?)	250		Ta	S	6,098	171.40	316	10- 5-65	T50, Ca.
29-87-15cc	Sun Land and Cattle Co	1930(?)	60		To(?)	S	6,050	30		10-15-64	
25caa	Dumbell Ranch	1964	35	7	Qal	D	5,930	15	402	8-12-66	T60, Ca.
32dac		1924	9	2	Qal	N	6,005	5.18		6-21-67	

29-88-17acd	E. Gantz		35		Qal	S	6,055	15		11-10-64	
17cdc	Sun Land and Cattle Co	1931	70	8	Ta	D	6,055	16		10-15-64	
30-79-31bcc	Fred Steinle	1961	155	6	Twr	S	6,660	60	360	8-23-66	T48.
32add	Bureau of Land Management		Spring		Twr	S	6,520	Flowing	395	8-23-66	T50, D6.
33ddd	Garrett Ranch		Spring		Twr	S	6,630	Flowing	360	8-19-66	T54, D115.
30-80-11cba	do	1954	46	4	Qal	D	5,890		770	10-21-65	T47.
30abc	do		15	10	Qal	D	5,995		1,495	10-20-65	T50.
30-80-30abd		1967	64	4	Qal	N	5,913	22	2,050	6-15-67	T49, Ca.
30-81-4ddb	Cottonwood Livestock Co	1955	310	9	KJcm	S	5,740	Flowing	2,150	10-20-65	T63, D2.
9aa		1923	320	10	KJcm	S	5,770	Flowing	2,160	9-14-66	T66, D1.
20ccc	Harold Josendal		65	5	Kn	S	5,610	26.79	5,600	9-14-66	T51.
30-82-9cba	E. G. Weber		30		Qal	D	5,316	25	780	9-16-65	T55.
19cbb	Miles L. and L. Co	1962	56		TRPge	D	5,350		2,330	11-17-65	T64.
30-83-13ddc	Edmund Storrs		90	4	TRc	D	5,360	28	900	11-18-65	
15bda	Miles L. and L. Co	1961	132	6	TRc	S	5,582	49.98	397	9-29-65	T59.
18dcd	do	1962	1,590	5	PPt	S	6,360	890	3,740	1-18-66	T50, D20, Ca.
24da	do	1961	110	7	TRPge	D	5,380		2,000	11-17-65	
24dda1	Bureau of Reclamation	1952	90	12	PPt	In	5,350	Flowing	820	4-26-66	T72, D1, 400R.
24dda2	do			8	PPt	N	5,350	Flowing	1,370	4-26-66	T108, D380R.
31bdc	Miles L. and L. Co	1961	375	7	Twr	S	6,350	154.58	560	4-26-66	T56.
30-84-2acc	Sanford Cattle Co	1960	107	6	Twr	S	6,245	70	485	6-16-66	T49.
6dcb	do	1960	109	6	Ta	S	6,085	57.45	385	6-16-66	T50.
9caa	do		150	6	Ta	S	6,140	84.59	440	6-16-66	T50, D7.
15daa	do		650	6	Twr	S	6,270	300+	550	11-15-65	T59.
21daa	do		210	6	Twr	S	6,220	180	500	6-16-66	T51.
30-85-8dda	do		60	24	Ta	S	5,955	17.44	2,500	11-15-65	T49.
15aac	Diamond Ring Ranch	1957	120	7	Qal	S	5,920	7.15		8-10-66	
17daa	Sanford Cattle Co		43	36	Ta	N	5,910	40.44		6-16-66	
19caa	do		125		Ta	S	5,898	16	350	11-15-65	T51.
21bab		1967	27	¾	Ta	N	5,887	20.97		7-10-67	
27abc1	Sanford Cattle Co		300(?)		Ta	D	5,880		970	5-20-66	T52, Ca.
27abc2	do		90(?)		Ta	S	5,880	6	5,380	5-20-66	T50, Ca.
30-86-5daa	Dumbell Ranch		120	6	Ta	S	6,328	78.78	400	11-16-65	T50.
14ccc	do	1956	135	6	Ta	S	5,963	60.39	350	1-30-67	T52, D10.5.
18ccc	do		80		Ta	S	6,054	35	560	4-28-66	T49.
18cdb	do		120	6	Ta	S	6,053	27.17	588	4-28-66	T49, Ca.
29bdc1	do		60		Qal, Ta	S	6,000	6.34	600	11-17-65	T49.
29bdc2	do		40		Qal, Ta(?)	D	6,000	10	650	8-12-66	
33bab	do		100		Ta	S	5,973	38.53	625	11-17-65	T46.
35caa	Sanford Cattle Co	1958	90	6	Ta	S	5,915	43.72	480	11-15-65	T48, Ca.
30-87-12aaa	Dumbell Ranch		140	8	Ta	S	6,238	73.67	280	11-17-65	T49.
15acb	do		45		Qal, Ta(?)	D	6,142	2	590	4-28-66	T67.
30-89-19db	Bureau of Land Management	1942	310	8	To	S	6,704	207.3		6-20-65	
31-77-19cdd	B. B. Brooks Co		Spring		Twr	S	6,975	Flowing	260	9-24-66	T49.5, D75.
31-79-8ccd			Spring		KJcm	S	7,380	Flowing	88	8-10-67	T44, D40 est., Ca.
9ada			Spring		KJcm	S	8,010	Flowing	55	8-10-67	T60, D10 est.
11cdd			Spring		KJcm	S	7,845	Flowing	70	8-10-67	T44, D10 est.
31bda	Milne Ranch		Spring		TRPcg	S	6,080	Flowing	630	8-19-67	T52, D8.
31-80-18bdd	A. M. Nall		54	8	Qal	D	5,435	19.00	2,100	9-12-67	T49.
19ddb	H. M. Schnoor		80	6	Qal	S	5,625	36	2,000	8-18-66	T63.
22caa	Jack Johnson		68	6	Qal	D	5,720	30	1,700	8-18-66	T68.

TABLE 4.—*Records of selected wells and sprngs*—Continued

Location	Owner or tenant	Year drilled	Depth of well (ft)	Diameter of well (in.)	Geologic source	Use of water	Altitude of land surface above mean sea level (ft)	Distance to water below land surface (ft)	Specific conductance (micromhos per cm at 25° C)	Date of measurement	Remarks
31-81-7abb	Homer Clark	1961	35	8	Qal	D	5,355	31	1,820	8-10-63	T65, Ca.
11dbc	Cliff Tobin		35		Qal	D	5,480		1,700	8-18-66	T60.
18aab	J. R. Rissler		55	48	Qal	N	5,365	37.85		8-18-66	
18add	do	1955	90	36	Qal	I	5,380	32.58	2,150	7-11-67	T49, D1,300.
31-82-12abd	do		100	8	Qal	S	5,310	55	2,100	8-19-66	
12acb	do		66	8	Qal	S	5,320	33.98	1,850	8-19-66	T57, Ca.
13add	Miles L. and L. Co.		129	6	Qal	N	5,358	94.05		7-11-67	
17ccc	do			6	Kmv	S	5,660	38.58		11-18-65	
21dcc	do	1964	92	5	Qal	S	5,485	15.77		12-16-65	
24abb	do	1959	109	7	Qal	S	5,330	73.75		11-18-65	
24bdc	do	1966	25	8	Qal	S	5,285	12.15	1,375	4-21-67	T46.
28add	W. C. Watson		13	24	Qal	D	5,430	7.50	1,490	5-23-67	T47.
28ddd	do	1924(?)	30	6	Qal	N	5,420	15.94	2,550	5-23-67	T49.
32ddb	Miles L. and L. Co.		28	6	Qal	S	5,530	3.57		11-18-65	
34abb	do	1950(?)	46	1½	Qal	N	5,388	16.74		10-16-67	
35dcd	C. Lusby	1930's	11	6	Qal	S	5,300	9	650	8-11-67	T54.
31-84-5ccd	Diamond Ring Ranch		60	7	Ta	S	6,400	23.12	405	8-10-66	T48.
16ccc	Sanford Cattle Co.	1960	174	6	Twr	S	6,355	140	350	9-29-65	T48.
19bcb	Diamond Ring Ranch	1957	118	7	Ta	S	6,215	50.37		8-10-66	
31-85-13cbb	do		127	6	Ta	S	6,170	67.17	370	8-10-66	T60.
31-87-8bbd	Bureau of Land Management	1964	100	7	Ta	S	6,645	45.43	340	11-16-65	T47.
9bdb	Joe France	1964	133	7	Ta	S	6,500	13.90	475	11-16-65	T50, D120R.
34bbb	Matador Cattle Co.		50	6	Qal	S	6,342	6.84		11-11-65	
31-89-27ddd	do		Spring		Ta	S	6,590	Flowing	306	7-10-67	T47, D120 est., Ca.
32-77-17aba	Lawrence Lamb		60	8	Qal	D	5,360	21	1,800	9-23-66	
31cdb	E. F. Rissler		Spring		Kf	D	5,850	Flowing	750	9-23-66	T49, D1 est.
31dbc	do		Spring		Kf	S	5,850	Flowing	235	9-23-66	T48, D2.
33cda	Banner Ranch		Spring		PPc	I, S, D	6,050	Flowing	400	9-20-66	T48, D550 est.
32-78-11bda	Boris Kicken	1964	250	8	Qal	S	5,390	40		9-29-65	
20dda	Bureau of Land Management		Spring		PPc	S	6,320	Flowing	440	9-27-66	T45, D400 est.
28dab	B. B. Brooks Co.		Spring		PPc	I,S,D	5,900	Flowing	520	9-27-66	T49, D600 est.
32-79-17aad			Spring		PPc	P	7,700	Flowing	160	8-10-67	T45, D3.
19acb			Spring		PPc	S	7,860	Flowing	395	8-10-67	T48, D30.
32-80-22cdb	Oliver K. Scott	1960	270	7	TRPge	S	6,510	189.58		8-10-67	
32-81-2cbb	E. W. Shindelhauer	1966	44	6	Qal	D	5,200	23		10-19-66	
2cdb	F. L. Doing		30		Qal	D	5,185	12	950	8-10-65	T54.
3dad	Fred Stratton		40	6	Qal	D	5,200	23	775	10-19-66	T51.
12aba	Dick Farrell	1954	87	6	TRPge	D	5,365	25	2,200	7-14-67	T65.
15bad	Dan Speas		Spring		PPc	In, I	5,240	Flowing	684	2- 1-67	T60, D7,630, Ca.
18abb	T. L. Holman		870	8	Kf(?)	D	5,460	60	2,600	6-14-66	T57.

32bbb	Tye Moore	1959	50	8	Qal	S	5,205	8	3,600	5-23-67	T53; influenced by return flow from irrigation.
32bcd	do	1961	50	8	Qal	D	5,205	10	675	5-23-67	T51.
32-82-20acb	Sanford Cattle Co		Spring		Tfu	S	5,570	Flowing	1,650	8-11-66	T54.
32-83-6cdc	Diamond Ring Ranch	1956	165	6	Twdr	S	6,600	114.00	440	6-27-66	T53.
16dba	do		188	6	Twdr	S	5,990	130.74	2,700	8-11-66	T75.
20bdd1	Sanford Cattle Co		Spring		Twdr	S	6,190	Flowing	110	8-12-65	T46, D0.5.
20bdd2	do	1958	224	6	Twdr	S	6,180	194.40	400	12- 8-65	T51.
24ddc	do		Spring		Twdr	S	5,720	Flowing	1,200	8-11-66	T58, D5.
25aca	do		32(?)	5	Twdr	N	5,800	29.41		8-11-66	
27dda	do	1958	230	6	Twdr	S	5,863	20	790	5-17-63	T49.
31ada	do		157(?)	6	Twdr	N	6,300	141.05		12- 7-65	
32-84-10cad	Diamond Ring Ranch		72	6	Twdr	S	6,261	9.53	550	6-27-66	T58.
32-85-1bcb	T. D. Dodds	1961	182	8	Twdr	S	6,180	40	900	5-17-66	T40.
32-86-4cac	Diamond Ring Ranch		45	6	Qal	S	6,550	4.25		6-24-66	
33-77-3bcc1	Graham E. Grady		45	6	Qal	D	5,030	8	860	4-27-66	T46.
3bcc2	do	1966	22	12	Qal	I	5,030	7.50	740	4-27-66	
3bdc	John E. Peirce	1959	20	27	Qal	I	5,025	6.26	1,450	8-17-66	T54, D250R, Ca.
3bdd	do		18	2	Qal	D	5,030	10		8-17-66	
4dab	W. H. Douglas	1960	24		Qal	I	5,030	8		4-15-60	
8cbb	Cole Creek Sheep Co	1957	97	4	Kmv	S	5,180	30.27	2,200	4-27-66	T49.
15bcb	Amax Petroleum Corp	1966	7,615	8	Mm	In	5,165	Flowing	3,660	4-18-67	T137 est., D65, Ca.
33-78-5caa	R. L. Launspach	1962	42		Qal	D	5,110	32		6-26-62	
15bba	Percy E. Jones	1954	235		Kmv	S	5,252	30		8- 6-54	
15dac	Cole Creek Sheep Co		65	6	Kmv	S	5,223	22.63	2,300	4-27-66	T59.
33-79-3abb	City of Casper	1962	29	48	Qal	P	5,100	8		6- 4-62	D700R.
4bcb	North Platte Water and Sewer District.	1956	54	6	Qal	P	5,125	20			
4bcc	do	1947 (?)	55	48	Qal	P	5,125	20			
4bda	do	1964	28	48	Qal	P	5,100	12		5-15-64	D600R.
4bdd	do	1964	28	48	Qal	P	5,100	12		May 1964	D300R.
5add	do	1956	96		Qal	P	5,160	69		9-13-56	D50 est.
7adc	American Oil Co	1964	30	48	Qal	In	5,110	9.15		5- 9-65	D450R.
7cbd1	City of Casper	1956	30	48	Qal	P	5,115	8.50		3-23-56	D600R.
7cbd2	City of Mills		29	60	Qal	P	5,115	5.50		7-20-53	D600R.
7cbd3	do		30	48	Qal	P	5,115	7.50		11- 5-65	D500R.
7ccc1	City of Casper		19	2	Qal	N	5,120	13.96		3-20-63	
7ccc2	W. Humborg	1938	16	36	Qal	N	5,120	11		1959	
7ccc3	do	1961	24	32	Qal	I	5,120	17.47		3-20-63	
7ccd	City of Casper	1956	33	48	Qal	P	5,115	8		2-22-56	D800R.
7cda	do	1964	31		Qal	P	5,120	12		6- 9-64	D600R.
7da	American Oil Co	1964	27	48	Qal	In	5,110	8.66		4- 6-64	D214R.
7dca	City of Casper	1964	34	48	Qal	P	5,120	12		6- 9-64	D1,000R.
7dcd	do	1964	31	48	Qal	P	5,120	12		6- 9-64	D500R.
14dac	do		5,058	7	KJcm	N	5,410	110		1959	
18bab1	do	1953	38	26	Qal	P	5,120	14.10	786	8-10-67	T53, D700R, Ca.
18bab2	do	1920	30	144	Qal	P	5,120	15		1-15-57	D500R.
18bab3	do	1920	30	144	Qal	P	5,120	14		1-14-57	D500R.
18bab4	do	1920	30	144	Qal	P	5,120	16		1-16-57	D500R.
18bbb	do		25	156	Qal	P	5,120				D1,550R.
18bbd1	do	1958	25	156	Qal	P	5,120				D1,450R.

TABLE 4.—*Records of selected wells and springs*—Continued

Location	Owner or tenant	Year drilled	Depth of well (ft)	Diameter of well (in.)	Geologic source	Use of water	Altitude of land surface above mean sea level (ft)	Distance to water below land surface (ft)	Specific conductance (micromhos per cm at 25° C)	Date of measurement	Remarks
33-79-18bbd2	City of Casper	1958	24	156	Qal	P	5,120				D1,550R.
18ccb	do		39	7	Qal	N	5,120	11		8-17-66	
24acc	Casper Country Club	1959	5,101	7	KJcm	I	5,340	Flowing	538	3-23-67	T87, D40 (flowing), 250 (pumping), Ca.
30bbb	W. R. Asbell	1964	85	4	Qal	D	5,277	82	860	10-20-66	T62.
30cbd	do	1963	68	4	Qal	D	5,420	64	690	10-20-66	T59.
31ddd	E. C. Balben		Spring		Qc	D	6,030	Flowing	280	8-25-67	T50, D20.
33bba	Dempsey Stables	1959	100	6	Kc	S	5,760	40	3,470	9-19-67	T51, Ca.
36ab	City of Evansville	1961	37	48	Qal	P	5,109	9		7-14-61	
33-80-3baa	J. J. Nichols		160	4	Kc(?)	N	5,285	8.24		10- 1-65	
3cbb1	F. Beard		31	7	Qt	D	5,272	7	1,830	6-13-67	T49.
3cbb2			21	1½	Qt	N	5,272	6.71		6-13-67	
4abb			68	1¼	Qt	N	5,289	10.65		10- 1-65	
4cbb			59	1½	Qt	N	5,273	7.62		5-18-66	
6cbc	T. J. Lang	1961	204	5	Kf	D, S	5,375	Flowing	4,110	12- 6-66	T74, D1 est., Ca.
8aad	Bill Dye		147		Kf	D, S	5,271	28	3,670	6-13-67	T64, Ca.
12daa	City of Casper		30	48	Qal	P	5,120	6.70		March 1956	D750R.
12dac	do		30	26	Qal	P	5,120	8		Aug. 1953	D750R.
12dda1	do	1953	32	26	Qal	P	5,120	8.50		6- 6-53	D600R.
12dda2	do	1953	34	26	Qal	P	5,120	7.25		6-17-53	D700R.
12ddb1	do	1953	30	26	Qal	P	5,120	4.80		5-30-53	D700R.
12ddb2	do	1953	28	26	Qal	P	5,120	7.90		5-18-53	D600R.
12ddd1	do	1953	36	26	Qal	P	5,120	9.75		5-26-53	D700R.
12ddd2	do	1953	34	26	Qal	P	5,120	8.60		6-12-53	D700R.
13bab	Frank Sherard	1961(?)	154	5	Kc	N	5,165	35.35	5,200	5-23-67	T57.
14daa	Paradise Valley Utility	1958	44	16	Qal	P	5,140	15(?)			
14dab	do	1958	47	16	Qal	P	5,140	15(?)			
14dad	do	1958	46	16	Qal	P	5,140	15(?)			D530R.
17bba	Morse Kimble	1963	180	6	Kf	S	5,360	Flowing	2,500	5-25-67	T55, D 0.2.
22dad	Closs Wyo. Co.	1960	27	48	Qal	P	5,140	22		7-18-60	
22dc	do	1960	27		Qal	P	5,145	21		7-15-60	
24dad	Dick Bison		100(?)	10	Qal	D	5,245	60 est.	680	10-20-66	T60.
24dbd	Walter Gibbs	1962	75	7	Qal	D	5,245	65	910	7-14-67	T58.
25cdd	Raymond Stoner	1964	6	48	Qal	D	5,470	4	540	10-20-66	T63.
27bbb		1966	120	10	Kc	D	5,180	30	2,300	9-13-66	T58.
27cdd	H. F. Purcell		Spring		Qc(?)	D	5,350	Flowing	390	6-14-66	T62.
33-81-2cca	W. E. Fantry				Kf(?)	S	5,465	Flowing	8,000+	6-17-66	T59, D<1.
7caa	L. C. Mills		16		Qal	D	5,404	14	1,670	12- 6-66	Ca.

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	10cbc	Poison Spider School		Spring		Kmt	P	5,530	Flowing	1,850	10-20-66	T55, D2 est.
	16bcb	Marjorie Speas	1966	29	6	Qal	S	5,356	15			
	17aad	Gene Vitto	1956	14	36	Qal	S	5,355	8	2,600	10-19-66	T55.
	20add	Dayton Allen		8		Qal	D	5,337	6			
	20bba	Clayton J. Robinette		12	36	Kc	D	5,415	9(?)	2,300	10-19-66	T55.
	33dda	Tom Rennard	1948	42	6	Qal	S	5,268	5.72	8,280	6-14-66	T58, Ca.
33-82-	8aab	Bill Mills				Kf(?)	S	5,510	Flowing	1,750	12- 8-65	T56, D2.
33-84-	4bba	Diamond Ring Ranch		73	6	Twdr	S	5,910	27.60	1,000	6-22-66	T50.
	10dcb	do		224(?)	3	Twdr	S	5,900		2,250	6-22-66	T53.
	11dcc	do		103		Twdr	S	5,995	72.79	1,150	6-22-66	T51.
	13cca	do	1956	145	6	Twdr	D	5,840		1,025	6-22-66	T51.
	13cdb	do	1958	60	7	Twdr, Qal	S	5,795	4.74	930	6-22-66	T47.
	17ddb	Don Dodds		60	8	Twdr, Qal	S	5,878	6.65		11-12-65	
	25cbc	Diamond Ring Ranch		145	6	Twdr	S	5,880	44.96	875	6-27-66	T53.
	28bca	T. D. Dodds	1963	140	8	Twdr	S	5,932	45		12-17-65	
	29dba	do		100	5	Twdr	S	5,955	29.65		11-12-65	
	36ddc	Diamond Ring Ranch	1966	150	6	Twdr	S	5,970	25.76	740	6-27-66	T49.
33-85-	3dbb	do		128	6	Twdr	S	6,040	81.86	1,300	6-23-66	T49, Ca.
33-86-	33bdd	do		168	6	Kc(?)	S	6,500	40.06		6-23-66	
	34adc	do		64	6	Kmv	S	6,400	17.00	1,500	6-27-66	T48, Ca.
33-87-	16cca	Forest Oil Corp.	1961	3,501		Kmt	N	6,460	130			Ca (oil test well plugged and abandoned).
	29aab	Shell Oil Co.	1964	3,498	7	PPt	In	6,744	Flowing	430	6-24-66	T56, D20.
33-88-	2cbd	Fulton C. Jameson		Spring		KJcm(?)	S	6,680	Flowing	1,100	6-24-66	T49, D5.
	6cbc			Spring		Qc(?)	S	6,965	Flowing	750	10-27-65	T48, D<1.
	7aab			Spring		Qal	S	7,380	Flowing	550	10-27-65	T42, D<1.
	10aba	Fulton C. Jameson		500	3	PPt	D	6,730	Flowing	470	6-24-66	T68.
33-89-	15acd	Globe Mining Co.	1959	537	7	KJcm		6,990	260	694	7-16-64	T58, Ca.
	15bcb	do	195[illegible]	484	8	KJcm	D	7,000	256		7-20-59	
34-77-	5ccb	Cole Creek Sheep Co.		39	6	Kl	S	5,400	10	2,900	11-10-65	T50.
	8bad	do		137	6	Kl	S	5,378	12	7,900	11-10-65	T50.
	9bcc	do		90	6	Kl	S	5,384	12	1,710	11-10-65	T50, Ca.
	19bbb	Waldon Strand		165	6	Kl(?)	S	5,400	68.50	3,200	11- 9-65	T52.
	28cdb	do		355	6	Kfh	S	5,180		2,350	11- 9-65	T55.
	31cca	do		45	6	Kle	N	5,080	27.28		11- 9-65	
	31dca	do		45	6	Kmv(?)	S	5,055		2,350	11- 9-65	T52.
34-78-	5dbc	do		200	5	Kfh	S	5,300		4,400	9- 7-66	T52.
	9dac	do		75	10	Kfh	N	5,355	65.10		11-10-65	
	11dbb	do		100	8	Kfh	S	5,410	42.16	4,000	11-10-65	T52.
	16bcb	do		145	8	Kfh	N	5,340	50.48		11-10-65	
	19bab	do		165	6	Kle(?)	S	5,280	57.07	4,000	11-10-65	T38.
	23cbb	do		40	8	Kfh	S	5,252		1,425	11- 9-65	T51.
34-79-	3ccc	Ed Harford	1917(?)	120	8	Kmv	D	5,450	100	3,600	6-12-67	T68.
	8ddd			67	4	Kc	N	5,340	34.93		6-12-67	
	17baa	R. M. Nunn	1953	200	6	Kc	S	5,345	55	6,100	11- 4-65	T52.
	17dba	do	1955	405	6	Kc	S	5,275	30	4,840	6-12-67	T53, Ca.
	29bcc	A. Kleiner	1956	21	30	Qs	D	5,290	17	2,000	6-12-67	T53.
	34dcd1	City of Casper	1961	33	48	Qal	P	5,100	8		7-24-63	D1,030R.
	34dcd2	do	1961	28	48	Qal	P	5,100	8		7-19-61	D920R.
	34dd	do	1962	32	48	Qal	P	5,100	7		7- 6-62	D850R.
	36dbb	City of Evansville	1961	37	48	Qal	P	5,100	10.00		7-14-62	D500R, Ca.

