Report of Investigations No. 109

GROUND-WATER RESOURCES OF THE WESTERN HALF OF FALL RIVER COUNTY, S. D.

by Jack R. Keene

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GEOLOGICAL SURVEY
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Jack R. Keene

Science Center
University of South Dakota
Vermillion, South Dakota
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ABSTRACT

In western Fall River County, an area of approximately 800 square miles, only five formations can be considered principal aquifers; the Quaternary alluvial deposits, the Fall River, Lakota, Sundance, and Pahasapa Formations. A total of 269 wells, 17 springs, and almost 200 oil and uranium tests were recorded through library research, interviews with mining companies and government agencies, and a field inventory of the area.

A structural contour map, using the top of the Fall River Formation as a datum, showed that the expected depth to the shallowest artesian aquifer ranged from 100 to 2600 feet. The structural contour map also indicated that the Cottonwood and Cascade Anticlines were larger than previous investigations had shown.

All of the principal aquifers produce water in the area. Sixty-five percent of the wells obtain water from the alluvium and Inyan Kara aquifers. The Sundance Formation is used only in the northern townships near the outcrop area and the Pahasapa Formation provides municipal water from seven wells. A detailed study of the potentiometric data and water analyses revealed that the Minnelusa Formation is the probable source of large springs located near Cascade.

Water quality of the strata in the area varied considerably. Water from the alluvial deposits appeared to be influenced by the chemical constituents of water found in adjoining streams or by the mineralogy of the underlying Cretaceous shales. The two aquifers of the Inyan Kara Group are recharged from depth by the Minnelusa Formation through fault zones and breccia pipes. The calcium-sulfate water of the Minnelusa Formation is sequentially changed to a sodium-sulfate water then locally to a sodium-bicarbonate water as it migrates basinward through the Fall River and Lakota Formations. It appears that the relatively high concentrations of hydrogen sulfide found in some of the Inyan Kara water may be attributed to sulfate reducing bacteria. The hydrogen-sulfide water is localized near structural fault zones and appears to be influenced as to areal extent by variable permeability zones in the aquifers.

Drinking water was obtained from all five aquifers; however, all available analyses indicated that ground water in the area was of marginal to poor quality for domestic uses.

Most water found in the area is suitable for livestock water. Only the Pierre Formation and the shallow water found near Rumford consistently exceeded the safe threshold limits for stock water.

All ground water, regardless of source, appears to be unsuitable for irrigation because of high salinity.

Adequate quantities of ground water exists to support light industry in the area.

Landowners were urged to form a water conservancy organization to correct existing wasteful practices in the area.

INTRODUCTION

Location and Area

The area covered by this report lies in the western half of Fall River County, South Dakota. The northern boundary of the area follows the Custer-Fall River County line, its western limit is the Wyoming-South Dakota state line, the southern limit is the Nebraska-South Dakota state line, and the eastern boundary follows several drainage divides running approximately north-south near the 103° 30′ meridian (fig. 1).

The study area lies within the Cheyenne River basin which drains a total area of 24,500 square miles.

Purpose of the Investigation

The objective of this study was to research, evaluate, correlate, and assemble all data concerning ground water in the western half of Fall River County into a single document which could serve as a reference for future and more detailed hydrologic studies of the area.

Previous Investigations

The first geologic investigation of the general Black Hills area was made by N. H. Winchell and George B. Grinnell, geologist and paleontologist respectively, in General George A. Custer's expedition to the Black Hills during the summer of 1874 (Ludlow, 1875). Newton and Jenney (1880) prepared a report on the geology and resources of the Black Hills, but it was Darton and Smith (1904) who provided the first information concerning ground water in the Edgemont quadrangle. This classic of geologic information included three logs of early wells in the area and an analysis of the water from Cascade Springs.

In 1909, N. H. Darton discussed the geology and ground water for Fall River County in Water-Supply

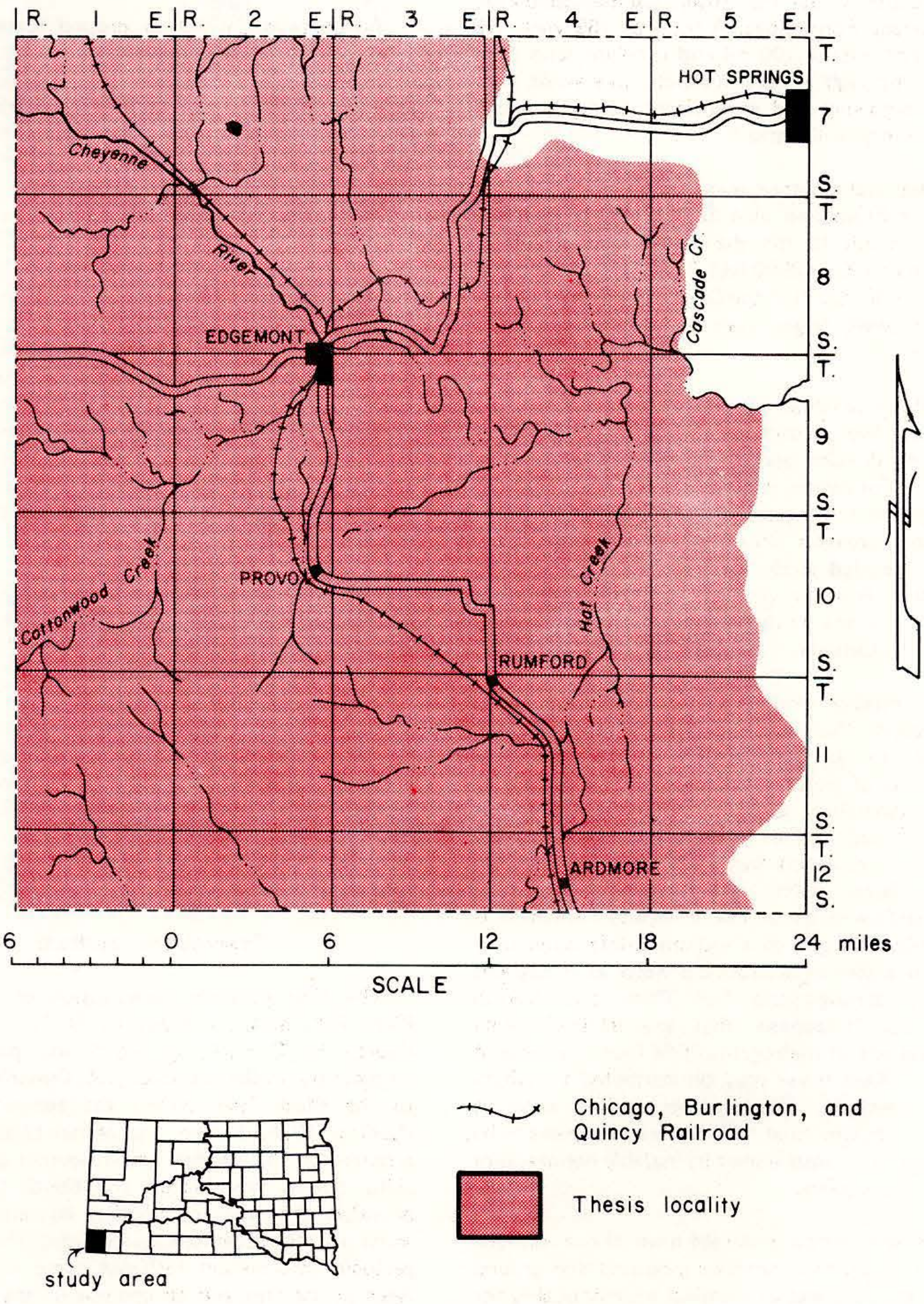


Figure 1. Map showing location of study area indicating major streams and cultural features.

Paper 227. Nine years later, Darton published Water-Supply Paper 428 which was concerned with artesian waters in the vicinity of the Black Hills. In this publication, Darton provides several logs and water analyses of wells in the Hot Springs-Edgemont area.

The U.S. Weather Bureau has recorded and published climatological data for the area in excess of 50 years and stream discharge records for the Cheyenne River basin have been monitored continuously by the United States Geological Survey (USGS) for approximately 20 to 25 years.

Davis et al. (1961) provided records for 25 selected artesian wells in the County.

The U.S. Geological Survey monitored a single well from 1949-59 in 8-6-13 which produced from the Quaternary eolian sand deposits. At present, the U.S. Geological Survey is monitoring three wells, numbers 8-2-8aa, 8-2-20da, and 8-2-36ac (see Well-Numbering System, p. 3) for water levels and quality.

Schoon (1968) published a circular providing selected formation data for six wells in Fall River County.

Method of Investigation

Each ranch and farm in the study area was visited by the author to obtain the ground-water inventory in this report. Persons not at home when visited were contacted later or were mailed a questionnaire. Additional information concerning various wells was correlated from local drillers' logs, information obtained from state and federal agencies, the files of the Department of Geological Engineering, or publications listed in the bibliography.

The discussion concerning the hydrology of the Cheyenne River basin was based on climatological data from the U.S. Weather Bureau and surface-water records compiled by the USGS.

The stratigraphic information of the area was extracted from many sources.

The structural contour map was prepared from oil test reports, electric logs, information on water wells, and uranium test-hole data.

Hydrologic data of the principal aquifers were obtained from the ground-water inventory, drill-stem tests, water-well observations and measurements, and electric logs. The discussion on water quality was extracted from several references in the bibliography.

One of the early objectives of this study was to try to establish a recharge rate for one or more of the aquifers in the area. A study of the hydrologic cycle using flow duration curves during periods of low stream discharge was made in an attempt to establish a ground-water infiltration rate for the Fall River-Lakota aquifer. These flow duration curves established an anomaly suggesting that ground-water infiltration exists, but additional data are required to isolate the quantity of this infiltration. The author discusses a method which should provide the infiltration rate for this combination aquifer.

Well-Numbering System

Wells, test holes, and springs are numbered in this report in accordance with the procedure followed by the United States Geological Survey, i.e., according to the location within the land subdivisions of the General Land Office survey of the area. The first numeral of a well number designates the township, the second numeral the range, and the third the section in which the well is located. The letters indicate the location of the well within the section. The first letter denotes the quarter section, the second the quarter-quarter section. These letters are arranged in a counterclockwise direction beginning in the northeast quarter of the section, quarter-quarter section, etc. If more than one well is located in the same tract, the letters will be followed by consecutive numbers. A graphical representation of this well-numbering system is shown in figure 2.

Acknowledgments

Most of the data obtained for the ground-water inventory were supplied by the residents of the area. The author hopes that this report will partially repay their cooperative and friendly assistance.

Special acknowledgment is due Al Stoick of Mines Development Industries and Darrell Spilde of Homestake Mining Company who contributed valuable subsurface information used in the preparation of the structural contour map in this report.

Special credit is also due the drillers who have worked in Fall River County. Stanley Bice, Ray Bettenhausen, Roy Boner, and Joe Munger provided several logs and valuable information used in the preparation of this report.

Several government agencies generously supplied information from their files. The United States Geological Survey in Rapid City and Newcastle, the U.S. Forest Service in Hot Springs, the U.S. Soil Conservation Service in Hot Springs, and William Chenoweth of the Atomic Energy Commission contributed much of the hydrologic and water quality data.

The author also acknowledges the assistance of

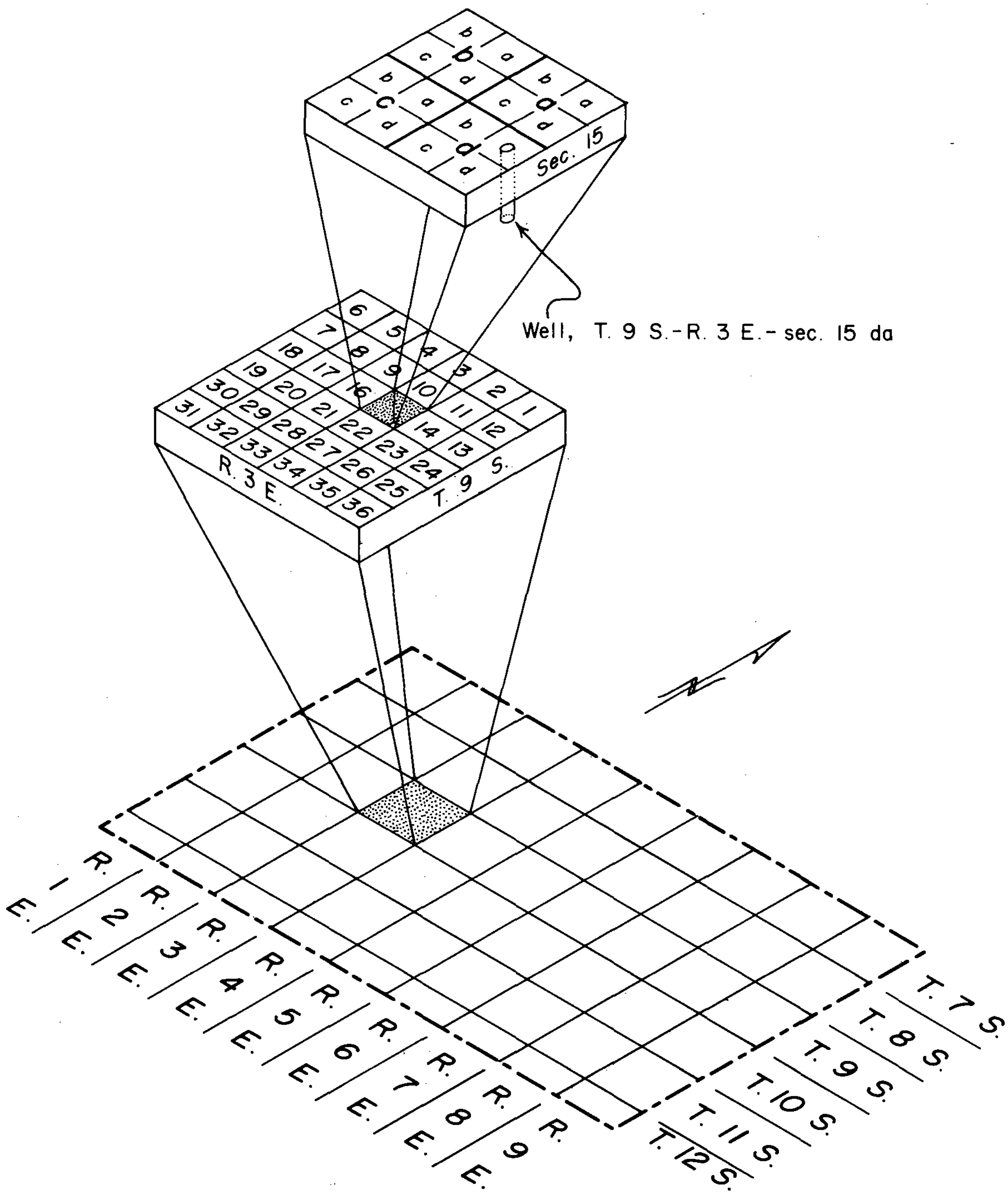


Figure 2. Diagram showing well-numbering system.

Fred Steece and Jack Harksen of the South Dakota Geological Survey for many helpful suggestions and for making available several logs of exploratory oil wells in the area. Dale S. McDowell of the South Dakota Water Resources Research Institute provided the author with 11 water analyses.

J. P. Gries assisted the author greatly by supplying well data from his personal files and both he and Perry Rahn provided the author with encouragement and suggestions throughout the preparation of this study.

The author is indebted to his wife, Bernitta, who was responsible for the typing of this report. Her patience, understanding, and encouragement are appreciated.

Lastly, the author expresses his sincere appreciation to his father- and mother-in-law, Mr. and Mrs. Byron Cox, who provided their home as a base of operations during the field study. Their gracious hospitality, suggestions, and information concerning the area aided the author greatly. Without their help, the task of preparing this report would have been much harder, and it is to them that this study is dedicated.

GEOGRAPHY

Topography and Vegetation

The study area can be divided into two distinct physiographic regions which vary considerably in geomorphology, climate, and vegetation. The Cheyenne River flows through the area along the southern edge of the Black Hills and divides these two regions.

The rolling plains lying south of the Cheyenne River are part of the Great Plains Physiographic Province (Darton and Smith, 1904). A cuesta formed by the south dipping Greenhorn Limestone separates this province from the Cheyenne River valley. All of the streams in this region are tributary to the Cheyenne River. They flow across the gently dipping Upper Cretaceous shales and exhibit dendritic stream patterns. The land is generally grassland with big sagebrush (*Atemisia tridentata*), western wheatgrass (*Agropyron smithii*), blue gramma grass (*Bouteloua gracilis*), and buffalo grass (*Buchloe dactyloides*) dominating as the principal flora on the plains. Cottonwood trees (*Populus angustifolia*) are found along the streams and the Cheyenne River floodplain.

The Cheyenne River valley generally flows over the Graneros shales along the Graneros-Fall River contact, although the river has cut meanders through the Fall River and Lakota Formations between Edgemont and Cascade Springs. The main valley is about 2 miles wide and the southern side is gently sloping. In the area downstream from Edgemont, the valley narrows abruptly and the meanders are entrenched several hundred feet through Inyan Kara rocks.

Although the topography of the area is influenced by structure, the type and relative hardness of the rocks appear to be the significant cause for the differences between the Great Plains Province and the Black Hills. Structures, such as the Chilson and Cascade Anticlines, have little effect on the geomorphology of the plains south of the Cheyenne River. On the other hand, the abrupt change in relief north of the river coincides with the first of a series of alternating consolidated rocks and softer shales. The sandstones and limestones form hogback ridges and the shales produce the valleys in the Black Hills.

The river is braided within the alluvial floodplain which would indicate that the Cheyenne is at present a graded stream. In the wider sections of the river valley, large cottonwood trees are abundant for several hundred feet on either side of the river.

The Fall River Formation parallels the Cheyenne River on the north and forms the foothill hogback of the Black Hills. The Black Hills Province comprises about one-third of the study area. The terrain near the periphery of the hills is highly dissected with water gaps and canyons hundreds of feet deep. There is a distinct trend of these features in a general northwest-southeast direction. The northern part of the area is a broad, relatively flat valley formed in the Spearfish Formation. This Red Valley (Darton and Smith, 1904) extends from Minnekahta completely around the Black Hills and is surrounded by a steep hogback ridge on the outer side. Other than grasses and scattered shrubs, little vegetation grows in the Red Valley. The flat upland areas and terraces along the steep sided canyons support growths of pine (*Pinus ponderosa*), red cedar (*Juniperus scorpulorum Sarg.*), and a few quaking aspen (*Populus tremuloides*). The bottoms of the canyons provide enough water to support scattered groves of cottonwoods.

Climate

General

Ground water in western Fall River County is directly related to the climate of the Cheyenne River basin. It would be impossible to make a serious study of ground water without considering the other aspects of the hydrologic cycle. The hydrologic cycle, or sometimes referred to as the water cycle, is a continuous natural phenomenon of the circulation of water over, on, and within the earth. It has neither beginning nor end, but for the purposes of this study, the writer will begin with the condensation of water vapor into clouds. This cloud moisture then falls to

the earth as precipitation, i.e., rain, snow, sleet, etc. Part of the water runs over the surface to streams, part infiltrates into the soil, and the majority is returned to the atmosphere by evaporation and transpiration. The hydrologic cycle as it occurs in the Cheyenne River basin is shown in figure 3. Stated another way, the hydrologic cycle is the system by which nature circulates water from the oceans through the atmosphere and returns it both overland and underground back to the sea (Johnson, 1966).

Precipitation

Precipitation data for seven stations in and near the study area are contained in appendix A. Although it is standard practice to use 30 years of data for analyzing precipitation, a period of water years 1949 through 1968 was used in order to correlate rainfall with stream runoff in the area. This was the longest sequence of years for which discharge records were available for all but one of the stream gages in eastern Wyoming and western Fall River County. Both precipitation and discharge tables are compiled using the USGS system of water years, i.e., October 1 through September 30.

The average precipitation varied from 13.12 inches per year at Spencer, Wyoming, to 15.62 inches per year at Ardmore. Ardmore received more precipitation than Hot Springs; this is surprising in view of their respective location, elevation, and relief. Long term data indicate that the 20-year period used

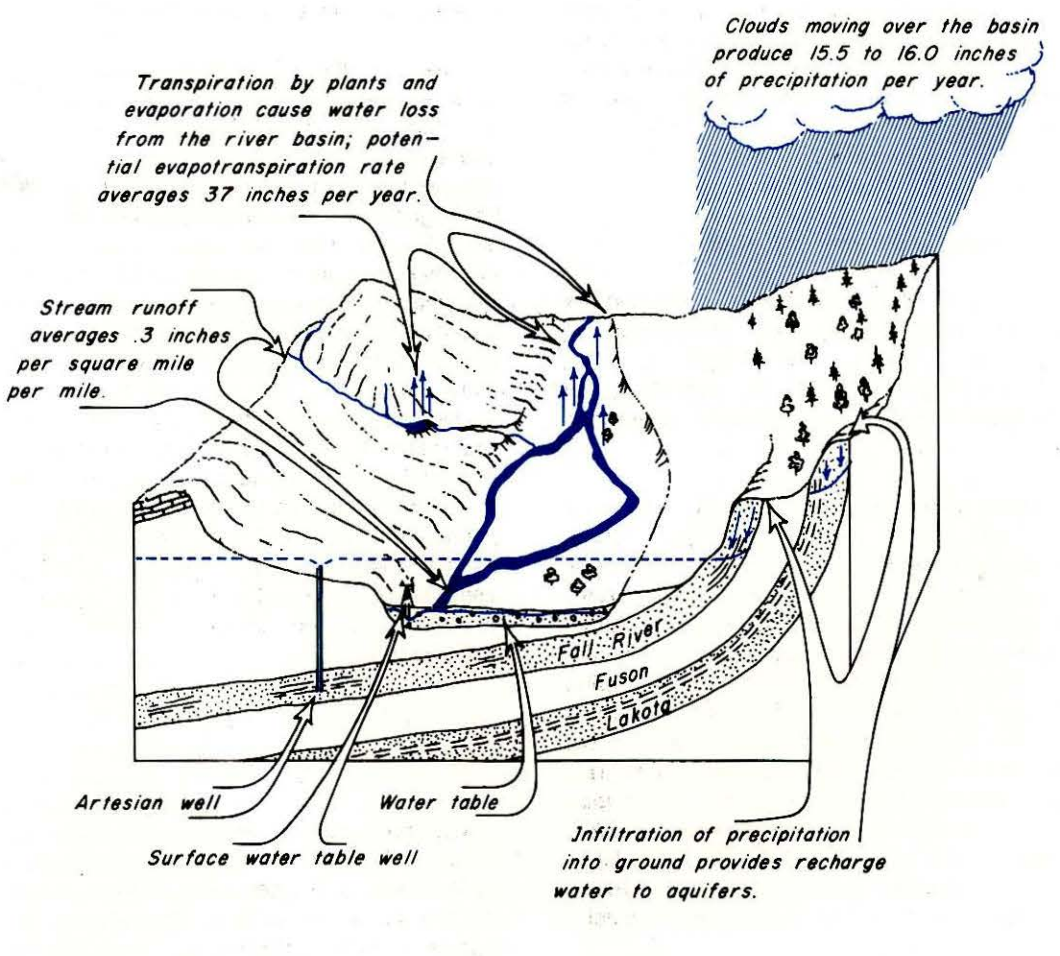


Figure 3. The hydrologic cycle of western Fall River County.

by the author was below normal for Hot Springs. The 30-year normal for Hot Springs was 16.06 inches whereas a 50-year normal for Ardmore was 15.68 inches, or only .06 inches departure from the data in appendix A.

Angostura Reservoir registered the maximum yearly rainfall for the area in 1963 with over 24 inches and Hot Springs had the lowest annual rainfall of 5.65 inches in 1960. Comparing this minimum with the low years of the other stations indicates that the Hot Springs recording was almost 2 inches below the expected minimum for the region and this fact probably accounts for the departure from normal for Hot Springs during this 20-year period.

Monthly distribution shows May to be the "wettest" month on the plains and June in the Black Hills. The least rainfall is received in November, December, or January depending upon the location of the gaging station. It is the monthly distribution that is important to the economy and ecology of the region. U.S. Weather Bureau maps show that most arid areas in Texas, New Mexico, and Utah receive as much and sometimes more precipitation than Fall River County. Were it not for the fact that most of the precipitation falls in the Cheyenne River basin during the growing season, the area would be a typical desert. Using the tables in appendix A, it was determined that 59 to 67 percent of the total precipitation falls during the months of May through August.

Stream Runoff

Appendix B is a tabulation of discharge records for the streams influencing the study area. The figures are in units of acre-feet (ac-ft); however, the monthly and yearly averages are also shown in acre-feet per square mile and inches of runoff per square mile.

All streams in the area are tributary to the Cheyenne River. Station 4005 was used to delineate the eastern boundary of the study area in order to study the hydrologic cycle for the river basin. Stations 3865 and 3940 are in Wyoming; however, their locations are within a few miles of the study area. The amount of runoff, stream pattern, and drainage density in this region of Wyoming suggest that the combined total of these two stations is representative of the inflow into Fall River County from the west. Only 253 square miles of drainage area upstream from Edgemont cannot be isolated from the study area. This figure constitutes less than 4 percent of the drainage area above Edgemont.

On the other hand, only one-third of the Hat Creek drainage lies within the study area; therefore, discharge at station 4000 would require an adjustment to be used in an analysis of the hydrologic cycle. Hat Creek drains an area which is uniform in lithologic character, i.e., the Pierre Formation. Therefore, the discharge is assumed to be proportional to the drainage area, i.e., one-third of the total discharge can be assumed to be derived from runoff in Fall River County.

Discharge into South Dakota from Wyoming averaged 64,966 acre-feet per year. Average yearly discharge from Hat Creek was 17,653 acre-feet of which 11,770 acre-feet is assumed to enter the County from Nebraska. The mean annual discharge at station 4005 was 100,278 acre-feet. Thus, the runoff derived from the study area can be estimated.

100,278 - (64,966 + 11,770) = 23,542 acre-feet

This converts to one-half inch per square mile, which is high in comparison to runoff figures for each gaging station. However, the reader must realize that of the 23,542 acre-feet, the discharge of Cascade Springs represents 16,622 acre-feet of this total. The remainder of this runoff, after subtracting the contribution of Cascade Springs, is .15 inch per square mile. This figure compares favorably with those of the Spencer and Edgemont stations, .15 inch and .17 inch respectively.

To summarize, the amazing aspect of stream runoff is that the runoff averages only .15 inch per square mile in the river basin. When the reader remembers that the average precipitation for the same period was about 15 inches per square mile, he can readily determine that runoff is only 1 percent of the yearly precipitation. This figure is considerably less than had been anticipated.

Evapotranspiration

Evapotranspiration is a term used by hydrologists to designate that portion of the precipitation which is (1) lost to the atmosphere through evaporation of streams, lakes, stockdams, ponds, and swamps, and (2) transpired into the atmosphere by plants.

Transpiration is the process whereby plants extract available water from the ground and discharge this water into the atmosphere. Plants have been divided into two principal classes based on their role with regard to the transpiration process. Phreatophytes are plants whose roots extend to the water table and obtain water from ground water. The other class of plants depends upon soil moisture derived from recent rains. This "dry plant" is known as a xerophyte. Both phreatophytes and xerophytes transpire water; however, only the phreatophytes directly effect the ground water in the area.

The principal phreatophytes of western South Dakota are cottonwood trees, willows, boxelder, salt bush, rabbitbrush, saltgrass, wiregrass, buffalo berry, and alfalfa. Alfalfa may be important where it is

cultivated as forage and buffalo berry is an excellent indicator of relatively good water, but the cottonwood tree has the greatest influence as a phyreatophyte over most of the area. Cottonwoods grow along all of the streams and in many of the dry draws. Robinson (1958) reports that areas in Arizona which support a growth of cottonwood trees at a density of 100 percent may transpire as much as 7.64 feet of water per acre per year with the water table at 7 feet.

Evaporation is dependent on several factors, principally relative humidity, wind, temperature, and surface area. Evaporation is measured by means of an evaporation pan which resembles a small stock tank. The U.S. Weather Bureau (1965) lists the following data for average yearly evaporation in inches at Angostura Reservoir: April, 5.71; May, 7.23; June, 8.30; July, 10.28; August, 9.78; September, 7.35; October, 4.32; total, 52.97.

These data represent evaporation potential and not necessarily the actual evaporation for the region. The ratio of pan evaporation to lake evaporation is quite consistent and does not vary appreciably from year to year or region to region (Linsley et al., 1958). A pan coefficient of 0.7 is normally used to estimate actual water surface evaporation. Thus, potential evaporation for Fall River County can be estimated to be 37 inches per year.

History of the County and Population

In 1946, archaeological evidence uncovered near Angostura Reservoir established that an Indian camp site existed in the area 5,000 years B.C. This discovery is the oldest evidence of man's existence in South Dakota (Schell, 1961).

The fur traders were the first white men in the area. Schell states that the Verendrye Party entered South Dakota and may have seen the Black Hills but did not enter the area. General William S. Harney established a post at Ft. Pierre in 1855 and Lt. G. K. Warren entered the Fall River area in that year (Schell, 1961).

In 1878, the first cattlemen entered the County. Harry Oelrichs of the Anglo-American Cattle Company established three ranches in 1882. The winter of 1886-87 ended the bonanza of open range cattle ranching with one of the most severe storms in the memory of the long time residents (Byron Cox, personal communication).

Homesteaders followed the construction of the railroads into the County from 1885-90. The sheep industry was also established by 1890 and a shearing pen was built at Marietta by that year (Schell, 1961).

From 1900 to World War II, the County remained an agricultural economy. During World War II, the Black Hills Ordnance Depot was established at Provo and remained operational until 1966 when it was inactivated. During the late 1950's, uranium was discovered near Edgemont and the uranium industry was established. The Fall River County Clerk of Courts shows the following population figures for the County:

1940 -	8,089
1950 -	10,439
1960 -	10,688
1966 -	8,200

The closing of the Army Depot and the migration of young people to the urban areas account for the sharp drop in population from 1960 to 1966. At the present time, the population density averages 4.7 persons per square mile in the rural areas and 38.8 persons per square mile in the towns.

Transportation

Hard-surfaced, all-weather roads include U.S. Highway 18 running from Hot Springs to Edgemont and west to the Wyoming state line, 10 miles of State Highway 87 from the Nebraska border near Ardmore north to Squaw Flat, and State Highway 52 running between Edgemont and Provo. Several graded gravel roads supplement the primary highway system and provide reasonable access to ranches in the region (see fig. 1).

The Chicago, Burlington, and Quincy Railroad crosses the area from Ardmore north to Edgemont where it branches; one branch parallels the Cheyenne River on the north traveling northwest via Marietta and Burdock, while the other branch continues roughly due north through Minnekahta and into Custer County. A branch line starting at Minnekahta provides rail service to Hot Springs.

Municipal air fields exist at Edgemont and Hot Springs, neither of which are scheduled stops for commercial airlines.

Continental Trailways provides bus service at Edgemont and Hot Springs.

Economy of the Area

Agriculture is the principal industry of the area. The main crops are corn, grains, and alfalfa; however, farming is restricted by the semiarid climate to the Cheyenne River valley where irrigation is possible, and to the irrigation district below Angostura Reservoir. The raising of livestock dominates the economy of the region. The U.S. Census of Agriculture showed that livestock populations for Fall River County in 1960 were 38,699 cattle, 29,708 sheep, 3,073 hogs, and 9,039 chickens.