TABLE 4.—*Records of selected wells and springs*—Continued

Location	Owner or tenant	Year drilled	Depth of well (ft)	Diameter of well (in.)	Geologic source	Use of water	Altitude of land surface above mean sea level (ft)	Distance to water below land surface (ft)	Specific conductance (micromhos per cm at 25° C)	Date of measurement	Remarks
34-80- 7daa			23	18	Qt	S	5,360	11.47		4-24-67	
8ccc		1967	26	1	Qt	N	5,353	12.47		4- 7-67	
21cad	Casper Air Terminal	1963	3,100	7	KJcm	I	5,305		453	12-21-66	T95, Ca.
29add			Spring		Qt	S	5,240	Flowing	3,590	6-13-67	T53, D15, Ca.
30add	R. W. Noland		11	48	Qt	D	5,305	6.13	1,740	6-13-67	T53, Ca.
32cbc	Wyatt Bros	1961	735	8	Kf	S	5,265	Flowing	2,830	5-25-67	T56, D0.2, Ca.
34-81-23ddd	Walter Schlager	1951	48		Qt	S	5,280	6	7,180	5-24-67	T51, Ca.
34-82-4bbb	Roxana Barker		Spring		Kf	S	5,523	Flowing	1,650	11-11-65	T49.
16abb	do		35	8	Kf	N	5,678	5.92		11-11-65	
23aab			60	6	Kf	S	5,660	35	5,000	11-11-65	T50.
34-83-9bac	Evelyn Potter		80	6	Kf	S	5,750	36.14		1-18-66	
9cab	do		80	6	Kf	D	5,740	35	1,250	7-12-67	T65, Ca.
19ada	Louie Stronecker	1940	60	10	Kf	D	5,735	36.10		8-11-65	
19adb	do		40		Kf	S	5,735	20.98		8-11-65	
34-85-27dcd	Diamond Ring Ranch		80	6	Twdr	S	6,020	56.89	2,000	6-23-66	T48.
36bbb	do		36	6	Twdr	N	5,955	17.14		6-23-66	D1½.
34-86-1dcd			150(?)	4	Twdr	S	5,970	32.39		8-11-65	
9bbc			38	4	Twdr	S	5,990	25.43		8-11-65	
21caa			7	36	Qal	N	6,090	6.00		8-11-65	
34-87-27dab	O. E. Forgey			6	Twdr	S	6,212	18.84		11-10-65	
34-88-8bcb				6	Kc	S	6,365	27.40		10-26-65	
21add	Matador Cattle Co.		84	6	Kc	S	6,390	72.94		5-19-66	
26abc	do		270	8	Kc	S	6,245	16.77		5-19-66	
34-89-25acc			Spring		Twdr		6,870	Flowing	1,000	10-27-65	T44, D5 est.
35-79-2bcd	B. B. Brooks Co.	1963	126	6	Kle	N		11.28		9-15-66	
3dcd	do	1963	130	6	Kfh	S		30.87		9-15-66	
9dcd	do		150	6	Kfh	N		24.72		10-18-65	
35-80-31cbb			33	1¼	Qt	N	5,350	3.13		10-18-65	
31ddd		1967	45	1	Qt	N	5,339	15.01		4-24-67	
32ccc	Don Hood	1959	65	6	Qt	N	5,335	12.03		4-24-67	
35-82-27ccd	Vern Robinett	1963	858	4	Kf	S	5,500	Flowing	1,800	8-31-65	T54, D0.1
29add	Roxana Barker		35	6	Kf	S	5,601	7.19		11-12-65	
32aad	do		53	6	Kf	N	5,653	47.68		11-11-65	
33dbd	Warren Duthie		46	6	Kf	N	5,500	15.32	3,100	10-20-65	T51.
33dca	do	1955	60	6	Kf	D	5,525	38	1,560	5-19-66	T56, Ca.
34cbc	do		45	6	Kc	S	5,479	14.61	8,000+	10-20-65	T51.
35-83-1dac	Wayne Buzan		17	6	Qs	D		10.60	1,800	11-12-65	T50.
3adc	Tom Combs	1965	26	24	Qs	N		12.29	1,450	11-12-65	T50.
3bdd	Wayne Buzan		20	36	Qs	S		16	1,390	11-12-65	T62.
3dad	Tom Combs		33	24	Qal	S			4,600	11-12-65	T52.

5dac	Wayne Buzan	1955	35	24	Qal	D		15	3,160	7-12-67	T68, Ca.
30adc			Spring		Kmt	S	5,915	Flowing	1,850	9-22-66	T62.
33ccc	C. A. Manning	1925(?)	14		Qal	D	5,840		2,000	1-18-66	T57.
35-84-1cd	Pine Mountain Livestock Co.	1964	30	24	Qal	S		13.39		9-29-65	
4ca	Daniel H. Miller	1960	62	6	Qs	S		30		9-30-65	
6bcc	Burlington R. R.			6	Qs	D		25	1,650	5-24-67	T52.
35-85-1cbb	M. L. Brekken		40	18	Qs	N		27.85		8-11-65	
2add	Robert Morton	1961	40	18	Qs	D		37	2,750	2- 8-66	Ca.
35-86-4bac			Spring		Twdr	S	5,880	Flowing	5,000	10-25-65	T69.
5cca	Springstein Ranch		250	4	Twdr	S	5,882	Flowing	2,050	10-26-65	T49, D1.25.
5cdd	do		250		Twdr	S	5,880	Flowing	2,050	10-26-65	T49, D1.25.
7acc	do		80	4	Twdr	S	5,919	28.86		10-26-65	
7adb	do		143	3	Twdr	N	5,910	4.40		10-26-65	
8cab1	do		205	6	Twdr	I, S	5,880	28.85	2,050	10-26-65	T48.
8cab2	do		20	48	Qal	S	5,880	18	850	10-26-65	T49.
35-87-7dda	C. A. Fenton	1964	50	24	Twdr	S	6,270	25.01	600	9-26-65	T49.
12dac	Springstein Ranch		80		Twdr	S	5,939	38.94		10-26-65	
18dcd	C. A. Fenton	1962	52	6	Twdr	S	6,110	20		10-14-62	
19aab	do	1964	62	24	Twdr	D	6,130	44.55	1,500	10-27-65	
19bca	do	1964	27	24	Twdr	S	6,140	7.94	900	10-25-65	T51.
22aaa	do	1960	105	6	Twdr	S	6,120		3,250	5-17-65	T51.
29dba	Pine Mountain Livestock Co.			6	Twdr	S	6,115	110.74	2,500	10-26-65	T51.
35-88-2bbb	Diamond Ring Ranch		400+	6	Twdr	S	6,200		930	6-21-66	T54.
6dda	do		400+	6	Twdr	S	6,180		1,600	6-20-66	T56.
24aab	C. A. Fenton	1963	143	6	Twdr	S	6,190	98.03		10-25-65	
24ddb	do		111	6	Twdr	S	6,180	65	1,400	5-17-63	T50.
32bbb	Diamond Ring Ranch		7.8	18	Qal	N	6,490	7.00		10-26-65	
35dcc	Pine Mountain Livestock Co.		181	4	Tfu	N	6,235	163.50		10-26-65	
35-89-22dad	Diamond Ring Ranch		400(?)	6	Twdr(?)	S	6,300		3,000	6-21-66	T57.
36bbd	do				Tfu	S	[illegible],610		3,500	10-27-65	T49.
36-77-5bbb	Amerada Petroleum Corp	1962	496	6	Kl	D	5,990		2,600	8-11-67	T54, Ca.
36-78-3caa	Teapot Sheep Co	1964	95	7	Kl	S	5,600	28.93	2,000	9-29-65	T47.
18ada	B. B. Brooks Co	1963	73	6	Kl	S	5,610	23.86		8-24-66	
29daa	do			6	Kl	S	5,508	20.71	2,200	10-21-66	T49.
30ccb	do	1963	152	6	Kl, Kfh	S		33.17		9-15-6[illegible]	
36-79-6dba	Burke Sheep Co		92	6	Kle	N		57.17		8-16-66	
12dbd	B. B. Brooks Co	1963	139	6	Kfh	S		16.68		10-21-66	
20bcb	Joe Forgey			6	Kfh	S		27.40	2,800	8-27-65	T62.
24ada	B. B. Brooks Co	1963	158	6	Kl	S		26.65		10-21-66	
29bcb	Joe Forgey			8	Kfh	S		33.50	4,000	8-27-65	T51.
32dbd	do		85	6	Kfh(?)	S		37.10	6,000	8-27-65	T53.
36-80-12dab	Burke Sheep Co	1966	76	6	Kle(?)	N		29.84		8-16-66	
22bbb	do		101	6	Kmv	S		34.69		8-17-66	
36-81-7bcd	M. F. Gowin	1924	175	7	Kf	S		Flowing	1,600	9-26-66	T70, D10.
36-82-24ac	do		1,000(?)	7	Kf	S		Flowing	1,150	3-21-63	T71.
36-83-15dd			10	18	Kc	N		8.19		8- 9-66	
28cc	William Brewer, Jr.	1964	40	24	Qs	S		25	700	9-29-65	
36-84-7bd	Leona Brewer	1958	41	18	Kc	S		26.83		12- 9-65	
33ddc	Daniel H. Miller	1964	25	24	Qs	S		16.85		12-10-65	
36-85-23daa	Irvine Bros. Ranch		950(?)		Kf	D		Flowing		3- 1-67	T68, Ca.
36-86-19cda	Daniel H. Miller	1964	180	6	Twdr	S	6,065	76.15	6,000	10-27-65	T48.
19cdc	Joe Forgey		145	4	Twdr	S	6,052		4,500	10-28-65	

TABLE 4.—*Records of selected wells and springs*—Continued

Location	Owner or tenant	Year drilled	Depth of well (ft)	Diameter of well (in.)	Geologic source	Use of water	Altitude of land surface above mean sea level (ft)	Distance to water below land surface (ft)	Specific conductance (micromhos per cm at 25° C)	Date of measurement	Remarks
36-86-33dcc	Springstein Ranch		10	48	Twdr	N	5,880	5.50	2,100	5-24-67	T49.
36acc		1967	350	7	Tfu	N	6,027	180		4-27-67	Ca.
36bab			133	6	Twdr	N		44.19	380	8-31-65	T50.
36dbc	Hells Half Acre	1964	600	6	Tfu	P		150 estimated	2,210	4-25-66	T69, Ca.
36-87-23ccc			8	72	Twdr	D	6,080	2.69	812	10-22-65	T50, Ca.
36-88-2dcd	Guy Wight		200	4	Twdr	D		64		10-21-65	
3dad	A. L. Carlson	1963	63	6	Twdr	S	5,870	28.86		10-18-65	
6ddb	Neff Ranch		180		Twdr	S	5,965		2,500	Oct. 1964	
8baa	Rochelle Sheep Co	1958	113	7	Twdr	S	5,987	70.42		10-21-65	
10aaa	A. L. Carlson		63	5	Twdr	S	5,980	42.97		10-18-65	
31cad	Diamond Ring Ranch	1960(?)	300+	6	Twdr	S	6,110		2,300	6-20-66	T53.
36-89-10aad	Guy Wight		90	4	Twdr	S	5,873		3,500	10-22-65	T52.
13aaa	Neff Ranch		120	6	Twdr	S	6,016	108.42	4,500	Oct. 1965	
25abb	do				Twdr	S	6,142		413	11- 9-65	T49, Ca.
36ddc	Bob Neigh		287	6	Twdr	N	6,100	283		Oct. 1965	
37-78-7dcd	Atlantic Refining Co	1962	1,796	10	Kmv	In	5,498	200	3,080	8-24-67	T72, D116R, Ca.
25dd	Teapot Sheep Co	1966	82	6	Kfh	S		17.30		6- 9-67	
30bca	do		78	7	Kfh	S		9.80		8-24-67	
37-79-4dda	Burke Sheep Co		56	7	Kmv	N		36.51		9-26-66	
19dda	do		210	6	Kmv	S		90	1,950	8-15-66	T54, Ca.
19ddd	do		130	6	Kmv	S		90.06	3,600	8-15-66	T55.
20cac	do	1965	281	7	Kmv	S		66.67	800	9-29-66	T48.
30aac	do		105	6	Kmv	S		42.68	1,800	8-15-66	T49.
30dcd	do		511	7	Kmv	S		78.92	625	8-16-66	T56, Ca.
36bab	Teapot Sheep Co		67(?)	8	Kfh	N		19.35		8-24-67	
37-80-25adb	Burke Sheep Co	1954	500	10	Kc	N	5,560	62.24		8-15-66	
37-82-36bbb	M. F. Gowin		925	6	Kf	S		Flowing	2,000	2- 2-67	T52, D0.25, Ca.
36ddd	do		1,275	10	KJcm	D	5,560	Flowing	2,540	2- 2-67	T52, Ca.
37-84-32ad	Leona Brewer		37	18	Kc	S		19.59		12- 9-65	
37-85-17ab	Van Irvine	1960	1,508	2	Kf	S		6.13	1,400	5-17-63	T49.
37-86-10ddd	Rochelle Sheep Co	1959	152	4	Kf	S	5,890	22.97		11- 9-65	
13dd	Van Irvine	1960	1,657	7	Kmc	N	5,920	Flowing	3,640	11- 9-65	T75, D45, Ca.
37-87-17dcd	Bureau of Land Management		100	6	Twdr	S	5,960	48		5-14-63	
18dd	do	1961	156	7	Twdr	S	5,935	27.20		10- 8-64	
24ddd	M. F. Rochelle		122	6	Kmv	S	6,110	34.78		10-27-65	
32bca	J. M. Donlin	1957	125	6	Twdr	S	6,240	47.90		11- 9-65	
37-88-10aba	Steve Sullivan	1951	400	6	Twdr	D	5,820	25	1,100	9-23-65	

18ac		1964	345	7	Twdr	N	5,800			4-16-64	Well reported to flow 10 gpm when drilled, but did not flow in 1967.
24bb	Steve Sullivan	1958	160	6	Twdr	S	5,925	40		5-17-63	
32add	M. F. Rochelle	1957	65	6	Twdr	S	5,865	5.72		10-21-65	
33ada	A. L. Carlson	1963	94	6	Twdr	S	5,926	47.37	3,200	9-29-65	T49.
34dcc	do	1964	101	6	Twdr	S	5,940	27.81	1,600	9-29-65	T48.
37-89-14bbb	Todd Ranch		78	5	Twdr	N	5,700	35.17		10-22-65	
38-78-24cad	Bureau of Land Management	1950	740	6	Kmv	N	5,740	400		11- 1-50	
38-79-22cda	Teapot Ranch Co			6	Kmv	S			1,800	8-27-65	T58.
34bda	do		100	6	Kmv	S		70.43	5,000	4-26-66	T53, Ca.
38-80-13cbb	Con O'Brien		94	6	Kc	S		26.30		9-21-66	
25ccc	do		180	6	Kmv	S		40.46		9-21-66	
38-80-27bbd	do		180	5	Kc	S		Flowing	8,000+	9-21-66	T50, D0.25.
28ccd	do		80	6	Kc	S		40	4,900	9- 8-66	T57.
34ddb	do		80	5	Kc	S		40.90		9-21-66	
38-81-14bac			18	42	Qal	N		16.78		2- 2-67	
38-87-11aba	Clear Creek Cattle Co	1959	120	6	TRc	S	6,760	68.63		10-20-65	
14cdc	do		215	6	KJcm	S	6,390	24.06		10-20-65	
38-88-23ada	Steve Sullivan		61	6	Twdr	S	6,140	22.60		10-20-65	
38-89-25bac			Spring		Twdr	S	5,818	Flowing	1,500	10-19-65	T51, D<1.
39-78-26cdc	MKM Oil Co	1965	7,180	7	Mm	In	5,130	Flowing	4,940	8-11-67	T190, Ca.
39-79-11aad	Amax Petroleum Corp	1962	5,688	13	Mm	In	4,878	Flowing		2- 1-66	D4,750R.
11dd	do	1939	2,069	6	Kf	D			3,530	3-22-67	D7R,Ca.
39-81-6aac	Lone Bear Ranch Co			7	Kf	S		Flowing	3,500	11- 3-65	T52, D3.
7bbb	do			4	Kf	S		Flowing	3,200	11- 3-65	T56, D1.5.
8ddc	V. I. Sheep Co	1961	1,163		Kf	S		Flowing	3,100	9-29-65	T58, D2.5.
39-82-6caa	James M. Young	1963	304	6	Kmt	S		20.05		10-19-65	
9cbc	Lone Bear Ranch Co	1964	1,030	2	Kf	S		Flowing	3,230	2- 2-67	T56, D5, Ca.
11ddb	do	1960	878	2	Kf	S		Flowing	3,400	9-29-65	T57, D3.
30ad	Bureau of Land Management		850	6	Kf	S		Flowing	5,800	11- 5-64	T51, D0.5.
39-83-5aad	do		Spring		Jsd	S		Flowing	671	9- 9-66	T45, D30, Ca.
7aab	do		Spring		TRc	S		Flowing	1,570	8-21-66	T48, D120, Ca.
13 bda	James M. Young		78	10	Kmt	S		Flowing	2,200	10-19-65	T51, D0.25.
13bdd	do		117		Kmt	D		Flowing	1,140	2- 2-67	T51, D0.25, Ca.
13ddc	do		743	10	KJcm	S		Flowing	2,100	10-19-65	T51, D0.2.
16dab	do	1960	254	7	Kmt	S		Flowing	2,200	9-29-65	T49; well reported to flow about 2 gpm when not pumped.
39-83-18cad	Home Sheep Co	1954	1,540	4	PPt	S	5,817	Flowing	809	10-19-65	T61, D150, Ca.
27aac	James M. Young	1960	248	7	Kmt	S		7.44	2,200	9-29-65	T51.
39-84-3bbc	do		Spring		KJcm	S		Flowing	1,920	9- 8-66	T48, D31, Ca.
39-88-2aca	do		Spring		p€r	S	7,380	Flowing	280	8-22-67	T73, D5 est.
18cad	James Hendry		Spring		PPt	D	6,270	Flowing	600	10-22-65	T52, D15 est.
40-78-10cbd	Sinclair Oil Co		1'5	6	Kfh	N	5,020	80		10- 6-53	
11acb	Town of Edgerton	1961	950	8	Kfh, Kl	P	5,120	64.00	1,703	9- 9-65	T57, D22, Ca; specific capacity, 0.03.
11dba	do	1965	733	7	Kfh, Kl	P	5,172	113.93	1,790	10-13-65	T58, D30, Ca; specific capacity, 0.04. (Plugged back from 1,005 feet.)

TABLE 4.—*Records of selected wells and springs*—Continued

Location	Owner or tenant	Year drilled	Depth of well (ft)	Diameter of well (in.)	Geologic source	Use of water	Altitude of land surface above mean sea level (ft)	Distance to water below land surface (ft)	Specific conductance (micromhos per cm at 25° C)	Date of measurement	Remarks
40-78-14aad	Town of Edgerton	1961			Kfh	N	5,260	113.93		4-30-65	
15aab		1956	317	7	Kfh	N	5,060	72.89	4,100	8-12-65	Specific conductance measured in 1956.
15abb	Town of Edgerton		126	8	Kfh	P	5,049	68.39		9-22-53	D10; water reported to contain 388 mg/l of dissolved solids.
16aaa	Sinclair Oil Co.		130	7	Kle	N	5,050	92.44		8-18-65	
26cba	Bob Parsons		90	7	Kfh	D	5,030	60	2,850	7-13-67	T61, Ca.
26ccc	do		100		Kle	S	5,040	60	5,100	7-13-67	T52.
40-79-2ada	Pan American Petroleum Corp.	1949	7,467	7	PPt, Mm	In	4,766	Flowing		11-18-66	D565R.
23ddb	do	1954	5,049	7	Mm	In		Flowing		11-18-66	D880R.
25caa	do	1928	4,400	6	PPt	In	4,808	Flowing	4,280	11-18-66	T160, D500 est., Ca.
26caa	do	1961	4,889	16	Mm	In	4,938	Flowing	3,980	11-18-66	T183, D3,900 at 150 psi flowing pressure, Ca.
35acb	do	1961	4,975	11	Mm	In		Flowing		11-18-66	D7,000R at 179 psi flowing pressure in 1961.
35ccc	do	1959	4,968	13	Mm	In		Flowing		5-20-59	D25 at 99 psi flowing pressure, Ca.
40-80-5abb	Lone Bear Ranch Co.	1962	875	4	Kf	S		Flowing	3,300	9-29-65	T57, D<0.1.
27ba	John J. Tobin	1966	1,150	2	Kf	S		Flowing	1,460	7-13-67	T71, D2, Ca.
34bd	Lone Bear Ranch Co.	1961	874	2	Kf	S		Flowing	1,200	7-13-67	T69, D2.
40-81-20cad	do	1962	1,029	2	Kf	S		Flowing	2,930	2- 2-67	T58, D2, Ca.
40-81-21ac	do	1963	660	2	Kf	D		Flowing	795	8-31-66	T61, D3R.
26add	do		658	6	Kf	S		11		9- 7-65	
30bb	do	1960	279	2	Kf	S		Flowing	1,210	9-29-65	T58, D4.
31bcb	do		260	2	Kf	S		Flowing	2,950	10-17-65	T52, D3.
40-82-23dac	do	1964	645	2	Kf	S		Flowing	1,900	9-29-65	T52, D0.6.
24cbd	do		540	4	Kf	S		Flowing	2,650	9- 7-65	T55, D1.
33bcd	do	1962	748	2	Kf	S		Flowing	2,350	10-17-65	T54, D0.7.
33dab	do	1961	540	2	Kf	S		Flowing	3,500	2- 2-67	T52, D0.2.
35aa	do	1963	1,004	2	Kf	S		Flowing	2,950	9-29-65	T57, D1.3.
40-83-1ddc	Firnekas Bros. Ranch		675(?)	4	KJcm(?)	D		Flowing	3,200	4-27-67	T70, D1 est.
11aaa	do		180	4	KJcm(?)	D		Flowing	3,500	4-27-67	T70, D0.5.
15ddb	W. H. Holman	1961	65	3	Qal	D		20	720	4-27-67	T51.
19cca			Spring		PPt	S		Flowing	520	9- 9-66	T57, D400, Ca.

40-84-9aab	Willow Creek Ranch			7	PPt	S		42.50	1,800	4-27-67	T49.
9aba	do	1953	300	12	PPt	I		12		2- 3-66	D1,200R.
40-85-24cdc	Buffalo Creek Ranch		164	4	PPt	S,D		150.00	510	9- 9-66	T49, D20.
40-87-15cad			Spring		p€r	S	8,780	Flowing	140	8-22-67	T40, D10 est.
41-80-33dda	John J. Tobin	1964	660	2	Kf	S		Flowing	2,400	11- 3-65	T55, D1.
35dba	Mildred M. Weidth	1964	1,620	2	Kf	S		Flowing	2,000	11- 3-65	T55, D1.5.
41-83-30add	Willow Creek Ranch	1964	375	7	PPt	N		12.77		4-27-67	

Many of the geologic formations were deposited under similar conditions, or environments, and have similar water-bearing properties. In some instances, water from one formation is characteristic of water from all the formations deposited in a similar environment. Therefore, for the purposes of this report, the stratigraphic section is arbitrarily divided into six rock units on the basis of the environments in which the formations were deposited. The units are (1) igneous and metamorphic rocks, (2) marine rocks, (3) continental and marine rocks, (4) marine and continental rocks, (5) consolidated continental rocks, and (6) unconsolidated continental rocks. These units are in order from oldest to youngest except for the igneous and metamorphic rocks which include rocks of Precambrian and Tertiary age. The discussion of geology in the following sections is principally from publications that are cited where appropriate.

IGNEOUS AND METAMORPHIC ROCK UNIT

Igneous and metamorphic rocks are exposed in most of the mountains within Natrona county. (See pl. 2.) Their total outcrop, however, composes less than 10 percent of the county. Most of these rocks are of Precambrian age and consist of granite, gneiss, and schist. Igneous rocks of Tertiary age occur in the vicinity of the Rattlesnake Hills in the southwestern part of the county and are dacitic and alkalic (Van Houten, 1955).

Water-Bearing Properties

The ability of igneous and metamorphic rocks to store and transmit water is dependent on permeability that has been developed by weathering and fracturing after the rocks were formed. Fractures include joints not associated with displacement and faults where movement has occurred. The displacement along a fault may be measured in hundreds of feet, and it may take place either in a single plane or through a wide zone.

Openings in which water occurs in igneous and metamorphic rocks are predominantly near the surface. Data from mines show that both the number and the size of fractures decrease with depth and that open fractures seldom occur at depth. Data for Wyoming are few, but weathering is known to occur to a depth of 50 feet in the Laramie Range west of Cheyenne (Darton and others, 1910).