Mercantile business in Edgemont, Oelrichs, and Hot Springs is the second largest source of income in the County. Most of the urban business district's trade is provided by the rural landowners in the County; however, some additional income is received from tourism in the summer.

Uranium mining is important in the Edgemont area. Mines Development Industries, a subsidiary of Susquehanna Western Mining Corporation, operates a uranium processing mill at Edgemont.

STRATIGRAPHY

General

The consolidated sedimentary rocks present in western Fall River County essentially range from the Mississippian Pahasapa (Madison) Formation to the Late Cretaceous Pierre Formation (see fig. 4). Darton (1909, 1918) reported that the wells drilled at Edgemont were obtaining water from the Cambrian Deadwood Formation and he shows the Deadwood and Englewood Formations extending south into Nebraska. Evidence obtained from wells drilled since Darton's report shows that the Edgemont wells reported by Darton as in the Deadwood were finished at the base of the Minnelusa Formation. Darton's log showed no Opeche or Minnekahta beds and gave a total thickness for the Minnelusa and Pahasapa Formations of about 600 feet. Wells drilled in the last 20 years show a thickness of 1030 feet for the Minnelusa Formation at Edgemont, and the Pahasapa at Provo is at least 270 feet thick.

Well number 10-2-3dd at Provo shows 20 feet of pink limestone at 3870 feet and 30 feet of red sandstone and conglomerate at 3890 feet. The geologist considered these beds as Englewood and Deadwood Formations; however, this section could also represent reworked Precambrian material at the beginning of the Pahasapa deposition. Gott and Schnabel (1963) indicate that the Deadwood and Englewood probably exist in the northern part of the County based on outcrops of these formations a few miles north in Custer County.

The question of the existence of the Deadwood and Englewood Formations in the County is academic. It is probable that thin sections of these formations exist in the subsurface of the northwestern townships of the area; however, these units are unimportant as potential sources of water due to their depth, thickness, and the existence of shallower proven aquifers. Therefore, the author will consider the Pahasapa Formation as the basal formation in the area. With the exception of the Pahasapa Formation, all of the strata shown in figure 4 are exposed in the area studied.

Many of the Cretaceous rocks are overlain in places by various unconsolidated deposits of Quaternary age and possibly a few Tertiary terrace deposits (Ryan, 1964). The Quaternary deposits range from gravel, sand, and silt terraces to eolian sand and silt deposits. Alluvium covers the floodplains along the larger streams in the area.

Quaternary System

Several types of unconsolidated Quaternary deposits exist locally throughout the study area. These deposits are typed according to their deposition, i.e., terrace gravels, alluvium, eolian deposits, and colluvium or talus deposits.

Terrace deposits of comparatively thick gravels cover many areas of the older Cretaceous beds and border several of the stream valleys. The gravels are composed of the Paleozoic and Precambrian rocks exposed to the north (Gott and Schnabel, 1963).

Alluvial deposits are found along most of the streams in the area. The alluvium found along the Cheyenne River, Hat Creek, and Indian Creek valleys covers considerable surface area and range from a few feet to 30 feet in thickness.

Eolian or wind-blown deposits of sand and silt occur in deposits ranging up to several square miles in area on the down-wind or south side of the Cheyenne River. These deposits are generally thin, rarely obtaining a depth greater than a few feet.

Talus deposits or colluvium can be found along the sides of most of the canyons in the Black Hills province. This material is derived from the rock formations forming the walls of the canyons.

Cretaceous System

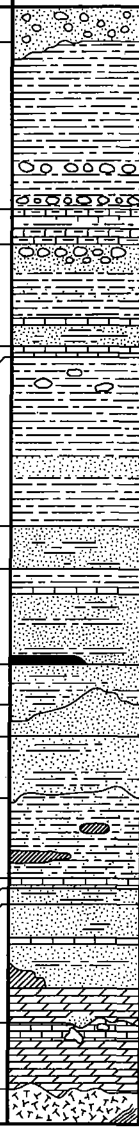
Pierre Formation

Surface exposures of the Pierre Formation constitute over one-half of the land surface of the County. The formation can be described as a thick, black to dark gray, fissile shale containing zones of limestone concretions and thin seams of bentonite. The shale weathers to form a thin and relatively poor quality light-brown soil. It erodes to form low rolling hills and exhibits typical dendritic stream patterns.

The Pierre Formation was originally defined in 1861 by Meek and Hayden with Elias (1931), Searight (1938), and Spivey (1940) making contributions to the stratigraphy of the individual units and members within the formation.

Subsurface records show that erosion causes considerable differences in the thickness of the Pierre Formation. Near the Black Hills uplift, the upper part of the formation has been eroded, e.g., at T. 7 S., R.

Figure 4. Generalized geologic section of western Fall River County.

PERIOD	FORMATION NAME	SYMBOL	COLUMN	LITHOLOGIC DESCRIPTION	THKNS. IN FEET	HYDROLOGIC CHARACTERISTICS
Quaternary	Alluvium	Qal		Gravel, sand, and silt floodplain deposits. Alluvial terraces and windblown material.	1-30	Good to excellent aquifer along floodplains; terraces generally non-productive except for scattered springs.
Cretaceous	Pierre Fm.	Kp		Dark gray shale, weathering brown or buff and containing many fossiliferous concretions. Scattered concretions which form "teepee buttes" Black fissile shale, cone-in-cone concretions.	1000+	Relatively no value as an aquifer; locally large diameter wells in stream valleys may yield small amounts of highly mineralized water during wet seasons.
	Niobrara Fm.	Kn		Gray calcareous shale, weathering yellow and impure chalk with Ostrea Congesta.	100-225	No known wells.
	Turner sand Carlile Fm. Wall Creek sand	Kcr		Light gray shale with large concretions. Gray shale with thin sandstone layers. Bed of impure limestone. Thin sandstone.	520-540	Relatively impermeable; possible small yields from Turner and Wall Creek sands.
	Greenhorn Lms.	Kg		Thin bedded hard limestone, weathering creamy white, contains Inoceramus Labiatus.	50	Too thin and dense to be an aquifer.
	Belle Fourche Fm. Mowry Shale Graneros Group Newcastle sand Skull Creek Shale	Kgs		Light gray shale, bentonite, large concretions. Light gray siliceous shale. Thin brown-to-yellow sandstone. Black shale.	870	Newcastle sand may yield water, permeability is variable.
	Fall River Fm.	Kfr		Interbedded red-brown massive sandstone and Carbonaceous shales.	30-165	Largest producer in the area. Yields up to 60 gpm of highly mineralized water (flow). Water quality generally poor, sometimes yields hydrogen sulfide.
	Fuson Shale			Gray-to-purple shale, thin shales.	0-180	
	Minnewasta Lms.			Light gray massive limestone.	0-25	
	Lakota Fm.	Klk		Coarse, hard, cross-bedded sandstone, buff-to-gray, coal beds locally near base.	130-230	Relatively good aquifer from the lower Chilson member, up to 30 gpm artesian flow.
	Morrison Fm.	Km		Green-to-maroon shale, thin sandstone.	0-125	No known wells, possible aquifer.
Jurassic	Unkpapa Fm.	Ju		Fine grained, massive, vari-colored sandstone.	0-240	No known wells, possible aquifer.
	Sundance Fm.	Jsd		Alternating beds of red sandstone and red-to-green marine shales.	250-450	Produces small amounts of water from the sands suitable for domestic use.
Triassic	Spearfish Fm.	TRs		Red silty shale, limestone, and anhydrite near the top. Redbeds. Gypsum locally near the base.	400	Poor producer, small yields of sulfate water.
? Permian	Minnekahta Lms.	Cmk		Pale brown, to gray dense, crystalline limestone.	50	Locally secondary fracture porosity.
	Opeche Fm.	Co		Red thinly bedded sandstones and shales, purple shale near top.	100	No known wells.
? Pennsylvanian	Minnelusa Fm.	Cml		Converse sand, red-to-yellow cross bedded sand. Red marker, thin red shale near middle. Leo sands, series of thin limestones. Dolomite at bottom with basal laterite zone.	755-1040	Permeability variable; tremendous flows of warm mineralized water recorded near the perifery of the Black Hills. Excellent potential.
Mississippian	Pahasapa Fm.	Cps		Massive, light colored dolomite and limestone, cavernous in upper 100 feet.	165-465	Most promising aquifer in the area. The 2 wells in this aquifer produce large amounts of water suitable for domestic use.
Precambrian	Metamorphic and Igneous rocks	P€		Granite, schists, quartzite, and slates.	---	No potential.

7 E., only 247 feet of the Pierre is present. At T. 11 S., R. 5 E., the Pierre Formation is almost complete with a thickness of 1336 feet.

Niobrara Formation

The Niobrara Formation consists of 200 to 250 feet of gray to yellow marl or chalk which weathers to an ochre color. It is relatively soft and forms the lowland across the middle of the County. Many of the small streams near Rumford follow the trough formed in the Niobrara Formation between the relatively harder overlying Pierre and underlying Carlile Formations.

The Niobrara Formation is valuable as a subsurface marker because of its speckled character.

Carlile Formation

The Carlile Formation is a light-colored shale with interbedded sandstone layers and numerous large concretions. Two sand zones generally exist in the formation. The upper sandstone, called the Turner Sand Member, consists of approximately 145 feet of interlaminated noncalcareous dark-gray shale, fine-grained sandstone, and carbonaceous siltstone (Connor, 1963). A lower zone of fine sand or silt interbedded with shale appears on several of the electric logs. This sand may represent the eastern edge of the second Wall Creek Sand found in Wyoming. The thickness of this sand is usually less than 10 feet.

The overall thickness of the Carlile Formation is about 520 feet.

Greenhorn Formation

The Greenhorn Formation is a valuable marker bed used by drillers throughout most of South Dakota. This marker bed underlies all of Fall River County and consists of approximately 50 feet of fossiliferous chalk and limestone. Darton and Smith (1904) and Rothrock (1949) considered this limestone section to comprise the Greenhorn Formation; however, later authors including Rubey (1930), Cobban (1951), and Bagan (1955) include a lower unit of 250 feet of noncalcareous shales with a thin basal limestone as part of the formation. Although these studies were localized, the inclusion of the lower unit appears to be stratigraphically correct. However, the question of where to place the lower contact is immaterial with regard to water resources. For this reason, and because drillers consider only the upper unit as Greenhorn, the author will continue to use the Greenhorn Formation as defined by Darton and Rothrock.

Because the limestone lies between the softer Carlile and Graneros Shales, drilling rates will reveal when the Greenhorn has been reached. In addition, cuttings will commonly reveal fragments of *Inoceramus labiatus*, an Upper Cretaceous mollusk. Perhaps the most useful characteristic of the Greenhorn Limestone is its distinct sharp "kick" on the electric log. The writer used this electric log marker as an aid in predicting the top of the Fall River Formation. The Fall River Formation will lie between 815 feet (southwest corner of the County) to 885 feet (northeast corner of the County) below the top of the Greenhorn Formation. The average interval between the Greenhorn and the top of the Fall River Formation was 830 feet. In this way, the estimated depth to the Fall River could be determined for many of the oil tests which were terminated in the Newcastle or Muddy sands.

The formation is quite distinctive on the surface, forming the north facing escarpment along the south side of the Cheyenne River.

Graneros Group

The Graneros Group was originally defined as the Graneros Formation by Darton and Smith (1904). Later, work by Collier (1922) divided the Graneros Formation into the Belle Fourche Shale, Mowry Shale, Nefsy Shale, Newcastle Sandstone, and Skull Creek Shale. Later studies, principally by Reeside (1944), raised the Belle Fourche, Mowry, Newcastle, and Skull Creek Members to formations. With the exception of the Newcastle Sandstone, the entire sequence consists of gray, fissile marine shales.

The Belle Fourche Formation as used by the author (see Greenhorn Formation) consists of 400 feet of dark-gray noncalcareous shale interbedded with thin limestones and bentonite beds. Connor (1963) reports that the Belle Fourche Shale is the lowest Upper Cretaceous formation in the area.

The Mowry Shale is about 125 feet thick and consists of gray noncalcareous shale. The Mowry is gradational with the overlying Belle Fourche Shale (Connor, 1963) and it is difficult to separate these two formations. The Mowry Shale locally contains sandstone dikes. Gamberg (1950) indicates that the Mowry can be determined by its silver-gray color when dry and by the fact that the outcrop usually supports evergreen trees.

The Newcastle Sandstone is a thin, soft, white sandstone. Ryan (1964) reports this sandstone as discontinuous in the Edgemont quadrangle. However, subsurface logs do not substantiate this statement. The Newcastle was present in all townships in the County except where it had been removed by erosion near the outcrop.

As stated in the discussion of the Fall River Formation, the Newcastle (or sometimes called the Muddy or "J" Sand) represents the Black Hills

equivalent of the Dakota Formation of eastern South Dakota. Two additional sands enter the County from the east and are present as far west as the Chilson Anticline. An excellent study of these sands is contained in an unpublished Master of Science thesis by Jack Roadifer (1962). These sands, designated "D" and "G," appear to have caused considerable confusion for drillers not familiar with the area.

The Newcastle Sand has been extensively tested for oil and gas throughout the County. Noncommercial quantities of gas were discovered near Ardmore during the 1940's and 1950's. The D, G, and J (Newcastle) sands produce oil and gas in Nebraska and Wyoming.

The Skull Creek Formation lies between the Newcastle Sandstone and the Fall River Formation. This formation consists of approximately 235 feet of dark-gray noncalcareous, argillaceous shale. Connor (1963) reports that the shale contains scattered light yellow cone-in-cone concretions and thin lenses of dark-brown, ferruginous, calcareous siltstones in the lower part of the formation. The base of the Skull Creek Shale is transitional with the underlying Fall River Formation.

Fall River Formation

Because it is an important aquifer, the stratigraphy of the Fall River Formation will be discussed in greater detail. The Fall River Formation is the most used aquifer in the area and yet the results from researching files, well logs, and interviews with local residents indicate that many reports are in error with regard to the Newcastle (Dakota) - Fall River - Lakota relationship. Part of this confusion is a result of nomenclature. Newton and Jenney (1880) appear to have introduced the term Dakota into the Black Hills, applying the name to the entire Inyan Kara sequence. Later, Jenney (1899) restricted the name Dakota to what is now the Fall River Formation. Darton (1901; Darton and Smith, 1904) also used the term Dakota to describe the sandstone above the Fuson Shale. It was not until 1928 that Russell concluded that the Dakota in the Black Hills was of an older age than the Dakota Formation of eastern South Dakota. For this reason, he suggested the term Fall River Formation be applied for the Dakota in the Black Hills. Rubey combined the Fall River, Fuson, and Lakota Formations into the Inyan Kara Group in 1930.

Studies of the Skull Creek Shale by Collier and Reeside, and the Newcastle Sandstone by Hancock, Grace and Dolbin, and Horn, dated the Newcastle as Dakota in age (Roadifer, 1962). Later, in 1958, J. P. Gries published a paper, based on electric well-log evidence, showing the presently accepted relationship of the Newcastle-Dakota, Fall River, and Lakota Formation northwest of Edgemont (fig. 5). The total thickness of the Fall River Formation ranges from 115 feet in T. 7 S., R. 1 E., to 180 feet in T. 11 S., R. 1 E. Both the upper and lower contacts generally are gradational with the Skull Creek Shale and Fuson

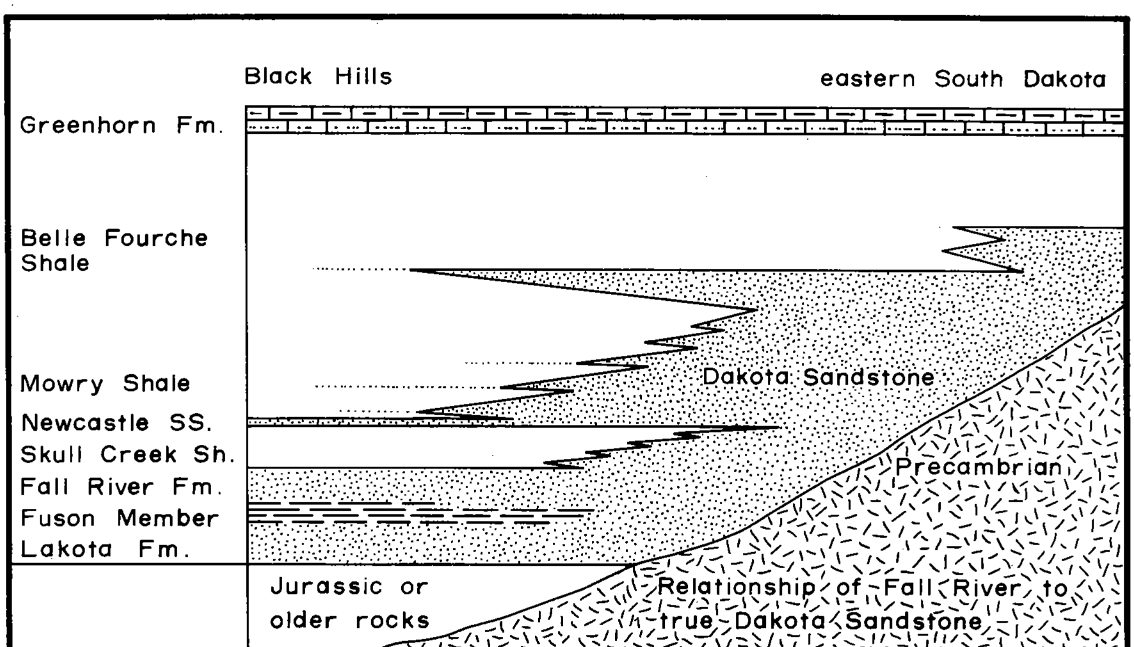


Figure 5. Generalized cross-section showing relationship of the Dakota Sandstone to the Cretaceous section in western South Dakota. *(From Gries, 1958 not to scale)*

Shale respectively. This report will use Schnabel's (1963) criteria for selecting the top of the Fall River as the top of the highest sandy unit in the formation and the bottom at the base of the carbonaceous interbedded sandstone and siltstone where it is in contact with the noncarbonaceous mudstone of the Fuson Member of the Lakota Formation (fig. 6).

Lakota Formation

Darton's early work in the Edgemont folio designated the Fuson Shale, Minnewaste Limestone, and Lakota Sandstone as separate formations. In 1959, Waage redefined the Inyan Kara Group into two formations, the Fall River and Lakota Formations. Waage recognized a similarity of the Inyan Kara to the Purgatoire Formation in Colorado and designated the discontinuous Minnewaste and Fuson Formations as members of the Lakota Formation. Later, Post and Bell (1961) identified the lower sandstone unit of the Lakota as the Chilson Member. Due to the variable lithology of the Fuson Shale, which locally is gradational with the overlying Fall River Formation, and the absence of the Minnewaste Limestone west of Edgemont, the writer feels that the relationship shown in figure 7 best describes the Lakota Formation.

Post and Bell (1961) divide the Lakota Formation into three subdivisions in descending order: the Fuson Member, the Minnewaste Member, and the Chilson Member. The Fuson Member is a changing sequence of variegated mudstone, light sandstone lenses, and coarse channel sandstones. Post and Bell (1961), Schnabel (1963), and Ryan (1964) generally agree with the following description: variegated mudstone is the principal facies of the Fuson Member. The mudstone is massive and usually appears in various shades of green or red-brown. Locally, a channel-type sandstone composed of well-rounded quartz grains and interstitial clay is found near the base of the mudstone. Schnabel (1963) has designated this sandstone the S-3. In addition to thin lenses of white sandstone throughout the mudstone, a second larger channel sandstone can be found locally near the top of the Fuson Member. This sandstone, designated S-4 by Schnabel (1963) is a yellow-gray, medium-grained, cross-bedded sandstone. Mudstone is found above the S-4 in places; however, it is important to recognize that the Fuson Mudstone is noncarbonaceous. The overlying Fall River mudstones are distinctly carbonaceous and, therefore, the contact between the Fall River and Lakota Formations should be chosen at the contact of the carbonaceous mudstone and the noncarbonaceous variegated mudstone or the S-4 sandstone of the Fuson Member.

The Minnewaste Limestone Member is a thin, impure, gray limestone. It is generally about 25 feet thick but appears to be absent in the subsurface west of Edgemont. However, Schnabel (1963) indicates that the limestone is present in sec. 4, T. 7 S., R. 2 E. He also suggests that the Minnewaste had a lacustrine origin based on remains of fresh-water sponges.

The Chilson Member of the Lakota Formation is what Darton and most drillers refer to as the Lakota Formation. It is a 130 to 230 foot thick series of

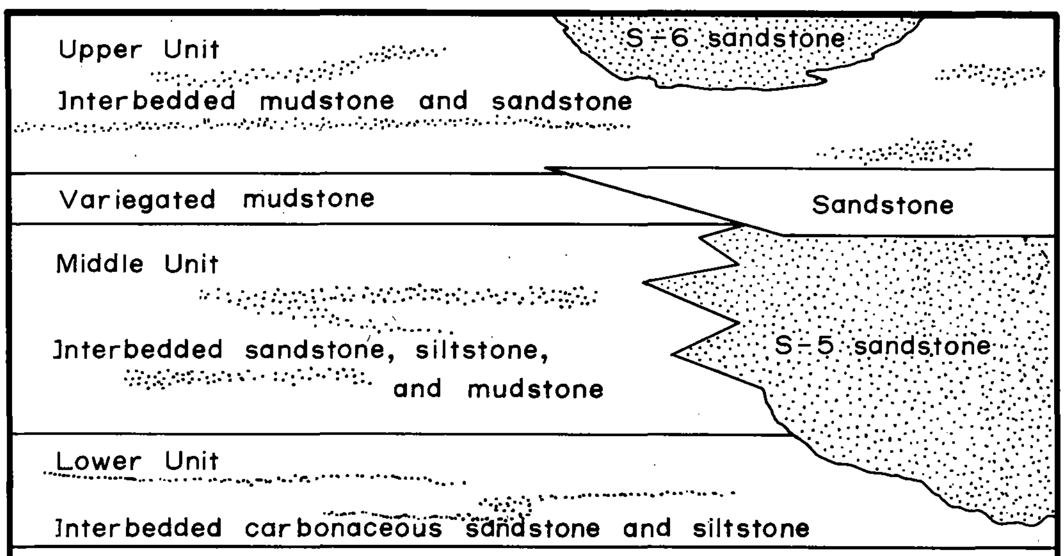


Figure 6. Diagram showing the relationship of members and lithology of the Fall River Formation. *(after Gott and Schnabel, 1963)*

interbedded sandstones, mudstones, and a channel sandstone, designated by Mapel and Gott (1959) as the S-1 sandstone. This unit is a thick, cross-bedded, light-yellowish-gray quartz sandstone with carbonaceous material in the form of macerated plants and coal found locally near the base (Schnabel, 1963). The interbedded sandstone and mudstone unit is interstratified with the S-1 sandstone and consists of a series of thin, discontinuous, fine- to medium-grained, cross-bedded, light-gray sandstones, interlaminated with dark-gray to black carbonaceous shales and mudstones (Schnabel, 1963).

Jurassic System

Morrison Formation

According to Post (1967), the Morrison Formation was named by Eldridge while working with Emmons near Denver, Colorado. The name was extended by Darton (1901) when he correlated the "Beulah shales" with the Morrison of Colorado. The formation is generally described as a sequence of light greenish-gray shales, claystone, and light-gray limestone (Schnabel, 1963). The Morrison is about 125 feet thick in the northwest corner of the County but it thins rapidly to the east. Post (1967) reports the Morrison as missing in the Cascade quadrangle. Subsurface logs show the Morrison to be 150 feet thick at Provo, 122 feet in T. 11 S., R. 1 E., and present in T. 10 S., R. 5 E., and T. 11 S., R. 5 E.

Unkpapa Sandstone

According to Post (1967), the Unkpapa Sandstone was named by Darton after a tribe of Dakota Indians. The Unkpapa Formation is restricted to a relatively small area in the southern Black Hills. Excellent surface exposures can be seen near Cascade and in Hells and Falls Canyons. The formation is about 250 feet thick near Angostura but thins rapidly to the west and is absent in well logs at Edgemont and Provo. Connor (1963) divides the Unkpapa into two lithologic units; a massive, soft, red or white siltstone which weathers to steep slopes and exhibits a knobby surface, and a fine-grained, poorly sorted, white to red cliff-forming sandstone. Post (1967) divided the formation into three units: a basal unit consisting of 50 to 100 feet of cross-bedded white to brown argillaceous sandstone, an upper unit of friable slope forming maroon to yellowish-orange siltstone, and 30 feet of varicolored argillaceous siltstone or claystone near the top where the formation has not been scoured by pre-Lakota erosion. The upper contact appears to be an overlap as the Lakota and Morrison Formations are both overlying the Unkpapa in the

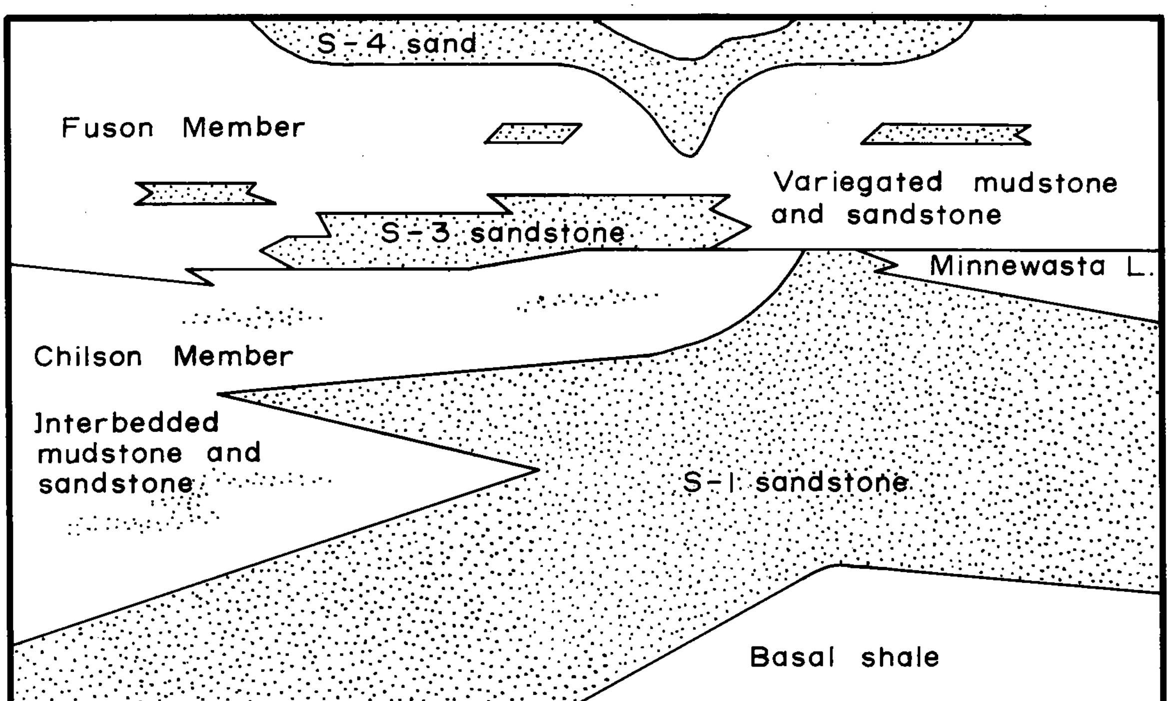


Figure 7. Diagram showing the relationship of units of the Lakota Formation. *(after Schnabel, 1963)*

County. The sandstone of the Unkpapa Formation is beautifully colored and banded and has been used for ornamental purposes in several buildings in the Black Hills.

Sundance Formation

The Sundance Formation was described by Darton in 1901 as a series of marine shales and sandstones. Imlay (1947) divided this formation into five members. Figure 8 shows the relationship of these lithologic units as they appear in the northern part of the study area.

The following descriptions are taken from Gott and Schnabel (1963):

The Redwater Shale Member is generally composed of gray, thin-bedded, laminated siltstone interbedded with thin arenaceous claystones and limestone. Locally, 10 to 15 feet of white calcareous sandstone marks the top of the member.

The Lak Member is composed of about 70 feet of salmon-colored, very fine-grained sandstone and reddish-brown siltstone.

The Hulett Sandstone Member consists of 35 to 45 feet of light-gray, fine-grained, glauconitic sandstone. It is interbedded throughout its thickness with thin beds of gray shale.

The Stockade Beaver Member is a dark-gray, highly argillaceous shale interbedded with thin fossiliferous beds of limestone. It is 40 to 50 feet thick.

The Canyon Springs Sandstone Member is commonly referred to by local drillers as the "basal red Sundance." The member unconformably overlies the Spearfish Formation and is conformable with the Stockade Beaver Shale Member. The Canyon Springs Member consists of 90 feet of red, yellow, orange, salmon, and sometimes white fine-grained quartz sandstone. Beautiful exposures of this member can be seen along the road in sec. 7, T. 7 S., R. 3 E.

The overall thickness of the Sundance Formation ranges from 250 to 450 feet thick over Fall River County.

Permian and Triassic System

Spearfish Formation

Darton (1901; Darton and Smith, 1904) defined the Spearfish Formation as a series of redbeds, shales, and gypsum beds overlying the Minnekahta Limestone and underlying the Sundance Formation. He tentatively considered the formation to be of Triassic age because of its stratigraphic position; however, later work by Goldsmith established the Permian-Triassic boundary at the top of the upper gypsum bed of Spearfish Formation (Post, 1967). Excellent exposures of the formation can be seen in the "Red Valley" extending from Minnekahta to Hot Springs. Darton and Smith (1904) gave a thickness for the Spearfish Formation of 335 feet; Post (1967) showed 328 feet of strata in sec. 18, T. 8 S., R. 5 E. Subsurface logs indicate that the Spearfish Formation ranges in thickness from 556 feet in T. 7 S., R. 2 E. to 280 feet in T. 10 S., R. 4 E.

REDWATER MEMBER		130′	*Gray siltstone and claystone with thin limestone.*
LAK MEMBER		60′ to 80′	*Salmon colored sandstone and siltstone.*
HULETT MEMBER		30′ to 60′	*Gray sandstone and shale*
STOCKADE BEAVER MEMBER		25′ to 50′	*Gray shale with thin layers of limestone.*
CASCADE SPRINGS MEMBER		85′ to 90′	*Red, salmon, orange, and sometimes white, massive sandstone.*

Figure 8. Lithology of the Sundance Formation.

Minnekahta Limestone

Lying between the Spearfish and Opeche Formations is a 30 to 50 foot thick, thin-bedded limestone. The formation normally forms a ridge around the Black Hills. It consists of a pale brown to grayish-red laminated, finely crystalline limestone which weathers into 1- to 6-inch slabs (Post, 1967). The Minnekahta Limestone was named by Darton (1901) for exposures near Hot Springs, South Dakota, Minnekahta being the Sioux Indian name for hot springs. Although many of the springs in Fall River County emerge from this formation, the Minnekahta Limestone is of little importance as an aquifer. The temperature, dissolved minerals, and volume of water emerging from the springs indicate that the source of the water is from deeper formations. Both Darton and Smith (1904) and Post (1967) mention the intricate and crumpled folds in the formation coincident with localized faulting and brecciation. Gott and Schnabel (1963) theorize from drill core information that the Minnekahta breccia pipes are related to solution and removal of deeper formations, i.e., anhydrite in the Minnelusa Formation.

The Minnekahta Limestone is a valuable "marker" on the electric log and is used throughout the Black Hills as a building stone and in the manufacture of portland cement.