Chemical Quality

The water from these rocks throughout the outcrop area is chemically suitable for most purposes. The total dissolved solids in the water is inferred from specific conductance measurements to be less than 500 mg/l. Analyses from areas outside of Natrona County show that water from these rocks is usually a calcium bicarbonate type.

son, consists of the basal red to gray sandstone (Darwin Sandstone Member(?) of Mississippian age) and an overlying thin-bedded cherty dolomite and limestone, red shale, and red to gray sandstone sequence. The Amsden attains a thickness of 200 feet in the northwest, but is absent in the southeast. The Tensleep Sandstone of Pennsylvanian and Permian age, which consists of medium-grained cross-bedded massive sandstone, was deposited in all except the southeastern part of the county. In Late Pennsylvanian and Early Permian time, the site of deposition shifted to the southeast and the Casper Formation was deposited. The Casper consists of thick-bedded sandstone underlain by interbedded sandstone, limestone and dolomite, and red shale. The Casper was derived, in part, from the Tensleep, and therefore the two formations are similar in the county. Total thickness of the Tensleep and Casper Formations is about 500 feet.

The marine formations are exposed in and near the mountains and crop out in less than 10 percent of the county. In most of the county, they are deeply buried.

Water-bearing properties

The marine unit, with the exception of the Gros Ventre and Gallatin Formations, is considered a single aquifer and yields the largest amounts of water to single wells and springs of any aquifer in the county. The largest flow from a well (40–79–26caa) is about 4,000 gpm (gallons per minute) with 150 psi (pounds per square inch) flowing pressure at the surface. Open-flow yield from this well is reported to be about 9,000 gpm. Sandstone in the unit is generally well cemented, but there is sufficient primary permeability at most sites to permit yields of nearly 50 gpm to wells. The larger yields are obtained from zones of high secondary permeability. Even where permeability is low, large flows are sometimes possible because of high pressures. Pressures in excess of 500 psi, at land surface, have been measured in the area of Salt Creek oil field. Table 4 lists three wells in the Madison Limestone that flow more than 4,000 gpm and three wells in the Tensleep Sandstone that flow more than 400 gpm.

Several large springs occur in the vicinity of Casper Mountain. The Casper Formation, which crops out on to[illegible] mountain, is considered to be the source of these springs. [illegible] Egg Spring (32–81–15bad) is the largest in the county, fl[illegible] about 17 cfs (cubic feet per second), or about 7,630 gpm. Es[illegible]ed yields from three other springs at the east end of Casper M[illegible]ain range from 1.0 to 2.0 cfs. Numerous other springs and seep[illegible]ch yielding less than 0.1 cfs, can be found along the north side [illegible]asper Mountain.

Future Development

Most wells in these rocks will probably yield less than 5 gpm, and many locations may not yield any water to wells. Davis and Turk (1964, p. 11) stated that a domestic well in crystalline rocks should be less than 150–250 feet deep. They further stated that in many areas there is not enough increase in yield below 100 feet to justify deeper drilling. These conclusions were based on data collected from diverse areas, some of which may have deeper weathering than is found in Natrona County; therefore, the 100-foot depth may be a maximum depth in the county.

Ground water can be developed from the igneous and metamorphic rocks in the outcrop area. The best areas for drilling would be either near the center of the broad interstream divides or in the valleys. On the broad interstream areas erosion of weathered material is slow, and as a result some permeable material may accumulate. The water-table gradient is comparatively low; therefore, the saturated materials may be thickest in the interstream areas. On narrow ridges and valley sides, the water-table gradient is very steep, and material is eroded away nearly as fast as it is weathered. Valleys commonly are developed along fractures and may be underlain by more permeable zones. Erosion of weathered material in the valleys differs, but there may be considerable thickness of weathered material. The water table is probably at shallower depths in the valleys than elsewhere.

MARINE ROCK UNIT

The marine rock unit is about 1,900 feet thick and includes seven geologic formations. The Flathead Sandstone of Middle Cambrian age is the oldest sedimentary rock in the county. It consists of as much as 400 feet of tan and reddish sandstone, some of which has been highly indurated. The Flathead is overlain by the Gros Ventre and Gallatin Formations of Cambrian age, which consist of greenish shale with thin interbedded limestone, limestone-pebble conglomerate, and sandstone. They are about 500 feet thick in the northern part of the county, but are truncated by erosion and absent in the southeastern part of the co[illegible] The Madison Limestone of Mississippian age consists of a bas[illegible]stone unit and overlying cherty limestone and dolomite. The[illegible]ess of the Madison varies from 400 feet in the northwest to 2[illegible]t in the southeast. Measured thickness differ in the area wher[illegible] Gros Ventre and Gallatin are absent, as some geologists incl[illegible]art of the sandstone overlying the granite and underlying the [illegible]one with the Madison; others consider the sandstone to be part[illegible]he Cambrian Flathead. The Amsden Formation of Mississippian [illegible]nd Pennsylvanian age, which overlies the Madi-

Chemical quality

The concentration of dissolved solids in water from the marine rock unit ranges widely. From the samples collected during this investigation, there appears to be a direct relation between concentration of dissolved solids and distance from the outcrop. An analysis of water from the Tensleep Sandstone at spring 40–83–19cca showed it contained 338 mg/l of dissolved solids. About 5 miles away from this spring in well 39–83–18cad, water from the Tensleep had 603 mg/l of dissolved solids. About 40 miles east of the outcrop in well 40–79–25caa, water from this formation contained 2,920 mg/l of dissolved solids. Water from the Madison Limestone at well 39–78–26cdc, about 48 miles from the outcrop, had 3,240 mg/l of dissolved solids. Samples of water were not collected from the Madison near its outcrop, but the quality of water is assumed to be nearly identical to that from the Tensleep near the Tensleep outcrop. This assumption is based on analyses of water from wells near Tensleep, Wyo. (Lowry, 1962).

Analyses of water from Goose Egg Spring showed it contained 422 mg/l of dissolved solids. Specific conductances of water from other springs in the area of Casper Mountain, which are considered to be from the Casper Formation, indicate that the dissolved-solids content is less than 500 mg/l.

Specific conductances of water from the Tensleep Sandstone on the north flank of the Rattlesnake Hills show that the water contains less than 500 mg/l of dissolved solids. It is not known how far this water having less than 500 mg/l of dissolved solids extends from the recharge area in the Rattlesnake Hills.

Analyses of waters from the Madison Limestone and the Tensleep Sandstone, given in table 2, show similarity, but may be distinguished by the comparison of water analyses shown in figure 7. These diagrams were constructed by plotting the analyses expressed in milliequivalents per liter of anions and cations as suggested by Stiff (1951). All the analyses of water from the Madison Limestone exhibited a characteristic shape. One sample from the Tensleep Sandstone (well 40–79–25caa) had characteristics similar to Madison water, but possibly there could be some hydraulic connection with the Madison which permits the waters from the separate formations to mix. Waters from the Tensleep Sandstone and the one sample from the Casper Formation show dissimilarity, but the water quality, or type, is partly dependent on the distance of the collection point from the outcrop. The Tensleep Sandstone water from well 30–83–18dcd may be mixed with water from the Goose Egg Formation of Permian and Triassic age.

The water samples from the Tensleep were of several types: sodium sulfate, calcium sodium sulfate, and calcium sulfate. The water sample from the Casper Formation was calcium bicarbonate type and was obtained from Goose Egg Spring, which is close to the recharge area. Many complex changes may occur to the water during its movement through these formations to change the water type eventually to sodium sulfate. From table 2, however, it appears that the quality change is due to additional solution of sodium and sulfate. The other types of water are probably in a transition stage except possibly cal-

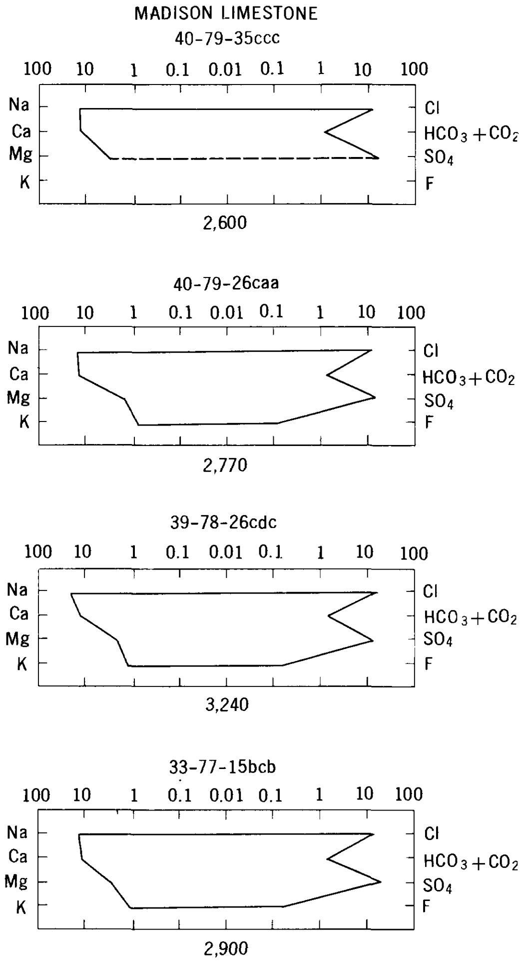

FIGURE 7.—Stiff diagrams of chemical analyses (in milliequivalents per liter) of water from the Madison Limestone, Tensleep Sandstone, and Casper Formation. The number above the diagram is the location where sampled; the number below the diagram is the total dissolved solids, in milligrams per liter.

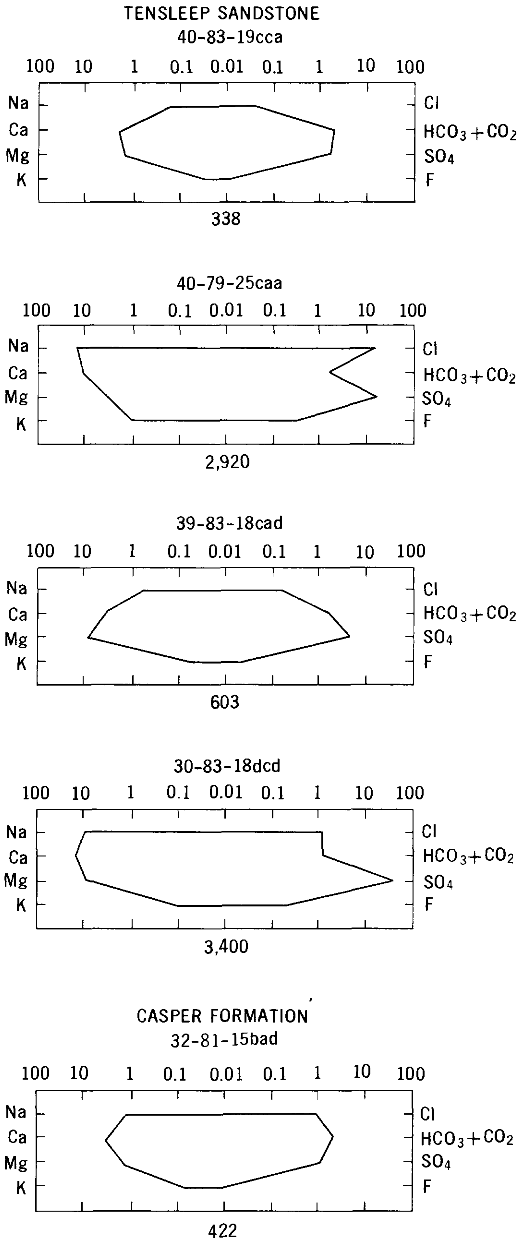

FIGURE 7.—Continued

cium sulfate, which could occur in formations where insufficient sodium is available for either ion exchange or additional solution, as in carbonate rocks.

Of the four water samples from the Madison Limestone, three were sodium calcium sulfate type, and one was sodium chloride type. The latter sample indicates mixing with oil-field brines.

Classification of water from the marine rock unit for irrigation is shown in figure 8. The salinity hazard is very high in five of the eight samples shown, and the sodium hazard ranges from low to high. The best water for irrigation that might be expected from the marine rocks in Natrona County would probably be classified as medium salinity and low sodium hazard. Water of such quality would probably be found only near the outcrops. Data in table 2 show that bicarbonate and carbonate in the water from this unit will not present a hazard for irrigation, as the residual sodium carbonate was zero for the samples analyzed.

FUTURE DEVELOPMENT

There has not been enough exploration for water in the marine rock unit to estimate the probability of drilling a large-capacity well, but chances for such a well would be greater near geologic structures where secondary permeability is more likely. All the known large yields from the aquifer are from wells or springs associated with folds and (or) faults.

The best areas for prospecting for supplies are along the south side or west end of Casper Mountain, the north slope of the Rattlesnake Hills, and the east flank of the Bighorn Mountains. A well drilled in these areas between the dip slope of the Tensleep Sandstone, or Casper Formation, and the "red wall" that forms a prominent escarpment facing the mountains (fig. 9) should penetrate the top of the Tensleep or Casper Formation at a depth less than 1,000 feet. The uncertainties of yield and quality of water from this aquifer make exploration in other areas uncertain, but the aquifer may be within economical drilling depths for some purposes. Plate 2 shows the depths to the top of the Tensleep and Casper Formations and to the tops of other formations at selected sites. These data are from oil tests, many of which were drilled on structural highs; therefore, these depths are the minimum depths that may be expected in the immediate area.

CONTINENTAL AND MARINE ROCK UNIT

The continental and marine rock unit includes the Goose Egg For-

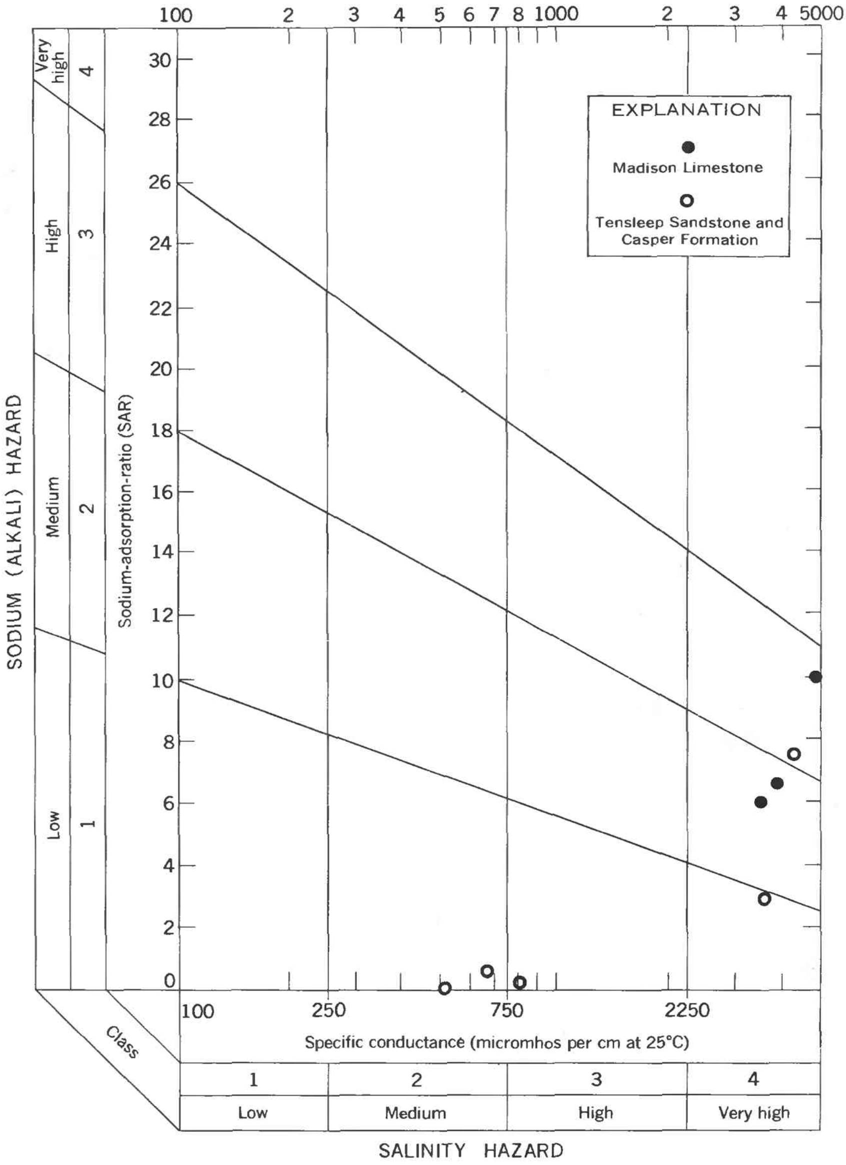

FIGURE 8.—Irrigation classification of water from the marine rock unit. (Diagram adapted from U.S. Salinity Laboratory Staff, 1954.)

mation of Permian and Triassic age, the Chugwater Group of Triassic age, the Nugget Sandstone of Triassic(?) and Jurassic(?) age, the

Sundance and Morrison Formations of Jurassic age, and the Cloverly Formation of Early Cretaceous age. Total thickness of the unit is about 1,900 feet.

Normal marine deposits in this unit are represented only in the Sundance. Other dominant environments are shallow marine (Goose Egg Formation), paralic and near shore (Red Peak Formation of Chugwater Group), and fluviatile and lacustrine (Morrison and Cloverly Formations).

The Goose Egg Formation consists of interbedded red shale and siltstone, thin limestone, and gypsum. The formation is 380 feet thick at the type section near the old Goose Egg Post Office in Natrona County (Burk and Thomas, 1956, p. 5).

The Chugwater Group in Natrona County is composed of three formations: the Red Peak Formation, the Alcova Limestone, and the Jelm Formation. The Red Peak Formation consists of red siltstone, claystone, and some very fine grained sandstone. It has a fairly uniform thickness of 600–700 feet (Picard, 1967, fig. 2). Overlying the Red Peak Formation is the Alcova Limestone, which is about 10–20 feet thick. The Alcova is resistant and forms a prominent hogback. The "red wall," present near the flanks of the mountains in many areas, consists of a cliff of the Red Peak Formation capped by the Alcova Limestone, as on the north side of Muddy Mountain and in the vicinity of Buffalo Creek in the northwestern part of the county (fig. 9). The Alcova is overlain by the Jelm Formation, which consists of red sandstone and siltstone. The thickness of the Jelm is generally less than

FIGURE 9.—Hogback formed by Alcova Limestone. The face of the slope is the "red wall" formed by the Red Peak Formation. Photograph was taken looking east from Roughlock Hill in sec. 27, T. 40 N., R. 84 W.

100 feet, but it differs considerably from place to place owing to erosion prior to deposition of younger strata.

Only the Bell Springs Member of the Nugget Sandstone is present in Natrona County. The member consists of red and gray sandstone and red, green, and pale-purplish-red to pale-red siltstone and shale (Pipiringos, 1968, p. 16). It crops out in the Rattlesnake Hills and is present only in the southwestern and west-central parts of the county; its maximum thickness is about 90 feet. The Sundance Formation, which unconformably overlies either the Bell Springs Member of the Nugget Sandstone or the Jelm Formation, is about 300 feet thick and consists principally of olive-gray shale and greenish- or grayish-black claystone or siltstone. Sandstone beds are also present and are most persistent at the top and base of the formation.

The Morrison and Cloverly Formations, which overlie the Sundance, consist of variegated shale, sandstone, and conglomerate which aggregate as much as 300 feet thick. Conglomerate and conglomeratic sandstone are extensive, but not necessarily continuous.

Water-bearing Properties

Water-bearing properties of aquifers within the continental and marine unit differ markedly because of the differences in lithology and cementation. The Goose Egg Formation and (or) Chugwater Group are low-yield aquifers in the county. Eight wells (seven listed in table 4) are known to be completed in these formations, although two have been abandoned because of insufficient yield for stock wells. In addition, well 30–83–18dcd originally was completed in the Chugwater, but it was drilled deeper to obtain sufficient water for stock. None of the producing wells yield more than about 20 gpm. Springs yielding several hundred gallons per minute that issue from openings in the Goose Egg and Chugwater, such as 32–81–15bad (7,630 gpm) and 32–78–28dab (600 gpm), are associated with geologic structures, and the source of water is the marine rock unit.

Other formations composing the continental and marine unit have sandstone aquifers that would yield varying amounts of water to wells. Sandstone in the Sundance, Morrison, and Cloverly Formations probably would not yield more than 20 gpm to wells except in areas of high artesian pressure or zones of secondary permeability. Sandstone beds of the Morrison are not as continuous as other sandstone beds in the unit; therefore, the Morrison is perhaps the lowest yielding aquifer in the upper part of the continental and marine unit. Only sixteen wells are known to tap the upper part of the unit, and all but one tap the Cloverly Formation exclusively. Thirteen of the wells flow, or flowed when drilled, at rates from less than 1 gpm at well 39–83–13ddc to 40 gpm (250 gpm pumping) at well 33–79–24acc. Well 38–87–14cdc, which taps 35 feet of sandstone in the Cloverly, reportedly has a 2-hour specific capacity (yield in gpm per foot of drawdown) of 0.12 gpm per foot of drawdown. Conglomerate beds of the Cloverly, where they are not indurated, may have sufficient primary permeability to yield 100 gpm or more to wells. It is concluded from the information available that the Cloverly has the best potential for water supplies of any formation in this rock unit. Well yields generally will range from about 5 to 20 gpm.

CHEMICAL QUALITY

Analyses were made of nine water samples from this rock unit. One each was taken from the Chugwater Group and the Sundance Formation; the remainder were taken from the Cloverly and Morrison Formations. Specific conductances were measured in the field wherever possible, and several samples were collected to determine chemical types. The concentration of dissolved solids in the samples analyzed ranged from 70 to 1,780 mg/l. The water with the low concentration was from a spring (31–79–8ccd) in the Cloverly Formation on Muddy Mountain south of Casper. Specific conductances of water from other Cloverly springs on Muddy Mountain also indicated less than 100 mg/l of dissolved solids.

Specific conductances of water from the Goose Egg Formation ranged from 2,000 to about 2,300 micromhos per cm at 25°C. On the basis of 0.65 as the estimated ratio of dissolved-solids concentration to specific conductance, the dissolved solids range from about 1,300 to about 1,500 mg/l. Water from the Goose Egg is predominantly calcium sulfate type, as a result of gypsum in the formation.

The water sample analyzed from the Chugwater Group was calcium magnesium sulfate type and contained 1,330 mg/l of dissolved solids. Another water sample considered to be from the Chugwater was analyzed for type only and found to be calcium bicarbonate type. The water contained less than 300 mg/l of dissolved solids, as indicated by the specific conductance based on an estimated ratio of 0.65.

Water collected from the Sundance Formation was found to be bicarbonate associated with magnesium and calcium, and sodium. The magnesium calcium bicarbonate type water contained 416 mg/l of dissolved solids. The sodium bicarbonate type was estimated from specific conductance to contain about 1,800 mg/l of dissolved solids.

Water collected from the Cloverly and Morrison Formations was predominantly sodium bicarbonate type. Other types of water obtained from these formations were calcium bicarbonate, calcium sulfate, sodium sulfate, and calcium sodium sulfate.

The frequency distribution of the specific conductance of waters from the continental and marine rock unit is shown in figure 10. The cumulative frequency plot on log-probability paper shows two distinct trends grouped according to the predominant anion in the water.

Group A is the specific conductance of water from three springs in the Cloverly Formation on Muddy Mountain. Bicarbonate is the

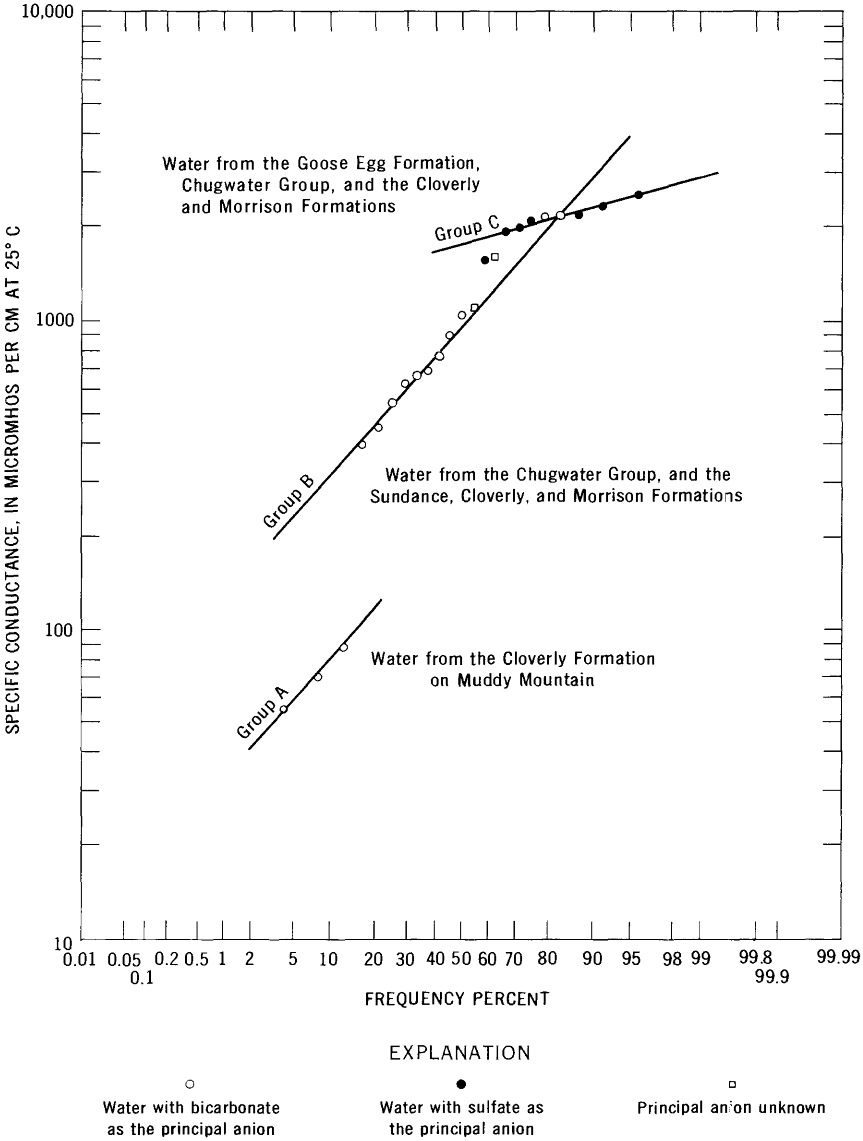

FIGURE 10.—Cumulative frequency plot of specific conductance of ground water from the continental and marine rock unit.

principal anion, and calcium is the principal cation. The specific conductance of this group is lower than the next bicarbonate group because the water of group A travels a shorter distance from the recharge area to the point of discharge. The Cloverly Formation crops out in an area of about 30 square miles on top of the mountain and provides an extensive recharge area in the vicinity of the springs.

Group B is also bicarbonate type water. The slope of the line through these data is the same slope as the line through group A. Group B includes water from the Chugwater Group and the Sundance, Cloverly, and Morrison Formations. Sodium is the principal cation in this group, but calcium and magnesium cations are also included. The type of cation appears to have little effect on the scatter of the distribution.

Group C includes waters from the Goose Egg Formation, Chugwater Group, and Cloverly and Morrison Formations. Sulfate is the predominant anion associated with sodium and calcium cations. Magnesium probably is another major cation associated with the sulfate, even though this was not verified in the samples analyzed.

It can be seen in figure 10 that the quality of water from the unit is variable. Some of the water of group C is not suitable for domestic use. The poorest quality of water was found in geologic structures where the circulation may be impeded.

Classification of water from this unit with regard to irrigation use is shown in figure 11. Because of the high sodium content, much of the water from the Cloverly and Morrison Formations is not suitable for irrigation. Water obtained from the Cloverly and Morrison near the outcrops would be suitable for irrigation of soils with good drainage because the water contains less sodium and usually less dissolved solids. Sufficient data are not available to make a general statement about the suitability of water for irrigation from other formations in the continental and marine rock unit.

Future Development

The aquifers in this unit are deeply buried throughout much of the county. The most economical locations for development are in the outcrop areas. In most other areas, formations in this unit are overlain by other aquifers at shallower depth. Yields of about 100 gpm have been obtained from this unit, but generally the yields would range from about 5 to 20 gpm, which is usually adequate for stock or domestic use.

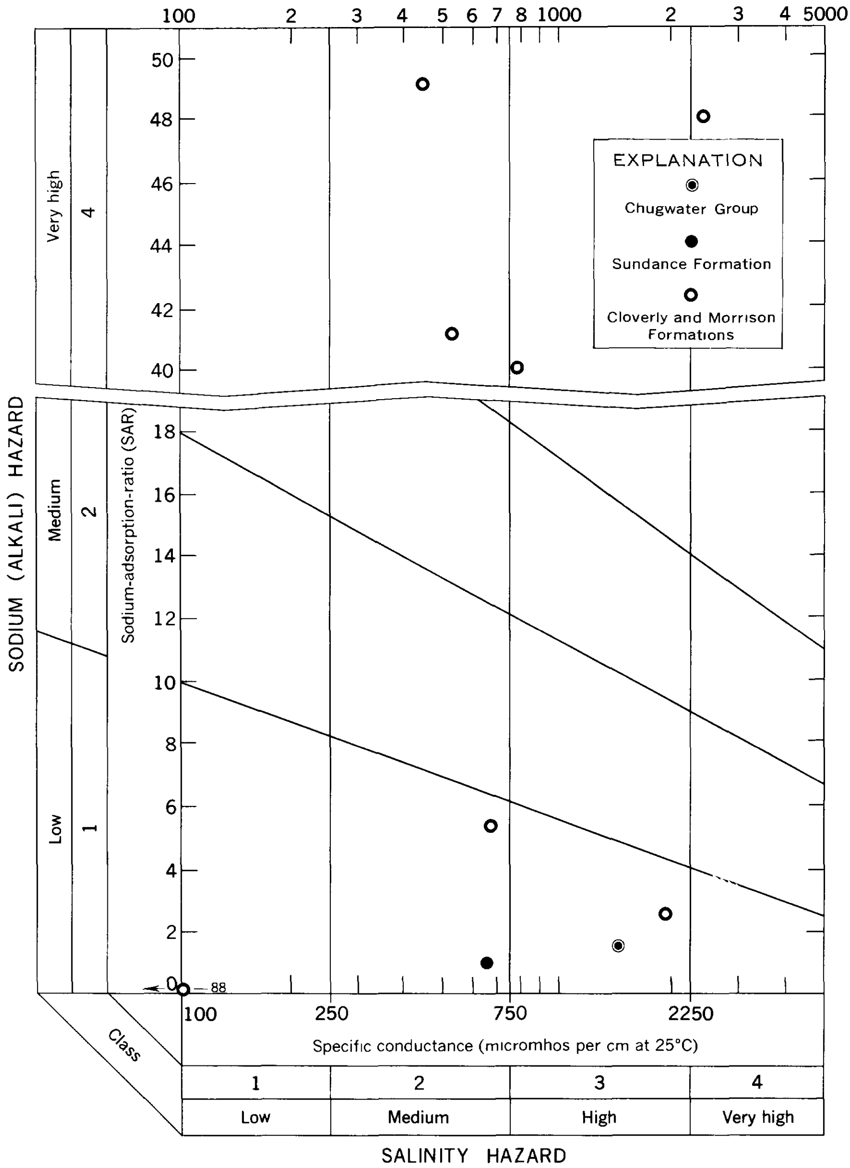

FIGURE 11.—Irrigation classification of water from the continental and marine rock unit. (Diagram adapted from U.S. Salinity Laboratory Staff, 1954.)

MARINE AND CONTINENTAL ROCK UNIT

In contrast to the continental and marine unit, which contains only one normal marine formation, the marine and continental unit is predominantly marine. The marine and continental rock unit includes the Thermopolis and Mowry Shales of Early Cretaceous age and the Frontier Formation, Cody Shale and its lateral equivalents (Niobrara Formation and Steele Shale), Mesaverde Formation, Lewis Shale, and Fox Hills Sandstone of Late Cretaceous age. The aggregate thickness of these formations ranges from about 7,000 feet in the northern part to more than 9,000 feet in the southern part of the county.

The formations included in the marine and continental unit are principally shale deposited during a period of general advance and retreat of the seas; however, minor oscillations of the sea resulted in episodes of marine sandstone, as well as continental, deposition.

The Thermopolis Shale is about 200 feet thick and is predominantly black marine shale. The Muddy Sandstone Member near the top of the Thermopolis consists of sandstone, siltstone, claystone, and bentonite. The Muddy is a recognizable zone because it contrasts with overlying and underlying shale, not because it is an extensive sandstone. Overlying the Thermopolis is the distinctive gray-weathering siliceous Mowry Shale. The Mowry is about 200–300 feet thick throughout most of the county.

The Mowry is overlain by the Frontier Formation, which is as much as 900 feet thick and of which more than half is black marine shale. Sandstone beds within the Frontier are locally called the first, second, and third sands of the Wall Creek Sandstone Member of the Frontier Formation. The first Wall Creek, which is the uppermost sandstone, was deposited throughout the county; the second Wall Creek was deposited in all but the south quarter of the county; the third Wall Creek, the least extensive, was deposited in all but most of the southern and eastern parts of the county (Goodell, 1962, fig. 1). The sandstones differ in the amount of shale partings and matrix and may range from a single massive sandstone to several sandstones interbedded with shales.

Overlying the Frontier is the Cody Shale, which ranges from 3,000 to 5,000 feet in thickness. In the southeastern part of the county, rocks equivalent to the Cody are divided into the Niobrara Formation and overlying Steele Shale. The Niobrara consists of light-gray limestone and limy shale, and the Steele consists of gray shale with numerous bentonite beds and thick lenticular sandstones. The Cody Shale consists predominantly of dark-gray shale, which is limy near the base of the formation, but contains lenticular sandstones in the upper part of the formation. Some of these beds are persistent enough to be mapped locally and are shown on plate 2. The principal sandstone beds in the Cody are the Shannon Sandstone Member, which is about 2,000 feet above the base of the formation, and the Sussex Sandstone Member, which is about 400 feet above the Shannon.

The Mesaverde Formation consists of three members. The Parkman Sandstone Member, the lowest, is a massive sandstone that ranges in thickness from about 500 feet in the southwestern part of the Powder River Basin to about 50 feet in the southeastern part of the Wind River Basin (Rich, 1958, p. 2428). (See fig. 6.) The unnamed middle member consists of alternating beds of marine sandstone and shale in the southwestern part of the Powder River Basin and ranges in thickness from 260 to 340 feet. In the southeastern part of the Wind River Basin, the middle unit is about 450–750 feet thick and consists of nonmarine sandstone, shale, and coal. The upper member is the Teapot Sandstone Member, which consists of fine- to medium-grained sandstone with shale partings. The thickness of the member varies from about 50 feet at places in both the Wind River and Powder River Basins to as much as 115 feet in the Wind River Basin.

The Lewis Shale, which overlies the Mesaverde, represents the last advance of the Cretaceous sea into the area. The formation extends westward into the Hiland-Clarkson Hill area, where it interfingers with the continental deposits of the Meeteetse Formation of Late Cretaceous age. In this area, Rich (1962, pl. 8) divided the Lewis into two parts. The lower tongue consists of 300 feet of thick-bedded shale grading into brown sandstone, and the upper tongue consists of about 250 feet of gray fine- to medium-grained sandstone. The two tongues are separated by an eastward projecting tongue of the Meeteetse. In the northeastern part of the county, the Lewis is about 470 feet thick (Horn, 1955).

The Fox Hills Sandstone represents the final marine rocks deposited during the retreat of Cretaceous seas from the area. The formation is not present in the western part of the county, but it is about 700 feet thick in the eastern part. The basal sandstone, which lies on the Lewis Shale, has been described for the area near Edgerton by Babcock and Morris (1953, p. 6) as consisting of about 100 feet of fine- to medium-grained sandstone separated in the middle by a 6-foot bed of brown to gray carbonaceous shale. Overlying this sandstone is alternating sand and shale, grading upward into nonmarine sandstone of the Lance Formation of Late Cretaceous age.

Water-Bearing Properties

This rock unit consists principally of shale and relatively minor amounts of sandstone that compose the aquifers of the unit. The formations in this unit that are predominantly shale and contain only thin lenses of sandstone or sandy shale are the Thermopolis, Cody and its equivalents, and Lewis Shales.

The Muddy Sandstone Member of the Thermopolis Shale is continuous throughout most of the county. Yields of any consequence from the Thermopolis would have to come from this member. One well (37–86–13dd) flows 45 gpm from the Muddy. This is a yield of about 0.6 gpm per foot of penetration according to the completion record and is the largest yielding well from the Muddy found in the county by the authors.

The Mowry Shale is a brittle thin-bedded shale in which greater secondary permeability has developed than in the more plastic shale of the Thermopolis, Cody, and Lewis; however, the Mowry is still considered a low-yield aquifer. There are several wells in Tps. 39 and 40 N., Rs. 82 and 83 W., with flows ranging from about ¼ to 2 gpm. One well in this area yields about 10 gpm by pumping. Estimated maximum yield from wells that completely penetrate the Mowry (about 200 ft deep) would be about 20 gpm if the formation contains uniform secondary permeability throughout. Dean Springs in sec. 33, T. 38 N., R. 86 W., have a combined yield of approximately 20 gpm.

The Shannon and Sussex Sandstone Members of the Cody Shale contribute the majority of the water obtained from wells in the Cody. Yield from a well penetrating the sandstones probably would not be more than 20 gpm. There are numerous seepage areas in draws and creek bottoms in the Cody outcrop that probably receive small amounts of water from sandy shale; however, it is doubtful that a well penetrating only shale would produce enough water for stock use. Drilling into the Cody Shale for a water supply would not be successful unless one of the extensive sandstone beds in the upper (Steele equivalent) part of the formation was penetrated.

Only two wells in the county are known to produce water from the Lewis Shale. It is estimated that well yields of no more than 10 gpm could be obtained from this formation because of the discontinuity of the sandstone lenses.

The formations that are considered to be the principal aquifers in this unit are the Frontier and Mesaverde Formations and the Fox Hills Sandstone. These formations have the greatest thicknesses of sandstone in the unit, but because of low permeability, yield to wells in most cases is estimated to be no more than 50 gpm. Exceptions might be in areas where there is secondary permeability and in areas of high artesian pressure.

The Frontier Formation is the most widely used aquifer underlying the Cody Shale in the northern and central parts of the county. In this area, many flowing wells have been completed in the Frontier (pl. 1), and yields range from less than 1 gpm to about 10 gpm. The depth of most wells tapping the Frontier in this area is about 1,000 feet, but shallower wells are near the outcrop.

Little information is available concerning the yield of wells completed in the Mesaverde Formation, but it is reported that a yield of more than 100 gpm is obtained by pumping well 37–78–7dcd. Most of the wells completed in this formation are used to supply water for livestock and are drilled in or near the outcrop. These wells are usually drilled only deep enough to obtain about 10–20 gpm. Complete penetration of both the Teapot and Parkman Sandstone Members would be necessary for maximum yield. If drilling were started in the Mesaverde outcrop area, complete penetration of the sandstone beds would require drilling nearly 1,000 feet.

Pumping tests were made at one well completed in the Fox Hills and at two wells completed in both the Fox Hills and Lance Formations. The latter two wells also penetrated the Lewis Shale, but negligible amounts of water were contributed by the Lewis. Results of the three tests are tabulated below:

Date	Location of pumped well	Geologic formation	Transmissivity [1] (ft ^{2} per day)	Length of test (hr)	Yield (gpm)	Specific capacity (gpm per ft of drawdown)
Sept. 7, 1965	40–78–11acb	Fox Hills and Lance	10.2	8	25	[2] 0.03
Oct. 13, 1965	40–78–11dba	Fox Hills and Lance	22.2	8	11	[3] .04
1953	40–78–15abb	Fox Hills	214	7	10.9	[4] .37

[1] Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.
[2] Determined from step-drawdown tests, each step being 6 hours in duration.
[3] Determined from step-drawdown tests, each step being 8 hours in duration.
[4] Computed from drawdown at end of 7-hour pumping period.

Chemical Quality

Sodium sulfate in the predominant type of water from the marine and continental rock unit. Exceptions are usually found only near the aquifer outcrop. Water samples from wells 34–83–9cab and 35–82–33dca, which are near a sandstone outcrop, were calcium sulfate bicarbonate and sodium calcium sulfate types, respectively. Low calcium content in most of the water from this unit is probably due to lack of calcareous rocks, which are the source of this element, and to ion exchange whereby sodium replaces calcium.

Sodium bicarbonate type water was found quite often in this unit. High bicarbonate concentrations were found in water from the Muddy Sandstone Member of the Thermopolis Shale and in some waters from the Frontier Formation. Maximum bicarbonate concentrations in the respective formations were 1,960 and 2,220 mg/l. The occurrence of concentrations of more than 450 mg/l of bicarbonate (as calcium carbonate) may be attributed to the presence of carbonaceous material

(Foster, 1950). The chemical reduction of sulfate may also increase the relative bicarbonate content. Reduction of sulfate is indicated by the presence of elemental sulfur and hydrogen sulfide gas (H_2S) or other sulfides.

The specific conductances of water from this unit ranged from 235 to more than 8,000 micromhos per cm at 25°C. A specific conductance of 1,140 micromhos per cm at 25°C was the lowest for water samples taken from the predominantly shale formations.

The quality of water in the Cody Shale and its equivalents is more uniform than the quality of water in other formations in the marine and continental rock unit; however, water from the Cody and its equivalents is considered to be of inferior quality because it is too highly mineralized for most uses. On the basis of the samples analyzed from the Cody Shale, 0.76 is the ratio of dissolved solids to specific conductance. By using this value as the conversion factor to be applied to the specific conductance, the best quality of water in the Cody (and equivalents) was found to contain about 1,600 mg/l of dissolved solids. However, because water of this quality is also found in the formations considered to be the principal aquifers in the marine and continental unit, no distinction can be made between any of the formations in the unit on the basis of water quality.

Uranium has been found in some ground water from the Cody Shale. The uranium content of the water, along with that of water from younger rocks, was listed by Rich (1962, p. 527–528).

The frequency distribution of the specific conductance of waters from this unit along with those of two other rock units are shown in figure 12. These are plots of the cumulative frequency on log-probability paper. Straight lines can be fitted to the plots; thus, log-normal distribution is indicated. The value of the mean, or average, specific conductances is at the intersection of the straight line and the 50 percent frequency and is about 2,500 micromhos per cm at 25°C. The standard deviation is a parameter used in statistical analysis as a measure of variability and is plotted plus and minus from the mean at probabilities of 16 and 84 percent frequency, respectively. About two-thirds of the sample points plot between these limits, and the specific conductances range from about 1,500 to 4,400 micromhos between these limits. Therefore, in any random sampling of waters from the marine and continental unit in Natrona County, the waters from about two-thirds of the well sampled probably would have specific conductances within this range. The points that are off the line at the lower end are specific conductances of ground water near the aquifer outcrop and should not be considered representative of the marine and continental rock unit throughout the county. These points,

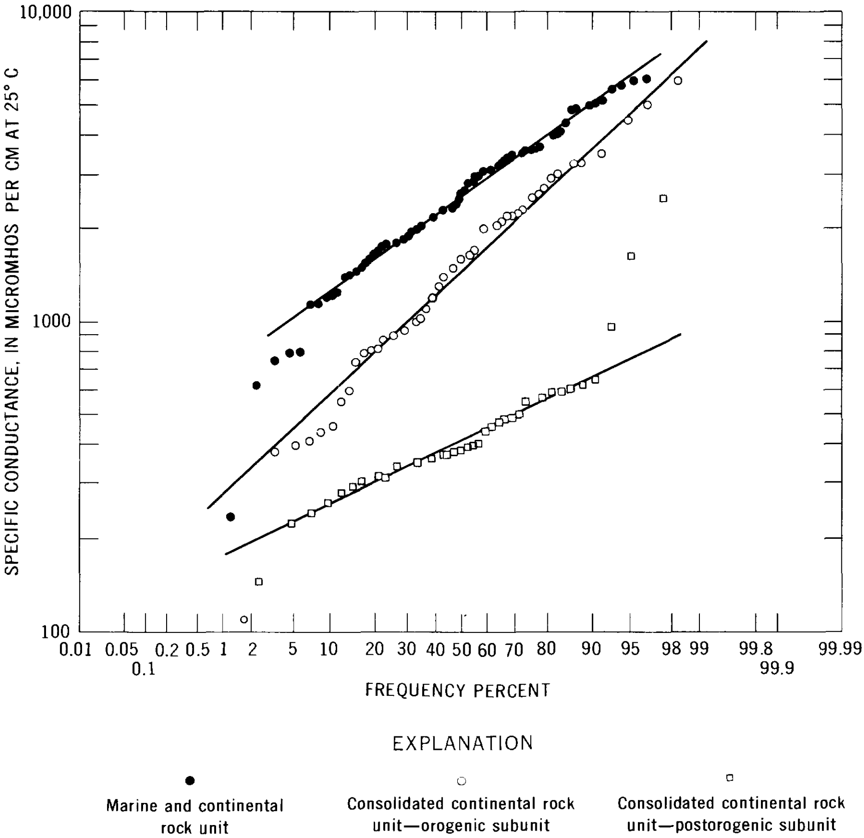

FIGURE 12.—Cumulative frequency plot of the specific conductance of ground water from the marine and continental and the consolidated continental rock units.

however, are significant because they show that the best quality of water is near the outcrop.

The mean specific conductance for the unit is about 2,500 micromhos per cm at 25°C. On the basis of the samples analyzed, 0.69 is the average ratio of dissolved solids to specific conductance for water sampled from all the formations in this unit. The conversion factor of 0.69 thus indicates that the dissolved-solids content of ground water produced from wells, the depths of which are 1,000 feet or less, in this unit will average about 1,700 mg/l and will range from about 1,000 to 3,000 mg/l in approximately 68 percent of the wells. This water could be classified as fair for stock use, but unsuitable for domestic use in many instances.

Figure 13 is the irrigation classification diagram for waters analyzed from this unit. It is concluded that the best water analyzed should be used only on soils with good drainage. Most of the water would not be

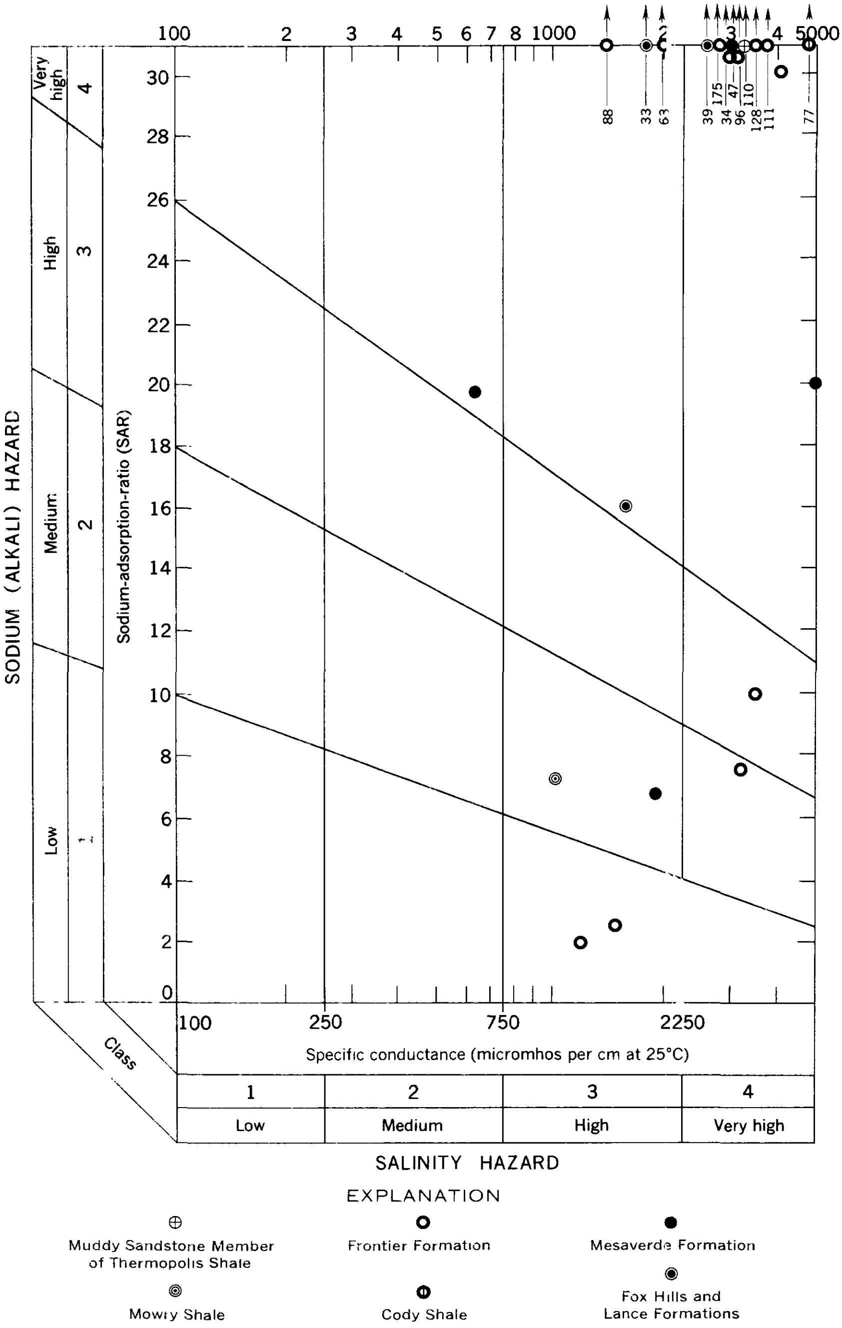

FIGURE 13.—Irrigation classification of water from the marine and continental rock unit. (Diagram adapted from U.S. Salinity Laboratory Staff, 1954.)

suitable for irrigation because of the high salinity and sodium hazard. The residual sodium carbonate (table 2) is also too high in most of the waters for irrigation.