Opeche Formation

The Opeche Formation was named by Darton (1901). He defined the formation as a series of soft, red, thin-bedded sandstones containing variable amounts of clay, which lies between the Minnekahta Limestone and Minnelusa Formation. The upper part of the formation contains a considerable amount of dark-red to purple silty shale which is quite persistent throughout the Black Hills. This feature makes the Opeche Formation readily identifiable in the field. Darton and Smith (1904) give the thickness of the Opeche as 115 feet; Gott and Schnabel (1963) as 60 to 115 feet; and Post (1967) as 150 feet near Cascade Springs. Subsurface logs in the County show the Opeche to range from 26 feet to 88 feet with an average thickness of 80 to 85 feet. Outcrops are exposed along the east side of Alabaugh Canyon near Cascade Springs.

Pennsylvanian and Permian System

Minnelusa Formation

The Minnelusa Formation is a thick series of sandstone, anhydrite, limestone, dolomite, and thin shales lying between the Pahasapa Formation and the overlying Opeche Formation.

The Minnelusa Formation was first named and described by Winchell in a survey report undertaken by N. H. Winchell and Captain William Ludlow (Corps of Engineers, U.S. Army) during the summer of 1874 (Berg, 1950).

Berg (1950) correlated the divisions of the formation with those of Condra and Reed in the Hartville area of Wyoming. This lithologic classification divided the formation into eight units which were designated in descending order as the Cassa, Broom Creek, Wendover, Meek, Hayden, Roundtop, and Reclamation Groups with a basal Fairbank Formation. These divisions cannot be readily determined from subsurface logs and therefore will not be used in this report. The lithology of the Minnelusa Formation varies too much to use such a division.

There are lithologic zones and markers which are valuable for subsurface work. In 1964, Gries, in describing the geology of the Barker Dome, provided a description of these zones which can be correlated with subsurface logs. The upper contact appears to be unconformable. Locally, a thin limestone may be found at the top of the formation. The upper part of the formation is generally quite sandy. A medium- to coarse-grained, red, cross-bedded sandstone called the "Converse" sand is found in this zone. Gries indicates that the thickness of this sand varies between 45 and 90 feet at the Barker Dome. Approximately 350 feet below the base of the Converse, a thin red shale designated the "Red Marker" is found. The zone between these two markers consists of dolomite, thin sandstones, redbeds, and large quantities of anhydrite. Work (1931) and Bowles (1968) described brecciated zones in this section. Work attributes this brecciation to subaqueous slides during Pennsylvanian time. A more plausible explanation for these breccia pipes is presented by Bowles. While working with Braddock in 1963, Bowles found evidence that these pipes have stoped upwards as much as 1300 feet into rocks of the Inyan Kara Group. He feels that these conduits were formed by solution of the anhydrite by percolating ground water in the Minnelusa Formation.

The "Red Marker" is a thin series of bright red shales which are used as a marker on sample logs and electric logs by the oil industry.

The "Red Marker" is used to indicate the approach of the Leo sands (Gamberg, 1950). A zone approximately 300 to 400 feet thick of thin sands, dolomites, and several thin black radioactive shales exists below the "Red Marker." One to four sandstones, varying from 10 to 40 feet, are found in this zone and have been designated by the drillers as the "Leo" sands.

The lowest 300 to 350 feet of the Minnelusa consists of variegated shales, thin sands, limestones,

anhydrite, and a basal detrital section. Drillers have termed the basal sand (or sands) as the "Bell" sands. Wells in the southeastern corner of the County show two and sometimes three red lateritic zones.

The overall thickness of the Minnelusa Formation ranges from slightly greater than 1000 feet in the northwest to 850 feet in the southeast part of the County. Figure 9 shows a generalized section of the Minnelusa Formation.

Mississippian System

Pahasapa Formation

The Pahasapa Formation is essentially the deepest formation in the area. It is possible that thin remnants of the Englewood and Deadwood Formations are present in the northern half of the County; however, for the purposes of a water resources study, the question of the presence of these formations is unimportant.

The Pahasapa Formation in Fall River County averages 250 feet of gray to buff, massive, dense limestone with thin layers of chert and laterite. The upper 150 feet is cavernous and all of the commercial caves in the Black Hills are found in this cavernous section. It is the principal "cliff former" in the Black Hills producing the buff colored, black manganese and lichen-stained cliffs in Spearfish, Little Elk Creek, and Rapid Canyons.

The formation has a maximum thickness of about 450 feet in the northwest part of the County (Gott and Schnabel, 1963) and thins to the southeast. Rothrock (1949) states that the Pahasapa is missing in the southeastern corner of Fall River County and was supported by evidence of drillers' logs of the Amerada Voorhees and Amerada Red Eagle (Shannon County) oil tests. Well number 10-8-30cd, which shows 63 feet of Pahasapa Limestone, probably lies near the erosional margin of the formation. Gries and Mickelson (1964) show that the Pahasapa Limestone does not exist in the southeastern corner of Fall River County.

STRUCTURAL GEOLOGY

A structural contour map was prepared for the County to determine the depths at which a driller could expect to find the various aquifers (pl. 1). The top of the Fall River Formation was chosen as the datum for this structural map because (1) the Fall River Formation is the most extensively developed subsurface aquifer in the County, (2) the Fall River Formation is the shallowest artesian aquifer in the region, and (3) the top of the Fall River Formation can be easily correlated on electric logs.

The structural contour map can be used to determine the depth to the Fall River Formation for any future wells. All that is required is the surface elevation of the proposed well. The contours on plate 1 are elevations of the top of the Fall River Formation above sea level. Therefore, to obtain the depth to the Fall River Formation, the contour elevation should be subtracted from the surface elevation. The accuracy of this method will vary according to the subsurface control per unit area. That is, where wells are fairly close together as along the Cheyenne River northwest of Edgemont or along the Cottonwood and Chilson Anticlines, the accuracy of the structural contours should not vary more than half a contour interval. Where the subsurface control is poor, e.g., close to the synclines and the eastern third of the County, the contour map should be used as a projected estimate based on the evidence available at the time of its drafting (see app. C).

The structure north of the Cretaceous hogback is not shown on plate 1. Most of the wells in this province are shallow. One structural feature which will be discussed in a later section merits mention at this point. The Long Mountain structural belt is a linear zone of small faults trending northeast from near Marietta (middle T. 8 S., R. 2 E.) into Custer County 3 miles north of Minnekahta (northeast corner T. 7 S., R. 3 E.). This structure is a series of small faults which Bowles (1968) attributes to recurrent structural deformation of northeast-trending Precambrian fault zones. Some of these faults are shown on plate 1.

Generally, the structures south of the Cheyenne River may be traced northward into the Black Hills area. Rothrock (1949) states that the Cascade Anticline can be followed at least as far as Hot Springs, and the Chilson Anticline projects northward to near Minnekahta. Post (1967) shows the Cascade structure extending north through sec. 8, T. 8 S., R. 5 E. Gott and Schnabel (1963) show influence of the Chilson Anticline in the "Red Valley" northeast of Red Canyon.

The Cottonwood Anticline does not appear to extend north of the Cheyenne River. This can be seen on plate 1 and is further supported by the map produced by Ryan (1964).

The three structural "highs" appear to project outward from the Black Hills in a distorted radial pattern.

The western-most structure is called the Cottonwood Anticline. This anticline plunges toward the southwest from Edgemont into Wyoming at the southwestern corner of the County with an average pitch along the crest of the anticline of 125 feet per mile. The pitch is steeper for the first 5 miles southwest of Edgemont. At the end of this plunge, a terrace 5 miles long and almost 3 miles wide trends

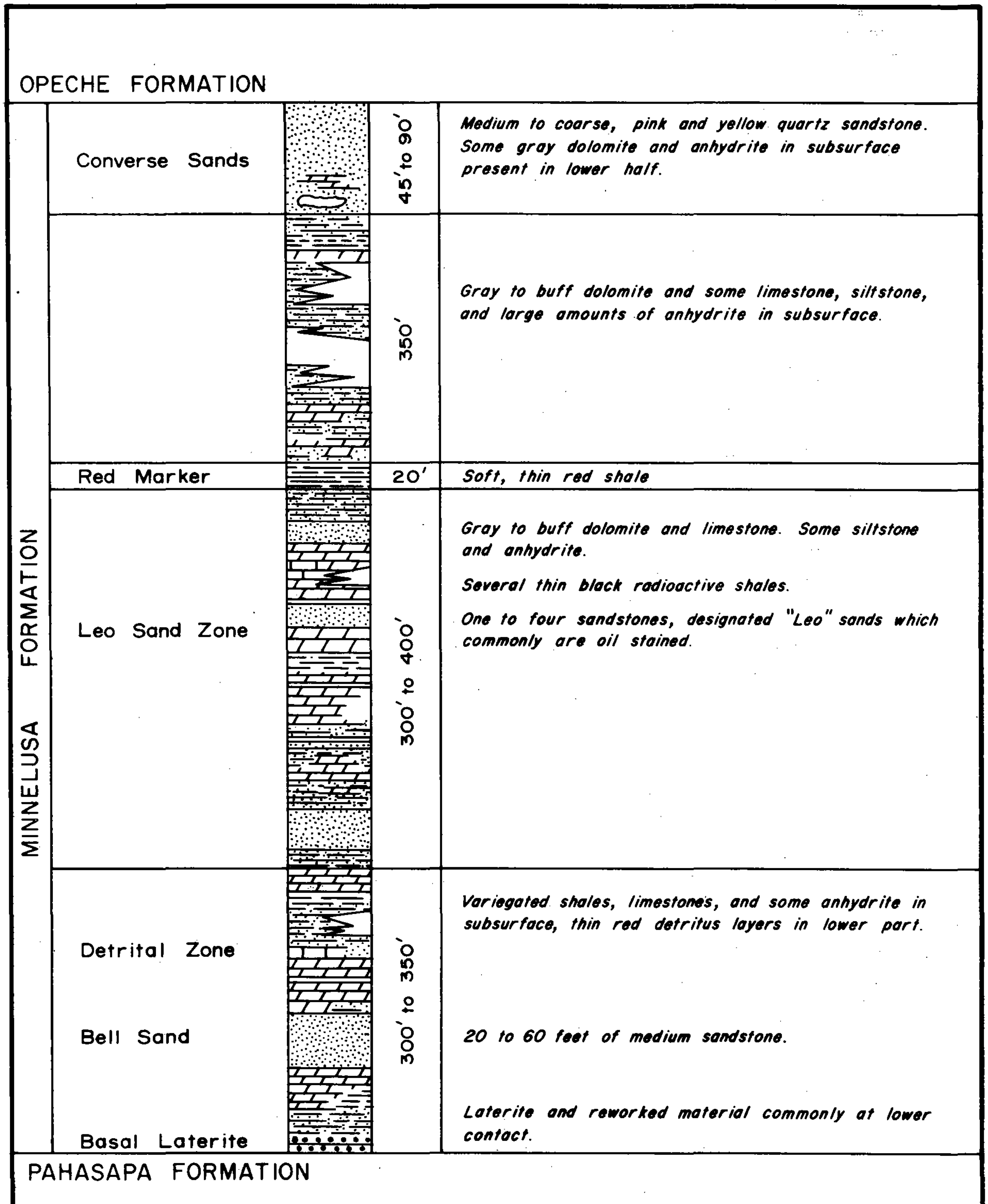


Figure 9. Lithology of the Minnelusa Formation.

southwest to within 1¾ miles of T. 12 S., R. 1 E. where the axis of the anticline again dips toward the southwest. A small dome estimated to be at least 3 square miles in area with a minimum closure of 165 feet exists on the terrace. The center of this dome appears to be in sec. 3, T. 11 S., R. 1 E. The Cottonwood Anticline is generally symmetrical although the eastern flank dips slightly more than the western flank in the vicinity of the terrace.

The Chilson Anticline has also been called the Hat Creek Anticline (Rothrock, 1949). The axis of the fold trends southeast from sec. 24, T. 9 S., R. 3 E. to sec. 29, T. 10 S., R. 4 E. where the axis changes direction to the south through the town of Ardmore and into Nebraska. There are three "terraces" along the plunge of the anticline. The axis of the fold plunges 80 feet per mile for 2½ miles south of the Cheyenne River, then flattens out for approximately 5 miles. The first terrace has an average slope of 40 feet per mile. The axial plunge then drops 500 feet in 3½ miles to the second terrace 2 miles north of Ardmore. This terrace is relatively level. At Ardmore, the fold plunges steeply, dropping 400 feet within 1 mile to the third terrace which extends into Nebraska.

The northern half of the Chilson Anticline is asymmetrical with the western flank of the fold being considerably steeper than the eastern flank. The western flank dips southwest about 600 feet per mile just north of Rumford. On the other hand, the eastern flank dips only 100 feet per mile in this vicinity. South of Rumford, the fold becomes relatively symmetrical with the average dip on both flanks being 250 feet per mile.

Rothrock (1949) mapped a small dome in sec. 20, T. 10 S., R. 4 E. Data available to the author did not show this closure; however, additional drill holes would be required to prove or disprove its existence.

The Cascade Anticline is the largest structure in the County. Rothrock (1949) mapped this structure using the Greenhorn Limestone as the datum plane. He showed an asymmetrical anticline running essentially north-south. Plate 1 reveals that the Cascade Anticline is not a simple fold but is actually a compound structure. A second larger fold plunges east from the north-south fold at T. 10 S., R. 6 E.

The anticline begins in the Black Hills and plunges south to T. 10 S., R 6 E. where the axis of the fold changes direction toward the southeast. Near the center of the township, the fold bifurcates, one anticline continuing south, the other extending east for 12 miles and then trending toward the southeast where it joins the Chadron Arch structure near the Shannon County line. The pitch of the main "trunk" of the anticline is fairly steep, dropping 1700 feet from the Cheyenne River to the point of bifurcation (260 feet per mile). The north-south fold pitches relatively gently toward the south and rate of pitch is reduced with each successive contour.

The east-west fold also has a more gentle pitch than the main "trunk" of the anticline. In fact, the crest of this fold is relatively level for almost 15 miles, dropping only 200 feet in that distance. Near sec. 23, T. 10 S., R. 8 E., the pitch becomes steeper, dropping 200 feet in 2 miles to a "saddle" where the fold joins the Chadron Arch.

As can be seen on plate 1, the western flank of the main fold is much steeper than the eastern flank. The strata on the western flank of the Cascade Anticline are standing nearly vertical along the eastern side of Alabaugh Canyon. This steep flank trends south for 6 miles south of the Cheyenne River then trends southeast to where the double fold begins. Although the geology on the surface shows no evidence of faulting, the author believes that the steepness of this flank indicates some faulting, or at least a fracture zone along the axis of the fold. This opinion is supported by the several springs located in Alabaugh Canyon. The volume and type of water issuing from these springs suggest that the originating aquifer is the Minnelusa Formation.

The east-west trending fold of the Cascade Anticline is also asymmetrical. The north flank of this fold dips about 50 feet per mile toward the northeast and appears to terminate into a broad flat area in the northeastern corner of the County. The south flank of this fold descends into a large basin which bisects the South Dakota-Nebraska boundary. The structure plunges about 200 feet per mile into the basin.

The large fault shown in the southeastern corner of the County was drawn from data obtained from Jack Harksen of the South Dakota Geological Survey. The fault is traceable on the surface; however, the author could find no evidence of the fault using the Fall River Formation as a datum plane. The top of the Fall River Formation was +1407 feet at well number 10-8-25ca. This well is located on the down thrown side of the fault. On the other hand, well number 10-8-34bd located 2 miles southwest of well number 10-8-25ca and on the up thrown side of the fault had an elevation of +1398 feet for the top of the Fall River Formation. This would indicate that the fault shown by Harksen may not extend to the depth of the Fall River Formation. Additional subsurface data will be required to ascertain the actual displacement along the fault.

The dashed dome shown in the northwestern corner of T. 8 S., R. 1 E. (pl. 1) is strictly the author's interpretation of the anomalous data obtained from the uranium test in sec. 6, T. 8 S., R. 1 E. The areal pattern has sufficient data to justify its existence of the monocline near the margin of the

Black Hills (T. 7 S., R. 1 E.). The uranium test hole appears to be correct; therefore, a structural "high" is probably present in the vicinity of the conjectured dome. This "high" could possibly be influenced by the Mule Creek structures located a few miles west in Wyoming. Because only one control point was available, the author cautions that the interpretation of the size and shape of this structural "high" is only estimated.

GROUND-WATER HYDROLOGY OF WESTERN FALL RIVER COUNTY

Ground-water Inventory

Land owners living in the study area were interviewed during October, 1969, through May, 1970. A total of 269 wells were recorded during these interviews (180 artesian and deep aquifer wells, and 89 shallow surface wells). The Fall River Formation was the most common aquifer with 69 wells, followed by Lakota, 54; Quaternary alluvium, 48; Sundance, 30; Pahasapa, 8; Pierre, 7; Carlile, 5; Greenhorn, 5; Graneros, 5; Spearfish, 3; Unkpapa, 2; Morrison, 2; and Niobrara, 1. A Quaternary gravel and a Quaternary landslide deposit each yielded a single well. An aquifer could not be determined for 25 wells. Seventeen springs were recorded for the area during the inventory.

Geologic and hydrologic data pertaining to wells and springs in the study area are recorded in appendix C. In addition, information concerning oil and gas tests and uranium exploration bore holes in Fall River County are also shown in appendix C. These latter data were used during preparation of the structural map and interpretation of the subsurface geology of the area.

Hydrologic Characteristics of the Principal Aquifers

The principal aquifers of western Fall River County are (1) the Quaternary alluvial deposits, (2) Fall River Formation, (3) Lakota Formation, (4) Sundance Formation, and (5) Pahasapa Formation. Locally, a few wells are found in other strata; however, the yields and quality of water from these wells are generally poor.

The Cretaceous shales above the Fall River Formation locally yield small amounts of highly mineralized water. The few wells drilled in these formations are located in the intermittent stream valleys. Water quality is extremely poor (see app. E) and static levels are very low during extended periods of low precipitation. Oil tests show that the Newcastle sands carry water (file, South Dakota Geological Survey) and in one case the Turner sand was found to yield a small amount of water (7-7-34bc). However, these sands are relatively thin and no wells in the area obtain water from them. The Quaternary eolian and terrace deposits overlying these Cretaceous shales occasionally yield small springs or seeps at the base of the terrace gravels or dune sands. The springs are found in small gullies on the south or downdip side of the Quaternary deposits. The water issues from the sides of the gullies at the contact of the overlying dune or terrace deposits and the underlying shales. An examination of the geologic maps of the area shows that the drainage density on these deposits is practically zero, i.e., stream channels are few and absent on the surface of the gravels or sand dunes. This indicates that most of the available precipitation infiltrates these deposits. The thinness of these deposits, however, limits their use as an aquifer. Ryan (1964) indicates that the eolian deposits are generally too thin to be mapped and published a stratigraphic section of a terrace gravel showing a total thickness of 8 feet 3 inches. To summarize, the Upper Cretaceous shales and overlying terrace and eolian deposits are poor prospects as a dependable source of ground water.

Appendix C shows several wells located in the Greenhorn Limestone. Each of these wells is located immediately downstream from a stockdam and in all probability obtain water from the soil or thin layer of loess lying on top of the Greenhorn limestone. Drilling data indicate that the Greenhorn Formation is not an aquifer in the County.

Only two wells were found in the Morrison Formation. One well (8-4-31cb) was only 15 feet deep and produced a small amount of what was described by the owner as "very strong water." The Morrison Formation should not be considered an aquifer.

The Unkpapa Sandstone was the source of water in two wells located near Chilson Station. In both cases, the yields were relatively low. Because the sand thins to the south and west, the Unkpapa Formation should be considered as a possible aquifer only in the southern half of T. 8 S., R 3 E. and T. 8 S., R. 4 E.

Some shallow wells located in the "Red Valley" near Minnekahta are drilled in the Spearfish Formation. Water from these wells is unsatisfactory for purposes other than watering of livestock because of high iron and sulfate concentrations.

The Minnelusa Formation is not presently a producing aquifer except for the springs near Cascade. The source of water for Cascade Springs has been questionable for some time. Darton and Smith (1904) indicated the source of these springs as the Minnekahta Formation as did Davis et al. (1961). The springs have also been considered a resurgence of the water which disappears into the sinkholes of the Pahasapa Formation. Post (1967) cites Braddock and Bowles in suggesting that the water rises through

breccia pipes along a zone of weakness from the Minnelusa Formation where the anhydrite of that formation has been dissolved at depth.

There is substantial evidence that Post is correct in his suggestion that the Cascade Springs water originates from the Minnelusa Formation. The volume of water issuing from the springs (23 cfs), the high calcium-sulfate content in the water, and the relatively high temperature of the water makes the Minnekahta Limestone a doubtful source for these springs. Water analyses of Cascade Springs and samples known to be Minnelusa and Pahasapa water were plotted using the Stiff Method of presentation (see fig. 10). A Stiff diagram is a graphical representation of the dissolved ions in the water. The concentration of each ion (ppm) is converted to equivalent parts per million (epm) which are then plotted on a horizontal scale, cation values to the left, anion values to the right. Figure 10 shows that Minnelusa water is high in calcium and sulfate, which would be expected because of the large amounts of anhydrite ($CaSO_4$) found throughout the Minnelusa Formation. Only small amounts of sodium and chloride are found in the Minnelusa waters. Sample B shows some sodium; however, this sample is from a drill-stem test on a wildcat oil test and part of the sodium is probably a result of contamination by the drilling mud. On the other hand, Pahasapa water has a higher concentration of sodium and chloride and only moderate amounts of calcium and sulfate. Looking at the Stiff diagram of Cascade Springs water, the reader can see that it is more characteristic of water found in the Minnelusa Formation than typical Pahasapa water.

An additional and more conclusive argument for a Minnelusa source for Cascade Springs is the potentiometric surface of the Pahasapa Formation. The springs at Cascade flow out of the ground at an elevation of 3400 feet above sea level. Appendix D contains potentiometric data for various wells throughout the County. Figures from this appendix show that the Pahasapa would flow at Edgemont at 3677 feet above sea level. The figures for the Provo well appear high (4023 to 4252 feet above sea level). However, the testing procedures and results appear to be correct. The Provo No. 1 well flowed 165 g.p.m. at an elevation of 3655 feet; therefore, it is conclusive that the potentiometric surface is above that elevation. It seems improbable that the potentiometric surface for the Pahasapa Formation at Edgemont and Provo would be 200 feet higher than the ground elevation of Cascade Springs if the spring water were of Pahasapa origin. Therefore, the author suggests that the water from the springs located in Alabaugh County derive their water from the Minnelusa Formation.

The question is then raised, if Cascade Springs is Minnelusa water, why are there no wells that obtain water from that formation? The answer appears to be an areal variation in permeability. Rapid City obtains part of its municipal water from the Minnelusa Formation near the Minnelusa outcrop; however, wells drilled a few miles east of the town at Ellsworth Air Force Base were unable to recover sufficient water from that formation (personal communication, J. P. Gries). This loss of permeability downdip from the Minnelusa outcrop seems to occur in Fall River County. Wells drilled at Edgemont, Provo, and north of Rumford yielded only small amounts of brackish water from the Minnelusa sands. However, the Gary 7-31 Dodson oil test experienced considerable problems with water in the Minnelusa Formation. This well is located near the edge of the Black Hills (7-2-31ac) and flowed at an elevation of 3521 feet (personal communication, Fred Steece). It is reasonable, therefore, to suggest that the Minnelusa Formation represents a potential aquifer near the periphery of the Black Hills, i.e., where infiltration and percolation of ground water has removed anhydrite and other minerals from the formation.

As previously stated, only the larger Quaternary alluvial deposits, the Fall River and Lakota Formations, the Sundance sands, and the Pahasapa Formation can be considered dependable aquifers in western Fall River County.

Quaternary Alluvial Deposits

Shallow wells drilled in the alluvium bordering the larger streams in the area are locally an important source of ground water. Figure 11 shows the areal extent of these alluvial deposits.

Most of the wells are located along the floodplains of the Cheyenne River, Hat Creek, and Cottonwood Creek. A few wells are found in the bottoms of the canyons which cut through the Cretaceous hogback.

As can be seen in appendix C, the wells are quite shallow, ranging from 8 to 59 feet in depth. The average depth of these wells is about 15 to 25 feet and the water level averages 12 to 16 feet below ground surface. Examination of drillers' logs from Bice Drilling Company revealed that the typical well in the alluvium penetrated 5 to 15 feet of topsoil and clay, 4 to 10 feet of sand, gravel, or sandy shale, and lastly, an impervious basal shale. The deeper wells were drilled into the shale 10 to 20 feet for added storage. Most wells in the alluvium are hand dug or 36-inch rotary drilled wells with concrete casing. Production is small, usually 1 to 2 g.p.m.

A comparison of drilling records of the shallow wells revealed that the permeable zone varied both laterally and in thickness throughout the floodplain. It appears that the best wells are located in sandbars deposited by the stream channels as the streams meandered back and forth across their respective

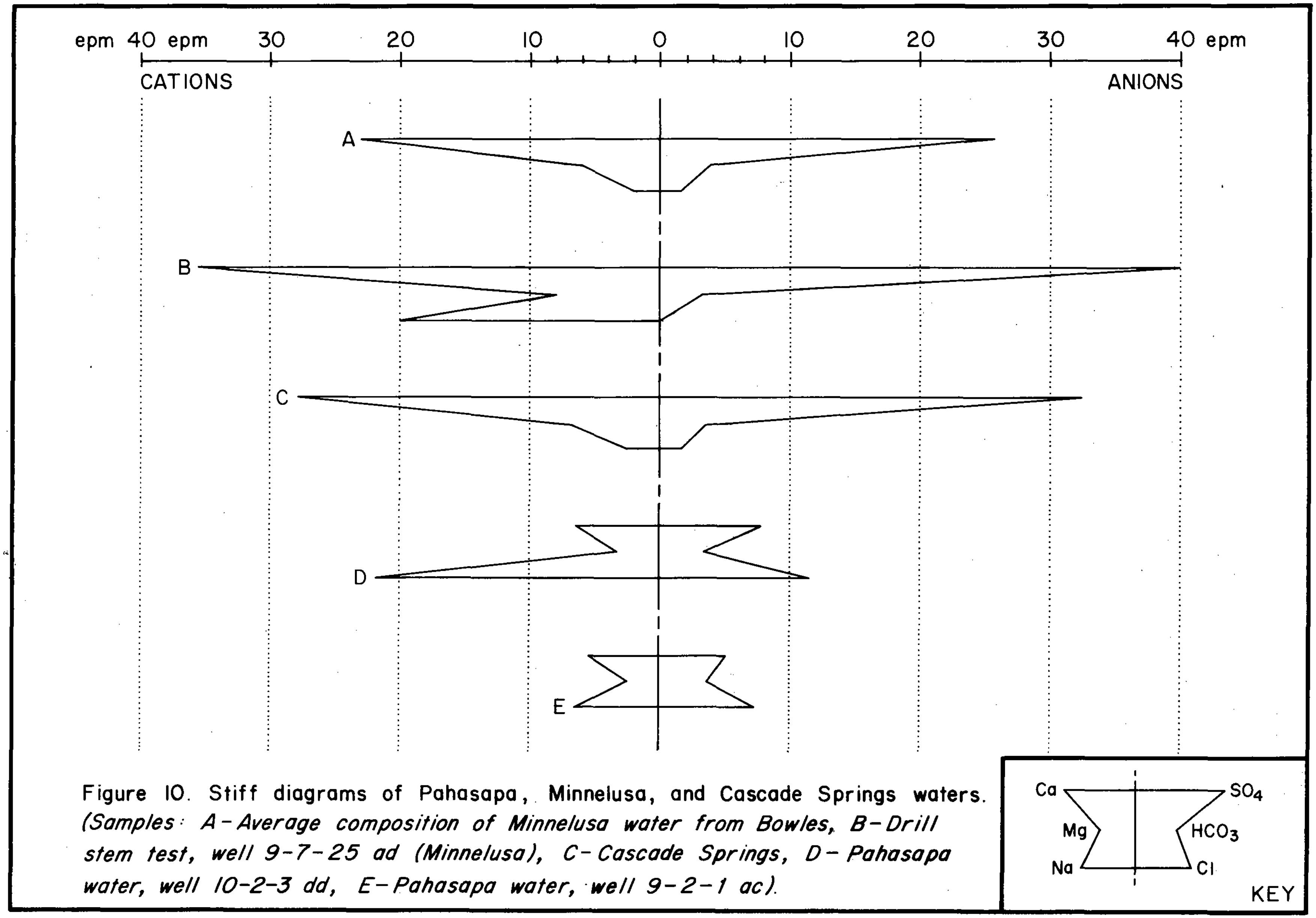


Figure 10. Stiff diagrams of Pahasapa, Minnelusa, and Cascade Springs waters. *(Samples: A-Average composition of Minnelusa water from Bowles, B-Drill stem test, well 9-7-25 ad (Minnelusa), C-Cascade Springs, D-Pahasapa water, well 10-2-3 dd, E-Pahasapa water, well 9-2-1 ac).*

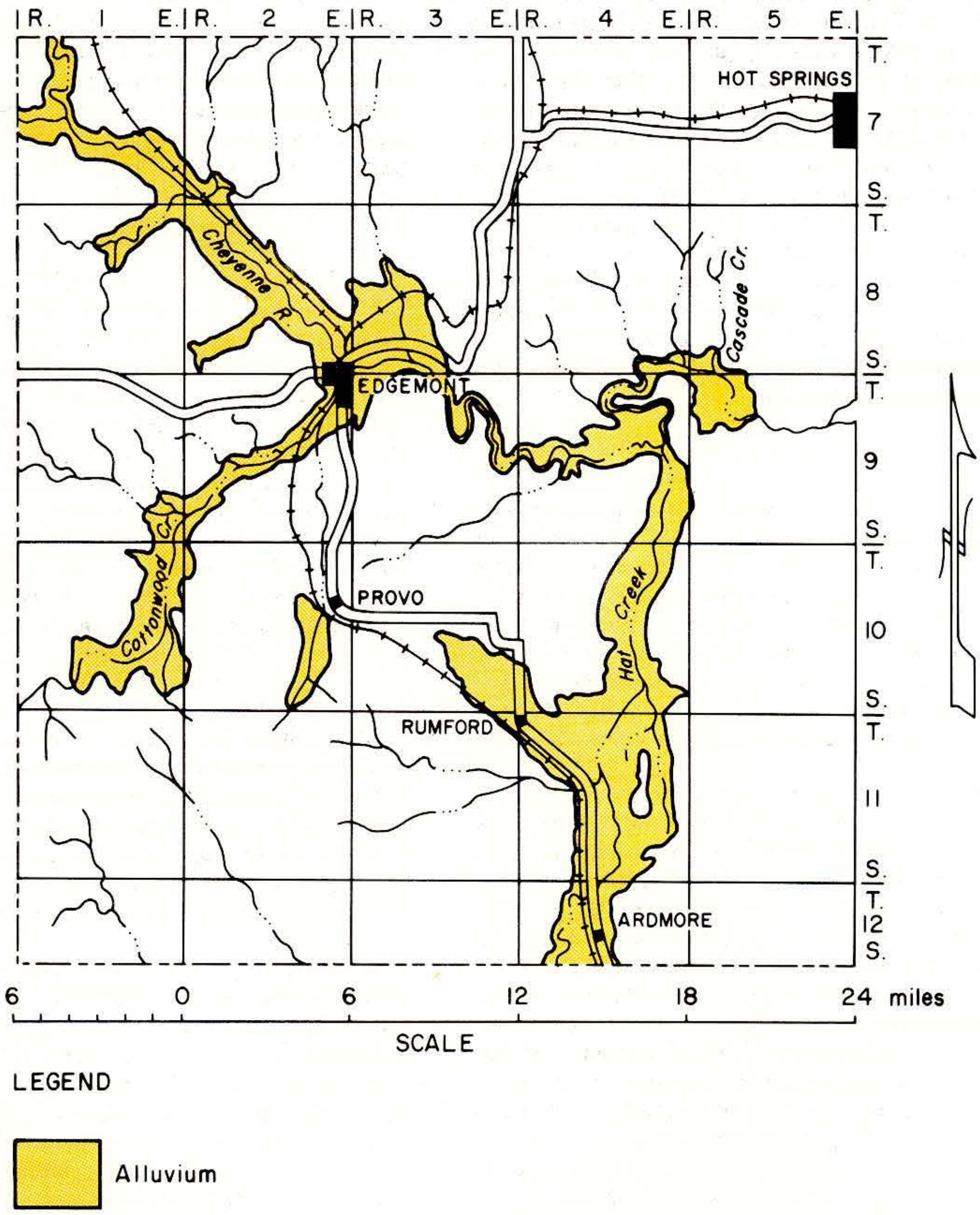


Figure 11. Major deposits of alluvial fill in western Fall River County *(after Darton and Smith, 1904).*

floodplains. These sandbars have subsequently been covered by fine material and presently cannot be seen on the surface. Mapping of these old stream channels would provide an excellent problem for future study of the water resources of the area. An earth resistivity survey would be an inexpensive way to locate these gravel bars. Test holes made with a vehicular-mounted auger would satisfactorily confirm the limits and thickness of the permeable zones. These bore holes would be quite shallow, probably less than 30 feet along the Cheyenne River and 20 feet along the larger creeks in the area. Such a study would be inexpensive in comparison with the potential benefits to the citizens of the County. Another possibility that warrants consideration is the use of infrared photogrammetry of the floodplains. Cottonwood trees and other phreatophytes would be quite discernible on infrared photographs and should be a good indicator of the permeable water-bearing sand zones and shallow water table.