Future Development

The marine and continental rock unit has the least potential of any of the rock units as a source of water to wells because of either the low yield to wells or the high mineral content of the water, or both. The Frontier and Mesaverde Formations and the Fox Hills Sandstone have more extensive aquifers than any other formations in the marine and continental rock unit, and yields of 20 gpm can be developed from sandstone beds wherever they are saturated. The best quality of water in the unit can be obtained from these three formations. Water of suitable quality for domestic use is usually present only near the outcrop, but water suitable for stock use is found away from the outcrop at depths as great as 1,000 feet. Where these aquifers are deeper than 1,000 feet, the quality of the water from them may be unsatisfactory for stock.

Sandstone beds found in the other formations composing the unit are not as continuous and, therefore, are not reliable aquifers. Because of the lenticularity of the sandstone, circulation of ground water is also reduced. On the average, therefore, yields will be less, and the water will be of poorer quality than that in the continuous sandstones. The shales do not have sufficient potential for future development.

CONSOLIDATED CONTINENTAL ROCK UNIT

The consolidated continental rocks are divided into two subunits: orogenic and postorogenic. Deposition of the oldest, or orogenic, rocks began in Late Cretaceous and continued through early Eocene time. This was the time of active mountain building when the Rocky Mountains were formed. Large relief existed, but the altitude of the basin floors was about 1,000 feet above sea level; the climate was warm and moist. Sediment from the mountains was deposited in adjacent basins.

By early Eocene time, mountain-building movements had stopped and there was a regional uplift accompanied by a gradual change to a cool, dry climate. The younger, or postorogenic, rocks deposited during this time have a marked increase in material derived from volcanic sources.

OROGENIC SUBUNIT

Formations included with the orogenic rocks are the Meeteetse and Lance Formations of Late Cretaceous age, the Fort Union Formation of Paleocene age, and the Wind River Formation of early Eocene age. In Natrona County, the Meeteetse and Wind River Formations are not present in the Powder River Basin, but the other formations are present in both the Wind River and Powder River Basins. The formations of this subunit were deposited in lakes, lagoons, and sluggish streams. Marine-type fossils found in the Waltman Shale Member of the Fort Union Formation suggest a close association with marine water, but no open-sea connection into central Wyoming is known (Keefer, 1965b, p. 1888). The temperate climate was favorable for accumulation of vegetal debris.

The Meeteetse Formation is characterized by a succession of alternating beds of sandstone, siltstone, mudstone, shale, carbonaceous shale, and coal (Rich, 1962, p. 473). Shale is the dominant rock type, and minor sandstone beds occur throughout the formation; basal beds of sandstone are as much as 80 feet thick. The sandstone is commonly friable, but may be well cemented.

The Lance Formation, which overlies the Meeteetse, is described from exposures in the Hiland-Clarkson Hill area by Rich (1962, p. 480) as follows:

> The Lance Formation consists of interbedded sandstone and shale. The lower 150 feet of the formation is gray to dark-gray shale with intercalated fine-grained crossbedded sandstone. * * * Above the basal 150 feet is a series of yellowish-gray crossbedded sandstone, gray carbonaceous shale, and thin coal beds that are cyclically repeated through an interval of about 860 feet.

In Natrona County, the Lance Formation is more than 5,000 feet thick in the Wind River Basin (Keefer, 1965a, p. 17), but is only about 3,000 feet thick in the Powder River Basin.

Rich (1962, p. 483–484) described the Fort Union Formation in the southeastern part of the Wind River Basin as generally containing discontinuous layers of dark-brown ferruginous sandstone and thin to thick beds of gray to white siltstone, sand siltstone, and sandstone. The formation is about 65 feet thick near the North Platte River, but to the northwest it thickens to possibly as much as 8,000 feet (Keefer, 1965a, p. 22). Near Waltman, the Fort Union is divided into an unnamed lower member, a middle member named the Waltman Shale Member, and an upper member named the Shotgun Member. The lower member is about 2,300 feet thick. It consists of white fine- to coarse-grained sandstone with numerous thin brown ironstone beds at the base and interbedded very fine grained sandstone and siltstone at the top. The Waltman Shale Member at the type section near Waltman, Wyo., is 643 feet thick and is characterized by chocolate-brown and gray silty shaly claystone with a few thin beds of ledge-forming sandstone (Keefer, 1965a, p. 23). The Shotgun Member is exposed only in T. 39 N., R. 89 W., where Tourtelot (1953) measured 1,000 feet of gray very fine grained sandstone and siltstone with a few beds of medium-grained sandstone.

In the southern part of the Powder River Basin, Sharp and Gibbons (1964, p. 5) described the Fort Union as consisting of about 3,000 feet of poorly consolidated to semiconsolidated sediments. The lower member is composed principally of clayey sandstone and minor amounts of claystone and coal. The upper member is composed principally of clayey siltstone with ironstone lentils and coal beds. Thin sandstone beds are also present.

The Wind River Formation is more than 7,000 feet thick in the Wind River Basin, but it is absent in most of the county because of nondeposition or erosion. The lower part of the formation consists principally of poorly bedded siltstone interbedded with lenticular channel sandstone. The upper part of the formation consists of medium- to coarse-grained arkosic sandstone and conglomerate with minor amounts of lenticular siltstone, claystone, and carbonaceous shale.

Water-Bearing Properties

Few data are available on the water-bearing properties of formations in this subunit other than those on the Wind River Formation. Most of the wells are pumped, and the yields usually do not exceed 25 gpm. Nearly all the wells are for stock or domestic use, and drilling is stopped when the required yield is obtained; this depth is usually within 500 feet of land surface. Whitcomb and Lowry (1968) listed yields of as much as 350 gpm from the Wind River Formation near Riverton and Shoshoni, Wyo. (See fig. 6.) They stated that specific capacities of 52 stock wells, as determined by bailer tests, ranged from 0.02 to 2.25 gpm per foot of drawdown in this formation. No statement was made about the thickness of saturation in these wells.

Chemical Quality

The concentration of dissolved solids ranged from 276 to 1,830 mg/l in the 10 water samples analyzed from the orogenic subunit. The analyses showed that sulfate is the principal anion associated with sodium, calcium, and magnesium cations. These samples were collected from wells generally less than 500 feet deep. Bicarbonate may be the principal anion in water at greater depths, either by chemical reduction of the sulfate or by an increase in bicarbonate through reaction from carbonaceous material.

The cumulative frequency plot of the specific conductances of water from this subunit shows a log-normal distribution (fig. 12); therefore, in the frequency interval between 16 and 84 percent, approximately 68 percent of the wells in the orogenic subunit drilled to depths of about 500 feet, or less, will produce water having specific conductances ranging from about 710 to about 3,000 micromhos per cm at 25° C. On the basis of the waters analyzed, 0.69 is the average ratio of dissolved solids to specific conductance. This ratio gives a range of dissolved solids from about 490 mg/l to about 2,100 mg/l. The mean specific conductance is about 1,450 micromhos per cm at 25° C; thus, the calculated mean dissolved-solids content is approximately 1,000 mg/l. This concentration of dissolved solids indicates that most of the water would be chemically suitable for domestic use, and all acceptable for stock use.

Classification of water from this subunit for irrigation is shown in figure 14. Most of the water analyzed would be limited to irrigation of coarse-textured soils with good drainage. Two samples were not suitable for irrigation because the sodium adsorption ratio was too high. The residual sodium carbonate given in table 2 shows that some waters from the Lance and Wind River Formations contain sufficient bicarbonate to limit their use for irrigation on most soils.

Future Development

The maximum total thickness of this subunit is about 20,000 feet; therefore, extensive development may be possible. It is difficult, however, to predict possible yields because of the heterogeneous lithology and the many separate aquifers in the orogenic subunit.

The Wind River Formation has the best potential of any formation in this subunit for large yields (200 gpm or more) at depths of 1,000 feet or less. Furthermore water from the Wind River will probably be of better quality than that from the other formations. Water suitable for domestic and stock use can be found at many locations.

POSTOROGENIC SUBUNIT

Postorogenic rocks include the Wagon Bed Formation of middle and late Eocene age, the White River Formation of Oligocene age, the Arikaree Formation of Miocene age, and the Ogallala Formation of Miocene and Pliocene age. These formations have been mapped only in the southern part of the county in an area of about 850 square miles. In the northwestern part of the county rocks of late and middle Eocene and Oligocene age are present as small erosional remnants in and near the mountains. The subunit, as well as individual formations, is variable in thickness because it was deposited on an erosional surface of large relief. Maximum thickness of this subunit is in the southwestern part of the county and is estimated to be about 4,000 feet.

The Wagon Bed Formation is as much as 1,000 feet thick. The formation consists of mudstone, sandstone, arkosic sandstone, and con-

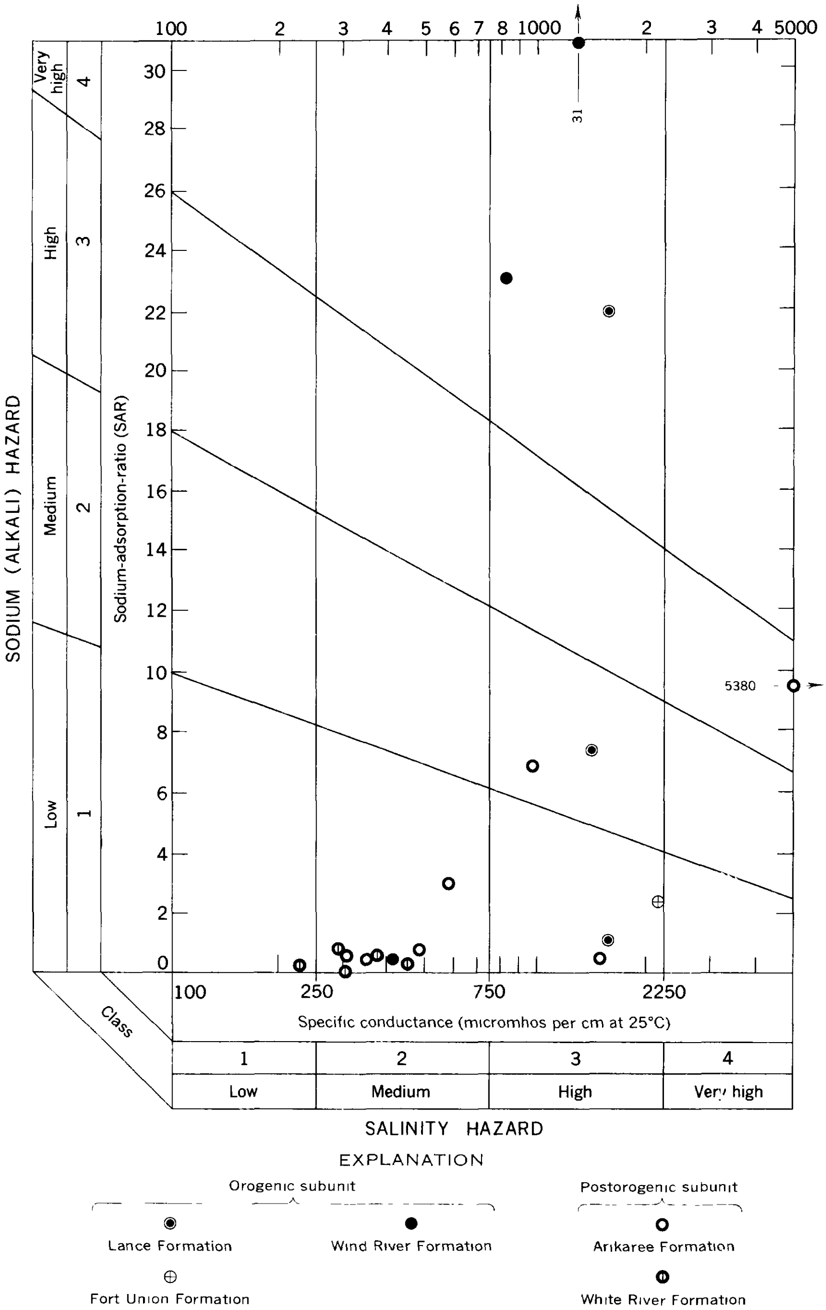

FIGURE 14.—Irrigation classification of water from the consolidated continental rock unit. (Diagram adapted from U.S. Salinity Laboratory Staff, 1954.)

glomerate. Most of the deposits are poorly sorted; however, Van Houten (1955, p. 10) reported the upper 140 feet in the vicinity of Beaver Rim contain conglomerate that includes minor amounts of mudstone and sandstone matrix. The conglomerate is not well cemented at all localities. A large percentage of the material in the formation consists of locally derived volcanics.

The White River Formation rests on an erosional unconformity cut into the middle and upper Eocene rocks and, in places, the older formations. The formation has been divided into upper and lower members by Harshman (1968) and Denson (1965, p. 72–73). Love (1961b), Rich (1962), and Van Houten (1964) did not divide the formation into members, but included the upper member with the overlying Miocene deposits.

The lower member of the White River Formation consists predominantly of tuffaceous siltstone and claystone interbedded with tuff, conglomeratic sandstone, and conglomerate. Rocks equivalent to this member were described by Rich (1962, p. 496–502) as being as much as 865 feet thick.

The upper member is the approximate interval described by Love (1961b, p. 10–12) as the lower porous sandstone sequence of the Split Rock Formation (of former usage). The member consists predominantly of conglomerate and sandstone, some of which is poorly cemented. The conglomerate consists of cobbles and boulders of Precambrian rocks in a course-grained sandstone matrix. Gray medium- to coarse-grained sandstone is interbedded with the conglomerate (Love, 1961b, p. 10). The upper member is persistent; however, individual beds are lenticular and cannot be traced for long distances. The member is as much as 600 feet thick.

The Arikaree Formation averages about 1,000 feet thick and was described by Denson (1965, p. 74) as composed largely of windblown fine- to medium-grained sandstone having thin relatively unimportant interbeds of limestone, tuff, and conglomerate. The beds are poorly to well cemented.

The Ogallala Formation consists of sandstone, claystone, shale, and conglomerate. Individual beds are lenticular, generally poorly consolidated, and poorly sorted. Maximum thickness is estimated to be about 800 feet.

Upper Tertiary rocks at the south end of the Bighorn Mountains have been described by Tourtelot (1953) as a sequence of andesite tuff, tuffaceous siltstone, and volcanic ash with interbeded conglomerate. The lower part grades laterally into sandstone and claystone toward the mountains.

WATER-BEARING PROPERTIES

Most wells in the postorogenic subunit are less than 500 feet deep and yield less than 50 gpm. Data from pumping tests of three wells, each yielding about 10 gpm, were inconclusive about the water-bearing properties of the subunit. Therefore, the water-bearing properties are inferred from data in other parts of the State where aquifer properties have been described.

The Wagon Bed Formation and the lower unnamed member of the White River Formation in most locations are not permeable enough to yield water to wells. Conglomerate beds, however, occur in both, and the highest yields could be obtained where the conglomerate is well sorted and unconsolidated. Yields of 450 gpm are obtained from similar deposits in the White River Formation in the City of Cheyenne's Federal Well Field about 10 miles northwest of Cheyenne. Secondary permeability in the White River results in higher yields locally than would be expected from areas having only primary permeability. Three springs (29–79–1bbc, 29–79–34b, 30–79–33ddd) in Natrona County have yields ranging from 115 gpm to an estimated 300 gpm. Permeable zones, such as shown in figure 15, are usually the source of large yields of water from fine-grained beds in the White River. Wells having yields of more than 2,000 gpm are developed from similar conditions near Pine Bluffs, Wyo., in Laramie County, but are not known in Natrona County.

Whitcomb (1965, p. 48) reported that the coefficients of transmissibility [1] determined from four pumping tests in the Arikaree in Niobrara County ranged from 8,000 to 77,000 gpd per foot. The larger transmissibility is attributed to secondary permeability. Weeks (1964, p. 44) reported transmissibilities ranging from 2,600 to 10,000 gpd per foot for the Arikaree Formation in the Wheatland Flats area in Platte County. Lowry and Crist (1967, p. 31) reported a range of 1,065–39,200 gpd per foot for the Ogallala in Laramie County. Preliminary data from two pumping tests in Carbon County near the North Platte River showed the transmissibility ranged from 10,000 to 40,000 gpd per foot for rocks equivalent to the Ogallala Formation. These data were all derived from well tests and are cited to illustrate the upper range of transmissibilities that might be expected from this subunit.

[1] Coefficient of transmissibility is the rate of flow of water at the prevailing temperature in gallons per day, through a vertical strip of aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent. The term "coefficient of transmissibility" has been replaced by the term "transmissivity." To convert from transmissibility to transmissivity, divide by 7.48 gallons per cubic foot.

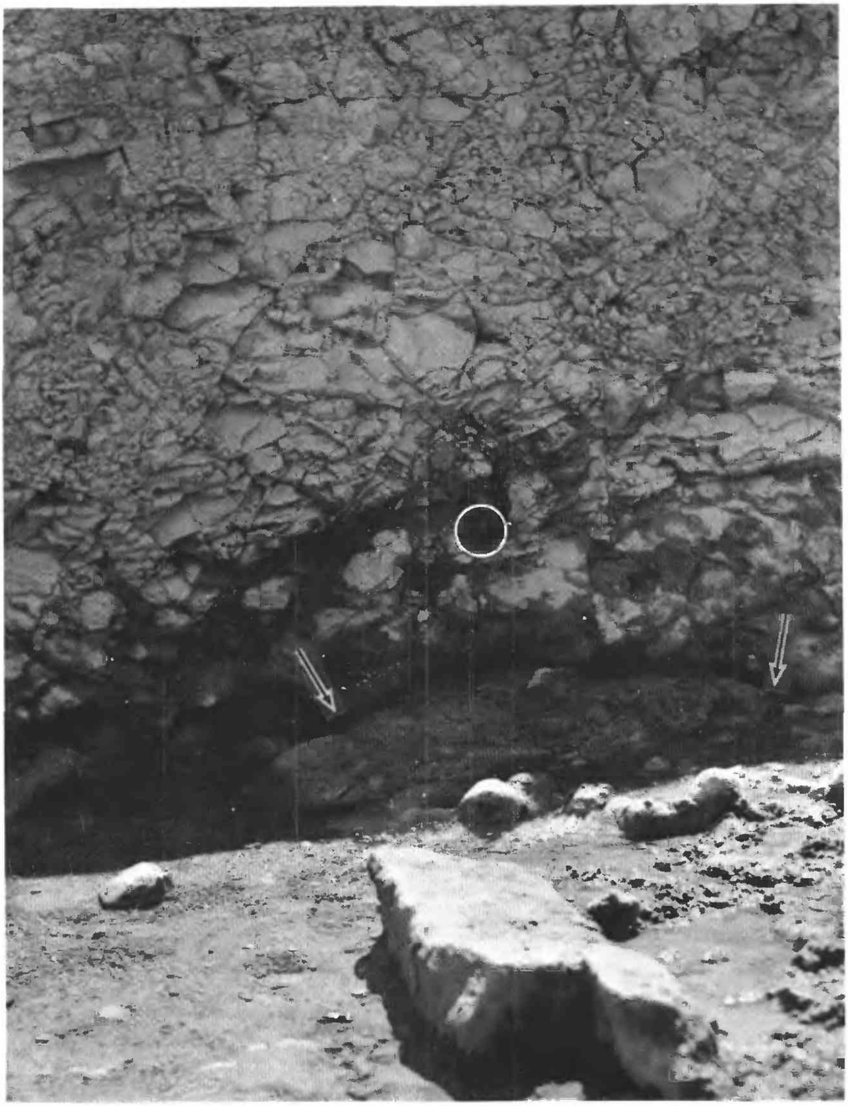

FIGURE 15.—Spring 30–79–33ddd in the White River Formation. Arrows point to principal openings where water issues at the rate of 115 gpm. Light meter (circled) is shown for scale.

CHEMICAL QUALITY

Twelve water samples were analyzed from the postorogenic subunit. The dissolved-solids content ranged from 182 to 4,770 mg/l. Both of the extremes were found in the Arikaree Formation. The waters from this subunit were primarily calcium bicarbonate type. Other types of water including sodium calcium sulfate chloride, sodium calcium sulfate, and sodium sulfate were found near Soda Lakes (T. 29 N., R. 86 W.) and near the west end of Pathfinder Reservoir (T. 30 N., R. 85 W.). Ground water in these areas usually has a higher dissolved-solids content than is found elsewhere in the postorogenic subunit. The authors believe the reason for this is that buried granite knobs restrict ground-water movement in these areas, and water is discharged by evapotranspiration, which in turn causes an increase in the concentration of dissolved solids. Potentiometric surface contours in the southwestern part of the county (pl. 1) show ground-water movement toward the depressions at Soda Lakes and at the west end of Pathfinder Reservoir. The evaporation rate is high from the depressions, which constitute major areas of discharge from the ground-water reservoir. The areas where ground water would be expected to contain the higher dissolved-solids content are indicated on plate 1. Plate 1 also indicates that the consolidated continental rock unit has the greatest areal extent of aquifers which contain water with less than 1,000 mg/l of dissolved solids.

Log-normal distribution is shown (fig. 12) by plotting the cumulative frequency of the specific conductances of waters from the postorogenic subunit. Therefore, approximately 68 percent of the wells in this subunit drilled to depths of less than 500 feet will produce water having specific conductances ranging from about 290 to about 600 micromhos per cm at 25°C. On the basis of 0.69 as the average ratio of dissolved solids to specific conductance as determined from the waters analyzed, the range of dissolved solids is from about 200 mg/l to about 400 mg/l. The mean specific conductance from figure 12 is about 410 micromhos, which is calculated to be about 280 mg/l of dissolved solids; this content indicates that most of the water from this subunit is suitable for domestic and stock use. The points off the upper end of the straight line were from samples collected from the Arikaree Formation near the areas where the quality is influenced by high evaporation rates or restricted ground-water movement. These samples are not representative of the major part of the Arikaree.

The classification of these waters for irrigation shown in figure 14 indicates that nearly all the water is suitable for irrigation on soils where a moderate amount of leaching occurs. Water from the Arikaree in areas of restricted ground-water movement would not be suitable for irrigation because of the high salinity hazard.

Future Development

The lower member of the White River Formation and the Wagon Bed Formation will probably yield as much as 300 gpm locally from conglomerate lenses and possibly from zones of secondary permeability. These high-yielding zones, however, are not extensive, and supplies will be meager in many places.

Potential for development of the upper member of the White River Formation and the andesite tuff and tuffaceous siltstone sequence is not known. It is inferred from the lithology that the upper member of the White River would be similar to the Ogallala, but it does have somewhat more potential than the Ogallala because of its lower topographic position and consequent increase in saturated thickness. The andesite tuff and tuffaceous siltstone sequence probably has little potential for yields of more than 50 gpm, which might be obtained where coarse material is well sorted.

The largest yield from a well in the postorogenic subunit is reported to be 120 gpm from well 31–87–9bdb, which taps the Arikaree Formation. Yields of 25–50 gpm could be obtained nearly everywhere there is a penetration of about 100 feet of saturation because of the homogeneity of the formation. Yields of 200–300 gpm could probably be obtained in much of the area from wells at least 600 feet deep which would penetrate about 500 feet of saturation. Unconsolidated sand may be a problem in some areas, and careful construction would be required to prevent sand from entering the well.

The Ogallala is not as dependable an aquifer as the Arikaree because it is more heterogeneous and is topographically higher. Yields ranging from 15 to 20 gpm can be expected from most of the Ogallala, but higher yields will be possible where saturated conglomerate is present. The White River and Arikaree Formations are considered to be the principal aquifers in this unit because of their areal extent and thickness.

UNCONSOLIDATED CONTINENTAL ROCK UNIT

Unconsolidated continental rocks include alluvial, landslide, and windblown deposits of Quaternary age. It is impracticable to show all the deposits on the geologic map; however, they are widespread. Alluvium, in particular, occurs at least to some extent along even the small ephemeral streams.

Alluvium, as shown on the geologic map (pl. 2), includes not only terrace and flood-plain deposits but colluvium and pediment deposits as well. Colluvium consists of poorly sorted debris at the base of steep slopes. Pediment deposits such as those on the north side of Casper Mountain (not mapped) consist of a veneer of lag gravel, cobbles, and boulders.

Terrace and flood-plain deposits consist of lenticular beds of clastic material ranging in size from clay to boulders. In areas where the parent material is clay, shale, and fine sand—such as along Bear Creek, the lower reaches of Stinking Creek, Powder River, and along the central reach of the Middle Fork of Casper Creek—the alluvium along the streams consists of fine material. Alluvium derived, at least in part, from parent material that includes resistant Precambrian and Paleozoic rocks and Tertiary conglomerate, such as along Bates Creek and Wolf Creek, have a greater percentage of coarse material. The general lithology and depth of the alluvium of some of these streams are shown on plate 3. The lithology shown is based on returns from augering. There is considerable mixing of the material returned by the auger, especially at depth, and thus the sections illustrate only the general lithology. Caution should be exercised if the sections are used as evidence of the thickness of the different types of material making up the alluvium.