Fall River Formation

The Fall River Formation is the largest producing aquifer in western Fall River County. Most of the wells obtaining water from this formation are located upstream from Edgemont within the Cheyenne River valley. The depth to the production zone in that area is 90 to 180 feet on the north side of the river, and 200 to 250 feet on the south side of the river. A few wells have been drilled several miles south of the river and attain Fall River water at depths up to 1206 feet.

The Fall River aquifer underlies most of Fall River County. The formation is absent only inside the Cretaceous hogback where erosion has removed it. Its sandstones produce artesian water and most of the wells located within the Cheyenne River valley northwest of Edgemont are flowing wells. Figure 12 illustrates the probable potentiometric surface for the Fall River Formation. The contour elevations in this figure represent the estimated elevation above sea level that the water from the Fall River sands will rise in a well casing. The dotted area shows the probable places where wells in the Fall River Formation will flow at the surface, i.e., where the ground elevation is less than the potentiometric surface. It should be noted that the potentiometric contours are almost perpendicular to those drawn by Darton and Smith (1904). Darton's projection was based on the elevation of the outcrop area and hydrologic data of wells in the Dakota Sandstone located in eastern South Dakota. As was discussed earlier, the Fall River Formation and the Dakota Sandstone are not directly connected.

The discussion concerning the stratigraphy of the Fall River Formation showed that the permeable sand zones varied considerably in thickness and number of zones throughout the area. The author emphasizes this point because several drillers' logs have shown the second sand penetrated as Lakota regardless of its thickness and interval below the first sand. In many cases, this second thin sand is a sandy zone in the lower part of the Fall River Formation.

Permeability appears to vary from sand zone to sand zone. The S-6 sandstone is quite porous and permeability is excellent where this channel sandstone is found. The S-5 sandstone also appears to possess good permeability as evidenced by the wells drilled near Bennett Canyon. Wells obtaining water from the thin white fine-grained sandstones in the upper unit of the Fall River Formation usually produce from 2 to 10 g.p.m.

Interview reports indicate that the yields from flowing wells of the Fall River sands have dropped within recent years. Part of this problem is probably due to incrustation and failure of well screens and casing. The water quality of much of the Fall River water would likely produce incrustation problems. However, some of this loss of head may result from the recent uranium exploration program. The author personally saw uranium test holes that were uncased, unplugged, and flowing at the surface. This practice is not only wasteful of water, but will ultimately lead to loss of pressure in the aquifer and possible contamination of the Fall River and Lakota aquifers.

Lakota Formation

The Lakota Formation is the second largest producing artesian aquifer in the area. Generally, its hydrologic characteristics are quite similar to those of the Fall River Formation. Only the Chilson Member of the formation appears to produce sufficient water, although it is possible that local sands in the Fuson Member could provide small volumes of water.

Attempts to produce a potentiometric map of the Lakota aquifer were inconclusive. It appears that many of the wells reported as Lakota must also be perforated at the Fall River zone. This is evidenced by several anomalous low water levels for the Lakota aquifer throughout the study area. These low water levels are approximately equal to the Fall River potentiometric surface which would suggest that some of the Lakota pressure is lost to the permeable zones of the Fall River Formation in wells opened to both aquifers.

Some general comments can be applied to static levels of the Lakota aquifer. First, the Lakota and Fall River Formations are lithologically similar and, therefore, the shape of the potentiometric surface of the Lakota aquifer should roughly parallel that of the Fall River aquifer; this does not imply that the contour elevations would be the same. Secondly, well 8-1-30dc has accurately reported that the source of water is Lakota and that the Fall River water was "cased out." The static level for this well was 240

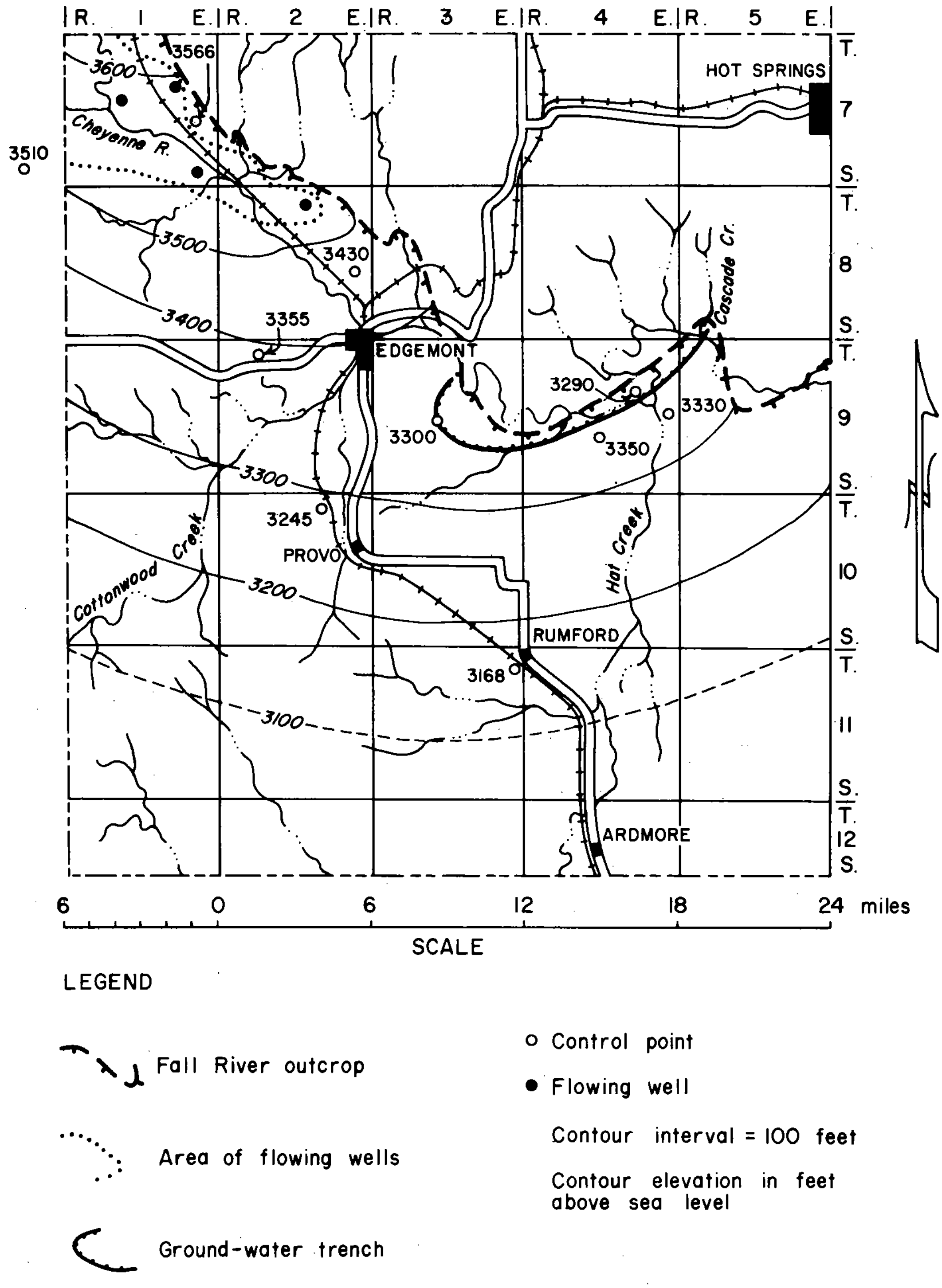


Figure 12. Probable potentiometric surface of the Fall River Formation.

feet or at a potentiometric elevation of 3610 feet; thus, pressures in the Lakota Formation appear greater than those of the Fall River aquifer in the northwestern townships of the County. This is reasonable when one considers the higher intake elevation of the Lakota Formation, the greater thickness of the Chilson Member than the thinner Fall River sands, and the smaller production from the Lakota aquifer.

Well 10-2-3dd has a potentiometric elevation for Lakota water of 3045 feet. This data was accurately established during tests made at the time of well construction. When compared with figure 12, one can see that the Fall River potentiometric surface is almost 200 feet higher than that of the Lakota; therefore, pressures must drop sharply between T. 8 S., R. 1 E. and Provo.

Potentiometric data for the northeastern part of the study area is unreliable.

Yields obtained from the Lakota aquifer are generally a little better than the Fall River Formation. Most yields from the Lakota ranged from 10 to 30 g.p.m.

Sundance Formation

The Sundance Formation underlies all of the study area except for approximately 14 square miles in the "Red Valley" near Minnekahta. Most of the wells producing from the Sundance aquifer are located in the northern townships near the Sundance outcrop area. Water is obtained from more than one horizon within the formation; however, the "Basal Sundance" or Canyon Springs Member is the principal zone of production. Yields from these wells were usually 3 to 15 g.p.m. of sulfate water.

Insufficient data precluded construction of a potentiometric map for the Sundance Formation. However, evidence exists which indicates that the pressures in the basal unit of the Sundance exceed the pressures found in the Fall River and Lakota aquifers. Wells 7-1-15dd and 7-2-21da flowed from the Sundance, and the 18th Annual Report of the South Dakota State Engineer (1942) reported that the Basal Sundance flowed brackish water at the Provo Water Well No. 1. Ground elevation at this well is 3655 feet or 415 feet higher than the water level of the Fall River Formation and 610 feet above the static level of the Lakota aquifer.

Pahasapa Formation

A total of 8 wells are presently producing water from the Pahasapa Formation within the area studied. All of these wells are located at Edgemont or Provo except for well 10-4-20da. Examination of the drilling reports from oil tests drilled in the County revealed that lost circulation of the drilling mud was a common problem in the Pahasapa Formation. This indicates that the upper part of the formation is quite porous even at depth. Shut-in pressures for the Edgemont wells and the BHOD No. 1 at Provo indicate that the Pahasapa will flow at elevations of at least 3675 feet. Shut-in pressures at Edgemont appear to be low when compared to bottom-hole pressures (bottom-hole pressure is the force exerted by reservoir fluids at the bottom of the well) at Provo. However, several wells penetrating the Pahasapa are located in Edgemont and undoubtedly some interference of the pressure cone of well 9-2-1ac must exist because of the close proximity of the other Edgemont wells. Oil test number 11-1-10cb measured a bottom-hole pressure of 1700 psi in the Pahasapa Formation which converts to a potential elevation of 4040 feet. This elevation is comparable to the potentiometric elevations for the formation at Provo (see app. D). The Amerada No. 1 Moody well (12-6-9ac) recovered 4620 feet of hot fresh water from 4950 feet. This would indicate that the potentiometric surface would be about 3320 feet; however, sufficient data were not available to determine if this test was run to completion, i.e., when the water level stabilized in the casing. A potentiometric elevation of 3320 feet appears low in view of the flows at Edgemont, Provo, 10-4-4da, and the projected elevation for 11-1-10cb. It is probable that water from the Pahasapa Formation will flow to an elevation between 3700 and 4050 feet above sea level anywhere in the study area.

The Pahasapa Formation has an excellent potential as an aquifer. Yields and pressures are the best of any stratum in the area. Water quality is relatively good for this region. At present, the cost of well construction, because of its greater depth, renders tapping of the Pahasapa Limestone prohibitive for uses other than municipal water supplies or other joint ventures.

Water Quality

All water, except that produced in a laboratory, contains impurities. Even rain will contain minute particles of dust, carbon dioxide, smoke (especially carbon) and other gases. The rain then infiltrates or runs off the surface of the land to streams. As the rain comes in contact with the soil or rocks of the earth, certain minerals are dissolved, accumulating additional dissolved and suspended materials. The Cheyenne River generally averages 2000 parts per million of total dissolved minerals (Matthew). The term parts per million (ppm) will be used throughout this section of the report. Basically, the term is a relative measure of the quality of water. The reader can think of this unit as the number of pounds of minerals contained in a million pounds of water.

Ground-water movement is much slower than that

of surface waters, usually in the range of a few feet per day. This slow movement allows ample opportunity for ground water to dissolve some of the minerals from the rocks and soils. Not only is the total amount of dissolved minerals important, but the amount and type of each chemical element can affect the usefulness of the water. Portions of the following discussion of ground-water properties have been extracted from the book "Ground Water and Wells" published by Edward E. Johnson, Inc. of St. Paul, Minnesota (1966).

Total Dissolved Solids (TDS)

The total concentration of dissolved minerals is a general indication of the overall suitability of a water for many types of uses. Water with a total dissolved solids of less that 500 parts per million is generally satisfactory for domestic use and for many industrial purposes. The South Dakota Department of Health has established a recommended maximum total dissolved solids of 1000 parts per million for water used for domestic purposes.

Hardness

Hardness is a relative measure of the amount of soap required to produce suds. Calcium and magnesium cause almost all hardness in water. Suds will not be produced until these elements have been removed from the water by combining with soap producing an objectionable scum. Hardness is usually expressed in parts per million as the calcium carbonate molecule, $CaCO_3$. A hardness of less than 50 ppm is soft, 50 to 150 ppm is not objectionable for most purposes, and above 150 ppm, water softening equipment is recommended.

Specific Electrical Conductance

This property is the ability of a substance to conduct an electrical current. Chemically pure or distilled water is an insulator and will not conduct electricity. Addition of only a small amount of dissolved minerals will render the water conductive. The specific conductance usually varies directly with the amount of total dissolved solids in the water and is really a simple test of TDS. However, the specific conductance of two solutions have the same TDS but different minerals is not the same. Usually, a factor ranging between 0.55 and 0.75, depending upon the type of ions in the water, must be applied to the specific conductance to obtain the total dissolved solids of the water. Specific conductance is usually used with the Sodium Absorption Ratio to determine a water's suitability for irrigation.

Hydrogen Ion Concentration (pH)

The relative concentration of hydrogen ions in water indicates whether the water will act like a weak acid or if it will perform as an alkaline solution.

The water molecule, HOH, has a tendency to ionize into a positive hydrogen ion (H+) and a negative hydroxyl ion (OH-). The relative number of hydrogen ions will determine the acidity or alkalinity of the water. Pure water is neutral and has a pH value of 7. The pH scale is a ten-fold scale. Values below pH 7 indicate that the water is acid and values greater than pH 7 indicate an alkaline water. Most ground waters have a pH value ranging between 5.5 and 8. Acid waters are corrosive and tend to attack well pipes and screens.

Sodium Absorption Ratio (SAR)

The sodium absorption ratio is a factor which is a measure of the sodium hazard to soil which is under irrigation. The suitability of a water for irrigation depends upon the type of soil (sand or clay), the total dissolved solids (salinity), and the sodium content of the water in relation to the amounts of calcium and magnesium in the water (SAR). This ratio is calculated from a formula. The parts per million of the ions are first converted to equivalents per million (epm) by multiplying the parts per million with the following factors:

IONS	FACTOR
Calcium (Ca^{++})	0.04990
Magnesium (Mg^{++})	0.08224
Sodium (Na^{+})	0.04350

The equivalents per million are then used in the following formula to determine the sodium absorption ratio:

$$SAR = \frac{\text{Sodium}}{\sqrt{\frac{\text{Calcium} + \text{Magnesium}}{2}}}$$

Values greater than 18 indicate a high sodium hazard; 10 to 18, a moderate hazard; and values below 10 offer little sodium danger to the soil. Repeated irrigation with waters having a SAR above 10 will reduce or destroy the productivity of the soil.

Sodium

Sodium and potassium are two elements from a group called the alkali metals. Potassium is found in ground water in very small amounts and the water analysis normally includes the amount of potassium in the sodium concentration.

Nearly all sodium compounds are soluble in water so that sodium leached from rocks or soil remains in solution. Sodium poses no scale problem nor does it contribute to water hardness. The common types of sodium ground water (sodium carbonate and sodium bicarbonate) are alkaline and may have pH values of 9 or more.

Calcium and Magnesium

The geochemical properties of these two elements are quite similar. Calcium in ground water is derived from the solution of calcite, dolomite, anhydrite, and gypsum while the usual sources of magnesium are dolomite, hornblende, augite, and talc. The solubility of both elements is controlled by the presence of carbon dioxide in the water.

The main effect of these elements in water is their tendency to react with soap (water hardness). Nature has provided a means for naturally softening high calcium-magnesium waters. Most clays will exchange sodium, if available, for both calcium and magnesium by the process of cation exchange.

Iron

Practically all ground water contains some iron. Iron content is of considerable concern because small amounts of iron limit the water's usefulness for some domestic and industrial purposes. The standard of the U.S. Public Health Service suggests that the iron content of drinking water should not be greater than 0.3 ppm. However, this limit is fixed for other than physiological considerations. Many times this amount of iron produces no adverse effect on humans or animals. In fact, the human body appears to require 5 to 6 milligrams of iron per day, which would be equal to 18 quarts of water at 0.3 ppm.

The principal objection to iron in water is that it causes staining of clothes and plumbing fixtures. Manganese affects ground water in the same way as iron, causing gray or black stains on porcelain, enamel, and fabrics.

Silica

Silicon is the second most abundant element in the materials that make up the earth's crust. Silicon combined with oxygen is called silica (SiO_2). The common mineral, quartz, is almost pure silica. Although silica is relatively insoluble in water, appreciable amounts of silica are found in some water analyses. It is believed that the silica found in ground water results from the decomposition (weathering) of silicate minerals such as the feldspar, micas, and hornblende found in granite.

Silica does not contribute to the hardness of water but can cause incrustations or scale on well screens and plumbing.

Fluoride

Fluoride is usually found in only small amounts in ground water; however, certain waters within South Dakota have abnormally high concentrations of fluorine. Too much fluoride in water can cause mottled enamel on children's teeth. On the other hand, some fluoride has been shown to reduce tooth decay. The Public Health Service established a maximum limit of 2.4 ppm fluoride in areas where the maximum daily average air temperature is in the range of 50.0° F. to 53.7° F. The State of South Dakota has specified a fluoride concentration between 0.9 and 1.7 ppm as ideal for artificially treated municipal water supplies.

Chloride

Chloride occurs in great abundance in sea water; however, it is generally unimportant in ground water unless wells are contaminated by salt water intrusion. Water that contains less than 150 ppm of chloride is satisfactory for most purposes, above 250 ppm is objectionable for drinking water, and above 350 ppm is objectionable for irrigation and industrial purposes. Some authors suggest that water containing as much as 3000 to 4000 ppm chloride is satisfactory for consumption by cattle.

Carbonate and Bicarbonate

The term alkalinity is used to measure the carbonate (CO_3) ions in water. Alkalinity is not the same as saying that a water is alkaline (i.e., when the pH is above 7). Alkalinity is measured by determining the amount of sulfuric acid required to titrate a water sample to an end point of pH 4.5.

Most carbonate and bicarbonate ions in ground water are derived from carbonate minerals, e.g., calcite in limestone, or from carbon dioxide present in the atmosphere, water, or soil.

Most ground water contains some carbonate. Concentrations between 40-400 ppm as $CaCO_3$ are most common.

Sulfate

Sulfate in ground water is derived principally from the solution of gypsum or anhydrite (calcium sulfate). It is also a by-product from oxidation of pyrite (iron sulfide). Waters high in magnesium sulfate and sodium sulfate have a "soda" taste and may act as a laxative for people not accustomed to drinking it.

Nitrate

Nitrate content of water varies considerably because of the many possible sources of nitrate. Small amounts of nitrates (NO_3) are contributed by high nitrate minerals and rocks. Some plants, e.g., alfalfa, extract nitrogen from the air and fix it in the soil as nitrate. Chemical fertilizers and animal wastes are high in nitrates. Sewage wastes also may be a source of nitrates. Because cesspools, privies, and barnyards are sources of organic nitrates, any water analysis with a high nitrate content should be considered suspect of contamination and should be tested for harmful bacteria.

Nitrate content in a water analysis can be reported as nitrate or as the element nitrogen. One part nitrogen equals 4.5 parts nitrate.

Nitrate in concentrations greater than 45 ppm (as NO_3) is undesirable for domestic purposes because of its adverse effects on young infants. This effect is called cyanosis and causes a baby to become listless, drowsy, and the skin takes on a blue color. Both federal and state health standards establish a maximum concentration of nitrate in drinking water of 45 ppm.

Trace Constituents

Many other minerals or elements not previously discussed are found in ground water; however, these constituents have relatively low solubilities and are, therefore, found only in small quantities, usually less than 1 ppm.

Only a few of these trace elements will be mentioned in this report. Boron is usually determined in water samples of wells which are to be used for irrigation. Although traces are essential for plant growth, relatively small amounts of boron can be injurious to plant growth. Crop tolerances to boron vary; sensitive crops include most fruit and citrus trees and require boron concentrations of less than 1.0 ppm. Semi-tolerant crops, e.g., beans, peppers, grains, tomatoes, and potatoes, can withstand concentrations up to 2.0 ppm and tolerant crops such as carrots, beets, lettuce, onions, and alfalfa can accept boron in amounts as high as 3.0 ppm.

Traces of uranium are found in ground waters; however, the Inyan Kara Group contains abnormal amounts of uranium compounds. The Atomic Energy Commission has established a maximum concentration for natural water of 4 x 10^{-5} microcuries per milliliter, which is equivalent to 120 ppm uranium (Davis and DeWiest, 1966). McKee and Wolf (1963) cite a reference which establishes a maximum allowable concentration of neutral uranium in drinking water of 0.5 to 1.0 ppm based on the chemically toxic effect of the element. No water in Fall River County was found that exceeded .018 ppm uranium.

Data concerning other trace elements existing in the water of the area are meager; however, the potential hazards, both to humans and livestock, warrant some discussion of selenium, arsenic, and molybdenum. Selenium, molybdenum, and arsenic are poisonous to animals. They are rarely found in ground water except as traces. However, only small amounts of these elements are acceptable for beneficial uses concerning man (maximum allowable concentrations of 0.01 for selenium and 0.05 for arsenic are specified by the USPHS Drinking Water Standards of 1962). Both molybdenum and selenium are capable of being concentrated in the roots and leaves of plants (notably "loco" weeds). The disease known as the "blind staggers" is normally a result of livestock eating plants with a high selenium content.

Hydrogen Sulfide

Although hydrogen sulfide is not usually found in ground waters in South Dakota, certain areas in western Fall River County have high concentrations of this dissolved gas. Hydrogen sulfide (H_2S) is easily recognized by its "sulphur or rotten-egg" odor. Water containing H_2S usually acts as a weak acid and is corrosive. Sulfate-reducing bacteria which are commonly associated with hydrogen sulfide will attack iron pipes and cause incrustation problems. Concentrations greater than 1.0 ppm are unfit for human consumption.

The hydrogen sulfide problem in ground water near Marietta will be discussed in a later section of the study.

Water Quality of the Principal Aquifers

General

Appendix E contains water quality data for selected wells and springs in Fall River County. An attempt was made to provide representative analyses of wells in each of the formations in the area; however, information relative to some of the formations was not available.

Water from the Upper Cretaceous formations lying above the Fall River aquifer is quite poor. The few wells drilled in the Pierre Formation generally contain large amounts of calcium, sodium, and sulfate. Iron content appears to be quite high. Total dissolved solid values for wells in the Pierre Shale ranged from 4561 to 9344 ppm. Such highly mineralized water is of little use except for watering of livestock.

A few springs and shallow wells obtain water from the Niobrara Formation. The few water analyses available for this Niobrara water indicate that it is of

extremely poor quality. Although the total dissolved solid values were generally between 3000 to 5000, the acidity of the water was markedly high, e.g., pH values of 3.5 to 4.5. Iron was also excessive, ranging from 18 ppm to 96 ppm. It appears that percolating ground water in the Niobrara Formation is actively oxidizing the iron sulfides found in the shales. This oxidation produces sulfuric acid and free iron in the water. A few landowners stated that even the cattle refused to drink the water found in these wells.

Although selenium poisoning of livestock in the Cretaceous shale areas of South Dakota and Wyoming is common and has been known for many years, none of the water analyses obtained during this investigation contained information relative to selenium or any of the other trace elements. After the first draft of this study had been completed, a conversation with D. Spilde, geologist for Homestake Mining Company, revealed that selenium, arsenic, and molybdenum minerals were commonly associated with the reduction zone in the Inyan Kara Group. The probable existence of these extremely toxic elements had concerned the author for several weeks; however, this was the first positive report of these minerals. Further investigation revealed reason for concern. Recent exploration studies by Mines Development Industries have involved mapping of selenium anomalies in the soil, vegetation, and water in the western half of the County. Mr. Kent Hudson, manager of MDI, provided the following data concerning selenium concentrations: soil anomalies ranged from 0.2 to 40 ppm; vegetation 1 to 330 ppm; water 1 to 10 ppm; areas of high selenium readings were the Niobrara Formation in the Alum Creek area, the Pierre and Niobrara Formations west of Provo, and the Graneros Group along Hat Creek south of Cascade. Arsenic, cesium, cerium, and yttrium were also reported associated with the selenium in abnormal amounts. Corporate considerations precluded release of detailed data within the time left to complete this study.

Cerium and cesium do not appear to be dangerous in ground water due to their insolubility (McKee and Wolf, 1963). Little is known regarding yttrium, but it is doubtful if the element is in sufficient quantity in ground water to be hazardous.

In view of the toxicity of selenium, arsenic, and molybdenum, the reports of minerals containing these elements require--even demand--further investigation for the presence and concentrations of these elements in ground water in Fall River County. The Federal Water Pollution Control Administration has placed the maximum limits for arsenic and selenium in water at 0.05 and 0.01 ppm respectively for both humans and animals (1968). Molybdenum poisoning is known to occur in rats fed 5 ppm molybdenum in their drinking water. Waters with a molybdenum concentration of 0 to 85 ppm have caused death in cattle in Florida (McKee and Wolf, 1963).

Until further study has been conducted concerning selenium, arsenic, and molybdenum, water from wells and springs in the Pierre and Niobrara Formations and the areas described by Mr. Hudson should be considered as suspect and potentially hazardous to man and animal alike. All such water sources should be tested for these trace elements.

Water quality data were not available for the few wells found in the Carlile, Greenhorn, Morrison, Unkpapa, and Spearfish Formations. Interview reports listed water from the Carlile and Morrison wells as "strong" or "highly mineralized." The wells listed as Greenhorn probably obtain water from ground-water seepage from stockdams located nearby. It would be expected that this water would be relatively poor in quality. Unkpapa water should be of good enough quality for most uses because its areal extent is within a few miles of the outcrop area. Spearfish water could be expected to be high in iron and sulfates because of the lithology of the formation. As stated earlier, the water from the Minnelusa Formation is high in calcium and sulfate and has a high total dissolved solids value.

Quaternary Alluvial Deposits

The chemical quality of the water obtained from the alluvial deposits appears to be related to the lithology of the underlying shales and the chemical quality of water from the adjoining stream.

Well 9-4-21bb has a total dissolved solids value of 1668 ppm. No chemical analysis for the water was available other than the above figure; however, the water has a strong taste of sulfate and has a laxative effect on people not used to it. Tullis et al. (1954) show that the water in Angostura Reservoir has a high total dissolved solids value of 1940 ppm, a low total dissolved solids value of 1240 ppm, and that the water is of the calcium-sulfate type. It appears, then, that surface water in the alluvium along the Cheyenne River is chemically related to the river water. Further investigation is needed to substantiate the above statement.

Water found in the alluvium overlying the Upper Cretaceous shales is quite similar to that of wells and springs found in the underlying formations. Well number 10-3-25dd is in alluvium overlying the Carlile and Niobrara Formations. The water from this well is not as acidic as water in the Niobrara Formation but does exhibit the high sulfate and a total dissolved solids value normally associated with Niobrara water.

Only two water analyses were found for waters in the alluvium overlying the Graneros Group. Both analyses were high in sodium and sulfate but for some unexplicable reason, well number 10-4-20cc was quite acidic, pH 3.2, and high in iron, 55 ppm.

Water found in the alluvium along Hat Creek is described by landowners as "soft with some soda." One analysis was provided by the Mining Experiment Station for a well near Ardmore. This analysis shows that the water is a calcium-sulfate water but is of relatively good quality for Fall River County, having a total dissolved solids value of 941 ppm. Most drinking water in the Hat Creek area is obtained from the surface water wells. No analysis was available for the water from Hat Creek; however, descriptions of the water provided by the landowners would suggest that the water from wells drilled in the alluvium is probably chemically related to the water in Hat Creek.

Inyan Kara Group

Waters of the Fall River and Lakota Formations are generally alike and probably related as to origin. Therefore, the water quality of these two formations will be discussed together as Inyan Kara water.

C. Gilbert Bowles (1968) published an excellent study of ground-water movement within the Inyan Kara Group for southwestern South Dakota. In this study, Bowles suggests that water in the Lakota and Fall River Formations originates in the Minnelusa Formation. This water then moves upward along the northeast trending Precambrian fault zones and breccia pipes. Breccia pipes are natural conduits formed by solution and removal of large amounts of anhydrite from the Minnelusa Formation by percolating ground water. The overlying formations then collaspe and the breccia pipe is then formed. Some pipes have been reported to have stoped upwards as much as 1300 feet into rocks of the Inyan Kara Group (Bowles, 1968). This allows recharge of the Lakota and Fall River Formations from artesian water rising from the Minnelusa Formation.

Appendix E shows several water analyses of Inyan Kara waters. Most of these data were made available by William Chenoweth of the Atomic Energy Commission in Grand Junction, Colorado. These analyses appear to support Bowles' original theory that three distinct types of water can be found in the Inyan Kara aquifers. Bowles classified these waters according to the major ions present in the water, i.e., calcium sulfate, sodium sulfate, and sodium bicarbonate. He then showed that the Inyan Kara waters changed composition as the ground water migrated upward from the Minnelusa to the Lakota and Fall River Formations and then basinward within the Inyan Kara aquifers. Figure 13 is a map modified from Bowles' paper showing the distribution of these waters. Data used in the construction of this map were only those available to the author; however, the boundaries compare favorably with those of Bowles.

Bowles interpreted the changes in water type as (1) calcium-sulfate water rises through breccia pipes to the Lakota and Fall River Formations. Calcite is precipitated during this ascension as evidenced by a decrease in the proportion of calcite to other cations. (2) After recharging the permeable zones of the Inyan Kara aquifers, the calcium-sulfate water migrates toward the basin. During the movement of water, the calcium and magnesium ions decrease and the percentage of sodium ions increase. This reaction is interpreted as a natural base-exchange softening of the waters. The average pH of the water increases from 7.4 (calcium-sulfate water) to pH 8.1 for the sodium water. (3) Locally, the sodium-sulfate water is altered to sodium-bicarbonate water by means of sulfate reduction. The process of sulfate reduction is attributed to the bacteria *Desulfavibrio desulfuricans* which reduce sulfate to hydrogen sulfide where sufficient carbonaceous material is present to support the bacteria. Water of the bicarbonate type has an average pH of 8.8.

Wells containing at least 1 ppm hydrogen sulfide are also shown on figure 13. As can be seen, the hydrogen sulfide is concentrated in the area where the calcium-sulfate water changes relatively quickly to sodium-sulfate water and then to sodium-bicarbonate water. Bowles suggests that the reducing environment is controlled by permeable zones which allow large volumes of calcium-magnesium sulfate water to be rapidly transmitted to carbonaceous host rocks and pH conditions ranging between 6.5 and 8.5. Optimum pH for sulfate reduction in soils is from 7 to 7.8.

Bowles' theory concerning the ground water of the Inyan Kara aquifers appears valid in many respects; however, a few pertinent points remain to be answered. First, why is the zone of sulfate reduction (and wells containing hydrogen sulfide) concentrated in an area approximately 3 miles in diameter? If carbonaceous material were required to support the sulfate reducing bacteria, one would expect to find H_2S along the entire outcrop of the Inyan Kara Formations. As can be seen in figure 13, the wells containing H_2S are found only in a relatively small area except for two wells farther south on the plains.

Secondly, Bowles limits the intense sulfate reduction to the lower carbonaceous units of the Fall River Formation and fluvial unit No. 1 in the lower Lakota Formation. However, interview reports indicate that it is more common to find the hydrogen-sulfide water in the upper sands of the Fall River Formation. For instance, the two wells located at the middle of 8-2-6 were drilled about 400 feet

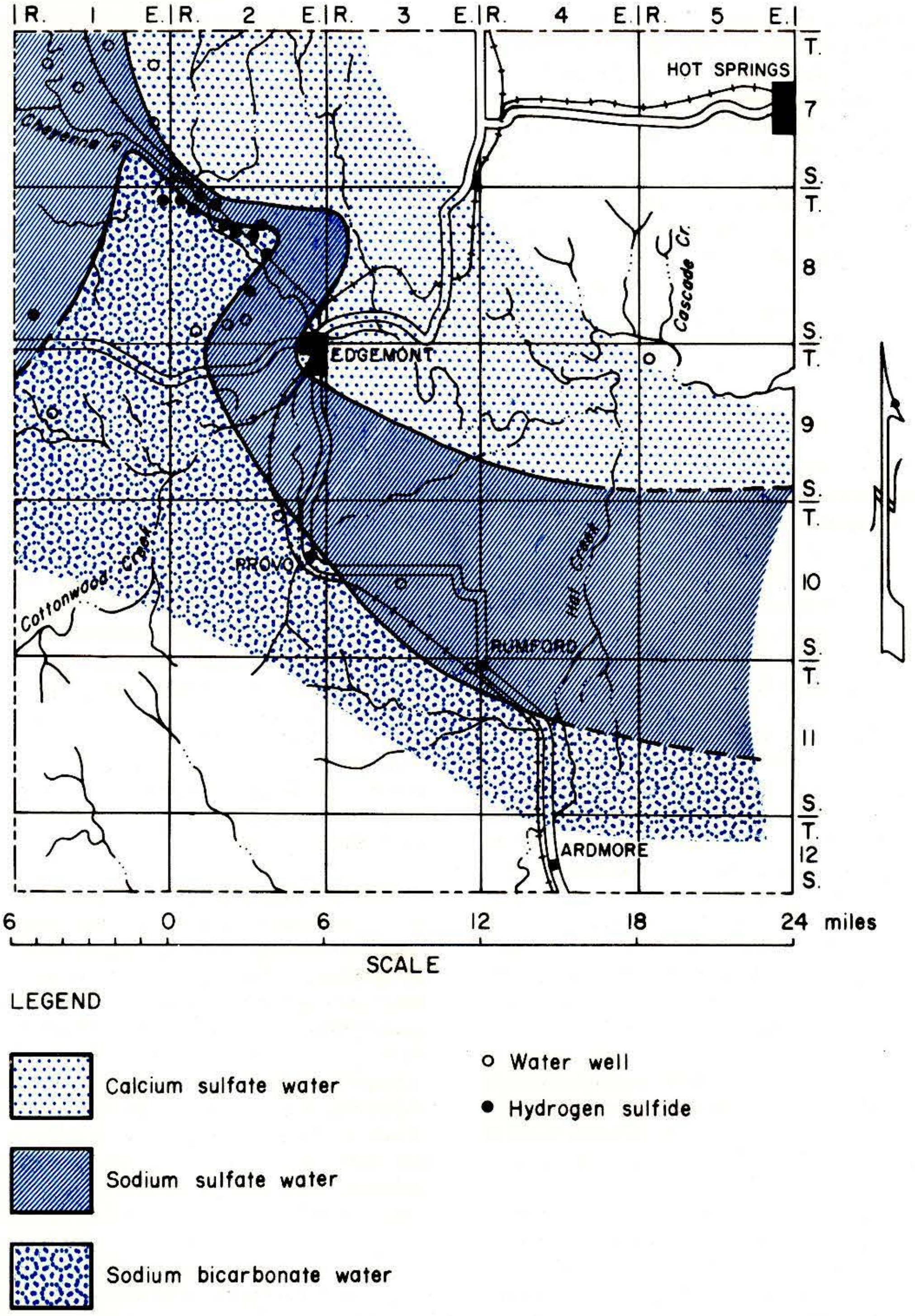


Figure 13. Areal distribution of types of water within the Inyan Kara aquifers *(after Bowles, 1968)*.

apart. The first well penetrated 4 feet of sand at 157 feet which was high in hydrogen sulfide. The second well was drilled to 305 feet where a second sand 2 feet thick produced good water after the water from the upper sand was sealed out of the casing. These sands are the S-5 and S-3 channel sands (electric logs, Homestake Mining Company). The author was able to substantiate this report by observing the construction of well 8-2-5ba. The well was started in the Skull Creek Shale and a fine-grained white sand, the top of the Fall River Formation, was reached at a depth of 102 feet. The well was finished at 118 feet which was the upper unit of the Fall River Formation, and yet the concentration of hydrogen sulfide was enough to discolor the water and produce an extremely strong odor several feet from the well. Therefore, the second question is, why is there a vertical variation of H_2S within the Inyan Kara aquifers if carbonaceous material is required to support the sulfate reducing bacteria?

Lastly, the concentration of dissolved hydrogen sulfide does not come close to equaling the amount of sulfur lost during the change from the sulfate water to water of the bicarbonate type. What ultimately happens to this sulphur?

The answers to these three questions appear to lie in the variable stratigraphy of the Inyan Kara aquifers. Bowles' theory is a plausible explantion of the formation of hydrogen sulfide in the Fall River and Lakota waters; however, an additional mechanism must be introduced to explain the areal and vertical distribution of the hydrogen-sulfide water. This addition mechanism appears to be the permeability of the S-1 and S-5 sandstone units.

During the interview with Darrell Spilde, geologist for Homestake Mining Company, the author was shown an isopach map for the S-5 sandstone. Grain-size analyses and thin sections indicated that the S-5 sandstone was deposited in an ancient floodplain by a stream that flowed northwest roughly along the present edge of the Black Hills. Figure 14 is a simplified illustration of Spilde's work showing the areal extent of the S-5 sandstone and zones of alteration of syngenetic pyrite within this unit. Spilde believes that the following sequence of events led to the deposition of uranium in the Inyan Kara rocks in the Edgemont area:

1. Ground water containing uranium percolated through the more permeable zones of the Inyan Kara rocks.

2. An environment of oxidation altered the syngenetic pyrite to limonite and hematite.

3. A second front that followed the oxidation front was a reducing environment. The uranium, selenium, molybdenum, epigenetic pyrite and other associated minerals found in the present day ore bodies were precipitated in this reducing environment.

There is little evidence that the present ground-water circulation was similar to that during the time of the deposition of uranium in this area. However, Spilde's zones of alteration appear to correlate with the relative permeability of the sands within the Fall River and Lakota Formation. Figure 13 shows that the change from calcium-sulfate water to sodium-sulfate water and ultimately to sodium-bicarbonate water proceeds gradually along the Inyan Kara outcrop except near Marietta. Near Marietta, the change in water composition is dramatic, occurring within a distance of 2 miles. Figure 14 shows that the zone of alteration within the S-5 sandstone ends within 1 mile of Marietta and a comparison of figures 13 and 14 shows that all wells containing appreciable amounts of H_2S lie within the alteration zone. This evidence suggested that as the calcium-sulfate water migrates through the Inyan Kara strata basinward from the heavily faulted area, it follows the more permeable zones of the channel sandstones. In areas where the permeability remains relatively constant, the water changes gradually to sodium-sulfate water by means of cation exchange. However, if the permeability suddenly is reduced, the movement of water toward the basin is appreciably slowed, and thus the calcium-sulfate water moves so slowly that sufficient time enables the cation exchange to take place within a short distance.

In order to substantiate this concept, a second trip was made to Newcastle, and Mr. Spilde provided the author additional information in the form of cross sections, drillers' logs, and electric logs of bore holes in the Marietta area.

The S-5 unit was quite sandy in the unaltered zones; however, at the edge of the alteration zone, the sand facies changed to a silt facies. Therefore, it appears that the zones of fine materials, i.e., silt and clay, and hence, zones of poor permeability, are responsible for the rapid change in water type.

Secondly, the zones of poor permeability would also produce a relatively stagnant environment and would provide ample opportunity for biochemical reduction of sulfate to sulfide. The S-5 unit is relatively thick in this area and is in contact with the lower carbonaceous unit of the Fall River Formation. Thus, all factors postulated by Bowles (1968) are present for the reduction environment. A second area of similar circumstances exists in the Red Canyon area. However, the alteration zone is not covered by the Skull Creek Shale as is the case near Marietta. Additionally, the Cheyenne River has eroded through the Inyan Kara rocks downdip from this alteration zone. Thus, water circulation in the Red Canyon area is not confined, and in spite of reduced permeability

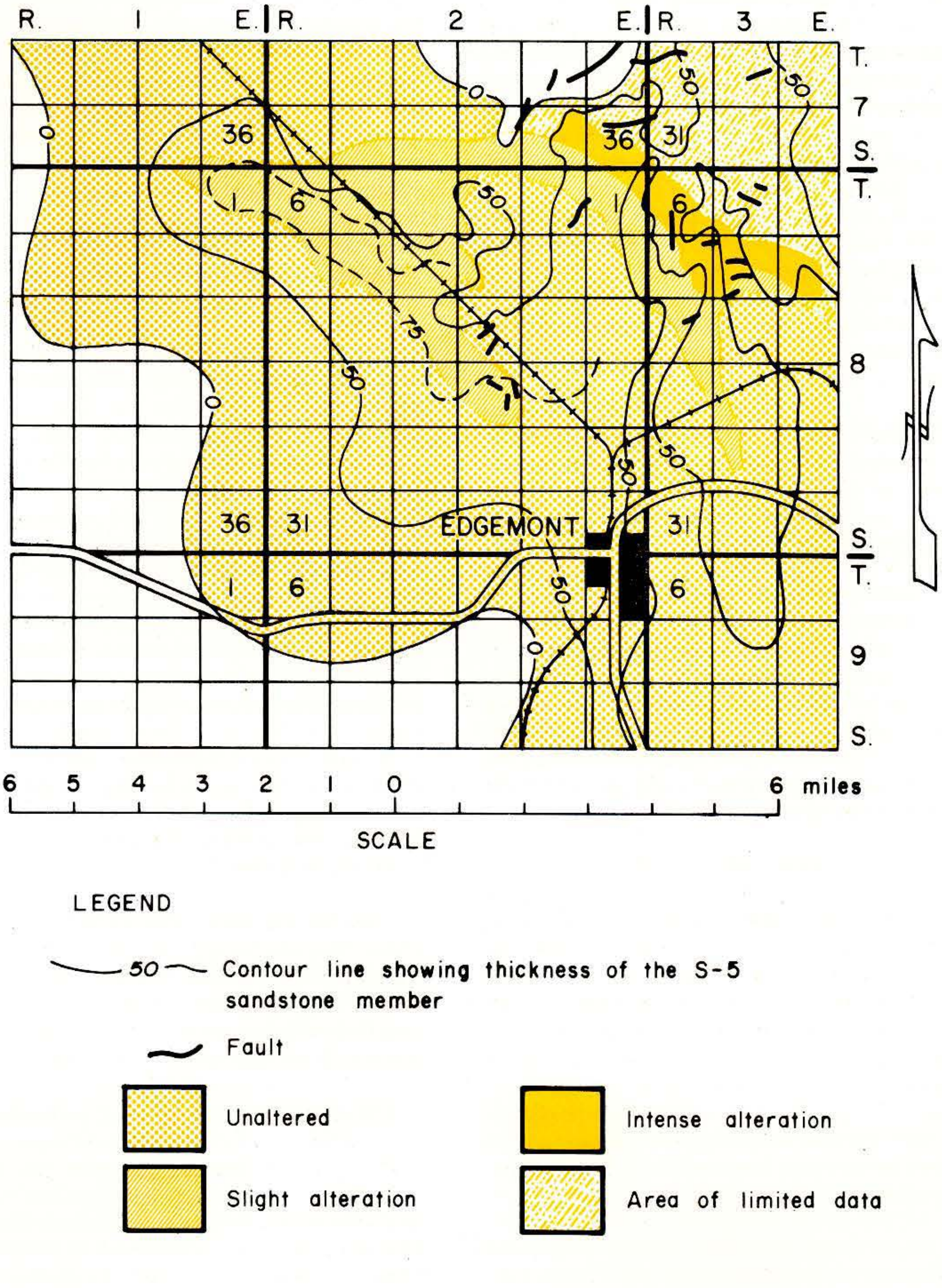


Figure 14. Isopach map of the S-5 Sandstone Member of the Fall River Formation showing alteration of pyrite to limonite and hematite. *(after unpublished data, Homestake Mining Company).*

in the alteration zone, water movement must be sufficient to preclude a reducing environment.

In summary, the author postulates the following theory for the localization of the hydrogen-sulfide water found in western Fall River County:

I. Calcium-sulfate water rises from the Minnelusa Formation through the faults and breccia pipes along the Long Mountain structural belt.

2. This water enters the Inyan Kara strata and migrates basinward toward the south, generally following the more permeable channel sands within the Fall River and Lakota Formations (S1, S4, and S5 sand units).

3. During migration, the water gradually changes to a sodium-sulfate water by means of cation exchange.

4. If the permeability of one of these channel sands is sharply reduced, two simultaneous conditions take place:

a. The reduced permeability provides ample time for the cation exchange to transform the calcium-sulfate water to a sodium-sulfate water in a short distance.

b. In a confined artesian system, i.e., if the channel sandstone is covered by overlying strata, a reducing environment is produced by the slow water circulation and reaction of the water with carbonaceous material. Action by anerobic bacteria would produce:

$$SO_4 + CH_4 \xrightarrow{\text{(bacteria)}} HS + H_2O + HCO_3$$

The carbonaceous material present in several of the units of the Inyan Kara strata would support the sulfate reducing bacteria if these carbonaceous strata were in contact with the channel sands carrying the sulfate water. However, water movement must be slow if sufficient time is to be provided for the above biochemical action to take place.

Most of the sulfide produced is precipitated out of solution in the form of epigenetic pyrite and other sulfide materials. This is evidenced by the loss of most of the sulfur in solution during transition from sulfate to bicarbonate water (Note: Homestake Mining Company reports large amounts of epigenetic pyrite in the alteration zones).

Water movement outside of the zones of poor permeability appears to be rapid enough to preclude formation of a sulfate reduction environment, i.e., an Eh value below -150 millivolts. Any hydrogen-sulfide water entering the areas of more rapid water movement would probably lose the dissolved gas by dissociation and thus explain why H_2S is found only in the areas of poor permeability.

Sundance Formation

Only two water analyses were found for water in the Sundance Formation. One analysis (7-4-29dc) appears unreliable because the anions and cations are not equal (epm). Sundance water is principally a calcium-sodium sulfate water with a relatively high iron content. Interview reports describe the water as "soda" which would agree with the high sulfate content of the two analyses.

Total dissolved solids probably range from 1500 to 2500 in the northern townships; however, the water appears to become quite brackish as it migrates away from the intake area. The drilling report for the BHOD No. 1 well indicated that the Sundance water was brackish and had a total dissolved solids value of 7380 ppm.

The Sundance water is used for drinking and stock watering purposes in the northern townships of the study area.

Pahasapa Formation

The water from the Pahasapa Formation is some of the better water to be found in Fall River County. The average classfication of this water would be a sodium-bicarbonate water with moderate amounts of calcium and sulfate. Total dissolved solids appear to range from 1000 to 1500 ppm. Well 9-2-1bc shows an abnormal amount of sodium and sulfate for Pahasapa water. It is possible that the sampling technique was incorrect or that some leakage from other aquifers is occurring in the well.

The Pahasapa water appears to be satisfactory for all purposes including watering of lawns and gardens. The calculated sodium absorption ratio is low; however, the salinity hazard would suggest that irrigation with this water should be approached with caution. One disadvantage of Pahasapa water is that it must be cooled before use. Water temperature was 125° F. at Edgemont and 139° F. at Provo.

Aquifer Recharge

Recharge of the aquifers in Fall River County generally occurs by infiltration of precipitation where these formations crop out at the surface. The determination of a recharge rate is extremely important in a study of ground-water conditions of a watershed although little has been done with regard to recharge rates until recently. Usual methods for obtaining this information are costly, time consuming, and involve extensive pumping tests, infiltration tests, and a relatively large amount of instrumentation. However, only by the determination

of a recharge rate for a particular aquifer can realistic withdrawal rates be applied to preclude "mining" of our ground-water resources.

Recharge of the Quaternary alluvial deposits is dependent upon the amount of precipitation, and in some cases, the water level of the adjoining stream. Future studies correlating the water level in a few test wells located in the alluvium with precipitation and stage of the streams should yield the permeability, storage coefficient, and recharge rate of this aquifer.

The Sundance, Minnelusa, and Pahasapa Formations are presently in no danger of overproduction because of the small number of wells obtaining water from these aquifers. Hydrologic data of the Pahasapa aquifer should be determined for future development. One method of obtaining these data would be to conduct a pumping test on one of the BHOD wells and measure shut-in pressures of the other BHOD well. A similar test could also be run at Edgemont.

Determination of a recharge rate for the Fall River and Lakota Formations would be extremely difficult. Figure 12 shows a "trench" in the potentiometric surface of the Fall River aquifer where the Cheyenne River flows through the Inyan Kara rocks. This trench suggests that the Inyan Kara strata are contributing some water to the river. Earlier in the investigation, an attempt was made to establish the volume of this additional water by using a water budget study of the stream flow data. Residents living along the Cheyenne River report that the river will flow at Rocky Ford (T. 9 S., R. 4 E.) when the river at Edgemont and Hat Creek are dry. Thus, the Cheyenne River appears to be an effluent stream as it flows over the Inyan Kara rocks. Using periods of low flow, an attempt was made to isolate the water contributed by the Inyan Kara strata. Although the total flow of Cascade Springs was known to be 45.54 acre-feet per day, no figures were available for the amount of water withdrawn from Cascade Creek by the two irrigation ditches in Alabaugh Canyon. Thus, there was no method of determining the actual amount of water contributed by Cascade Creek to the Cheyenne River at station 4005. Collection of data concerning the withdrawal by the two irrigation ditches should allow future investigators to determine the amount of ground-water seepage into the Cheyenne River from the Inyan Kara strata. Using flow data during periods of low flow and after the first heavy frost (thus eliminating transpiration), it should be possible to establish a coefficient of transmissability for the Inyan Kara aquifers. However, establishing a recharge rate for the Fall River and Lakota Formations would be very difficult because of the contribution of water from the Minnelusa Formation along the faults in the area.

CONCLUSIONS

General

Five principal aquifers produce ground water in western Fall River County. Although a few wells that produced small amounts of highly mineralized water were found in other formations, only the Quaternary alluvial deposits and the Fall River, Lakota, Sundance, and Pahasapa Formations can be classified as dependable aquifers. The Minnelusa Formation appears to hold some future promise as an aquifer along the edge of the Black Hills. Poor permeability in subsurface and extremely saline water found in the formation at depth suggest that the Minnelusa holds little potential as an aquifer except in a narrow belt along the Cretaceous hogback.

In spite of a dearth of surface water, western Fall River County has tremendous reserves of available ground water. For instance, using conservative assumptions of 5 percent porosity and a total thickness of 40 feet of saturated sand, it is estimated that the Inyan Kara aquifers have a storage capacity of 880,000 acre-feet in the study area, or roughly five times that of Angostura Reservoir. When the reader considers that this example represents only two of the five principal aquifers, he can readily see the potential of the ground-water resources for the area.

The present water problem in the Cheyenne River basin results from a combination of economic factors, geology, and quality of the ground water. As stated earlier, the quality of most ground water in Fall River County is relatively poor, especially that of the shallower aquifers. The areas in dire need of water lie on the plains south of the Black Hills where strata that are capable of satisfying local water requirements lie at depths ranging from 1500 to 4000 feet. The present cost of constructing a well to that depth is economically beyond the means of most residents or is likely to be uneconomically feasible at the present level of return for agricultural products. Future developments in well construction technology may reduce the cost of securing satisfactory water. Likewise, the margin of profit for livestock may increase such that the cost of drilling a deep well may become economically practicable.

An alternate solution with more immediate possibilities would be cooperative or corporate ventures. A feasibility study utilizing one or more wells and a water distribution system to individual ranches has been completed within the past year. A well 4000 feet deep would cost approximately $10 to $12 per linear foot or roughly $45,000. A pump and associated equipment would increase the cost of the well to $50,000. Obviously, such a well is beyond the economical capabilities of the average landowner.

However, several landowners could probably jointly finance a project of this magnitude. Modern materials are being used to produce several excellent and economical types of water pipe. Recently, the introduction of light-weight, non-corrosive, plastic pipe has made a water distribution system to individual ranches from a single water source economically feasible. One of the Federal Government wells at the Black Hills Ordnance Depot could be used as a water source for a cooperative water system. In view of the possible savings, the central location to the arid ranching area, the relatively high surface elevation (3665 feet) at the well sites, and the volume and quality of the water produced by these wells, this idea warrants investigation.

The above example was for a well producing from the Pahasapa Formation. Depending upon volume and quality of water required, the Fall River and Lakota aquifers could possibly fulfill the requirements of a community well. In this case, the cost of the well would be considerably less than that stated for a well of 4000 feet depth.

The community well concept with a water distribution system appears to be the only feasible means of obtaining water in the southwestern part of the County; however, the stream valleys covered with the larger deposits of alluvial sands and gravels (fig. 11) warrant investigation before deep wells are contemplated. This recommendation is especially true along the Cheyenne River and Hat Creek. The relatively small number of wells in the alluvial deposits attest to the fact that this shallow aquifer has been overlooked in the past. Water quality of the alluvial deposits is generally suitable for livestock and in many cases for drinking water. The wells in the alluvium would be shallow, generally less than 40 feet, and thus cost only a few hundred dollars. Although yields from these shallow wells are only a few gallons per minute, the low cost would allow several such wells to be located at various points along the stream valley. Even 2 gallons per minute would provide over 2500 gallons of water each day which should water at least 100 head of cattle. Interview reports indicate that a few landowners have recently shown a renewed interest in tapping the alluvium along the Cheyenne River (well 8-2-28da$_2$) and Hat Creek (well 11-4-29db).

In several cases, springs were found to issue at the contact between the Cretaceous shales and the overlying eolian or terrace deposits, but these deposits are too thin to supply water for wells. The largest springs in the area are located near Cascade, and the Minnelusa Formation appears to be the probable source of these springs.

The solitary disappointment of this investigation was the failure to ascertain even an estimate of aquifer recharge. As explained earlier, the determination of recharge rates requires relatively sophisticated measurements with expensive instrumentation. One attempt to determine the transmissability of the Inyan Kara aquifers by means of a water budget study was thwarted because no records of irrigation diversions from Cascade Creek could be found.

A useful and organized method of summarizing the results of this study appears to be a discussion of the ground-water resources of the area in terms of the possible uses of the water. Application of water to specific uses is usually classified as (1) domestic (which, according to South Dakota Water Law, includes watering of livestock and irrigation of home gardens not to exceed one-half acre), (2) irrigation, (3) industrial, (4) fish and wildlife propogation, (5) recreation, (6) power production, and (7) navigation. Only domestic, irrigation, and industrial uses are, at present, applicable to ground water.

Drinking Water

All five of the principal aquifers in western Fall River County are used for domestic purposes, including drinking water. Figure 15 is a résumé of the most commonly encountered or typical water found in these aquifers and the recommended drinking water standards of South Dakota. The concentrations of the various ions for each aquifer are estimates of the average concentrations of each water type based on the water analyses in appendix E and several other water analyses not listed in this study.

As can be seen in figure 15, none of the aquifers meet all of the standards recommended by the South Dakota State Department of Health. The reader is cautioned to remember that these limits are recommended or desirable limits and not necessarily absolute maximums.

All of the ground water in the area exceeds the recommended limit for total dissolved solids. With regard to total dissolved solids, the water produced from the Hat Creek alluvium, the sodium-sulfate and sodium-bicarbonate waters of the Inyan Kara Group, and the Pahasapa water appear to be the best sources of drinking water. All water except that found in the alluvium along Hat Creek, the sodium-bicarbonate water of the Inyan Kara aquifers, and Pahasapa water exceed the standard for sulfate. All water for which data was available met the nitrate standard. Iron content of the water from the alluvium in the "uplands" was exceedingly high as was the water from the Niobrara Formation. Of the principal aquifers, the calcium-sulfate water of the Lakota Formation and Sundance water exceeded the recommended limit for iron. As stated earlier,

however, excessive iron is not injurious to man but is considered a nuisance element in water because of its property of staining laundry and plumbing fixtures.

Only the sodium-bicarbonate water of the Inyan Kara aquifer appeared to exceed the maximum limit for fluoride. Children using this water may suffer from dental fluorosis or "mottled teeth" (Steece and Howells, 1965).

The water from the Pahasapa Formation exceeds the recommended limit for chloride. This chloride content is only slightly above the standard of 250 ppm. Noteworthy is the fact that the World Health Organization uses a recommended limit for chloride of 350 ppm.

Water containing 1 ppm or more of hydrogen sulfide should not be used as drinking water (Davis and DeWiest, 1966). The area of hydrogen sulfide is generally localized within a few miles of Marietta, and even in this area it appears that careful well construction and "casing off" the hydrogen sulfide producing sands will eliminate the hydrogen-sulfide problem.

The water found in the Cretaceous shales is almost always unsuitable as drinking water. Although the Sundance and much of the Inyan Kara water are relatively high in total dissolved solids, they can be used for household use. As a general observation, the Lakota Formation is generally higher in iron but yields slightly better water than does the Fall River aquifer. The alluvium along Hat Creek, the sodium-bicarbonate water from the Inyan Kara aquifers, and the Pahasapa Formation appear to be the most satisfactory sources of drinking water.

The above comments are general observations concerning water for drinking purposes. Appendix E illustrates that considerable variations occur over relatively short distances within the same aquifer. For this reason, wells drilled in the future for drinking purposes should have a water analysis performed by a competent laboratory prior to use.

Livestock Water

During this investigation, it was surprising to find that very little research has been done regarding tolerances of various types of livestock to chemical

No.	Chloride	Fluoride	Iron	Nitrate	Sulfate	T. D. S.
SD	250	0.9-1.7	0.3	45	500	1,000
Q1					+	1,600
Q2	50		0.05		500	1,200
Q3	35		10.0+		3,000+	4,000+
Kp	50+		1.0		3,000	4,000
Kn	20		20.0		2,000	3,200
F1	70	1.0	0.25	1.0	850	2,000
F2	60	2.0	0.20	1.0	100	1,500
L1	7	0.2	1.0+	1.0	1,000	2,000
L2	12	0.6	0.5	1.0	500	1,200
Js	35	0.7	2.0+	1.0	850	1,600
Cml	40	1.0	0.03	4.0	1,000	1,500+
Cp	300	1.0	0.15	2.5	300	1,200

Figure 15. Drinking water standards for South Dakota *(SD)* and typical ion concentrations of water in the Cheyenne River alluvium *(Q1)*, Hat Creek alluvium *(Q2)*, Rumford alluvium *(Q3)*, Pierre Formation *(Kp)*, Niobrara Formation *(Kn)*, Fall River sodium-sulfate water *(F1)*, Fall River sodium-bicarbonate water *(F2)*, Lakota calcium-sulfate water *(L1)*, Lakota sodium-bicarbonate water *(L2)*, Sundance Formation *(Js)*, Minnelusa Formation *(Cml)*, Pahasapa Formation *(Cp)*.

constituents in water. Most investigations of this nature have been conducted in Australia (McKee and Wolf, 1963).

Daily water consumption will influence the quality of water that is acceptable to livestock. McKee and Wolf (1963) provide the following water consumption figures for livestock and poultry:

ANIMAL WATER CONSUMPTION
BEEF CATTLE — 7 to 12 gpd/head
DAIRY CATTLE — 10 to 16 gpd/head
HORSES — 8 to 12 gpd/head
SWINE — 3 to 5 gpd/head
SHEEP AND GOATS — 1 to 4 gpd/head
CHICKENS — 8 to 10 gpd/100 birds
TURKEYS — 10 to 15 gpd/100 birds

Livestock can tolerate greater concentrations of minerals in their water than humans. The following data are the most recent figures available on the recommended limits of total dissolved solids for various types of livestock:

ANIMAL	A	B
POULTRY	2,860	4,000
SWINE	4,290	7,000
HORSES	6,435	7,000
CATTLE — DAIRY	7,150	7,000
CATTLE — BEEF	10,000	7,000
ADULT DRY SHEEP	12,900	7,000

Note: All figures are given as ppm. Source A is the Federal Water Pollution Control Administration (1968). Source B is Bulletin 481, South Dakota State University (1959).

The raising of livestock is the largest industry in the area and as such, warrants additional comments with regard to water for cattle. Figure 16 illustrates more detailed information on water quality requirements for cattle. The sources for this diagram were several and the data are the best available figures at this time. Figure 16 lists known safe levels of ions for cattle. In view of the higher tolerance to total dissolved solids for sheep, it is probable that the diagram can also be used by sheep ranchers until better data are available.

All water for which chemical analyses were available met the requirements for calcium, magnesium, and chlorides. Only the Pierre Formation exceeded the total dissolved solids limit in one analysis, but generally, total dissolved solid values for Pierre water are below the safe threshold for sodium.