The thickness of alluvium is greater in some of the tributary drainages than it is along the North Platte and Powder Rivers. The greatest thickness known in the county is 190 feet, found in alluvium along the Clear Creek Fork of Muddy Creek (well 32–78–11bda). In addition, there is about 100 feet of alluvium along Bates Creek (section *C–C′*, pl. 3) and 85 feet (well 33–79–30bbb) and 75 feet (well 33–80–24dbd) along Wolf and Squaw Creeks, respectively. Flood-plain deposits along the North Platte River are not known to be greater than 50 feet. Alluvium capping terraces in the Kendrick Project are as much as 80 feet thick (U.S. Bur. Reclamation, 1964, p. 4).

Windblown deposits are most conspicuous in an east-west band in the central part of the county, but occur elsewhere as well. The deposits consist principally of very fine to fine-grained sand and silt. The thickness of the deposits is known to be at least 40 feet near the town of Powder River.

Landslide deposits consists of material resulting from gravity movement in areas of unstable slopes. The material in the slides is the same as the parent material.

Water-bearing Properties

The water-bearing properties of the alluvium are variable because of the difference in the source material. Where the alluvium is derived largely from shale and sandstone, such as along Powder River and the central reaches of the Middle Fork of Casper Creek, the yield of wells probably would not exceed 20 gpm. Alluvium derived, at least in part, from more resistant rocks is much more permeable and, therefore, will yield larger quantities of water to wells. Wells, owned by the City of Casper, in the alluvium along the North Platte River yield as much as 1,000 gpm, and an irrigation well in the alluvium along Bates Creek yields about 1,300 gpm. A transmissivity of 8,560 square feet per day was determined from a 14-hour pump test of well 33–77–3bdc, which penetrates the alluvium along the North Platte River.

Many terraces and pediments are capped by coarse deposits; however, because these features are topographically high, the water drains rapidly from the edge of the deposits, thus there is generally little saturated thickness. Saturation in the terrace deposits on the Kendrick Project is maintained principally by seepage from irrigation.

Recharge from surface-water irrigation has saturated some rock strata at shallow depths and created aquifers in many areas on the Kendrick Project where previously no shallow aquifers were present. In many places the ground-water level has risen as much as 20 feet in the period 1950–67. The hydrographs in figure 16 show the water-level changes that occurred in wells 31–82–34abb and 33–80–4abb in

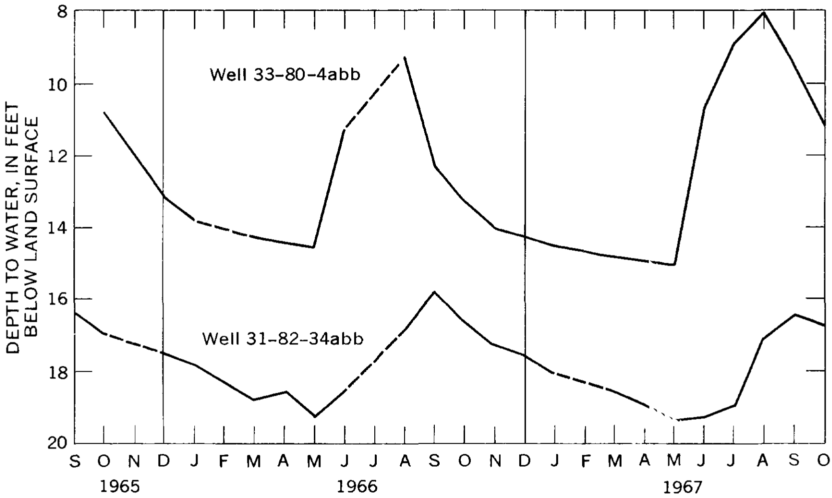

Figure 16.—Water-level changes in alluvial terrace deposits in response to seasonal irrigation.

response to intermittent irrigation. Generally, the water levels rise sharply in June, reach maximum level during August or September, then decline until the following spring. On the basis of the records available, water levels decline to approximately the same level each year before ascending again. Some minor fluctuations during April 1966 at well 31–82–34abb may have been caused by recharge from precipitation. Precipitation was about 1 inch more during April than during either March or May 1966.

Irrigation has caused some waterlogging problems in areas of low permeability, such as illustrated by the hydrograph of well 35–80–31cbb shown in figure 17. This well is 32 feet deep in a terrace deposit

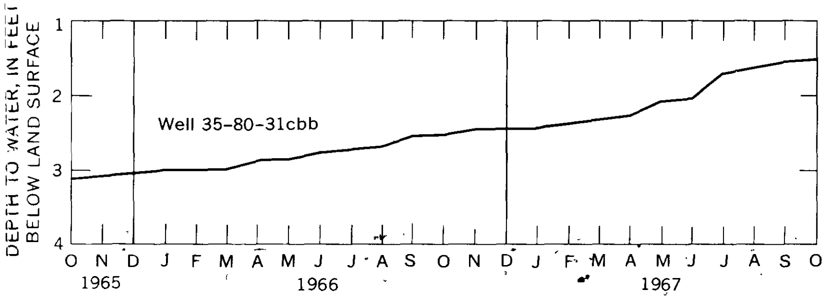

FIGURE 17.—Ascending potentiometric surface in alluvial terrace deposits caused by surface-water irrigation.

consisting of silt and clay mixed with a small amount of sand. Recharge to the semiconfined aquifer is derived from an irrigation ditch or an irrigated area west of this well, as illustrated diagrammatically in figure 18. The water level in the well is about 1½ feet below land

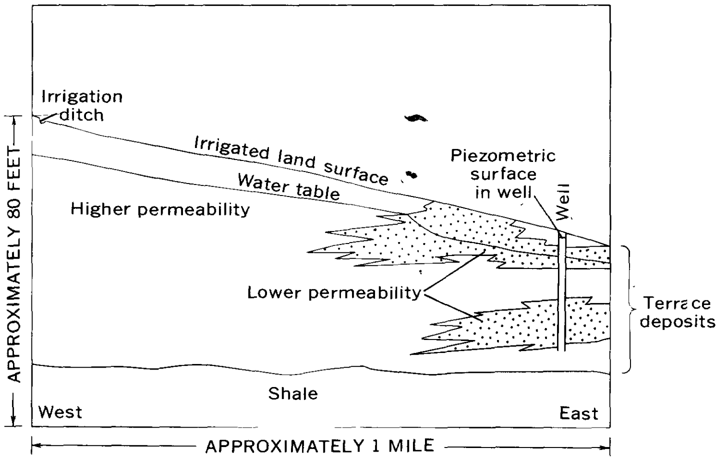

FIGURE 18.—Head differences resulting from differences in permeability in terrace deposits near well 35–80–31cbb.

surface and has risen at the rate of about one-half foot per year in the period October 1965 to October 1967 (fig. 17). If this rate continues, water will flow at land surface in about 1½ years. The exact depth of the water level in the zone of low permeability is not known, but it is more than 5 feet below land surface. Low vertical permeability is probably retarding the ascent of the potentiometric surface in the terrace deposits. If the water level in the terrace deposits continues to rise, waterlogging will occur. Where this happens in deposits of low permeability, dewatering will be difficult.

Windblown deposits serve as reservoirs for ground water in some areas; however, the yields of the wells tapping these deposits are small because the material is predominantly fine grained and because the saturated thickness is small. Sometimes less than 1 foot of water is perched in the deposits on top of the underlying bedrock. In some places, the water derived from wells apparently is from a combination of a thin water-bearing zone at the base of the windblown deposits and an equally thin weathered zone at the top of the bedrock. Water-level changes in a well that is completed in such a zone are illustrated by the hydrograph in figure 19. The water level generally declines from December to about June, then rises gradually until the following December. The relatively sharp rise in the water level in June 1967 is in response to the precipitation received during the month. It is also probable that a higher percentage of the precipitation from larger storms, such as received June 15, is able to penetrate to the water table before being lost to evapotranspiration. The minor water-level fluctuations are caused by changes in the barometric pressure and correlate with a plot of the barometric pressure readings taken at the airport at Casper, Wyo., about 28 miles east of the well. This well is completed in windblown sand overlying the Cody Shale; however, for barometric pressure to affect the water level, there must be some confining layer in the sand. This layer is probably a zone of considerably lower permeability than the zones above and below it.

Landslide deposits are topographically high, and ground water drains quickly; however, because the characteristic hummocky topography helps trap precipitation, recharge conditions are improved. Also because of the topography, small springs and seeps are common near the base of the deposits.

Chemical Quality

Fifteen samples of water from the unit were analyzed (one for selenium only); the results, given in table 2, show that the quality is variable. No single cation was predominant in these samples, but it was found that sulfate was the principal anion. The Cretaceous rocks that are abundantly exposed in the county are probably the main source of the sulfate.

Water in the alluvium along the North Platte River near Casper is very hard. In the three water samples analyzed, the calcium magnesium hardness ranged from 290 to 530 mg/l, and the concentration of dissolved solids ranged from 506 to 1,380 mg/l. The specific conductance of water at other locations along the North Platte indicates that water of similar quality can be found at most places in the alluvium between Alcova Dam and the eastern border of the county.

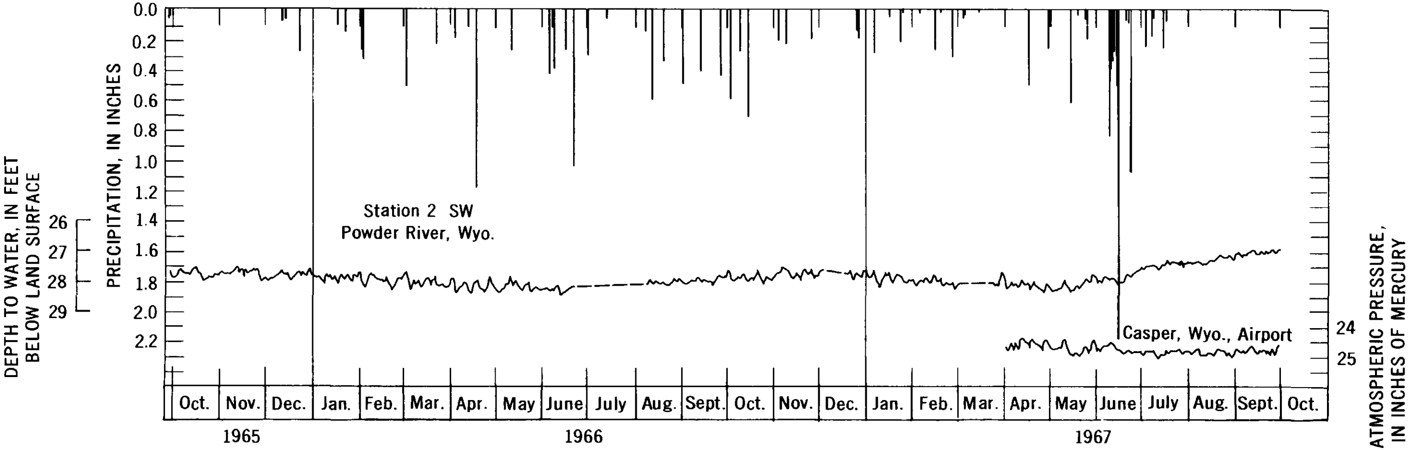

FIGURE 19.—Water-level fluctuations in well 35–85–1cbb, precipitation at Powder River, and atmospheric pressure at Casper.

The river probably helps maintain the better quality of water, as the concentration of dissolved solids in the stream ranged from 278 to 324 mg/l at Alcova and from 352 to 960 mg/l near Glenrock, Wyo., about 12 miles east of Natrona County, during the 1966 water year (U.S. Geol. Survey, 1966). Recharge and discharge of the alluvium by the North Platte River is illustrated in figure 20, which shows

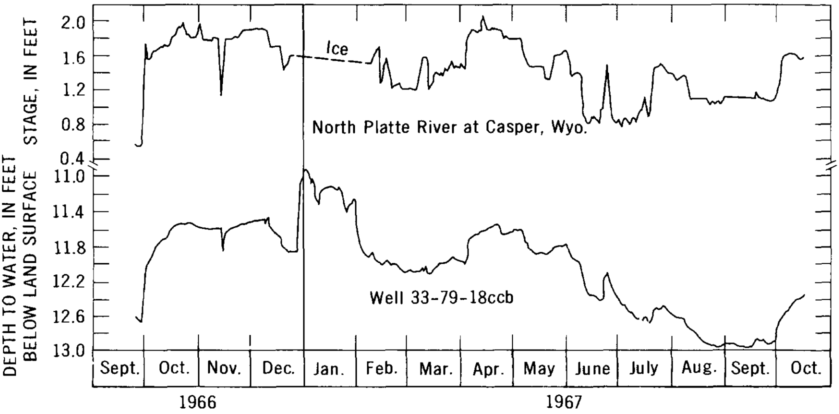

FIGURE 20.—Fluctuation of the water level in alluvium and stage of the North Platte River at Casper.

the hydrograph of well 33–79–18ccb and the stage of the North Platte. The well is completed in the alluvium and is within 300 feet of the stream. Cretaceous shale underlies the alluvium in this reach of the river. Contributions of ground water from the shale to the alluvium are considered to be small relative to the contributions to the alluvium from the river; therefore, change of water level in the well is attributed to recharge or discharge by the stream and not to the damming of ground-water inflow from the underlying shale, which could be caused by rising river stage.

In some reaches of the North Platte the water quality in the alluvium is influenced locally by the contributions of water from bedrock aquifers. In less permeable parts of the alluvium, the ground water that is discharged into alluvium from bedrock aquifers may have a greater influence on the quality of water than water from the river. Water from a part of the alluvium, near the Texaco refinery at Casper, contained as much as 6,800 mg/l of dissolved solids.

Selenium (0.02 mg/l) was found in water from the alluvium (SE¼SE¼NW¼ sec. 18, T. 33 N., R. 79 W.), which is recharged by the North Platte River near Casper. This location is near a collection channel dredged nearly parallel to the river, and the water probably represents the quality of water in the stream.

Near the Sweetwater River in the southwestern part of the county, water from well 29-87-25caa, which is completed in alluvium, contained 246 mg/l of dissolved solids. That the alluvium consists of sand and gravel derived from igneous and Tertiary rocks and partly accounts for the low dissolved-solids content. In the reaches where the river is a gaining stream (receives water from the ground-water reservoir), the quality of water in the alluvium would be similar to that in the Arikaree Formation, which probably contains less than 500 mg/l of dissolved solids in most of this area (pl. 1). The quality of the water flowing in the stream is also good, as total dissolved solids ranged from 178 mg/l to 360 mg/l in the 1966 water year (U.S. Geol. Survey, 1966). Therefore, water of similar chemical composition would probably be found in the alluvium in the reaches where the river is a losing stream (gives water to the ground-water reservoir).

The alluvium along Poison Spider, Casper, Iron, and Poison Spring Creeks within the boundary of the Kendrick Project is recharged primarily by water from irrigated areas. The irrigation water leaches many minerals from the soil before reaching the alluvium in the flood plain; as a result, the water in the alluvium along these creeks is usually too mineralized to be suitable for domestic use. The dissolved-solids content ranged from 1,230 to 8,240 mg/l in three samples analyzed.

Little is known about the quality of the water in alluvium along other streams in the county, but it is believed that the water would be of similar type as that found in the underlying bedrock. The amount of dissolved solids in ground water in the alluvium, however, would be influenced by permeability, evapotranspiration, and recharge from precipitation.

Total dissolved solids in three samples of water from the alluvial terraces west of Casper ranged from 1,290 to 6,610 mg/l. Selenium concentrations ranged from 0.03 to 1.1 mg/l in these three samples. Ground water from the terraces discharges into creeks and drains which empty into the North Platte River. Therefore, water containing this concentration of selenium may have an adverse affect locally on the quality of water in alluvium along the North Platte.

Water derived from the windblown deposits, which are predominantly sand, (pl. 2) is generally suitable for domestic use, but the quality is dependent upon the proximity of the underlying bedrock. Specific conductance of waters from the sand ranged from 700 to 2,750 micromhos at 25°C. The better quality water is obtained where there is more saturated thickness in the deposits. The poorer quality water is from areas of small saturated thickness where the water is influenced more by contact with the underlying Cretaceous shale.

Water sampled from the unconsolidated continental unit has been classified (fig. 21) as to its suitability for irrigation. About half the waters analyzed should be used only on soil with good drainage; about one-fourth contained sufficient sodium to limit use for irrigation to

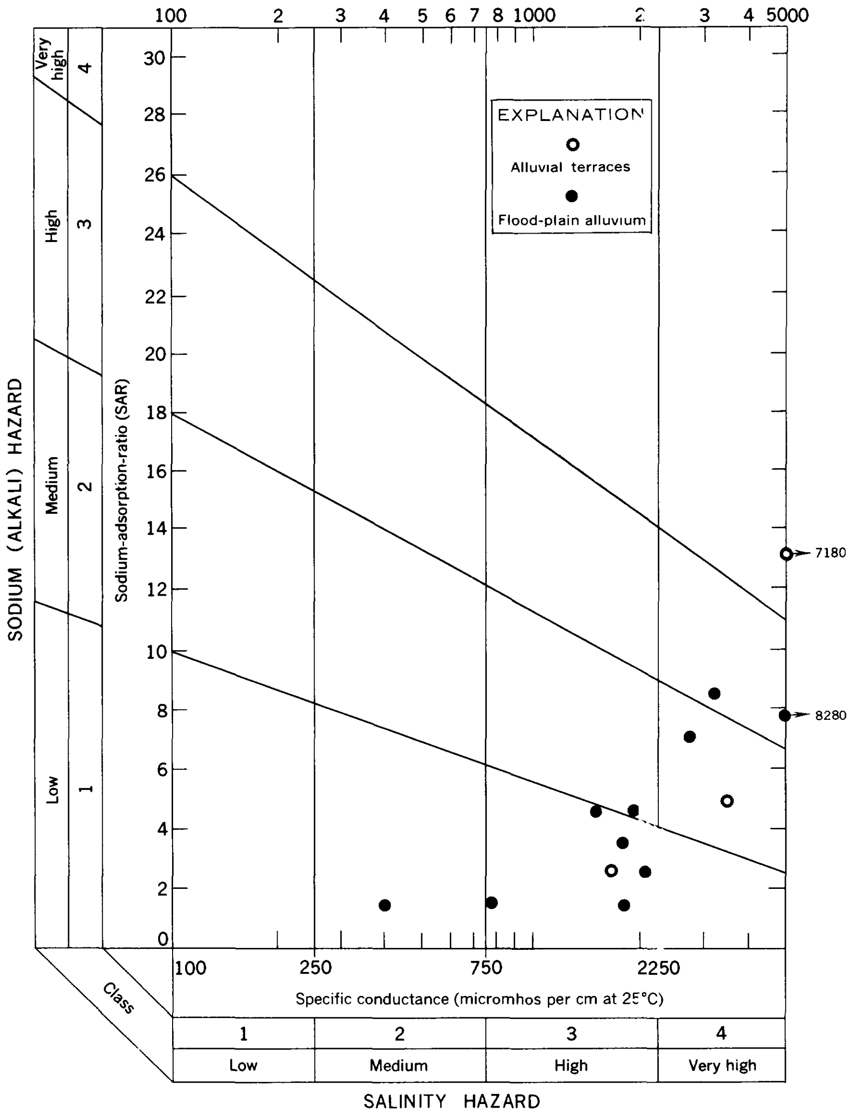

FIGURE 21.—Irrigation classification of water from the unconsolidated continental rock unit. (Diagram adapted from U.S. Salinity Laboratory Staff, 1954.)

coarse-textured soils with good drainage; and about one-fourth contained a high enough sodium concentration that the waters would probably cause accumulation of excess exchangeable sodium.

Future Development

The Quaternary deposits offer the best possibilities for satisfactory water supplies in many parts of the county, particularly in areas where marine and continental rocks predominate. Chances for adequate quantities would be best near mountains, where alluvium is more permeable; also, water is generally of better quality here. Permeable material, consisting of sandstone pebbles, may occur locally in areas of large relief and would be a good source of water.

Wells with yields ranging from about 300 to 1,000 gpm can be developed from alluvium along Bates Creek, Poison Spider Creek, and the North Platte River, and future exploration may find other areas as well. There is about 75 feet of saturated permeable material along Bates Creek, and irrigation water could be developed from wells. About 70 feet of saturated material was found along Poison Spider Creek. Although the water along Poison Spider Creek is too highly mineralized for a suitable domestic supply, it could be used for irrigation on soils with good drainage. Special well construction would be required to keep the fine sand from entering the well bore. Yields of more than 700 gpm from alluvium along the North Platte River at present are from collection galleries, or similar structures, but it may be possible through test drilling to find permeable sections thick enough to yield larger amounts from wells.

Windblown deposits will yield somewhat better quality water than underlying material in many areas, but the yields will be small. The absence of drainage in sand dune areas illustrates the capacity of the material to accept recharge from precipitation. The configuration of the bedrock beneath a dune, however, can be determined only by drilling or by geophysical methods; so there may be many failures in attempts to drill a satisfactory well. In general, it would be best to drill only in the larger dunes and at the greatest distance from the edges. The edges of the dunes are discharge areas and therefore have little saturation.

Landslide deposits would not be a good site to drill a well, but it may be possible to obtain small, perhaps seasonal, supplies by developing existing seeps and springs.

SURFACE WATER

Water flowing in the streams of the county is closely related to the ground water either as recharge to aquifers or as ground-water discharge. The quantity and quality of surface water is more variable seasonally than ground water, although some controls are used to regulate the flow of surface water.

The North Platte River is the only stream delivering a substantial quantity of water from the county. The flow is regulated by a series of dams on the upper reach of the North Platte. It is estimated that the mean annual pickup between Alcove Dam and the eastern county line is about 8 percent of the total streamflow, or about 96 cfs. This figure is based on streamflow records of the North Platte at Alcova and Glenrock and of Deer Creek, a tributary to the North Platte near Glenrock, for the water years 1961 through 1966. Natural flow of the river is affected by power development, diversion for irrigation, and return flow from irrigation. Most of the return flow from irrigation on the Kendrick Project occurs during the period May through September, when average return flows may range from 60 to 70 cfs. Average streamflow from the project area during the remaining months is estimated to be about 20–30 cfs.

Chemical analyses of some surface waters in the county are given in table 3. Selenium was found in waters from the North Platte River, Poison Spider Creek, Casper Creek, Poison Spring Creek, Oregon Trail Drain, and Lone Tree Gulch; the concentration ranged from less than 0.01 mg/l in the North Platte at Alcova to 0.94 mg/l in Oregon Trail Drain. Two successive samples collected from each of several surface-water sites indicated that the selenium concentration increases in the winter months. All the creeks empty into the North Platte River upstream from the source of Casper's municipal water supply, which is the North Platte River and the alluvium along the North Platte. Further study is being made of the occurrence of selenium in ground and surface waters in this area.

It is interesting to note the effect of irrigation on the water quality of streams crossing the Kendrick Project. (See table 3.) Poison Spider Creek and Casper Creek (includes Middle Fork of Casper Creek) were sampled upstream and downstream from the irrigated area. At the time of sampling, the flow in each stream had increased considerably in the reaches through the project, and the dissolved-solids content was increased in Poison Spider Creek and was decreased in Casper Creek by irrigation return flow from the area. Evidently the return flow in the Casper Creek area is of better quality than the water flowing in the creek. The amount of nitrate in both streams increased downstream owing probably to the leaching of nitrogen fertilizers from the farmed areas in the Kendrick Project.

The quantity and quality of water flowing in Salt Creek is influenced by discharge of oil-field waters in the area of Salt Creek oil field. The chloride concentration of 1,670 mg/l (table 3) indicates mixing with oil-field waters. The water contained 5,070 mg/l of dissolved solids, which was the highest concentration of any stream sampled in the county.

SUMMARY

Twenty-eight aquifers, ranging in age from Precambrian to Holocene, are known to yield water to wells and springs in the county. The quality of the water is varied. Ground water suitable for livestock can be developed at depths of less than 1,000 feet in most of the county. Ground water from approximately 40 percent of the county contains more than 1,000 mg/l of dissolved solids and is unsuitable for domestic use according to the standards recommended by the U.S. Public Health Service (1962).

The igneous and metamorphic rock unit includes rocks of Precambrian age and igneous rocks of Tertiary age. Most wells in these rocks will probably yield less than 5 gpm. The chemical quality of the water is suitable for most purposes.

The marine rock unit includes the Flathead Sandstone, Gros Ventre and Gallatin Formations, Madison Limestone, Amsden Formation, Tensleep Sandstone, and Casper Formation. The formations having the highest rates of yield to wells and springs are the Madison, Tensleep, and Casper, which are capable of yields of as much as 9,000 gpm to wells where secondary permeability is present; however, drilling depths and uncertainties of yield are usually too great to warrant much exploration in these formations, except near the outcrop.

Water in the marine rock unit generally contains less than 500 mg/l of dissolved solids near the outcrop, but the dissolved-solids content increases with distance from the exposed recharge area. Maximum concentration of dissolved solids is more than 3,200 mg/l. Generally, at greater distances from the outcrop, the water is not suitable for irrigation because of the very high salinity hazard.