Only the Sundance and Pahasapa Formations consistently met the recommended safe limits for sulfate. The sodium-bicarbonate water of the Inyan Kara aquifers is also below the safe sulfate level; however, all other waters exceed the limit of 1000 ppm cited by McKee (1963). There appears to be considerable confusion as to what is the safe threshold level for sulfate. McKee and Wolf (1963) cited Stander as establishing a sulfate threshold limit of 1000 ppm, then summarized by stating 500 ppm of sulfate would not be detrimental for watering of stock. Both McKee and Wolf (1963) and the Federal Water Pollution Control Administration (1968) indicated that cattle had weakened and died in Minnesota at a sulfate concentration of 2104 ppm. However, the latter reference also reported that livestock will tolerate 2050 ppm of magnesium sulfate and McKee and Wolf (1963) cited Ballantyne as setting the threshold limit of sodium sulfate for all livestock at 2050 ppm. These two chemical compounds convert to 1110 ppm and 1385 ppm sulfate, respectively. McKee and Wolf (1963) cite a reference indicating that 2400 ppm calcium-sulfate water was not injurious to rats (1700 ppm sulfate). In view of the experience of ranchers in western Fall River County, there is reason to believe that 1000 ppm sulfate is a conservative tolerance level for cattle. In all probability, cattle would suffer few, if any, adverse effects with sulfate concentrations as high as 1500 ppm; sulfate levels greater than 1500 ppm may cause problems in reproduction and weight gain.

All of the principal aquifers had less than the recommended safe limit for total dissolved solids. Some of the shallow water found in the alluvium approached the limit, and a few wells in the Pierre Formation were definitely unsatisfactory with regard to total dissolved solid limits.

The majority of ground water in the area is satisfactory for livestock water. All samples of water obtained from the Hat Creek alluvium, the bicarbonate water of the Fall River and Lakota Formations, the Sundance Formation and the Pahasapa Formation fell within the recommended safe limits. Water obtained from the alluvium found in areas other than the Cheyenne River and Hat Creek should be analyzed and used with caution if the sulfate content exceeds 1500 ppm. Water of the Pierre and Niobrara Formations should be viewed as hazardous to livestock until analyzed because of the possibility of selenium and the fact that several samples were above recommended limits in sodium, sulfate, and total dissolved solids.

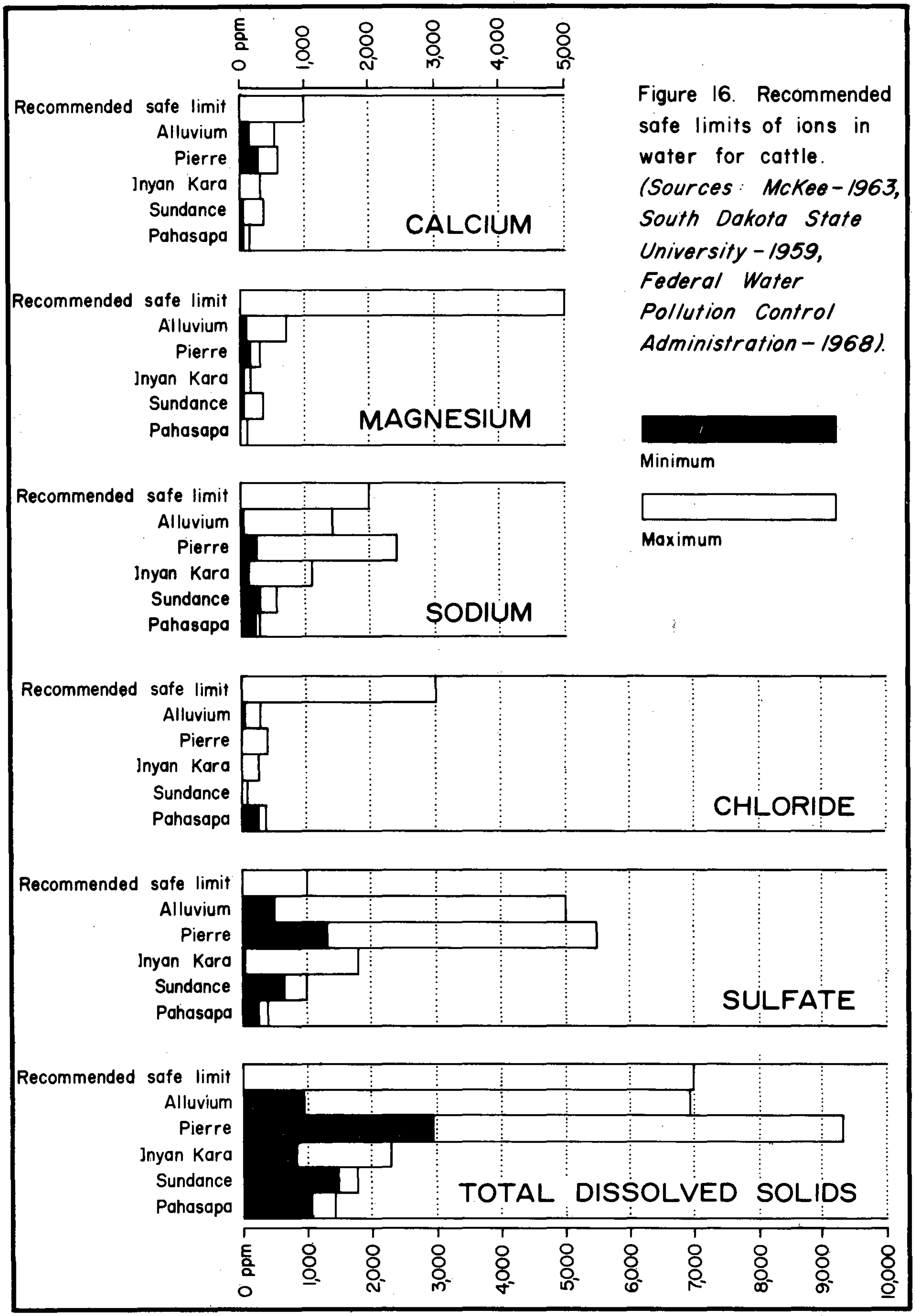


Figure 16. Recommended safe limits of ions in water for cattle. *(Sources: McKee - 1963, South Dakota State University - 1959, Federal Water Pollution Control Administration - 1968).*

A point that bears mention is a policy of the Animal Disease Research and Diagnostic Laboratory at South Dakota State University. Several water analyses which were tested for suitability for livestock were obtained by the author during the field investigation. The analyses performed by the above organization commonly recommended water as "unsatisfactory for all classes of livestock" based only on hardness and electrical conductivity. The variable chemical composition of waters in Fall River County precluded any correlation of specific electrical conductance with total dissolved solids (see app. E). E. E. Johnson, Inc. (1966) showed that electrical conductance of a sodium-chloride solution is 50 percent greater than that of an equal concentration of calcium bicarbonate. Well number 10-3-25dd had a specific conductance of 11,000 microhms and yet the total dissolved solids were below the safe threshold limit of 7000 ppm. Hardness is a relative measure of the suds-producing capability of a water and is not directly associated with physiological effects on living animals. This method also ignores the possibility of the presence of selenium and other toxic trace elements. The author, therefore, questions this method of determining whether a particular water sample is suitable for livestock. It is recommended that determination of the suitability of stock water be based on the concentration of ions and total dissolved solids.

Irrigation Water

The suitability of ground water for irrigation is not only dependent upon the chemical properties of the water, but also upon the physical and chemical properties of the soil, the type of plants being irrigated, and the climate of the region. The subject of irrigation is highly complex and all factors should be considered by an expert who is knowledgeable in that particular field. As this study concerns ground water, only a few general comments are in order concerning these other factors.

Climate determines whether or not irrigation is required. The amount of precipitation and rate of evapotranspiration also influence the quality of irrigation water acceptable for a particular type of soil. Regions which receive low amounts of precipitation will generally require better quality irrigation water because (1) low amounts of precipitation reduce the amount of salt leached from the soil and (2) semiarid regions usually experience high rates of evapotranspiration, thus increasing the concentration of salts in the soil as the irrigation water is evaporated or used by plants.

The type of soil is influential as to the acceptability of irrigation water. Soils having a high clay content require a better quality water than do sandy soils. Soils with good permeability allow more leaching to take place and thus accumulation of salts in the soil is reduced. Fine-grained soils, such as fine silt and clay, exhibit another adverse effect in that they commonly exchange calcium and magnesium ions for sodium ions. Clay soils having relatively high amounts of calcium and magnesium till easily and have good permeability; high concentrations of sodium salts develop alkali soils which have a low productivity (Johnson, 1966).

Plants are affected by the quality of irrigation water in that different species and varieties vary considerably in their tolerance to various ions in the water.

The important characteristics of an irrigation water are: (1) the total dissolved solids or salinity hazard, (2) the relative amounts of calcium, magnesium, and sodium in the water, and (3) the amount of boron in the water.

The total concentration of dissolved salts (TDS) is called the salinity hazard. The usual practice for analysis of irrigation water is to express the salinity hazard as specific conductance. Higher conductivity readings indicate higher salinity hazards.

In conjunction with the salinity hazard, irrigation water is also classified according to its sodium hazard. The sodium absorption ratio is used to determine sodium hazard. As stated earlier, clay type soils require a lower sodium hazard than do sandy soils.

Figure 17 is the standard diagram for classifying irrigation waters. All water analyses in the area having specific conductance readings have been plotted on this diagram. Irrigation water may be classified into 16 different classes of risk. Four levels of sodium hazard (S1, S2, S3, and S4) are plotted in conjunction with four levels of salinity hazard (C1, C2, C3, and C4) to produce the 16 classes of irrigation water. The higher numbers denote a higher risk with regard to the respective hazard. Thus, C1-S1 is the best water for irrigation, C2-S2 is preferred over C3-S3, and C4-S4 is totally unsuitable.

Only two figures were available concerning boron concentrations, both of which applied to the Fall River aquifer. Concentrations of .14 and .18 ppm were recorded for these wells (8-2-20da and 8-2-36a). This amount of boron would not be detrimental to irrigation.

At present, all ground water in western Fall River County is unsuitable for irrigation. The salinity hazard was high or very high (C3 and C4) for all water, regardless of aquifer. The water from the Pahasapa Formation and the calcium-sulfate water of the Inyan Kara aquifers appear to hold promise in the future as irrigation water because of their low sodium

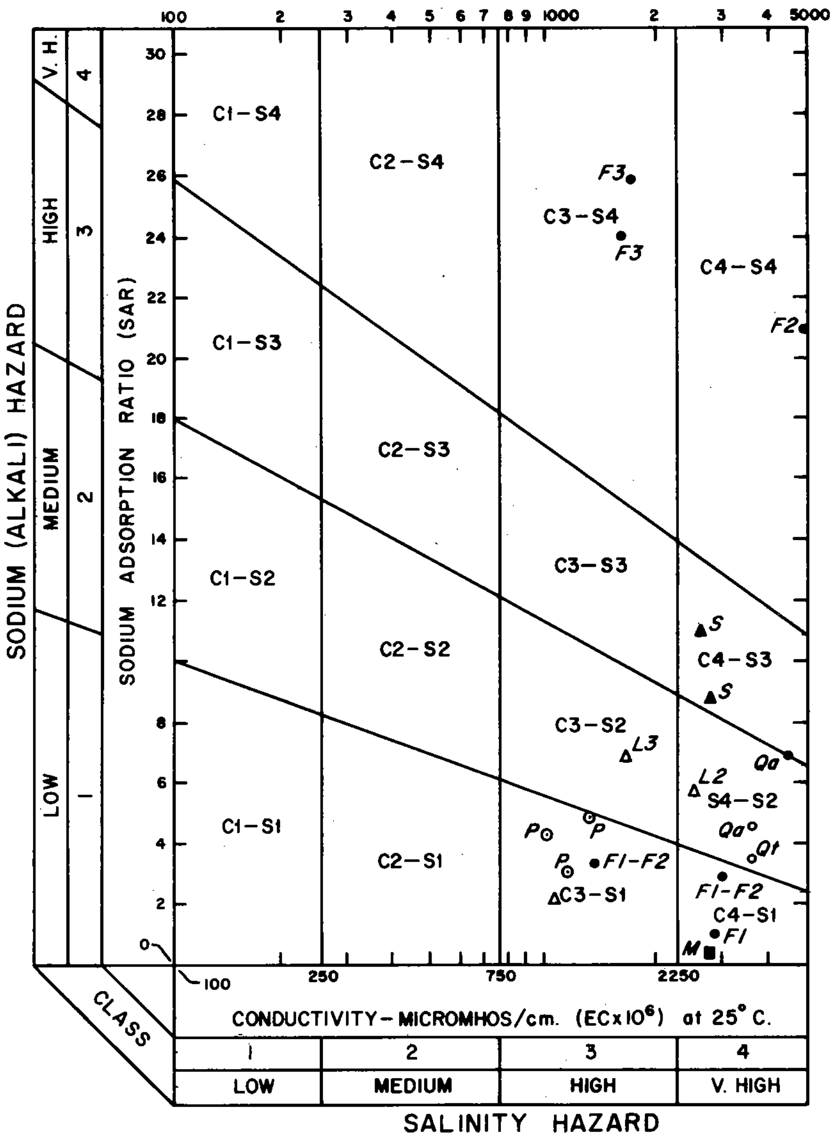


Figure 17. Irrigation classification of Fall River County aquifers.

LEGEND

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practice.

Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with a moderate salt tolerance can be grown in most cases.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants having a good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine textured soils having high cation-exchange-capacity. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes.

- ○ Quaternary alluvial and terrace deposits Qa and Qt
- ● Fall River Formation; F1 calcium-sulfate water, F2 sodium-sulfate water, and F3 sodium-bicarbonate water.
- △ Lakota Formation; L1 calcium-sulfate water, L2 sodium-sulfate water, and L3 sodium-bicarbonate water.
- ▲ Sundance Formation
- ■ Minnelusa Formation (Cascade Springs water)
- ⊙ Pahasapa Formation

hazard. However, desalinization techniques must first be improved to where they are economically feasible for irrigation purposes.

Industrial Water

Abundant supplies of ground water are available for use for light industry. No attempt will be made to delineate the application of water from the various aquifers to industrial purposes because of the many different types of industries that conceivably could locate in the area. Each type of industry, whether it be brewing, tanning, food processing, or literally dozens more, has its own requirements as to quality and quantity of water. The interested reader is referred to McKee and Wolf (1963) for detailed information regarding water quality criteria for specific industries.

Water Conservation

As a final statement, the author feels it appropriate to mention an existing condition which ultimately will have detrimental consequences for the citizens of the area. Because of the semiarid climate, water is the most important natural resource in western Fall River County. Historically, this nation has abused its natural resources since the first settlement at Jamestown. The American society was founded on the principal that individual land ownership is the right of all men. Individual property rights and the mistaken philosophy that the natural resources of the United States were inexhaustible have fostered an idea that the ground water found beneath an owner's land is his to use or misuse as he desires. This entire idea is wrong factually, legally, and morally. Time, especially the last 20 years, has shown that water resources are not inexhaustible. Western Texas has been "mining" water for years and the ground-water reserves are now approaching total depletion. Legally, the ground water of South Dakota belongs to the People of South Dakota, not the individual landowner. Wasting of ground water not only causes a reduction of the available water but also can lead to loss of hydraulic head and possible destruction of the aquifer. Recent studies have shown that aquifers that are overproduced often lose porosity and permeability due to compaction. In effect, mining may harm or destroy the aquifer forever. What right has one man to deny future generations water because of greed or pride?

The problem of loss of artesian head in the Fall River Formation has been noted earlier. Wasteful water practices by outside mining interests or individual landowners must not be condoned. Only an aware and aroused public can insure that uranium test holes are properly plugged. During the field investigation, it appeared to be the general policy to allow a flowing well to flow continuously, regardless of yield or actual water requirements. For instance, one well was flowing at 270 g.p.m. This yield would supply enough water to sustain over 24,000 cattle, which is more than half of the cattle in the County. Other ranches had two or more wells located within a few yards of each other, all of which were flowing. It is imperative that people stop such practices and become aware of their water resources. The formation of a water conservancy organization would benefit all citizens of the area in the wise development and utilization of the ground water in western Fall River County.

GLOSSARY OF GEOLOGIC AND HYDROLOGIC TERMS

Acre-foot (ac-ft): A unit used to measure the volume of water. It is equal to an acre of water one foot deep.

Alluvium: Silt, sand, and gravel deposited by streams.

Anticline: A structure formed by folding of the strata or beds upward. Its form may be likened to a hill.

Aquifer: A formation or permeable zone which produces water.

Dip: The angle between the bedding of a formation and a horizontal plane.

Drawdown: Lowering of the water table or potentiometric surface by pumping or artesian flow.

Electric Log: A log or graph of the electrical properties of the geological formations encountered during well construction.

Eolian: A term meaning wind deposited material, e.g., sand dunes.

Evapotranspiration: Water withdrawn from a river basin by evaporation from water surfaces and transpiration by plants.

Lacustrine: A term used to describe deposits formed in lakes.

Lithology: Physical character of a rock or composition of a rock.

Loess: A loose deposit of clay, silt, and fine sand deposited by wind.

Permeability: The capacity of a rock for transmitting a fluid. It depends on the size, shape, and interconnection of the pores in the rock.

Plunge: The vertical angle of a fold with respect to a horizontal plane.

Porosity: The volume of pore space (or voids between the grains of the rock) in relation to the volume of the rock. Expressed as a percentage.

Potentiometric Surface: A theoretical surface used to illustrate the static level of water in an aquifer.

Pyrite: An iron sulfide mineral (FeS_2), sometimes called "Fools Gold."

Saline Water: Water containing more than 1000 ppm of dissolved solids.

Salinity Hazard: The injury-causing potential of the total dissolved solids in water.

Sodium Hazard: The injury-causing potential of sodium in water.

Specific Conductance: Also called electrical conductivity. A term describing the ability of a fluid to transmit an electrical current.

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APPENDIX A

SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

Source of Data: Annual Summaries, Climatological Data, United States Department of Commerce, Weather Bureau.

All figures in inches of precipitation.

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR NEWCASTLE, WYOMING
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	.49	.50	.09	.38	.06	.46	1.61	2.68	3.08	.37	.58	.60	10.90
1950					.05	1.07	1.17	1.96	1.33	1.01	.63	1.20	8.69
1951	.54	.02	.16	.08		.07	.53	.96	2.38	1.59	1.78	1.84	9.95
1952	.15	.36	.71	.05	.21	1.27	.00	3.88	1.96	1.85	.74	.18	11.36
1953	.09	.31	.10	.85	.31	.48	2.54	1.34	3.16	1.11	4.01	.12	14.42
1954	.33	.54	.18	.07	.36	.62	.19	1.90	1.47	3.36	1.45	.00	10.47
1955	1.38	.25	.16	.75	.48	.86	.64	3.08	2.66	1.52	2.33	1.37	15.48
1956	.34	.91	1.14	.13	.16	.91	1.88	2.61	1.07	2.00	1.40	.04	12.59
1957	.53	.39	.37	.47	.25	.76	.78	4.42	4.31	1.95	.49	1.06	15.78
1958	.81	.62	.32	.25	.77	1.12	.63	1.37	3.34	5.46	.43	.01	15.13
1959	.33	.30	.46	.26	1.26	.55	.73	2.64	3.07	.64	.77	1.17	12.18
1960	.17	.78	.06	.19	.98	.27	1.05	.60	1.41	.11	.35	1.47	7.44
1961	.06	.47	.80	.00	.52	.56	.81	.83	1.25	1.03	.29	1.20	7.82
1962	1.02	.22	.43	.54	.99	.43	.59	5.74	4.12	1.95	.43	.73	17.19
1963	.08	.06	.30	.73	.41	.27	3.47	2.40	2.51	1.49	1.25	1.62	14.59
1964	.50	.00	.31	.10	.80	.42	1.68	2.26	6.04	.22	2.37	.53	15.23
1965	.00	.49	1.03	1.15	.23	.53	1.18	4.68	4.44	3.01	1.35	1.72	19.81
1966	.02	.28	.06	.23	.49	.48	2.58	.00	1.04	3.76	2.84	1.19	12.97
1967	.98	.97	.81	.50	.71	.73	2.65	1.68	3.15	1.98	1.12	2.85	18.13
1968	.65	.50	.60	.40	.60	.40	11.20	1.90	3.90	.60	1.50	1.50	13.75
TOTALS	8.47	7.97	8.36	7.12	9.64	12.26	25.91	46.93	55.69	35.01	26.11	20.40	263.88
AVERAGE	.45	.42	.44	.38	.51	.61	1.30	2.35	2.78	1.75	1.31	1.02	13.29

Note: 30 year normal equals 13.58

Source: Annual Summaries, Climatological Data,
U. S. Dept. of Commerce, Weather Bureau

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR SPENCER, WYOMING (STA. SPENCER 10-NE)
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	Records not available												
1950	Records not available												
1951	Records not available												
1952	1.00	.00	.57	.15	.57	1.63	.17	3.67	3.70	1.39	1.80	.08	14.73
1953		.76	.12	1.74	2.37	.42	2.17	1.24	1.65	1.23	2.74	.05	14.49
1954	.19	.58	.51	.15	.37	1.31	.08	2.66	1.44	2.96	1.92	.22	12.39
1955	1.89	.13	.18	.17	1.39	1.20	.68	3.68	2.49	1.83	2.03	.88	16.55
1956	.18	.76	.40	.14	.21	.94	1.71	3.34	.75	2.38	1.01	.00	11.82
1957	.96	.38	.21	.18	.12	.66	1.89	6.79	3.05	.56	1.00	1.29	17.09
1958	1.55	.23	.30	.11	.66	1.15	1.98	.71	2.58	5.75	.21	.07	15.30
1959	.00	.27	.16	.32	.26	1.01	.82	2.12	2.29	.78	.08	1.73	9.84
1960	.11	.51	.00	.26	.26	1.22	1.61	1.70	1.90	.65	.31	1.13	9.66
1961	.20	.21	.53	.06	.75	.79	1.14	.86	.41	2.25	.00	2.12	9.32
1962	Records not available												
1963	Records not available												
1964	Records not available												
1965	Records not available												
1966	Records not available												
1967	Records not available												
1968	Records not available												
TOTAL	6.08	3.83	2.98	3.28	6.96	10.33	12.25	26.77	20.26	19.78	11.10	7.57	131.19
AVERAGE	.608	.383	.298	.328	.696	1.033	1.225	2.677	2.026	1.978	1.110	.757	13.119

Note: 30 year normal equals 13.67

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR DEWEY, SOUTH DAKOTA (STA. DEWEY 9-NE)
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949		.68	.21	.61	T	.39	1.63	2.87	2.65	0.87		1.23	11.14
1950	.76		.36	.32	.06	1.46	1.45	1.31	1.24	1.31		2.13	10.40
1951	.46	.10		.09	.32	.35			4.22	2.72	2.29	2.59	13.14
1952	.95	.23	.56	.00	.32	1.33	.24	4.13	2.98	2.74	1.20	.49	15.17
1953	.20	.81	.04	1.04	1.23	.87	1.85	.82	2.45	2.53	1.21	.12	13.17
1954	.38	.78	.15	.04	.77	.96	.22	2.34	2.68	1.94	1.09	.52	11.87
1955	1.69	.09	.13	.80	.85	1.13	.94	3.85	2.06	2.69	2.56	1.08	17.87
1956	.29	.53	.91	.00	.42	.41	1.39	3.50	1.12	2.92	2.15	.04	13.68
1957	.78	.42	.46	.27	.15	1.48	1.06	4.60	5.60	.32	.42	1.87	17.43
1958	1.26	.32	.34	.13	.77	1.20	1.41	.66	2.36	6.43	.17	.19	15.24
1959	.08	.36	.52	.34	.65	1.01	1.10	2.24	3.50	2.41	.81	2.25	15.27
1960	.25	.71	.17	.29	.59	.41	.77	1.33	3.08	.87	.46	.32	9.25
1961	.00	.43	.58	.08	.38	.50	1.08	.79	.70	1.56	.78	1.93	8.81
1962	.41	.26	.24	.27	.86	.58	.66	5.65	4.28	4.95	.65	.34	19.15
1963	.27	.10	.18	.99	.29	.38	3.04	1.57	5.42	2.73	1.16	1.74	17.87
1964	.56	.00	.37	.33	.34	.86	2.29	2.06	6.35	.77	1.84	.76	16.53
1965	.09	.24	.99	.54	.46	.45	.75	4.97	5.64	2.86	1.31	2.02	20.32
1966	Station Discontinued												
1967	Station Discontinued												
1968	Station Discontinued												
TOTALS	8.43	6.06	6.21	6.14	8.46	13.77	19.88	42.69	56.33	40.62	18.10	19.62	246.31
AVERAGE	.53	.38	.39	.36	.50	.81	1.24	2.67	3.31	2.39	1.21	1.15	14.96

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR EDGEMONT, SOUTH DAKOTA
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNAUL
1949	1.05	.77	.34	1.50	.03	.35	1.61	2.91	1.18	1.00	1.35	1.00	13.09
1950	.75	.11	.27	.39	.05	1.63	1.55	1.65	1.41	1.27	1.45	1.64	12.17
1951	.38	.17	.27	.25	.12	.55	.64	2.44	3.51	2.85	.64	.73	12.55
1952	1.06	.03	.50	.00	.50	1.12	.15	3.35	3.63	.32	1.00	.16	11.82
1953	.28	.70	.20	.87	1.59	.30	1.89	.71	1.69	.91	.46	.39	9.99
1954	.20	.45	.25	.26	.54	1.41	.39	5.46	1.35	1.89	1.05	.71	13.96
1955	1.81	.09	.29	.30	.83	1.47	1.19	2.74	1.68	1.43	1.83	2.07	15.73
1956	.27	.84	.77	.07	.49	.36	1.53	3.64	2.06	.92	1.51	.30	12.76
1957	.66	.82	.39	.35	.12	1.47	1.30	5.98	2.61	1.10	.89	1.27	16.96
1958	1.03	.52	.20	.11	.60	1.53	1.80	.40	2.17	6.48	.67	.00	15.51
1959	.26	.28	.41	.66	.43	1.21	.55	1.99	2.84	1.59	.13	2.17	12.52
1960	.27	.59	.25	.33	.60	.28	1.46	.42	2.14	.82	.29	.32	7.77
1961	.02	.64	.84	.26	.25	.52	1.46	1.08	.29	1.75	.09	1.83	9.03
1962	.64	.49	.25	.27	.70	.73	.46	4.68	3.03	2.80	.49	.25	14.79
1963	.65	.38	.25	1.47	.37	.90	1.96	1.34	1.94	2.20	3.43	1.23	16.12
1964	.66	.08	.36	.22	.50	.61	1.83	2.31	4.34	.76	1.73	.43	13.83
1965	.18	.18	.69	.57	.62	.82	.83	5.97	3.52	3.26	.92	2.52	20.08
1966	.23	.17	.20	.14	1.14	.93	1.94	.42	.45	2.87	2.81	1.83	13.13
1967	1.50	.42	.52	.53	.31	.70	2.50	2.59	8.19	1.26	.25	1.18	19.95
1968	.43	.26	.90	.46	.42	.89	.97	2.68	3.19	.77	3.21	.36	14.54
TOTALS	12.33	7.99	8.15	9.01	10.21	17.78	26.01	52.76	51.22	36.25	24.20	20.39	276.30
AVERAGE	.617	.400	.407	.450	.511	.889	1.30	2.64	2.56	1.81	1.21	1.01	13.82

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR ARDMORE, SOUTH DAKOTA
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	1.52	.76	.60	2.05	.10		1.80	3.19	1.62	1.74	1.27	1.49	16.14
1950	1.19	.00	.52	.25	.00	.66		1.44			1.49	1.99	7.54
1951	.40	.09	.25	.06	.02	.79	.67	1.62	3.82		.95	2.34	11.01
1952	1.44	.00	.29	.00	.56	.47	.08	4.21	1.74	.78	1.90	.00	11.47
1953	.20	.66	.29	.75	1.44	.50	2.44	.59	2.65	.58	2.12	.39	12.61
1954	.23	.25	.50	.22	.61	2.26	.20	3.28	1.14	1.45	.78	.72	11.64
1955	1.82	.34	.23	.39	.75	.99	1.22	2.85	2.24	2.07	.87	3.03	16.80
1956	.32	1.02	.80	.36	.20	.50	1.41	3.10	3.35	.85	2.72	.20	14.83
1957	.30	1.85	.20	.16	.15	.90	1.69	5.96	2.89	2.94	.85	1.42	19.31
1958	1.23	.52	.20	.00	.60	1.19	3.11	1.34	3.34	6.13	.55	.00	18.21
1959	.00	.12	.18	.46	.36	.84	.37	2.94	2.87	2.19	.20	3.21	13.74
1960	.44	.26	.11	.51	.49	.61	1.49	1.06	.83	1.65	.48	.21	8.14
1961	.05	.95	.91	.14	.13	146	1.73	2.96	.84	3.70	1.11	.76	13.74
1962	.65	.07	.40	.19	1.21	.29	.23	5.69	3.51	4.02	.52	.19	16.97
1963	.81	.22	.29	1.11	.15	2.07	1.71	2.05	3.67	2.42	.60	1.53	16.63
1964	.97	.02	.31	.33	1.63	.31	3.03	2.58	4.52	.59	.42	.27	14.98
1965	.28	.07	.37	.56	.54	.64	1.30	5.65	1.96	3.65	.76	3.08	18.86
1966	.24	.21	.41	.69	1.18	.81	2.48	.31	1.09	2.71	2.92	.78	13.83
1967	2.74	.80	.39	.57	.21	.85	3.85	3.10	7.01	1.66	.12	.76	22.06
1968	.62	.33	.80	.23	.30	.44	2.78	3.42	4.05	1.74	4.93	.34	19.98
TOTAL	15.45	9.30	8.65	11.08	10.73	15.58	31.59	57.34	53.14	40.87	25.56	24.20	303.49
AVERAGE	.7725	.4650	.4325	.5540	.5365	.3200	1.61	2.867	2.81	2.81	1.278	1.21	15.62

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR ANGOSTURA DAM, SOUTH DAKOTA
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	1.24	.28	.42	1.58	.00	.41		4.61		1.81	.87	.89	12.11
1950	.79	.01	.52	.30	.07	1.02	1.72	1.69	.77	1.01	1.83	2.31	12.04
1951	.34	.28	.16	.22	.16	.76	.76	1.11	3.86	3.89	1.33	2.83	15.70
1952	1.04	.21	.46	.03	.71	.84	.31	4.53	3.04	1.39	1.40	.03	13.99
1953	.21	.96	.17	.84	.98	.46	2.86	1.42	2.14	1.62	1.23	.79	13.68
1954	.26	.29	.31	.17	.54	1.49	.69	3.29	1.98	1.48	.23	.65	11.38
1955	2.23	.20	.16	.33	1.26	1.18	.69	2.93	2.04	2.07	3.29	3.93	20.31
1956	.42	.35	.66	.29	.24	.48	1.09	5.09	1.97	1.22	1.38	.24	13.43
1957	.06	1.20	.57	.32	.22	1.84	2.44	6.11	3.10	1.65	1.89	1.19	20.59
1958	1.76	.38	.10	.07	.97	1.52	2.86	.87	2.49	3.70	.36	.06	15.14
1959	.16	.25	.30	.37	.29	.62	.76	2.95	3.69	1.23	.30	3.12	14.04
1960	.27	.55	.28	.41	.70	.17	.83	.82	2.74	.35	.48	.10	7.70
1961	.00	.87	.65	.05	.30	.94	1.06	3.02	1.15	2.98	.22	1.15	12.39
1962	.44	.36	.34	.23	.87	.83	.25	6.08	5.17	3.44	.50	.58	19.09
1963	2.19	.18	.27	.32	.35	2.22	3.41	1.58	5.75	3.51	1.46	2.90	24.14
1964	.95	.00	.22	.14	.67	1.26	2.14	3.28	4.20	.19	.88	.19	14.12
1965	.00	.88	.52	.59	.46	.83	1.30	4.27	3.86	2.70	1.47	2.30	19.18
1966	.30	.20	.26	.22	.59	.35	2.47	.31	.56	4.08	2.52	2.13	13.99
1967	1.19	.52	.38	.32	.10	.95	1.74	3.56	7.09	.68	.21	.76	17.50
1968	.49	.27	.75	.20	.13	.84	1.03	2.87	6.25	1.68	1.83	1.17	17.51
TOTALS	14.34	8.24	7.50	7.00	9.61	19.01	28.41	60.39	61.85	40.68	23.68	27.32	308.03
AVERAGE	.72	.41	.38	.35	.48	.95	1.50	3.02	3.25	2.03	1.18	1.27	15.54

APPENDIX A. SELECTED PRECIPITATION DATA FOR THE CHEYENNE RIVER BASIN

PRECIPITATION DATA FOR HOT SPRINGS, SOUTH DAKOTA
Monthly and Yearly Precipitation in Inches

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	1.43	.24	.37	1.39	.00	.24	.99	6.08	2.74	2.64	1.65	.91	18.68
1950	.60	.04	.47	.16	.04	1.45	2.32	1.46	.91	2.12	1.97	3.35	14.89
1951	.33	.19	.13	.26	.13	.28	.67	1.48	4.01	2.53	2.10	2.27	14.38
1952	.44	.17	.23	.03	.66	.94	.22	4.30	3.00	.70	.88	.22	11.79
1953	.17	.61	.21	.87	.78	.22	2.21	1.52	2.11	1.70	1.24	1.31	12.95
1954	.15	.47	.12	.32	.61	1.03	.60	2.79	2.59	.92	.49	.83	10.92
1955	2.20	.17	.19	.27	1.04	1.12	.45	2.68	1.96	2.34	1.24	3.84	17.50
1956	.32	.42	.53	.21	.31	.29	1.08	3.50	1.73	1.22	1.38	.61	11.60
1957	.12	.72	.40	.44	.17	1.39	2.48	5.65	3.33	1.33	1.19	1.29	18.51
1958	1.51	.16	.09	.08	.82	.61	2.02	1.19	1.82	7.61	.11	.04	16.06
1959	.15	.24	.16	.54	.18	.40	.80	2.52	3.97	1.61	.24	2.64	13.45
1960	.15	.54	.25	.11	.44	.20	.62	.27	1.88	.25	.76	.18	5.65
1961	.03	.77	.64	.03	.19	1.01	.89	2.70	1.16	4.54	.18	1.48	13.62
1962	.51	.21	.26	.09	.69	.77	.24	4.78	3.93	5.65	.33	.50	17.96
1963	1.82	.14	.28	.45	.31	1.10	2.40	2.28	5.52	3.65	.93	2.61	20.49
1964	.89	.02	.16	.11	.45	.83	1.47	2.76	4.38	.33	.73	.34	12.47
1965	.71	.23	.76	.42	.48	.86	1.01	5.74	3.47	1.55	1.01	2.18	18.42
1966	.15	.23	32	.37	.75	.27	2.29	.09	1.03	3.70	2.60	1.78	13.58
1967	1.00	.45	.38	.43	.12	.72	2.16	3.08	7.87	1.01	.31	.65	18.18
1968	.35	.17	.78	.30	.12	.63	.85	2.75	4.60	3.99	1.72	.68	16.94
TOTAL	13.03	6.19	6.73	6.88	8.29	14.36	25.77	57.62	62.01	48.39	21.06	27.71	298.04
AVERAGE	.6515	.3095	.3365	.344	.4145	.718	1.2885	2.881	3.10	2.4195	1.053	1.3855	14.90

Note: 30 year normal equals 16.06

APPENDIX B

SELECTED STREAMFLOW RECORDS OF THE CHEYENNE RIVER

Source of Data: USGS Water-Supply Paper 1729 and Annual Surface Water Summaries for South Dakota, water years 1961 through 1968.