The continental and marine rock unit includes the Goose Egg Formation, Chugwater Group, Bell Springs Member of the Nugget Sandstone, and the Sundance, Morrison, and Cloverly Formations. The unit is about 1,900 feet thick. Water-bearing characteristics are dissimilar among the formations because of differences in lithology and cementation. The upper part of the unit (Cloverly Formation), which has the best potential for water supplies, yields from 1 to 100 gpm, although yields generally range from about 5 to 20 gpm. The formations in this unit are deeply buried in much of the county; thus, only a few wells have been constructed outside of the outcrop areas.

The concentration of dissolved solids in nine water samples from this unit ranged from 70 to 1,780 mg/l. Much of the water from the Cloverly is unsuitable for irrigation because of the high sodium content. Sufficient data are not available to describe the water from other formations in the unit as to the suitability for irrigation.

The marine and continental rock unit includes the Thermopolis and Mowry Shales, Frontier Formation, Cody Shale and its lateral equivalents, Mesaverde Formation, Lewis Shale, and Fox Hills Sandstone. These rocks, as a unit, have the least potential of any of the rock units as a source of water to wells because of either low yield to wells or high mineral content of the water, or both. Shale is dominant in the unit, but sandstone beds make up a small percentage of the section. In the shale sequence, only the Mowry will yield as much as 20 gpm. In most of the county, however, the formations, which are predominantly shale, will not yield sufficient water for a livestock well. The principal aquifers in the unit are the Frontier, Mesaverde, and Fox Hills. Low permeability in the sandstone beds limits the maximum yield to about 50 gpm.

On the basis of specific conductances of water from the unit, it is estimated that 68 percent of the wells drilled to similar depths as existing wells would produce water containing dissolved solids ranging from 1,000 to 3,000 mg/l and average about 1,700 mg/l. Most of the water would be unsuitable for irrigation because of the high salinity and sodium hazard. The residual sodium carbonate of most of the water would also be too high for suitable irrigation water.

The orogenic subunit of the consolidated continental rock unit includes the Meeteetse, Lance, Fort Union, and Wind River Formations. Maximum total thickness of this subunit is about 20,000 feet. Most wells in this subunit are less than 500 feet deep and yield less than 25 gpm. The water is used for livestock and domestic supplies. Possible yields are difficult to predict because of the heterogeneous character of this subunit, but yields of 200 gpm or more can probably be obtained from wells at depths of less than 1,000 feet in the Wind River Formation at some places.

On the basis of water samples analyzed from the orogenic subunit, it is estimated that 68 percent of the wells less than 500 feet deep will produce water containing dissolved solids ranging from about 490 to about 2,100 mg/l and average about 1,000 mg/l. Use of this water for irrigation should be limited to coarse-textured soil with good drainage. Some water from the Wind River and Lance Formations would be unsuitable for irrigation because of high sodium content and high residual sodium carbonate.

The postorogenic subunit of the consolidated continental rock unit includes the Wagon Bed, White River, Arikaree, and Ogallala Formations. These rocks are exposed mostly in the southern part of the county, and in the southwestern part, these formations are estimated to be about 4,000 feet thick. The White River and the Arikaree are the principal aquifers. Yields of 50 gpm might be obtained from the upper part of the White River, whereas 50 gpm can be obtained nearly everywhere in the Arikaree where there is 100 feet of saturation. It is estimated that yields of 300 gpm can be obtained locally from the lower member of the White River Formation and the Wagon Bed Formation. Such a yield can be obtained from the Arikaree by wells approximately 600 feet deep which penetrate about 500 feet of saturation. The Ogallala Formation is estimated to be capable of producing only small yields (15–20 gpm) in most of the area because the Ogallala is topographically high and contains little saturation. Higher yields are possible where saturated conglomerate is present.

The water from the postorogenic rocks, except water from near the west edge of Pathfinder Reservoir, is suitable for most purposes. In the area west of Pathfinder Reservoir, it is believed that ground-water movement is restricted by buried granite knobs, and evapotranspiration causes an increase in the dissolved-solids content of the water. It is estimated that 68 percent of the wells in this subunit drilled to similar depths as existing wells will produce water containing dissolved solids ranging from about 200 to 400 mg/l; the average is estimated to be about 280 mg/l. Nearly all the water is suitable for irrigation in areas where a moderate amount of leaching occurs.

The unconsolidated continental rocks include alluvial, landslide, and windblown deposits. Alluvium is the major aquifer in this unit; only minor supplies of water are obtained from windblown deposits and landslide material.

Yields of wells in the alluvium vary with the type of material deposited and the saturated thickness. The maximum yield was 1,300 gpm along Bates Creek. Yields of as much as 1,000 gpm can be obtained from the alluvium along the North Platte River. In test holes augered along lines across four stream valleys, it was found that the alluvium is thicker along some of the tributaries to the North Platte River than along the main stem.

The alluvial deposits offer the best possibility of obtaining a water supply in many areas, especially in areas underlain by formations of the marine and continental rock unit. The chemical quality of the water is variable. Concentration of dissolved solids in 14 samples of water from this unit ranged from 246 to 8,240 mg/l. Water with the lower concentration was obtained from alluvium derived from volcanic and Tertiary rocks; water with the higher concentration was obtained from alluvium derived primarily from Cretaceous shales.

The windblown deposits overlie Cretaceous rocks, and the water quality differs according to the proximity to the underlying bedrock.

In localities where the saturated zone in the sand dunes is thick, the water is suitable for domestic use; however, the quality is generally poorer in localities with less saturation.

Selenium has been found in ground water near Casper; the concentrations ranged from 0.01 mg/l to 1.1 mg/l. Selenium was found in some water samples from the Frontier Formation, alluvial terrace deposits, and the alluvium along the North Platte River, all near Casper. Selenium in surface waters in the same area ranged from less than 0.01 mg/l in the North Platte River at Alcova to 0.94 mg/l in Oregon Trail Drain, which empties into the North Platte just upstream from Casper. Further study of the occurrence of selenium in ground and surface waters near Casper is warranted because the water supply for the City of Casper is obtained from the North Platte River and alluvium adjacent to the river.

REFERENCES CITED

Babcock, H. M., and Morris, D. A., 1953, Ground water in the vicinity of Edgerton, Wyo.: U.S. Geol. Survey open-file report., 9 p., 1 fig.

Beath, O. A., 1964, The story of selenium in Wyoming: Univ. Wyoming Agr. Expt. Sta., 35 p.

Beath, O. A., Gilbert, C. S., Eppson, H. F., and Rosenfeld, Irene, 1953, Poisonous plants and livestock poisoning: Wyoming Agr. Expt. Sta. Bull. 324, 94 p.

Burk, C. A., and Thomas, H. D., 1956, The Goose Egg Formation (Permo-Triassic) of Eastern Wyoming: Wyoming Geol. Survey Rept. Inv. 6, 11 p.

Carey, B. D., Jr., 1954, Geologic map and structure sections of the Rattlesnake Hills Tertiary volcanic field, *in* Wyoming Geol. Assoc. Guidebook 9th Ann. Field Conf., Casper area, 1954: p. 32–34.

Darton, N. H., Blackwelder, Eliot, and Siebenthal, C. E., 1910, Description of the Laramie and Sherman quadrangles [Wyoming]: U.S. Geol. Survey Geol. Atlas, Folio 173, 13 p.

Davis, S. N., and Turk, L. J., 1964, Optimum depth of wells in crystalline rocks: Ground Water, v. 2, no. 2, p. 6–11.

Denson, N. M., 1965, Miocene and Pliocene rocks of central Wyoming, *in* Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1964: U.S. Geol. Survey Bull. 1224–A, p. A70–A74.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geol. Survey Water-Supply Paper 1812, 364 p.

Fenneman, N. M., and Johnson, D. W., 1946, Physical divisions of the United States: U.S. Geol. Survey map.

Foster, M. D., 1950, The origin of high sodium bicarbonate waters in the Atlantic and Gulf Coastal Plain: Geochim. et Cosmochim. Acta, v. 1, p. 33–48.

Gillum, J. P., 1954, Stratigraphy and structure of the Alkali Creek-Willow Creek area, Natrona County, Wyoming: Univ. Wyoming, Master's thesis, 43 p.

Goodell, H. G., 1962, The stratigraphy and petrology of the Frontier Formation of Wyoming, *in* Wyoming Geol. Assoc. Guidebook 17th Ann. Field Conf., Symposium on Early Cretaceous rocks of Wyoming, 1962: p. 173–210.

Harshman, E. N., 1968, Geologic maps of the Bates Creek, Horse Peak, Mud Springs, and Squaw Spring quadrangles; Carbon, Natrona, Converse, and Albany Counties, Wyoming: U.S. Geol. Survey Misc. Inv. Map I–539.

Hem, John D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Horn, G. H., 1955, Geologic and structure map of the Sussex and Meadow Creek oil fields and vicinity, Johnson and Natrona Counties, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–164.

Keefer, W. R., 1965a, Stratigraphy and geologic history of the uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin, Wyoming: U.S. Geol. Survey Prof. Paper 495–A, 77 p.

——— 1965b, Geologic history of the Wind River Basin, Central Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1878–1892.

Larsen, J. H., 1951, Ground-water conditions of a part of the Kendrick Project, Natrona County, Wyo.: Univ. Wyoming, Master's thesis. 56 p.

Love, J. D., 1961a, Definition of Green River, Great Divide, and Washakie basins, southwestern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 10, p. 1749–1755.

——— 1961b, Split Rock Formation (Miocene) and Moonstone Formation (Pliocene) in central Wyoming: U.S. Geol. Survey Bull. 1121–I, 39 p.

Lowry, M. E., 1962, Development of ground water in the vicinity of Tensleep, Wyoming: U.S. Geol. Survey open-file report, 12 p.

Lowry, M. E., and Crist, M. A., 1967, Geology and ground-water resources of Laramie County, Wyoming: U.S. Geol. Survey Water-Supply Paper 1834, 71 p.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria [d ed.]: [California] State Water Quality Control Board Pub. 3–A, 548 p.

Meinzer, O. E., 1923, The occurrence of ground water in the United States with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, 321 p.

Miller, W. M., 1956, Summary of partial analyses of Wyoming waters salinity and selenium: Univ. Wyoming Agr. Expt. Sta. Circ. 64, 11 p.

Picard, M. D., 1967, Stratigraphy and depositional environment of the Red Peak Member of the Chugwater Formation (Triassic), west-central Wyoming: Univ. Wyoming, Contributions to Geology, v. 6, no. 1, p. 39–67.

Pipiringos, G. N., 1968, Correlation and nomenclature of some Triassic and Jurassic rocks in south-central Wyoming: U.S. Geol. Survey Prof. Paper 594–D, 26 p.

Rich, E. I., 1958, The stratigraphic relation of latest Cretaceous rocks in parts of Powder River, Wind River, and Big Horn Basins, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 10, p. 2424–2443.

——— 1962, Reconnaissance geology of Hiland-Clarkson Hill area, Natrona County, Wyoming: U.S. Geol. Survey Bull. 1107–G, p. 447–540.

Sharp, W. N., and Gibbons, A. B., 1964, Geology and uranium deposits of the southern part of the Powder River Basin, Wyoming: U.S. Geol. Survey Bull. 1147–D, 60 p.

Stiff, H. A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Jour. Petroleum Technology, v. 3, no. 10, p. 15–17.

Tourtelot, H. A., 1953, Geology of the Badwater area, central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map. OM–124.

U.S. Bureau of Reclamation, 1964, A review of land resources and economics: Kendrick Project, Wyoming, 89 p.

U.S. Geological Survey, 1967, Water quality records, Part 2 *of* Water resources data for Wyoming 1966: Cheyenne, Wyo., 131 p.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Pub. 956, 61 p.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. of Agriculture Handb. 60, 160 p.

Van Houten, F.B., 1955, Volcanic-rich middle and upper Eocene sedimentary rocks northwest of Rattlesnake Hills, central Wyoming: U.S. Geol. Survey Prof. Paper 274–A, 14 p.

——— 1964, Tertiary geology of the Beaver Rim area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Bull. 1164, 99 p.

Weeks, E. P., 1964, Hydrologic conditions in the Wheatland Flats area, Platte County, Wyoming: U.S. Geol. Water-Supply Paper 1783, 79 p.

Weitz, J. L., Love, J. D., and Harbison, S. A., 1954, Geologic map of Natrona County, Wyoming: Wyoming Geol. Survey map.

Whitcomb, H. A., 1965, Ground-water resources and geology of Niobrara County, Wyoming: U.S. Geol. Survey Water-Supply Paper 1788, 10[illegible] p.

Whitcomb, H. A., and Lowry, M. E., 1968, Ground-water resources and geology of the Wind River Basin area, Wyo.: U.S. Geol. Survey Hydrol. Inv. Atlas HA–270.

Wilson, R. W., 1951, Ground-water investigations of a portion of the Kendrick Project, Natrona County, Wyo.: Univ. of Wyoming, Master's thesis, 83 p.

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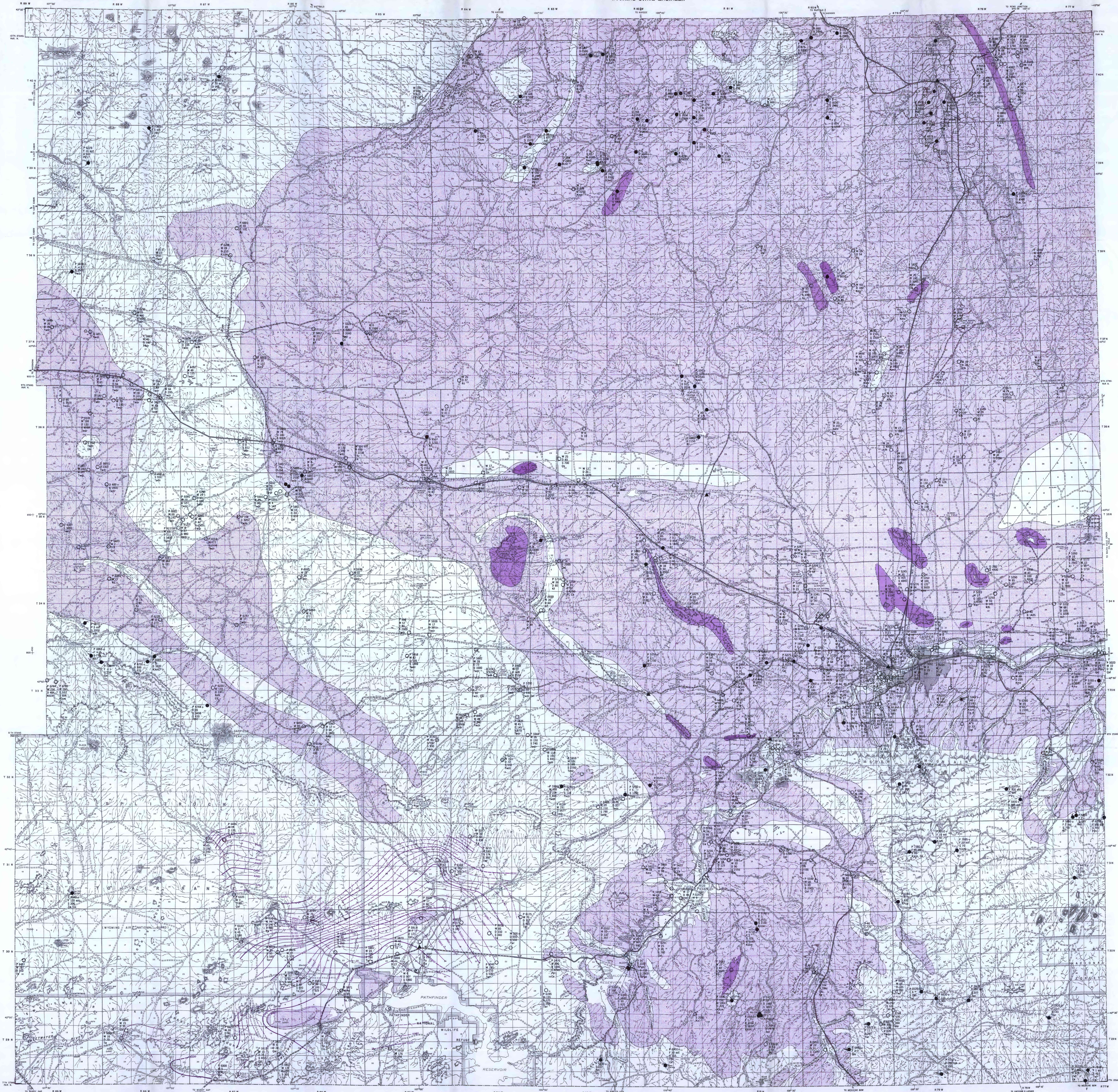
[Italic page numbers indicate major references]

U.S. GOVERNMENT PRINTING OFFICE: 1972 O—443-544

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WYOMING STATE ENGINEER



Base map prepared and copyrighted by Wyoming Highway Department, 1956, with all rights reserved: published with permission

Hydrology by Marvin A. Crist, 1967

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

HYDROLOGIC MAP OF NATRONA COUNTY, WYOMING

EXPLANATION

0-1000

1001-3000

3001-5000

>5000

Estimated concentration of dissolved solids in ground water in milligrams per liter. The areas indicate the best quality of water that could be expected within 1,000 feet of land surface. Boundaries dashed where approximate; queried where uncertain

6000

Potentiometric contour in Arikaree and Ogallala Formations

Shows the altitude to which water will rise in wells. Dashed where estimated. Contour interval is 20 feet. Datum is mean sea level

Surface-water sampling site for chemical analyses

Analyses are listed in table in text

WELL AND SPRING DATA

P 5372
W 12
D 90
S 1710
Kl
Ca

Flowing — Irrigation — Flowing irrigation — Domestic, stock, public supply, industrial, test hole, or unused

Wells

Spring

- P Altitude of potentiometric surface, in feet above mean sea level
- W Depth to water, in feet below land surface
- F Flowing yield of well or spring, in gallons per minute. (est after number indicates yield is estimated)
- D Depth of well, in feet below land surface
- S Specific conductance, in micromhos per centimeter at 25°C
- Ca Indicates chemical analysis is listed in table in text

Geologic source: p€r, Precambrian rocks; Mm, Madison Limestone; PIPt, Tensleep Sandstone; PIPc, Casper Formation; ŦPge, Goose Egg Formation; ŦPcg, Chugwater Group and Goose Egg Formation; Ŧc, Chugwater Group; Jsd, Sundance Formation; KJcm, Cloverly and Morrison Formations; Kmt, Mowry and Thermopolis Shales; Kf, Frontier Formation; Kn, Niobrara Formation; Kc, Cody Shale; Kmv, Mesaverde Formation; Kle, Lewis Shale; Kfh, Fox Hills Sandstone; Kl, Lance Formation; Tfu, Fort Union Formation; Twdr, Wind River Formation; Twr, White River Formation; Ta, Arikaree Formation; To, Ogallala Formation; Qt, alluvial terraces; Qls, landslide deposits; Qs, windblown deposits; Qal, flood-plain alluvium; Qc, colluvium

443-544 O - 72 (In pocket) No. 1

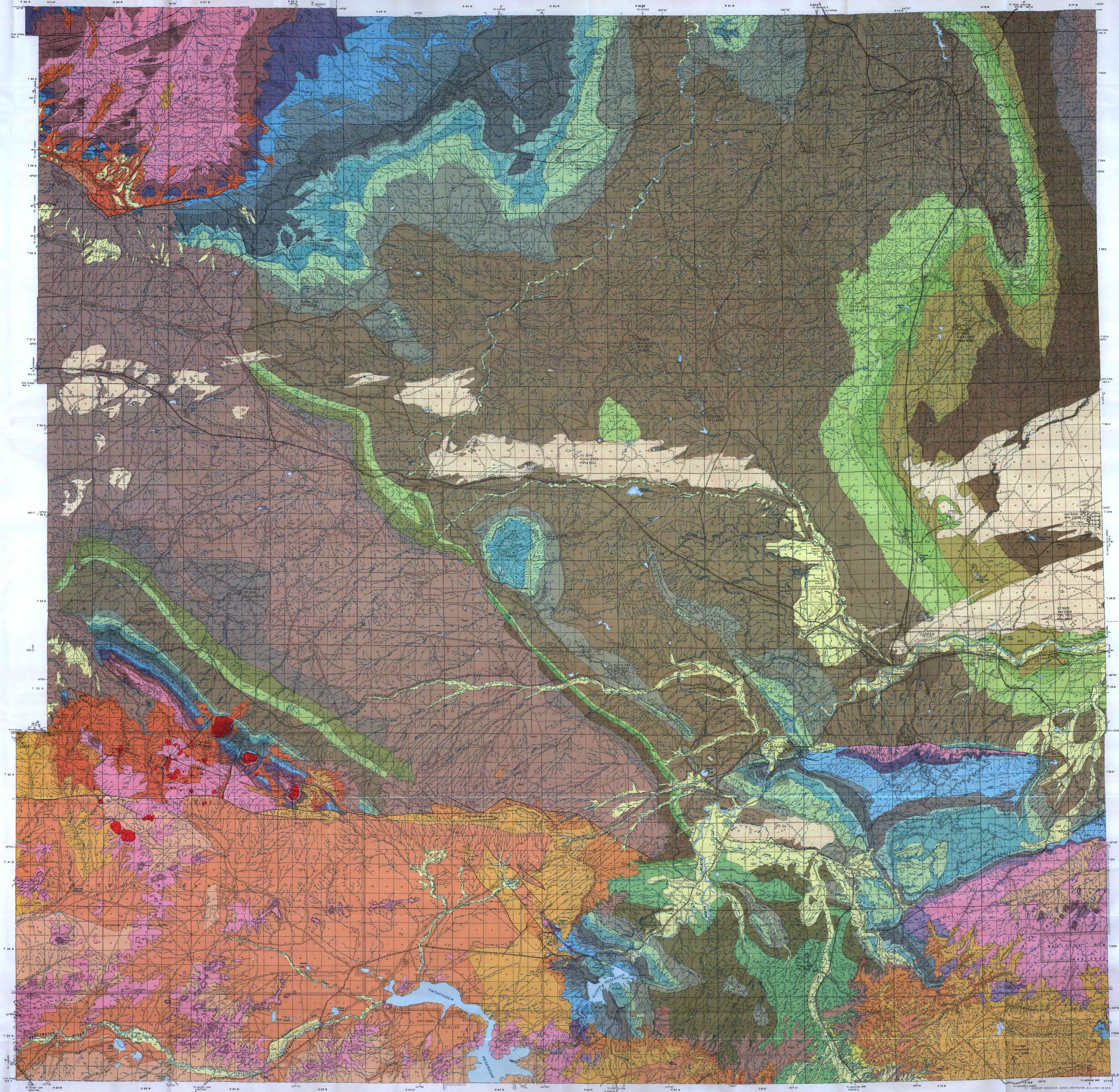
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WYOMING STATE ENGINEER

WATER-SUPPLY PAPER 1897
PLATE 2

GENERALIZED SECTION OF THE GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS IN NATRONA COUNTY, WYO.

ERA	SYSTEM	SERIES	SUBDIVISION AND THICKNESS, IN FEET	WATER SUPPLY	ROCK UNIT
CENOZOIC	QUATERNARY		Windblown deposits 0-40+	Will yield a maximum of 5-10 gpm of water to wells; the total dissolved-solids content of the water will range from about 500 to 2,500 mg/l.	Unconsolidated continental
			Landslide deposits	Will yield small supplies to springs and seeps; not a good site to drill a well.	
			Alluvium 0-190	Yields up to 1,300 gpm to wells, but yield depends on saturated thickness and grain size, which vary markedly; total dissolved-solids content of the water ranges from 246 to 8,240 mg/l.	
	TERTIARY	Pliocene	Ogallala Formation 0-800(?)	Will probably yield more than 200 gpm from conglomerate and zones of secondary permeability in some areas; the Arikaree will yield more than 200 gpm nearly everywhere there is 500 feet of saturated formation; smaller yields are readily available in most of the area underlain by these rocks; total dissolved-solids content of the water, at depths sampled, is generally less than 500 mg/l.	Postorogenic subunit; Consolidated continental
		Miocene	Arikaree Formation 0-1000		
		Oligocene	White River Formation: Upper member 0-600		
			White River Formation: Lower member 0-865		
		Eocene	Wagon Bed Formation 0-1000; Intrusive and extrusive rocks	Yields from intrusive and extrusive rocks generally less than 5 gpm.	Igneous and metamorphic
			Wind River Formation 0-7000	Yields mostly less than 10 gpm although larger supplies may be possible from conglomerate or large saturated thicknesses. Quality of water ranges from good for domestic use to unfit for stock use.	Orogenic subunit
		Paleocene	Fort Union Formation (Wind River Basin) 0-8000; Upper and lower members combined (Powder River Basin) 0-3000		
MESOZOIC	CRETACEOUS	Upper Cretaceous	Lance Formation 0-5000		
			Fox Hills Sandstone 0-700		Marine and continental
			Meeteetse Formation 400-630; Lewis Shale 0-550	Water-supply characteristics same as for orogenic subunit (above)	Orogenic subunit; Consolidated continental
			Mesaverde Formation: Teapot Sandstone Member 50-115	Sandstone beds in the Fox Hills, Mesaverde, and Frontier Formations in most places will yield no more than 50 gpm; sandstones in other formations will yield much less. The quality of the water is poor; total dissolved solids are in excess of 1,000 mg/l nearly everywhere.	Marine and continental
			Mesaverde Formation: Unnamed middle member 260-750		
			Mesaverde Formation: Parkman Sandstone Member 50-500		
			Steele Shale; Niobrara Formation; Cody Shale 3000-5000		
			Wall Creek Sandstone Member; Frontier Formation 650-900		
		Lower Cretaceous	Mowry Shale 200-300		
			Muddy Sandstone Member; Thermopolis Shale 200		
			Cloverly Formation 150-300	Generally will yield 5-20 gpm to wells, but yields of as much as 250 gpm are obtained. Total dissolved-solids concentration ranges from as low as 70 mg/l to as great as 1,780 mg/l and may be much higher in parts of the area.	Continental and marine
	JURASSIC	Upper Jurassic	Morrison Formation 150	Will yield only small supplies in most areas.	
			Sundance Formation 300		
	JURASSIC(?) AND TRIASSIC(?)		Bell Springs Member of the Nugget Sandstone 0-90		
	TRIASSIC		Chugwater Group: Jelm Formation 25-185	Yields only small supplies of water. Water from the Goose Egg is generally poor quality.	
			Chugwater Group: Alcova Limestone 10-20		
			Chugwater Group: Red Peak Formation 600-700		
		Lower Triassic	Goose Egg Formation 150-380		
PALEOZOIC	PERMIAN		Casper Formation 0-500; Tensleep Sandstone 0-500	Capable of yields in excess of 4,000 gpm from zones of high secondary permeability in sandstone and limestone beds; sandstone would yield much smaller (50 gpm) supplies nearly everywhere; total dissolved-solids content would be less than 500 mg/l near the outcrop but the quality would deteriorate with increased distance from recharge area.	Marine
	CARBONIFEROUS: PENNSYLVANIAN		Amsden Formation 0-200		
	CARBONIFEROUS: MISSISSIPPIAN		Madison Limestone 200-400		
	CAMBRIAN		Cambrian rocks, undivided 0-900		
PRECAMBRIAN			Precambrian rocks	Yields generally are less than 5 gpm; total dissolved-solids content less than 500 mg/l.	Igneous and metamorphic



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SCALE 1:125 000

Geology compiled by Marlin E. Lowry, 1968. Adapted from published and unpublished sources indicated on index map

GEOLOGIC MAP OF NATRONA COUNTY, WYOMING

EXPLANATION

QUATERNARY (Pleistocene and Holocene)

Qal — Alluvial deposits. *Unconsolidated silt, sand, and gravel*

Qs — Windblown deposits. *Unconsolidated sand*

Qls — Landslide deposits

TERTIARY

Upper Miocene and Pliocene: To — Ogallala Formation. *Heterogeneous deposits of silt, sand, and gravel; may be unconsolidated or well cemented. In some areas, may include thin deposits of sand and gravel of Pleistocene age, which on lithologic criteria cannot be separated from the Ogallala Formation*

Lower Miocene: Ta — Arikaree Formation. *Light-gray sandstone, fine- to medium-grained; contains some thin beds of limestone, tuff, and conglomerate*

Oligocene: Twr, Twru, Twrl — White River Formation. Twru, *upper member is predominantly sandstone and conglomerate*. Twrl, *lower member is pinkish-gray siltstone containing minor conglomerate lenses*

Middle and upper Eocene: Twb — Wagon Bed Formation. *Bentonitic mudstone, sandstone, and conglomerate*

Ti — Intrusive and extrusive rocks

Lower Eocene: Twdr — Wind River Formation. *Variegated claystone and shale, brown and gray sandstone, and lenticular conglomerate*

Paleocene: Tfu, Tfuu, Tful — Fort Union Formation. *Wind River Basin: Shotgun Member consists of very fine grained sandstone and siltstone; Waltman Shale Member consists of silty and shaly claystone with a few thin beds of sandstone; unnamed lower member consists of fine- to coarse-grained sandstone, very fine grained sandstone, and siltstone. Powder River Basin:* Tfuu, *upper member consists of sandstone, siltstone, carbonaceous shale, and coal;* Tful, *lower member consists of claystone and siltstone interbedded with sandstone; carbonaceous material less abundant*

CRETACEOUS

Upper Cretaceous:

Kl — Lance Formation. *Brown and gray sandstone and shale; thin coal and carbonaceous shale beds*

Kfh — Fox Hills Sandstone. *Light-colored sandstone and gray sandy shale*

Kle — Lewis Shale. *Gray sandy shale and lenticular sandstone*

Kml — Meeteetse Formation and Lewis Shale. *Meeteetse Formation consists of gray carbonaceous shale interbedded with sandstone and thin coal beds*

Klml — Lance, Lewis, and Meeteetse Formations

Kmv — Mesaverde Formation. *Gray and brown massive to thin-bedded sandstone, and carbonaceous shale and coal beds; Teapot Sandstone Member at top; unnamed middle member; Parkman Sandstone Member at base*

Ks — Steele Shale. *Gray shale with numerous bentonite beds and thick lenticular sandstones*

Kn — Niobrara Formation. *Light-gray limestone and gray to yellow, speckled limy shale*

Kc — Cody Shale. *Gray soft shale and lenticular sandstone beds; gray limy shale at base; Sussex Sandstone Member about 400 feet above Shannon Sandstone Member; Shannon Sandstone Member about 2,000 feet above base*

Kf — Frontier Formation. *Gray thick sandstone beds in upper part; lower part contains black shale and white bentonite interbedded with sandstone*

Lower Cretaceous: Kmt — Mowry and Thermopolis Shales. *Mowry Shale is black and gray, weathers silvery gray, is hard, contains thin bentonite beds. Thermopolis Shale is black and soft; Muddy Sandstone Member 150-250 feet above base*

JURASSIC

KJcm — Cloverly and Morrison Formations. *Cloverly Formation is light-gray sandstone and lenticular conglomerate interbedded with variegated bentonitic claystone; Morrison Formation is variegated claystone and gray silty sandstone lenses*

Upper Jurassic: Jsd — Sundance Formation. *Olive-gray shale and sandstone; persistent thin-bedded sandstone at base*

TRIASSIC(?)

Upper Triassic(?): JTRsn — Sundance Formation and Bell Springs Member of Nugget Sandstone. *Triassic(?) Bell Springs Member consists of very fine grained sandstone and pale red siltstone beds*

TRIASSIC

TRc — Chugwater Group. *Includes: Jelm Formation at top is red sandstone and siltstone; Alcova Limestone in middle is gray laminated limestone; and Red Peak Formation at base is red shale and siltstone*

PERMIAN

TRPge — Goose Egg Formation. *Red shale, gray dolomite and limestone, and anhydrite and gypsum beds*

TRPcg — Chugwater Group and Goose Egg Formation

PENNSYLVANIAN, MISSISSIPPIAN (CARBONIFEROUS)

PIPta — Tensleep Sandstone and Amsden Formation. *Massive tan clean sandstone underlain by thin-bedded cherty dolomite and limestone and red shale; red to gray sandstone at base may be the Upper Mississippian Darwin Sandstone Member*

PIPc — Casper Formation. *Gray and tan thick-bedded sandstone underlain by interbedded sandstone, pink and gray limestone and dolomite, and red shale; red to gray sandstone at base*

Mm — Madison Limestone. *Gray massive cavernous cherty limestone and dolomite*

€r — Cambrian rocks. *Thin glauconitic shale interbedded with limy shale in upper part; dull pink quartzite and sandstone in lower part*

Pzr — Paleozoic rocks. *Casper, Tensleep, Amsden, and Madison Formations, and Cambrian rocks, undivided*

p€r — Precambrian igneous and metamorphic rocks

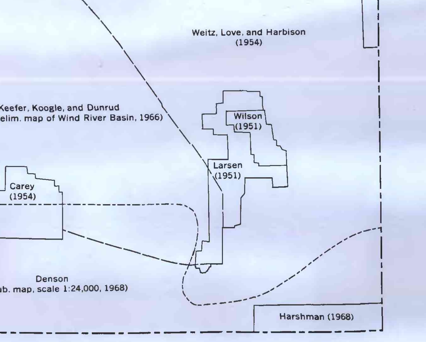
Contact. *Dashed where approximately located*

Fault. *Dashed where approximately located; dotted where concealed.* U, *upthrown side;* D, *downthrown side*

Mappable sandstone bed, in Cody Shale

A—A′ Location of section

KJcm 4365 — Oil test. *Number is depth to top of selected geologic map unit, in feet below land surface. Data from Petroleum Information completion cards*



INDEX SHOWING SOURCE OF GEOLOGIC DATA

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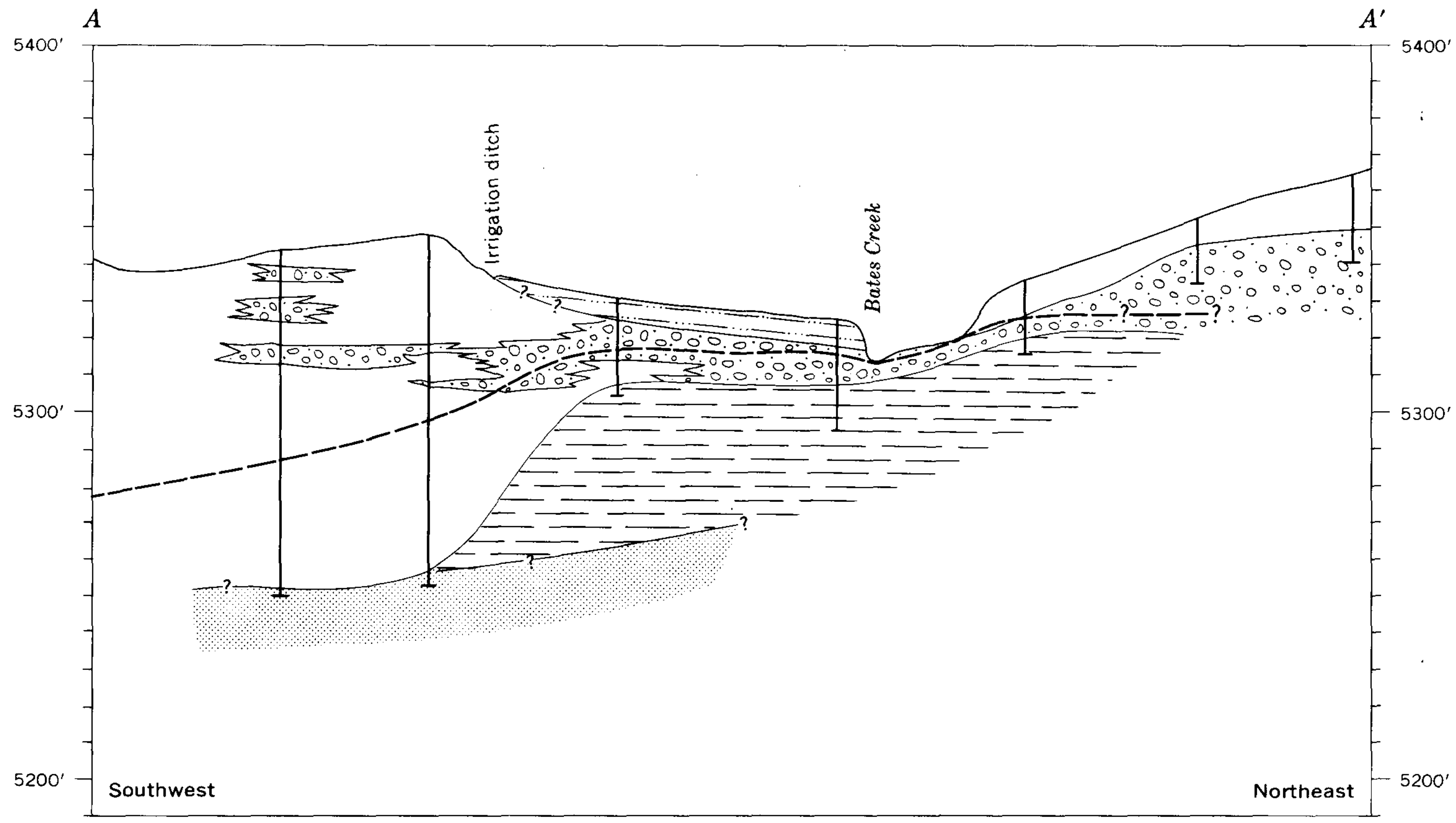
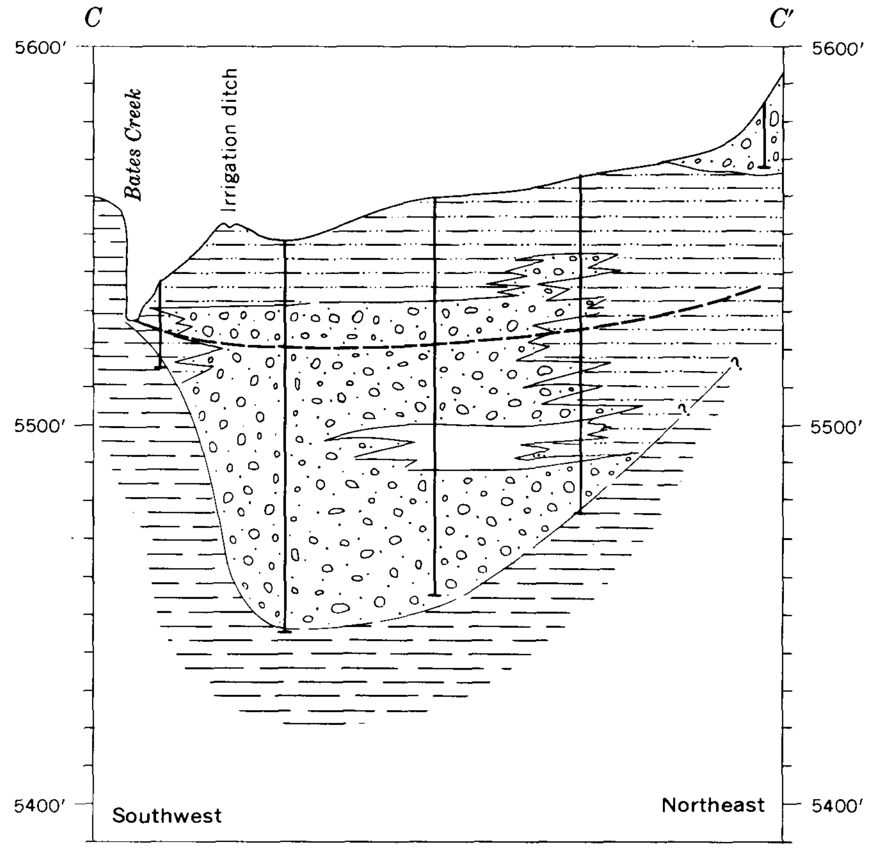
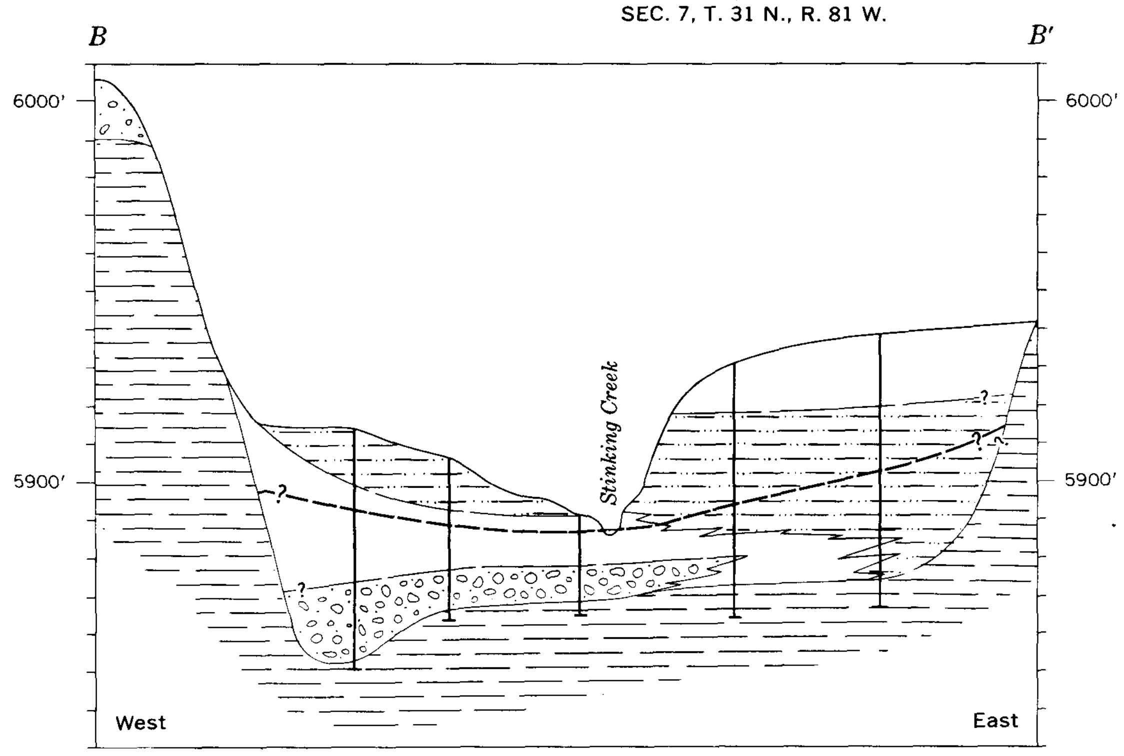


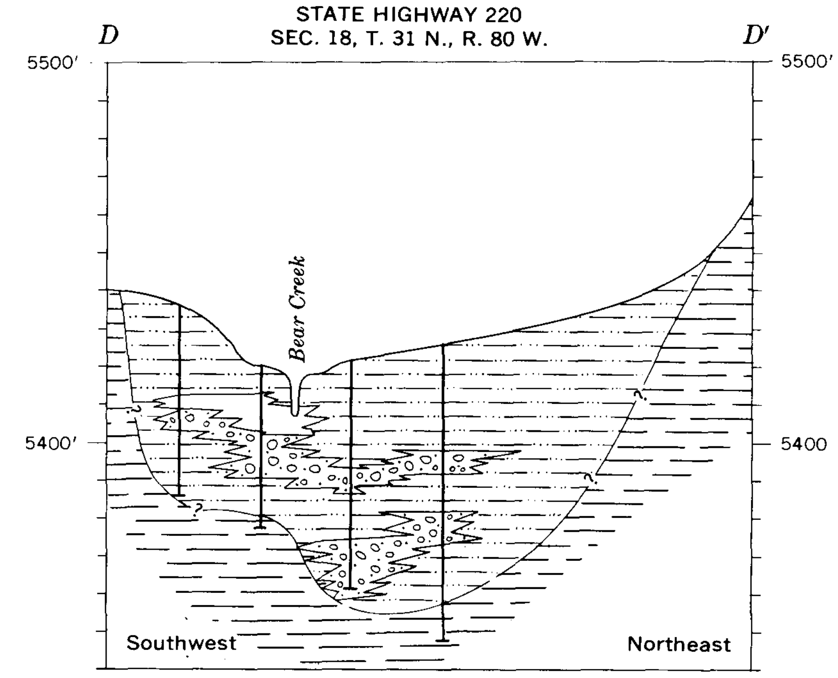
BATES CREEK AT WYOMING STATE HIGHWAY 220
SEC. 7, T. 31 N., R. 81 W.



BATES CREEK 7 MILES UPSTREAM FROM WYOMING
STATE HIGHWAY 220
SEC. 18, T. 31 N., R. 80 W.

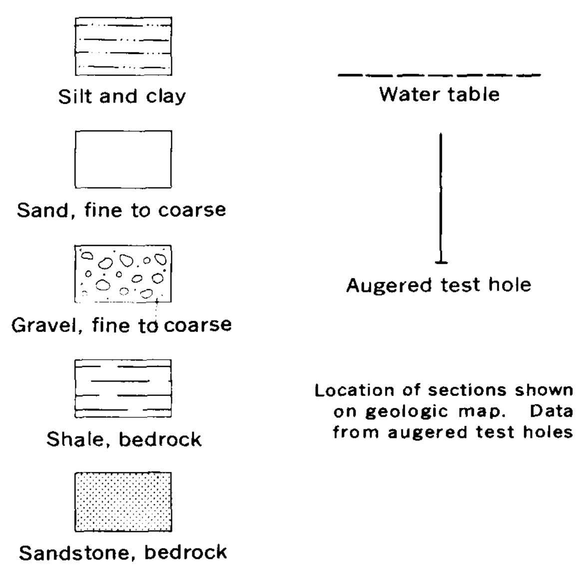


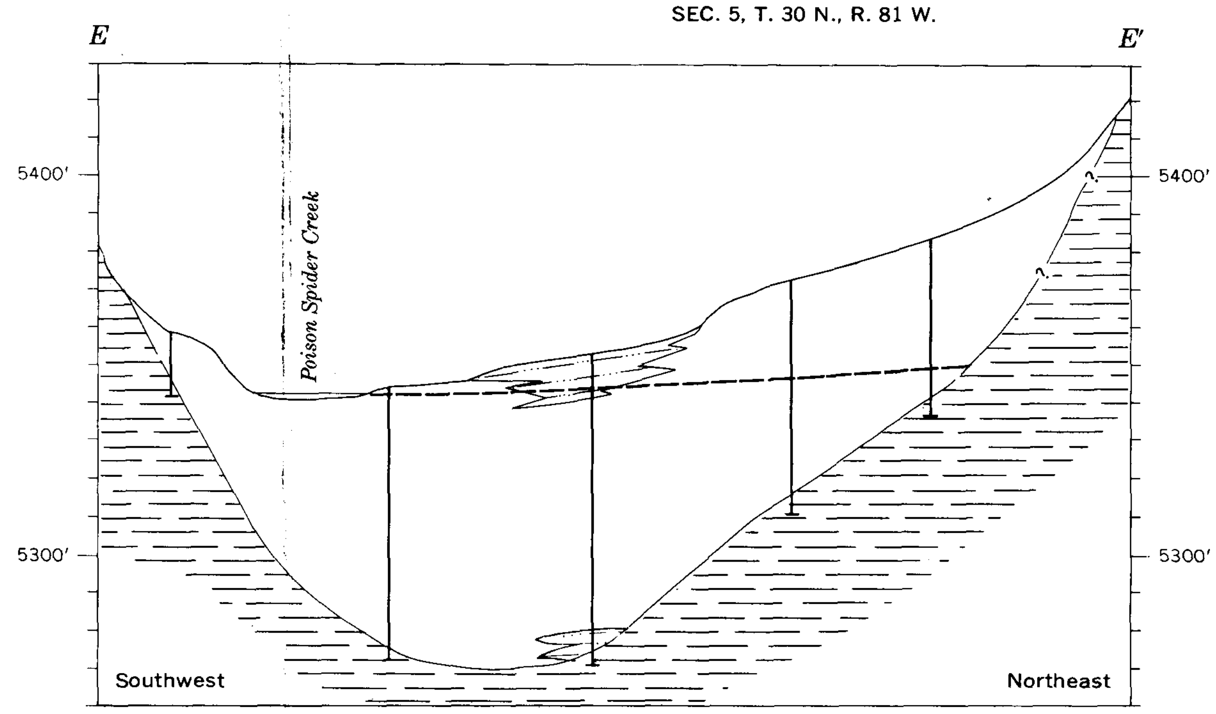
STINKING CREEK AT BATES HOLE STOCK TRAIL ROAD
SECS. 29 AND 30, T. 30 N., R. 80 W.



BEAR CREEK AT SPINDLE TOP ROAD
SEC. 5, T. 30 N., R. 81 W.

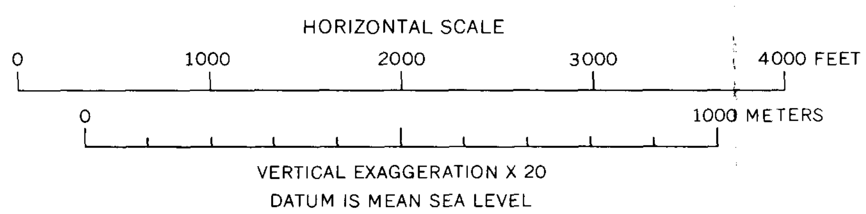
EXPLANATION





POISON SPIDER CREEK AT POISON SPIDER ROAD 5 MILES UPSTREAM FROM
NORTH PLATTE RIVER
SECS. 16 AND 17, T. 33 N., R. 81 W.

Geology by Marvin A. Crist



DIAGRAMMATIC SECTIONS SHOWING THE GENERAL LITHOLOGY OF ALLUVIUM ALONG BATES CREEK, STINKING CREEK, BEAR CREEK, AND POISON SPIDER CREEK NATRONA COUNTY, WYOMING

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