Figures expressed in acre-feet except bottom line which is expressed as inches of runoff per square mile of drainage basin.

APPENDIX B. SELECTED STREAMFLOW RECORDS FOR THE CHEYENNE RIVER

STATION 3865 - CHEYENNE RIVER NEAR SPENCER, WYOMING

Monthly and Yearly Discharge in Acre-feet

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	21	78	0	0	5,040	4,890	142	5,440	5,810	76	820	26	22,340
1950	1.8	0	0	0	0	2.8	585	3,350	5,510	9,740	140	23	19,350
1951	0	0	0	0	0	0	0	0	12,340	26,120	9,800	15,630	63,890
1952	35	0	0	0	37	400	16	21,830	23,380	7,470	3,670	3	56,840
1953	0	0	0	0	0	1,980	522	3,970	4,610	98	2,240	0	13,420
1954	0	0	0	0	0	0	32	5.6	40	1,270	7,410	0	8,760
1955	0	0	0	0	0	4,920	29,840	10,740	16,320	992	25,160	2,400	90,370
1956	94	15	79	0	47	498	133	5,060	8,380	115	1,970	0	16,390
1957	0	0	0	0	0	0	72	19,810	20,140	2,910	5,230	1,110	49,270
1958	6.7	2	0	0	124	934	5,130	470	5,910	41,790	5,750	0	60,120
1959	0	0	0	0	0	317	43	934	7,870	2,180	0	0	11,340
1960	0	0	0	0	0	0	0	84	2,790	1,450	0	0	4,320
1961	0	0	0	0	0	0	0	44	921	3,170	3,020	146	7,300
1962	0	0	0	0	3,680	597	0	102,200	74,960	18,680	2,330	79	202,600
1963	1,750	123	112	38	6,670	531	1,550	5,010	26,660	5,650	98	5,690	53,870
1964	2.0	0	0	0	0	48	109	537	8,770	2,240	9	0	11,710
1965	0	0	0	3	0	0	1	10,320	37,310	8,250	1,010	5	56,910
1966	20	13	6	0	0	4,860	328	81	0	10,530	8,190	646	24,670
1967	634	71	37	208	160	687	2,430	5,480	32,800	6,770	60	39	49,380
1968	0	0	0	0	13	216	667	1,080	11,860	635	2,780	1,730	19,000
TOTAL	2,564.5	3,020	3,340	246.0	15,771.0	20,880.8	41,600	196,446	306,381	150,136	79,687	27,524	841,850
AVERAGE	128	156	167	124.5	788.5	1,044	2,080	9,823	15,318	7,506	3,983	1,376	42,093
AVE ac-ft /sq. mi.	.02	.03	.03	.02	.15	.20	.39	1.86	2.91	1.42	.76	.26	7.99
AVE in/sq mi	.0004	.0005	.0005	.0004	.0028	.0038	.0073	.0349	.0546	.0266	.0142	.0049	.15

Source: USGS Water Supply Paper 1729 and Annual Surface Water Summaries for South Dakota.

APPENDIX B. SELECTED STREAMFLOW RECORDS OF THE CHEYENNNE RIVER

STATION 3940 - BEAVER CREEK - DRAINAGE AREA 1320 SQ. MI.

Monthly and Yearly Discharge in Acre-feet

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	559	733	472	432	434	15,090	3,950	2,330	7,600	251	721	349	32,920
1950	700	151	27	46	399	1,420	4,360	2,980	540	10	100	192	10,920
1951	739	500	509	74	357	1,420	622	128	1,340	1,040	1,510	3,430	11,670
1952	148	690	205	127	959	4,830	1,550	3,930	1,020	2,930	18	69	16,480
1953	0	73	566	571	495	6,380	439	4,040	8,460	486	6,580	135	28,220
1954	30	407	432	437	821	795	195	90	828	415	1,650	0	6,100
1955	40	30	370	258	290	6,630	5,320	6,960	1,870	85	1,070	1,350	24,270
1956	146	247	1,300	725	4,680	4,570	274	952	542	826	311	0	14,570
1957	553	284	116	114	1,910	2,550	208	3,400	7,430	1,360	1,550	3	19,480
1958	161	828	432	194	463	1,500	1,920	38	749	6,710	206	90	13,290
1959	162	215	188	197	382	2,960	275	103	1,730	409	504	8	7,130
1960	97	135	111	161	242	4,710	65	24	1,880	17	1	0	7,440
1961	0	11	48	187	449	227	23	4	166	2,590	2	8	3,710
1962	81	38	23	21	7,910	7,010	48	24,510	33,380	19,700	1,100	250	94,080
1963	118	412	612	493	635	1,230	2,200	2,580	11,680	582	122	146	20,800
1964	97	258	576	620	583	1,190	2,580	3,210	17,470	1,460	151	229	28,430
1965	241	399	793	1,170	1,150	2,240	2,740	7,040	17,290	4,230	1,030	1,010	39,350
1966	2,070	590	587	397	399	5,300	1,330	528	82	5,020	5,480	372	22,160
1967	1,430	859	900	2,280	4,050	12,000	1,420	5,690	5,330	2,160	333	1,280	37,730
1968	628	511	527	551	2,200	8,610	750	504	2,730	703	331	663	18,710
TOTAL	8,000	7,371	8,794	9,055	28,808	90,662	30,269	69,041	122,117	50,984	22,770	9,584	457,460
AVERAGE	400	369	440	453	1,440	4,533	1,513	3,452	6,106	2,549	1,139	479	22,873
AVE ac-ft /sq. mi.	.30	.28	.33	.34	1.09	3.43	1.15	2.62	4.63	1.93	.86	.36	17.33
AVE in/sq.mi.	.0056	.0053	.0062	.0064	.0205	.0644	.0216	.0492	.0869	.0362	.0161	.0068	.33

APPENDIX B. SELECTED STREAMFLOW RECORDS OF THE CHEYENNE RIVER

STATION 3950 -- EDGEMONT, SOUTH DAKOTA - DRAINAGE AREA - 7,143 SQ. MI.

Monthly and Yearly Discharge in Acre-feet

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	362	630	492	99	4,290	19,750	4,290	7,220	12,250	515	1,310	405	51,880
1950	57	153	5	0	311	1,280	5,150	6,050	4,870	8,900	203	167	27,660
1951	421	202	54	5	86	1,030	712	79	12,120	22,300	16,140	15,770	68,920
1952	272	268	39	12	181	2,360	1,960	26,860	28,690	9,320	3,530	8	73,500
1953	12	14	14	70	365	10,890	895	6,890	12,710	676	9,480	79	42,100
1954	7	130	169	118	726	936	265	2,840	416	1,220	8,040	1	14,870
1955	2	5	10	5	6	11,050	33,230	13,810	16,380	1,360	23,840	4,890	104,600
1956	188	94	1,650	520	3,840	7,220	504	5,590	9,900	483	1,730	0	31,720
1957	78	526	130	2	1,480	3,570	238	31,680	29,010	4,870	6,100	1,530	79,210
1958	201	1,040	254	80	474	2,110	6,100	317	5,870	49,530	8,110	22	74,110
1959	22	172	31	6	28	3,840	363	279	9,710	2,930	231	15	17,620
1960	6	4	0	0	0	6,840	89	17	4,950	475	0	0	11,880
1961	0	4	7	0	380	208	13	205	603	4,590	3,290	39	9,340
1962	0	1	2	2	3,590	5,140	79	133,800	124,000	39,240	8,170	383	314,400
1963	1,290	511	636	46	6,580	3,550	3,650	9,690	36,170	4,380	105	5,560	72,170
1964	51	136	163	0	60	1,720	3,320	3,880	26,810	3,830	119	66	40,150
1965	142	202	215	382	886	2,410	2,840	19,820	55,060	15,640	2,890	1,390	101,900
1966	2,390	614	540	257	132	9,850	2,030	645	105	14,690	14,090	1,020	46,360
1967	2,770	1,190	1,100	986	2,930	7,260	3,700	9,350	44,040	10,140	640	1,120	85,240
1968	543	695	906	373	1,020	6,440	1,450	1,350	15,260	1,700	3,660	2,230	35,940
TOTAL	8,814	6,591	6,417	2,963	27,365	106,954	70,878	280,369	448,924	196,789	111,678	34,695	1,303,570
AVERAGE	441	330	321	148	1,368	5,248	3,434	14,018	22,446	9,389	5,584	1,735	65,179
AVE. ac-ft /sq. mi.	.06	.05	.04	.02	.19	.73	.48	1.96	3.14	1.31	.78	.24	9.13
AVE. in/sq. mi.	.0011	.0009	.0008	.0004	.0036	.0137	.0090	.0361	.0585	.0246	.0146	.0045	.17

APPENDIX B. SELECTED STREAMFLOW RECORDS OF THE CHEYENNE RIVER

STATION 4000 - HAT CREEK - DRAINAGE AREA 1044 SQ. MI.

Monthly and Yearly Discharge in Acre-feet.

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1951	61	0	1	43	62	325	41	173	6,420	10,720	2,100	2,110	22,060
1952	212	202	141	33	377	4,400	641	3,480	5,890	930	609	8	16,920
1953	5	8	7	145	290	5,830	584	1,120	870	0	25	1	8,890
1954	0	0	0	0	0	496	174	8,280	445	67	132	0	9,590
1955	0	2	12	4	0	4,940	5,840	1,840	1,060	0	4,210	4,170	22,080
1956	148	42	981	226	188	651	47	1,250	1,160	615	396	0	5,700
1957	0	111	148	29	327	582	3,290	27,270	6,290	1,340	87	94	39,570
1958	182	129	113	136	208	833	1,740	54	1,010	6,510	244	0	11,160
1959	0	0	1	94	30	2,310	27	681	1,300	2,470	12	224	7,150
1960	30	19	38	20	46	1,320	164	328	43	0	0	0	2,010
1961	0	0	0	0	1	372	21	29	12	389	124	0	949
1962	0	0	0	0	1	656	22	4,530	7,990	2,500	155	0	15,860
1963	14	1	0	1	1,280	2,090	222	193	4,320	240	8	109	8,470
1964	57	5	2	8	5	45	706	215	3,120	29	0	0	4,190
1965	0	0	0	0	3	13	49	5,660	3,490	3,900	81	157	13,340
1966	405	98	47	87	83	5,880	929	74	9	796	2,760	13	11,180
1967	390	61	19	15	89	28	1,620	1,800	72,750	4,340	242	67	81,420
1968	108	400	216	277	657	315	8,370	3,070	16,190	5,570	1,940	108	37,220
TOTAL	1,612	1,078	1,726	1,118	3,647	31,086	24,487	60,047	132,369	40,416	13,125	7,061	317,759
AVERAGE	90	60	96	62	203	1,727	1,360	3,336	7,354	2,245	729	392	17,653
AVE ac-ft /sq. mi.	.09	.06	.09	.06	.19	1.65	1.30	3.20	7.04	2.15	.79	.38	16.91
AVE in/sq mi	.0016	.0011	.0017	.0011	.0036	.0310	.244	.0600	.1321	.0403	.0149	.0070	.32

APPENDIX B. SELECTED STREAMFLOW RECORDS OF THE CHEYENNE RIVER

STATION 4005 - CASCADE - DRAINAGE AREA 8710 SQ. MI.

Monthly and Yearly Discharge in Acre-feet.

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1949	1,350	2,170	1,570	1,460	11,790	52,670	7,910	12,650	14,910	1,950	1,820	1,190	111,400
1950	1,360	1,590	1,340	1,700	2,350	4,160	9,320	10,500	7,690	11,300	2,070	1,340	54,720
1951	1,800	1,430	1,440	1,450	1,670	3,860	2,200	1,000	24,650	38,860	23,330	24,160	125,800
1952	2,040	2,250	1,750	1,420	2,590	7,250	5,100	28,980	38,100	14,680	6,030	851	111,000
1953	1,120	1,160	1,120	1,590	2,640	17,190	3,100	6,620	16,220	1,110	10,730	1,470	64,070
1954	1,470	1,290	1,400	1,200	2,380	3,140	1,820	14,370	2,340	3,260	10,350	811	43,830
1955	1,260	1,220	1,310	1,260	1,290	15,910	52,930	19,410	21,400	2,820	29,860	10,820	159,500
1956	1,990	1,450	3,780	2,330	3,860	8,920	2,020	8,870	13,250	1,340	2,790	970	51,570
1957	926	1,210	1,410	1,170	2,180	4,720	5,780	70,800	36,750	6,500	6,890	2,220	140,600
1958	1,650	2,550	1,560	1,420	1,830	4,700	9,230	1,040	7.420	57,400	13,170	859	102,800
1959	966	1,230	1,160	1,100	1,090	6,160	1,590	1,450	11,500	6,690	724	902	34,560
1960	976	1,070	1,230	1,220	1,400	7,450	1,540	1,630	5,180	819	659	833	24,010
1961	1,320	1,160	1,410	1,310	1,260	1,890	1,380	1,040	2,040	5,660	2,990	936	22,390
1962	1,370	1,470	1,190	1,200	5,010	9,410	1,250	116,500	134,900	48,600	7,990	1,410	328,300
1963	3,110	1,980	1,820	1,440	8,830	6.860	4,490	9,600	40,770	5,130	1,040	5,690	90,770
1964	1,160	1,060	1,190	1,260	1,570	3,190	5,320	5,440	29,410	4,370	1,050	1,080	56,100
1965	1,200	1,200	1,310	1,740	2,140	4,960	5,290	27,700	61,460	20,810	3,980	2,260	134,100
1966	4,250	1,920	1,750	1,690	1,390	16,900	4,770	1,750	833	15,420	19,160	2,310	72,140
1967	4,260	2,780	2,330	2,420	5,180	30,850	6,410	11,370	114,300	20,290	2,420	2,390	205,000
1968	1,540	2,240	2,030	1,800	3,720	8,420	4,940	3,580	27,990	7,370	6,330	2,930	72,890
TOTAL	35,118	32,430	32,100	30,180	64,170	218,610	136,390	354,300	611,113	274,279	153,383	65,432	2,005,550
AVERAGE	1,756	1,622	1,605	1,509	3,209	10,931	6,820	17,715	30,556	12,719	7,669	3,272	100,278
Ave ac-ft /sq. mi.	.20	.19	.18	.17	.37	1.25	.78	2.03	3.51	1.46	.88	.38	11.51
Ave in/sq mi	.0038	.0036	.0034	.0032	.0069	.0235	.0146	.0380	.0659	.0274	.0165	.0071	.22

APPENDIX C

WELLS, SPRINGS, AND REFERENCE DATA

Location: Location of well.

Source: Source of data. *I*,Interview with owner; *S*, Files, South Dakota School of Mines and Technology; *SG*, South Dakota Geological Survey; *MDI*, Mining Development Industries; *SW*, Susquehanna Western Inc.; *H*, Homestake Mining Company; *AEC*, Atomic Energy Commission; *SE*, South Dakota State Engineer; *US*, United States Geological Survey; *1534*, Water-Supply Paper 1534; *428*, Water-Supply Paper 428.

Owner: Name of landowner or name of oil test.

Type: Type of data. *W*, Artesian water well; *SW*, Surface water well; *SP*, Spring; *O*, Oil test; *U*, Uranium test.

Elevation: Surface elevation or rotary table elevation of well.

Depth: Depth of well in feet.

Water Level: Depth to water (static level) in feet below ground surface.

Aquifer: Reported aquifer. *Qt*, Quaternary terrace deposits; *Qw*, Quaternary eolian (windblown) deposits; *Qa*, Quaternary alluvial deposits; *Kp*, Pierre Formation; *Kn*, Niobrara Formation; *Kc*, Carlile Formation; *Kg*, Greenhorn Formation; *Kgs*, Graneros Group; *Kf*, Fall River Formation; *Kl*, Lakota Formation; *Ju*, Unkpapa Sandstone; *Js*, Sundance Formation; *TRs*, Spearfish Formation; *Pmk*, Minnekahta Limestone; *Cml*, Minnelusa Formation; *Cp*, Pahasapa Formation.

Selected Formation Tops: Depth, in feet, to top of respective formation. All symbols same as above except for *Knc*, Newcastle Formation.

Remarks: *WA*, Water analysis; *SC*, Specific conductance; *TDS*, Total dissolved solids; *P€*, Precambrian.

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	Knc	FORMATION Kf	Kl	Js	TOPS TRs	Pmk	€ml	REMARKS
7-1-2bb$_1$	MDI	E. Darrow	U	3705	495	F				105	260					Morrison 480
2bb$_2$	I	E. Darrow	W	3708	370		Kf									H_2S "Linch Well"
2bc	I	E. Darrow	W	3700	280	16	Kl									
2cc	S,SG	E. Darrow	W	3680	470	F	Kl									
2dd	S	Dolezal #1 Darrow	O	3797K	2450					230	350	642	992	1479	1577	
3bb	I	M. Spencer	W	3660	500	F	Kl									30 gpm WA
4dd$_1$	MDI	G. Coats	U	3637	735	F				450	570					
4dd$_2$	MDI	G. Coates	U	3645	805	F				475	645					Morrison 805
5ac	AEC	L. Putnam	W	3600	?	F	Kl									30 gpm WA
9ad	S	CBO RR	W	3615	550	F	Kl									WA
11bc	MDI	E. Darrow	U	3678	525	F				175	305					Morrison 520
11cc	AEC	F. Peterson	W	3700	?		Kl									WA
12bc	S,I	W. E. Heck	W	3750	156		Kf			140						16 inch dia.
14db	I	G. Peterson	W	3610	280		Kl									Old uranium test
14dd	I	G. Peterson	W	3625	90?	F	Kf				371	670		1518	1645	Converted to well, 10 gpm flow/890
15dd	I,SG	Superior #1 Peterson	O	3576	2264	F	Js			185						Sc 1690
16dd	S	F. Peterson	W	3555	640	F	Kl									
17bb	I	W. E. Heck	W	3595	80	F	Oa									WA
17cc	S,I	E. Anderson	W	3555	530	F	Kf				710					Morrison 950
18cb	H	Homestake	U	3615	935					565						Converted to well 350 feet deep
19bb	SG,I	Big 3 #1 Gov't.	O	3585	910		Kf			322						1 gpm, could not locate
20cc	1534	A. Nelson	W	3586		F								1726	1895	Cp at 2990
21da	SG	Sun #1 Lance	O	3535	3057					366	415	750	1122	1610	1690	Morrison 560
22db	SG	Conroy #1 Peterson	O	3522	2400					260						H_2S "McCloud Well"
23bb$_1$	IS	G. Peterson	W	3574	500	F	Kl									
23bb$_2$	I	G. Peterson	W	3574	200	8	Kf									WA
23dc$_1$	I,AEC	G. Coates	W	3542	500	F	Kl									Perforated at 158-168 & 220-230
23dc$_2$	I	G. Coates	W	3542	240	F	Kf-Kl									
23dd	I	G. Coates	W	3550	?	F					240	548	942	1395	1470	Water flows at 50 feet
24cb	SG	Conroy #1 State	O	3577	2480					50						

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	FORMATION Knc	Kf	Kl	Js	TOPS ₨s	Pmk	Cml	REMARKS
7-1-25da	I	A. Manke	W	3530	90	F	Kf				196					Flow at 90-96 feet
$25db_1$	I,MDI	W. E. Heck	W	3508	375	F	Kf			95						
$25db_2$	I	W. E. Heck	W	3510	230	F	Kf									
$25db_3$	I	W. E. Heck	W	3510	230	F	Kf				165					Flow at 90-96 feet
25dd	MDI	W. E. Heck	U	3508	450	F	Kf			50						1 gpm
27ac	I,S	M. Miller	W	3560	?	F										2 gpm
29bb	I	M. Miller	W	3590	600	F	Kf				640	947			2020	
33ad	S	Gary 8-33 Fed.	O	3677	2875					560						20 gpm
35ac	I	M. Miller	W	3545	350	F										SC 1600
35da	I	C. Tubbs	W	3555	320	F										SC 1450
35dd	I	C. Tubbs	W	3555	320	F										Flows 15 gpm
36aa	I	A. Manke	W	3500	92	F	Kf									Converted uranium test
36ac	I	A. Manke	W	3535	100+	F	Kf									
7-2-1ca	I	J. Munger	SW	3980	16	11	Qa									
1db	I	G. Hey	SW	3975	14	10	Qa									Hard, gypsum
2bd	I	G. Hey	W	4075	125	100	Js									3.5 gpm
2ca	I	J. Munger	W	4100	179	60	Js									
3ac	I	M. Spencer	W	4150	247		Js									
6ca	S	M. Spencer	SW	3860	40		Qa									Forest Service
7bd	S	M. Spencer	SW	3810	80											Forest Service
7cb	I	Bennett Canyon Well	W	3755	365	280	Kl									
8bd	I	M. Spencer	W	3970	470		Js									
9ca	I	D. Spencer	W	4050	605		Js									Basal Sundance @ 570
10ac	SG	Gary #10-7 Fed	O	4339	2112							355	705	1218	1350	Morrison 230
12ab1	I	J. Munger	W	3960	108		Js									Top 5 feet pf Basal Sundance
12ab2	I	J. Munger	W	3960	200		Js									Old well, contaminated
12ba	I	M. Spencer	W	3955	161		Js									
12cal	I	M. Spencer	W	3950	170		Js									Pumps dry

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS Kg	Knc	Kf	Kl	Js	TRs	Pmk	Cml	REMARKS
7-2-12ca2	I	M. Spencer	W	3950	80		Js									10 gpm
12cc1	I	M. Spencer	W	3980	160		Js									3 gpm
12cc2	SG	Ozark #1 Robinson	O	3983	1526									800	908	Goose-egg 480, Opeche 842
13ca1	S,I	G. Hey	W	3950	162	30	Js									4 gpm
13ca2	I	G. Hey	W	3950	65	50	Js									Hard, gypsum
16ca	S	G. Hey	W	3800	120											Forest Service
19bd	I	A. Manke	W	3670	145	F	Kl									30 gpm
19cd	I	A. Manke	W	3368	148	F	Kl									2 gpm
19dc	MDI	A. Manke	U	3600	255	F					20					Chilson sand 105
21ac	SG	Conroy #1 Trotter Lane	O	3821	2225							265	635	1120	1237	3 gpm artesian water/Sundance
22d	S	Coal Canyon Well	SW	3900	20		Qa									
26ac	SG	Ackman Schulein #26-7	O	4160	2302						160	450	690	1246	1296	Morrison 250
30bb	MDI	A. Manke	U	3670	330	F	Kl				140					Converted to well 10 gpm(140 ft)
30cc	I	A. Manke	W	3522	90	F										Domestic
31aa	I	F. A. Heck	W	3545	100+	F	Kf									
31ac	SG	Gary 7-31 Dodson	O	3521	2333	F	Kf					547			1535	Morrison 395, converted to water well 140 feet.
31bc	I	F. A. Heck	W	3495	104	F	Kf									
31dd1	I	H. Dodson	W	3500	120	F	Kf									
31dd2	I	H. Dodson	W	3500	120	F	Kf									
31dd3	I	H. Dodson	W	3500	130	F	Kf									
32dd1	I,S	E. Gow	W	3560	600	F	Kl									SC 2620
32dd2	I	E. Gow	W	3570		F										3" converted uranium test
32c	I	H. Dodson	W	3535	90	F	Kf									
34cc	I	R. Runge	W	3640	200+	F	?									
35dd	I	J. Standen	W	3900	300	200	Kl									4 gpm, high iron
7-3-2cd	I	P. Anderson	W	4050	72	40	TRs									
9bc	I	J. Munger	W	3835	265	20	Js									water at 90 & 135-180
10cd	SG	Gary 10-14 Federal	O	4007	1248									281	496	Opeche 295
11cd	I	P. Anderson	SW	4200	7	1	TRs									Excellent producer
18cc	I,S	G. Hey	W	3990	270	60	Js									

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS Kg	Knc	Kf	Kl	Js	TRs	Pmk	Cml	REMARKS
7-3-20bd	I	F. Albright	SW	3750	15	11	Qa									
20cd	I	G. Hey	W	3755	100	60	Js									
24ac	I	P. Anderson	W	4200	100	70	Js									15 gpm
24bb	I	P. Anderson	W	4260	100		Js									
25ba	I	B. Miller	W	4200	435		Js									
25ca	I	B. Miller	W	4200	300		Js									
25dc	I	B. Miller	W	4150	300		Js									Dry
32dd	I	F. Albright	SW	3700	22	18	Qa									
35bc	I	L. C. Reider	SW	4450	25	20	Qa									Good water
7-4- 6bc	I	L. C. Reider	SW	4350	44	16	Qa									Hard, gravel 20-22
19ba	S	CBQ RR	W	4163	1348									558		Old well, little water
19dd	I	P. Anderson	W	4160	55		TRs									
29dc	I	B. Miller	W	4300	435		Js									0-145 shale, 145-150 sand, 150 red beds? WA
30dc	SG	Austral #1 Miller	O	4263	1680								320	740	1,335	Basal Sundance 270, Opeche 790
7-5-21cd	SG	Pac-Am. Rapid City #1	O	4260	1212											Precambrian 1115
7-7-34bc	SG	Atlantic #1 Emick	O	3086	1151			870								Niobrara 247(H_2S water) Turner Sand 703 (water)
7-9- 3dd	SG	Pure #1 Gov't. C	O	3150	2352			1655	2231							
9dd	SG	Gary 9-16 Federal	O	3198	2561			1768	2318							Niobrara 1318, Skull Creek 2376
15cd	SG	Ackman-Schulein 15-14	O	3237	2452			1796	2214	2360						Niobrara 1114, Carlile 1446
20bd	SG	Phillips #1 Gov't. A	O	3234	2655			1754	2170	2568						
8-1- 1ab	S,I	C. Tubbs	W	3548	380	F	Kl									SC 1460, Temp 56.5° Flows 40 gpm
2d	I	M. Porter	SW	3560	24	18	Qa									Hard 3 gpm
6dd	H	Homestake	U	3850	1180					740	830					Morrison 1115
10aa	H	Homestake	U	3680	1020					590	673					
12ad	S,SG	Gary 8-12 Federal	O	3680	2760					500		995	1,330	1,815	1,966	Morrison 800, Lk Chilson 725

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	Knc	FORMATION Kf	Kl	Js	TOPS TRs	Pmk	Cml	REMARKS
8-1-14bb	M	Unknown	W													No information
17ag	I	M. Miller	SW	3505	25		Kgs									
22bd	H	Homestake	U	3760	1310					964	1,035					Morrison 1310
30dc	I,SG	Beebe and Marke	W	3850+	1640	240	Kl			1339	1,392					Morrison 1635 WA
34ab	H	Homestake	U	3890	1520					1250	1,325					Morrison 1516
8-2- 2ac	I	R. Runge	W	3652	200	80	Kl									
2ad	I	R. Runge	W	3650	200		Kl									Domestic
3cc	I	R. Miller	SW	3558	18	7	Kgs									Hard
3cd	I	R. Miller	W	3550	155		Kf			57						Reported Lakota
4ca	S	B. Childers	W	3530	350						235					Old record, no confirmation
4db	I	R. Miller	U	3570	110	F	Kf									1 gpm Trace H_2S
4dd	SG	Marietta #1 Miller	O	3559	1800+	F	Kl					727				Presently water well 300' deep
5aa	I	E. Gow	W	3564	600	F										H_2S
5ba	I	F. A. Heck	W	3530	118	F	Kf			102						H_2S @ 118' 10 gpm
5bb	I	H. Dodson	W	3520	100	8	Kf									H_2S
5da	SW	E. Gow	U,W	3525	270	F	Kf			28	180					Strong H_2S
5dd	I	J. McElhaney	W	3517	230	F	Kl									2 gpm
5dd2	I	J. McElhaney	W	3517	230	F	Kl									2 gpm
6md1	I	E. Benton	W	2512	210	F	Kf									1st sand (4') @ 157 H_2S SC 1570
6md2	I	E. Benton	W	3512	305	F	Kf									2nd sand (2') @ 305' SC 1700
6cb	I	C. Tubbs	W	3545	360	F	Kl									H_2S
7ab	H,I	C. Tubbs	U,W	3530	690	1	Kf			240	320					Morrison 640 H_2S
8ab	H	J. McElhaney	U	3480	600					122	207					Morrison 500 H_2S
8ba	I	J. McElhaney	W	3480	220	F	Kf									Flow 270 gpm H_2S
9ab1	H	J. McElhaney	U	3550	515					118	265					Morrison 500 H_2S
9ab2	I	J. McElhaney	W	3550	230	F	Kf									2 gpm H_2S
9da	SG	Conroy #1 Childers	O	3534	1065					130	166	672	1,026			Morrison 270
10ca	W	R. Miller	W	3610	300		Kl									10 gpm, soft
10cb	SW	R. Miller	U,W	3570	280	F	Kf				235					Morrison 520 Kmw @375 Water @107 H_2S
10cc	SW	R. Miller	U	3533	155	F	Kf				214					H_2S 2gpm flow @90',30gpm flow @200'

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	FORMATION Knc	Kf	Kl	TOPS Js	TRs	Pmk	Cml	REMARKS
8-2-14ab	SW	B. Childers	U	3630	560	F				165	330					Morrison 560
14bd	SW	B. Childers	U,W	3670	690		Kf		15	255	380					Morrison 680 Converted/well (270')
15aa	SG	Conroy #1 Wulf-Ideen	O	3581	2472					145	300	700	1,102	1,503	1,580	Water "2nd Converse"
15bd	SW	B. Childers	U,W	3530	440	F	Kl			150	315					Flowed 25 gpm H_2S water 3" well
17cc	I	E. Benton	W	3542			Kgs									Dry
17mid	I	D. Heldman	W	3505		F										
20 da	I,S	D. Heldman	W	3532	410	30	Kf									USGS reported Lakota
21ca	I	C. Tubbs	SW	3490	32	10										Sand 10-12
21dd	H	C. Tubbs	U	3468	750					280	390					Morrison 750
22bb	H	C. Tubbs	U	3455	600					200	296					Morrison 596
22ca1	I	C. Tubbs	W	3450	300		Kf									H_2S
22ca2	H	C. Tubbs	U	3458	665					200	290					Morrison 640
23bd	SG	Hollingsworth #1 Chil.	O	3549	2537					280	380	790	1,190	1,585	1,710	Morrison 530
23cd	S,I	C. Rutter	W	3562	298	132	Kf			270						0-24 Qw, 24-270 Kgs, Temp 52°
24ca	S,I	B. Childers	W	3550	300		Kf			220						0-90' Qa
24bb	SG	Elk #1 Martinson	O	3605	2545					240	440	915	1,215	1,605	1,674	Redrilled Island View #1 Martinson
24dc	H	Homestake	U	3490	580					166	228					Morrison 532
26aa	I	B. Childers	SW	3485	65	45	Qa									
26ab	H	Homestake	U	3550	686					265	410					Morrison 670
27dd	I	B. Childers	W	3465	337	50	Kf			315						11 ft. water sand, TDS 1376, Tr. H_2S
28bc1	I	C. Tubbs	SW	3520	60	20	Qa									
28bc2	I	C. Tubbs	SP	3520			Qa									Qa-Mowry Contact
28ac	I	C. Tubbs	W	3508												Abandoned "Old Petty Well"
28da1	I	C. Tubbs	W	3502	415		Kf									SC 5100, turned H_2S last 5 yrs.
28da2	I	C. Tubbs	SW	3502	20		Qa									Two shallow wells 1 gpm
31bc	H	Homestake	U	3620	1115					870						
32cc	H	Homestake	U	3700	1020					850						
34ac	I	B. Tubbs	W	3500	90		Qa									Trace H_2S in upper sand
35cb	I	B. Childers	W	3502	650	100	Kl									Dry, abandoned
35dd	I	M. Fritz	W	3455	90											Domestic-contact of sand and Mowry

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS								REMARKS
								Kg	Knc	Kf	Kl	Js	TRs	Pmk	Ꞓml	
8-2-36aa	I	V. Childers	SP	3400			Qw									WA
36ad1	I	V. Childers	W	3480	320	60	Kl									2 gpm
36ad2	I	Geo. Tupper	W	3425	172	10	Kf									
36cc	I	M. Fritz	W	3450	138		Kf									
36da1	I	P. Kohler	W	3432	263	15	Kf									
36da2	I	P. Kohler	SW	3425	12	9	Qa									Abandoned
36da3	I	E. Chord	W	3425	270		Kf									
8-3- 1ca	I	L. C. Reider	SW	4350	44	16										0-20 clay, 20-22 gravel, 22-44 sh.
1da	I	L. C. Reider	SW	4000	22	10										Hard, bitter
6db	S,I	R. Runge	W	3750	200		Kf									
8db	SG	J. Bell	O	3560	2204							370	735	1125	1330	Converted to water well
11bd	I	J. McKnight	W	4250	150	140	Kl									Not cased 2 1/2 gpm
12ca	I	B. Miller	SW	3870	64	30	Qa									51-55 buff sand, 55-64 brn. shale
12da	I	B. Miller	SW	4250	20	10	Qa									
13ab	I	B. Miller	SW	3900	30	16	Qa									Gravel
13ac	I	B. Miller	W	3891	440	186	Js					125				Morrison 34, Unkpapa 117
13cd	I	B. Miller	SW	3900	20	10	Qa									
14ab	I	B. Miller	SW	4150	22	14	Qa									Hand-dug, 5 gpm
14ac1	SG	Gary #14-7 McKnight	O	4028	2425							300	585	990	1110	Morrison 60, Unkpapa 200
14ac2	I	J. McKnight	W	4050	140	130	Kf									Low producer
14bb	I	J. McKnight	SP	3950			Kf									Spring at base F.R. form.,dom. use
16 d1	I	J. Bell	W	3630	165											Abandoned, drilled by C.V. Gull
17ab	SG	Gary #17-2 Bell	O	3671	2303							614	980	1390	1545	Morrison 467
17ca1	SG	Hollingsworth R	O	3600	2230						70	595	975	1439	1625	Morrison 285, Oil show in Ꞓm
17ca2	SG	Gary #17-11	O	3589	2277							634	967	1355	1576	Morrison 410
21dd	I	C. V. Gull	W	3600	550		Kl									Bottom in Morrison
24ba1	I	B. Miller	W	3870	85	30	Kl									C5 sand 61-74 (water)

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS Kg	Knc	Kf	Kl	Js	TRs	Pmk	Cml	REMARKS
8-3-24ba2	I	B. Miller	SW	3900	10	8	Qa									
24da	SG	Austral #1 Fed. 24	O	4033	1980							252	540	990	1110	Morrison 60, Ju 200
25bd	I	C. V. Gull	W	4100	50	21	Kl									
25cc	I	C. V. Gull	W	4000	235		Ju									Reported Unkpapa,vented gas,2gpm
25cd	I	C. V. Gull	W	3950	200	50	Kl									
26ab	S	Chilson Station	W	3770	350?											No records available
26ac	SG	B & W #1 Gull	O	4019	2100									1325	1505	W/L 120
26bb	S,I	R. E. Gull	W	3800	196											
27ac	S,I	R. E. Gull	W	3800	190					25	145					
29bb	I	John Curl	W	3455	85	30	Kf									Domestic
29bc	I	John Curl	SW	3450	46	20	Qa									
30ac	SG	Tenneco #1 Martinson	O	3456	2504					147	284	738	1090	1506	1696	
31aa	I	G. Grable	SW	3425	30		Qa									Dry
31ab	I	K. Morrison	SP	3450	10		Qw									Improved spring Qw-Mowry contact
31ac	I	G. Gable	SW	3425	45	30	Qa									Domestic
34cc	I	J. Koller	W	3660	350	45	Kl									2 gpm, hard
35bb	I	C. V. Gull	W	3925	118	91	Kf									3 gpm
35db	I	C. V. Gull	W	4000	570	500+	Js									"1st Sundance"
36bd	SG	Continental #1	O	4046	2338						130	320	700	1120	1250	Cp 2220
8-4- 3cd	I	B. Miller	SW	3850	14	4	Js									1 gpm
6ac	I	L. C. Reider	W	4500	60	F	Kf									1 gpm Fuson contact
6db	I	L. C. Reider	SW	4600	10	6	Kl									Hard, bitter Fuson?
6dd	SG	Gary #6-16 Federal	O	4673	2039							550	944	1324	1532	Morrison 430,Js Porosity 30-43% Water sat. 100%.
10da	I	B. Miller	SW	4050	16	8	Ql									5 gpm-C5 gravel
15cc	I	T. McClure	W	3900	525											Abandoned-casing failed 1961
17d	I	B. Miller	SW	3650	32	18	Js									
19bc	I	B. Miller	SW	3950	28	27	Kf									4 to 20 sand
19dd	IS	C. V. Gull	W	4300	905		Kl,Js					535				Water @ 135
21bb	I	C. V. Gull	W	3700	35		Js									

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	FORMATION Knc	Kf	Kl	TOPS Js	TRs	Pmk	Cml	REMARKS
8-4-23ac	SG	Gary Federal 23-7	O	3990	2375							624	980	1374	1638	
24ab		Ball Brothers	SP	3900			Kf									KfS5-Klf contact(Post,1967)
31cb	I	Ball Brothers	SW	3600	30	15	Jm									1 gpm-strong water, hand dug
31da	I	Ball Brothers	W	3600	200	30	Js									4 gpm
35ba		C. McClure	SP	3270			Kf									Small spring KfS5-Klf contact (Post, 1967)
35bd1	I	C. McClure	W	3250	56	54	Kl									Pumps dry
35bd2	I	C. McClure	W	3250	87	80	Kl									Hard water
35cd	I	C. McClure	W	3310	120	115	Kl									
8-5-20bc	I,S	Cool Spring	SP	3400			Cml									Less than 1 cfs
20cd	I,S	Cascade Spring	SP	3470			Cml									Total flow 23 cfs WA
29dd	I,S	Bridal Veil Springs	SP	3470			Cml									1 cfs
31bd	I	T. McClure	SW	3250	22	12										36 inch diameter TDS 1651 ppm
32cc	I	R. Hall	SW	3225	30	22										3 gpm TDS 2820 ppm
32dc	I	F. Wyatt	W	3280	100											Abandoned, excessive iron
8-6-14bc	S	Hot Springs Devel.	W	3233	2072	210	Kf-Kl			1636						
14db	SG	Wright #1 Benson	O	3215	1655			832	1362	1590	1642					Kn 238, Ker 455
24aa	SG	Dakota-Mont #1 Burg	O	3280	1729			1195	1505							
8-7-27cc	SG	Amerada #1 College	O	3366	4548			1338	1773	2150	2265	2990	3195	3405	3500	Cp 4450
8-8- 2ac	SG	Shell #1 Thompson	O	3142	2720			1640	2065	2430						Niobrara 982
21ac	SG	Gary #1 Rasmussen	O	3242	2566			1694	2258	2520						
8-9- 4cb	SG	Pure #1 Barta	O	3250	2370			1710	2140							
10dd	SG	Mule Creek #1 Gov't.	O	3307	2871			1730	2189	2570	2655					
21aa	SG	Ackman Schulein 21-1	O	3243	2312			1672	2048							
9-1-12ad	SG	Sun #1 Wallaway	O	3838	3247			285	730	1115		1487	1767	2264	2355	
20dd	SG,I	Pfister & Danks	W	3750	2010		Kf-Kl	575		1410						Reported sulfur
23cc	SG	Ackman Schulein 23-13	O	3723	2743				1140	1330		1820	2100	2550	2726	

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS Kg	Knc	Kf	Kl	Js	TRs	Pmk	Ꞓml	REMARKS
9-2- 1aa1	S	Mines Development Inc.	W	3445	3060	F	Cp			300	440	860	1230	1650	1760	190gpm @ 3014,450gpm @ 3060 SIP 86 psi WA
1aa2	S,428	CB & Q RR.	W	3443	1125		Kl			295	430	977?				WSP 428,RR round hs.,abandoned
1aa3	S,428	CB & Q RR.	W	3459	2980	F	Cp			275	470	850	1230	1660	1870	Cp 2890, SIP 110 psi, F 1000gpm filled to 700
1ac	S,I	Edgemont #2	W	3455	2983	F	Cp			259?	459	839	1219	1649	1859	Park well, Flow 130gpm SIP 100 psi BHT 126°, WA
1bc1	I	D. W. DuToit	W	3470	550	25	Kl			410						60 gpm @ 409
1bc2	SG,S	Edgemont #3	W	3570	3183	F	Cp			475						Flow 170 gpm, SIP 40 psi, WA
2da	SG,S	Edgemont #4	W	3575	3430	F	Cp			475		845	1335	1810	1912	Cp 2970, BHT 106°
4cd1	I	O. Eberle	W	3715	860	360	Kf			800						
4cd2	I	O. Eberle	SW	3703	30	24	Kg									Below stock dam
9ba	I	O. Eberle	SW	3672												Abandoned - shallow
10ba	H	R. Miller	U	3680	960					690	816					Water at 60 feet
10dc	I	R. Miller	SP	3540			Qt									1 gpm-WA issues Qt-Kgs contact
10dd	SG	Conroy #1 Superior	O	3563	2910					634	695	1150	1610	1923	1988	Morrison 940
14da	H	R. Hudson	U	3570	960					650	750					Morrison 960 Kl sands @ 655, 750, 880, 920.
15cc	SG	Conroy #1 Wulf-Ideen	O	3586	3054					700	893	1255	1565	2010	2100	
15dd	I	R. Porter	SW	3520	15											
16dc	SG	Amarillo #1-16	O	3742	3095					848	1032	1380	1680	2120	2220	Morrison 1252
20db	SG	Vass-Mars #1 Porter	O	3623	2865					710	860	1270	1640	1980	2150	Cp 2850?
21bb	I	R. Porter	W	3628	1228	250	Kl				1059					
24ac	H	R. Hudson	U	3705	1163					854	947					Morrison 1163, sands @ 950, 1035, 1100 Water 860
9-3- 3bd	I	J. Koller	W	3660	250	40	Kl									Hard, high Fe
4db	H	Homestake	U	3470	645					167	225					Morrison 625
5db	AG	NW Exploration #1	O	3600	740					400?						
5da	H	Homestake	U	3500	640					360	450					Morrison 800
6da	H	Homestake	U	3560	965					468	580					

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	FORMATION Knc	Kf	Kl	TOPS Js	₨s	Pmk	Cml	REMARKS
9-3- 3bd	I	G. Happner	SP	3500			Qw									Flows all year
8cc	H	Homestake	U	3650	1050					650	710					Morrison 990
8da	H	Homestake	U	3550	975					465	580					Morrison 940
9ac	I	R. Ershen	W	3458	400		Kf									
9dd	H	Homestake	U	3450	705					190	309					Morrison 678
10ad	I	F. Koller	SW	3400	23		Jm									Top Morrison, Hard
15ac	I	M. Helsel	W	3425	180	130?	Kf									
19ca	I	R. Hudson	SW	3700	20	10	Kg									W/L 15' dry year
21cd	I	D. Stearns	SW	3650	30	25	Kg									Below stock dam
24bb1	I	M. Helsel	W	3700	130	110	Kl				112					
24bb2	I	M. Helsel	W	3690	45	25										Strong water
25ab	I,SG	Thompson #1	O	3450	1500											SDGS reports in Sect 24, stock wa.
25dc	I	M. Helsel	W	3450	220	165?	Kf-Kl			167						Upper water brackish
25dd	SG	Conroy #1 Helsel	O	3438	2485							580	1036	1350	1447	
26cc1	I	M. Helsel	W	3550	840		Kf			715						
26cc2	I	M. Helsel	SW	3550	25	15	Qa									Abandoned
28dc	I	G. Heppner	SW	3575	15	12	Qt									
29cc	S	G. Heppner	W	3675	150		Kg?	40								
33dd	I	G. Heppner	W	3575	1020		Kf	75	745	1000						"Soda water"
9-4- 1cc	I	T. McClure	SW	3400	60	40	Kgs?									
3cc	I	B. Cox	SW	3335		50	Qa									Stock well
7bb	SG	Gary #7-4 Federal Gary	O	3966	2000						410?	600		1350	1552	Morrison 510
7bc	I	Ball Brothers	W	3950	780	500	Jp									Reported as Unkpapa
7da	I	Ball Brothers	W	3850	300											Abandoned, dry Kl
9cd	I	B. Cox	W	3340	161		Kl									2 gpm
10cd	I	E. Hand	SW	3340	26	18	Qa									2 gpm
16cd	I	E. Hand	W	3310	150	20	Kf									4 gpm
13db1	I	A. L. Landers	W	3370	85	40	Kf									FR @ 82
13db2	I	A. L. Landers	W	3370	400	55	Kl									LK 250

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS Kg	Knc	Kf	Kl	Js	TRs	Pmk	Cml	REMARKS
9-4-13da	I	A. L. Landers	W	3365	60		Kf									Reported as muddy sand
14bc	I	Ball Brothers	W	3350	120	35	Kf									4 gpm, hard
15ac	I	Ball Brothers	W	3390	120	40	Kf									4 gpm, domestic
17da	I	Ball Brothers	W	3350	160	60	Kl									18 gpm
19cc	I	A. L. Landers	W	3550	255		Kl									
19cd	I	J. Manke	W	3555	320	250	Kl									
20ca	I	J. Manke	W	3500	216	176	Kl									
21bd	I	B. Cox	SW	3341	54	25	Qa									TDS = 1668
21cd	I	J. Manke	W	3350	90	67	Kf?									
28bc	I	J. Manke	W	3365	105	F	Kf									
30db	I	J. Manke	W	3425	233	75	Kl									
33bc	I	C. Kane	SW	3500	35	17	Kgs									48" diam.
9-5- 6ad	I	T. McClure	W	3200	218	10	Kl									
18mid	I	A. L. Landers	W	3400	450		Kl			160?						Kf cased off
19cc	I	A. L. Landers	SW	3365	40	18	Qa									2' gravel
27	SE	McKinley Houghton	W	3500	545	455	Kl			127	308					Water @ 479-82
27db	SG	Wier-Houghton #1 State	O	3550					96	133		1010	1360	1488	1904	Minnewasta 550
33db	SG	Trusteed-Witcher #1	O	3558	3000+					398	439	1135	1510	1802	3030	Converted water well @ 448
34ac	SG	Lakota Petroleum #1	O	3625	2528					390		1000		1545	1780	
34dd	US,I	Welch-Witcher #1	O	3725	723											Water @ 723 (Kl?)
9-6-18cd	SG	Colonial #1 Bailey	O	3359K	2692					458?	504	1030	1492	1826	2094	
23bc	SG	Pure #1 Peters	O	3306	1220			497	965							
9-7-25ad	SG	Ohio #1 Hedrick	O	3413	4617			1470	1890	2300		2992	3230	3580	3655	Cp 4525
29bb	SG	Amerada #1 Strat	O	3314K	1596			940	1400							
36bd	SG	Pure #1 State	O	3373	2360			1698?	2085?							
9-8- 9cc	S,I	Peterson Well #1	W	3350	2470			1600		2440						Reported dry
19dd	SG	Western SD Oil & Gas	O	3400	70											Abandoned
9-9-16bb	SG	Gary #16-4 State	O	3265	2185			1592	1950							Niobrara 965

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS: Kg	Knc	Kf	Kl	Js	Trs	Pmk	Cml	REMARKS
10-1-11ba	S,SG	Olds and Wrather	O	3728	1921			500	1130	1330	1420					
24ba	SG	Dillon #1 Huff	O	3750	1568					1202						
27n1/2	I	R. G. Pfister	SW	3725	36	20	Kp									Located along creek
27n1/2	I	R. G. Pfister	SW	3725	20	20	Kp									Located along creek
27n1/2	I	R. G. Pfister	SW	3725	40	18	Kp									Located along creek
27n1/2	I	R. G. Pfister	SW	3725	38	20	Kp									Located along creek
35mid	SG	Norbeck-Nicholsen #1	O	3850	3907											Cp 3750
10-2- 1bb	I	R. Soske	SW	3740	12		Ker									Water very "strong"
1ca	SG	Burrows #1 Gov't.	O	3759	1315			335	962	1195	1304					
2ca	SG	Provo Oil #1 Soske	O	3647	3072			230?		1087			2080	240	2600	
3ac	S	BHOD #2	W	3664	3855		Cp	200	850	1080	1290?	1610		2315	2500	Cp 3558
3dd	S	BHOD #1	W	3664	4000	F	Cp	230	870	1088	1210	1605	2037	2374	2560	Cp @ 3600 See drill stem data
12bc	I	Chas. Stearns	SW	3750	22	17	Ker									5 gpm, Hard
13cc	I	Chas. Stearns	SW	3690	28	12	Qa									3 gpm. Hard
24cd	I	Joe Trotter	SP	3765			Qa									Flows 5 gpm
25da	I	Joe Trotter	SP	3875			Kp-Kn									Flows all year, TDS-1370 ppm.
28cc	I	Robert Soske	SW	3950	11	1	Kp									Water level near top
10-3- 4	I	C. Heppner	SW	3600	6		Ker									Improved spring
5db	I	E. Stearns	SW	3650	12	3	Ker									18" gravel
11dd	I	W. Martinson	SW	3600	19	16	Ker									Below stock dam
15ba	S,I	A. M. Henderson	W	3560	1250	300	Kf	330	960	1206						Gas from 300'
19ac	I	J. Trotter	SP	3950			Kn									Silted in spring
20aa	I	A. M. Henderson	SP	3700			Kn									Runs dry
21ad	I	A. M. Henderson	SW	3700	12		Kn									5 gpm, hardness 4760
25dd	I	J. Chlecq	SW	3525	30	8	Qa									Water analysis, 42 gpm w/10'dd
30cd	I	C. Crowe	SW	3885	25	9	Qa									
32	I	G. Heppner	SW	3850?	20		Kp									Improved spring
10-4- 4ba	SG,I	Woodward Morton #1 Gov.	O	3484	3003					440		1080		1775	2030?	Cp 2880, original flow has stopped
4da	US,I	M. Kerns	O	3450	3320										2012	Cp 3172 Flows 30-40 gpm
8aa	SG	Tenneco #1 USA-Ideen	O	3501	2765					466	610	1075	1514	1795	2070	

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED Kg	Knc	FORMATION Kf	Kl	Js	TOPS TRs	Pmk	Ꞓml	REMARKS
10-4-15da	I	H. Danks	SW	3385	16		Qa									
16cb	I	G. Fishko	SW	3500	16	13	Qa									3' sand
19cc	I	John Chlecq	SP	3540			Qa									Improved spring, WA
20cc	I	John Chlecq	SW	3500	27	8	Kg									Pumps 42 gpm, WA
20da	I,SG	Kerns (Lakota Shiloh)	W	3560	3250		Ꞓml-Cp		416	780	900		1425	1190	1800	Cp 2785, flowed hot wtr. 35 gpm
23bc	I	G. Fishko	SW	3380	23	19	Qa									
24ad	SG	Pure #1 Landers	O	3483	1162			442	910							
27cd	I	G. Fishko	SW	3500	18	12	Qa									
29bd	SG	Ackman Schulein 29-14F	O	3532	2681					460						
29da	SG	Shiloh Oil #1 Shiloh	O	3537	2200											
10-5- 3dc	SG	York-Newell #1 Landers	O	3640	800				678	785?						
12dd	SG	Gary-Webb Res 12-16 S.	O	3567	1925											Abandoned
25dd	SG	Gary #1 State	O	3772K	4782			1505	1980	2395				3625	3700	Cp @ 4700
10-6-11db	SG	Amerada #45 Strat	O	3480K	1869			1215	1775?							
13mid	SG	Amerada #85 Strat	O	3383K	2114			1217	1655	2100						
22cd	SG	Fremont #1 State	O	3594K	1902			1148	1732							
24dc	SG	Fremont #1 Muhm	O	3574K	1894			1224	1799							
26ab	SG	Fremont #1 Jones	O	3542K	1676			1130								
27ad	SG	Cramer #1 Wilkinson	O	3591K	1630			1160	1890?							
10-7- 6aa	SG	Pure #1 Whetstone	O	3395	1927			1230	1695?							
28aa	SG	Amerada #81 Strat	O	3509K	2009			1120	1520	1930						
10-8-16aa	SG	Gary #16-1 State	O	3350	4310				1882	2108	2280	2770	2984	3286	3638	Niobrara 560
25ca	SG	Amerada #1 Vorhees	O	3332	4143			1060	1620	1925	2000	2495	2785	3065	3135	PC 4120
30mid	SG	Amerada #1 Manders	O	3381K	1827			1145	1567							
30cd	SG	Interior #1 Putnum	O	3389K	4088			1170	1580	1985				3185	3270	Cp @ 4022, PC @ 4085
34bd	SG	Amerada #43 Strat	O	3293K	1655			1055	1470							
10-9- 3ba	SG	Gary #1 White	O	3061	2180			1264	1831	2100						
28ca	SG	Continental Energy #1G	O	3223	2247			1290	1690	2140						Lost circulation 2200
35ca	SG	Continental Energy #2G	O	3187	2424			1189	1571?	1990						Codell reported @ 993

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS								REMARKS
								Kg	Knc	Kf	Kl	Js	TRs	Pmk	Cml	
11-1 3aa	S	Conroth Well	O	3950												Drilled 1920 No data
10cb	SG	Pacific Western #1 Gov	O	4115	4080			615	1228	1468	1690	1960		2690	2755	Cp at 3947
14ab	SG	Echo Rainbow 1-74 F.Ind.	O	4120	2150			900	1498	1728	1832					Morrison 2095
28cc	SG	Raymond #1 Gov.Mitchell	O	4009K	1510			730	1222							
29bb	SG	Pan Am #1 Sacony	O	4174K	4136			880		1720				2870	3100	Cp at 4110
11-2- 2ba	I	R. Soske	SW	3875	15	14	Kp									Tile lined dugout, potable
3db	SG	Pure #1 Gov't. D	O	3901	1630			905	1412?							
5cc	SG	Phillips #1 Gov't. B	O	4089K	1935			1010	1522	1850						
31cc	SG	Echo Rainbow 1-31 Ind	O	3873	2250			1100	1693	1905	2065					Morrison 2195
11-3- 1aa	I,SG	M. Kerns (Kunde Shiloh)	W	3525	1562	357	Kl	425	1050	1292						Analysis, Sp. cond = 2050
11-4- 4cb	SG	Kiowa #1 Christensen	O	3500	340?											Reported confirmation hole
5ad	SG	Gilbreath #1 Christen-sen	O	3500	255											Also known as Root #1-abandoned
21ac	I	L. Madsen	SW		26	24	Qa									Sand
21ac	SG	Woodward #1 Eckard	O	3493	835			330	800?							Lost circulation 835
21ba	SG	Phillips #1 Madsen	O	3489K	1140			167	665?	1051						
21cd	SG	Woodward #2 Eckard	O	3491	895			390	883							
21da	I	L. Madsen	SW	3550	8	7	Qa									Improved spring
21?	SG	Wyokota Oil #1	O													Old oil test 1917 or 1918
28bd	SG	Woodward #1 Hill	O	3528	930			295	877							
29db	I	H. Wassenburger	SW	3540	30	20	Qa									Sand 22 to 30'
29	I	H. Wassenburger	SP	3525			Qa									Several springs along Duck Creek
32dc	I	H. Wassenburger	SW	3500	37	18	Qa									Sand 25 to 37'
32dd	SG	Echo Rainbow 1-32 Holm	O	3518	1855			557	1128	1358						Morrison 1774
33cd	SG	Hughes #1 Anderson	O	3533K	1805			475	940	1325						
34cc	SG	Echo Rainbow #1-34 St.	O	3539	1809			540	1110	1375						Morrison 1790
11-5-30bb	SG	Ackman-Schlein 30-1 S.	O	3724	1745			1412								Frontier Sand reported 1168
35dc	SG	Webb Res #35-15 State	O	3732	3045			1980	2544	2810						Morrison 3008

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED		FORMATION		TOPS				REMARKS
								Kg	Knc	Kf	Kl	Js	TRs	Pmk	Ꞓml	
11-6-19bb	SG	Sinclair #1 State 4000	O	3719	4708				2300	2582	2760	3265	3540	3825	4093	
28ac	SG	Gary #1 Lounsberry	O	3753K	2803			1864	2474	2752						
11-7- 2dd	SG	Pure #1 Pettegrew	O	3753	1943					2750						
30dc	SG	Gary #1 Pettegrew	O	3560	3161			2261	2700	3105						
11-8- 6ba	SG	Charter #1 Putnam	O	3404	2206			1620	2154							
11-9-23cb	SG	Raymond #1 Goodnick	O	3332K	1740			1074	1650							
12-1- 6bb	SG	PanAm #1 Govt. Dorough	O	4009K	4185			840	1325	1670				2430	2600	Cp at 4128
9cc	SG	Ackman-Schulein 9-15	O	3868	3874					1739		2250	2565	2896		1st Leo 3113
13dd	I	E. Wallace	SW	3750	30	16	Qa									80 grains hardness
13dd	I	E. Wallace	SW	3750	31	16	Qa									
18dc	I	E. Wallace	SW		59	20	Qa									
12-2-13bd	I	Caylor Brothers	SW	3660	40	28	Qa									5 gpm
15ca	I	Caylor Brothers	SW	3660	35	25	Qa									
18ab	I	E. Wallace	SW	3745	30	16-20	Qa									
18bb	I	E. Wallace	SW	3745	30	16-20	Qa									
18bd	I	E. Wallace	SW	3745	30	16-20	Qa									
12-4- 3ba	SG	Echo-Rainbow 1-3 Fed I.	O	3613	1960			688	1265	1520						
4ba	SG	Woodward #4 Schmidt	O	3525	3175			440	1010	1270				2390	2490	
4bc	SG	Woodward #2 Schmidt	O	3536	1315			435	995	1255						
4db	SG	Woodward #5 Schmidt	O	3568	1860			470	1035	1315						
4cc	SG	Woodward #1 Schmidt	O	3550	1315			495	1050	1307						
5ac	I	H. Wassenburger	SW	3520	32	17	Qa									
8ab	SG	Woodward #1 McDonald	O	3529	1203				1130?							Water at 1157
8da	SG	Woodward #1 Turnbull	O	3545	1263				1130							
9bb	SG	Woodward #3 Schmidt	O	3550	1145			530	1136							
9cb	SG	Ardmore Oil #1	O	3351	1735?				1100	1530						

APPENDIX C. WELLS, SPRINGS, AND REFERENCE DATA

LOCATION	SOURCE	OWNER	TYPE	ELEV.	DEPTH	WATER LEVEL	AQUIFER	SELECTED FORMATION TOPS								REMARKS
								Kg	Knc	Kf	Kl	Js	TRs	Pmk	Ꞓml	
12-4-10b	I	H. Wassenburger	SW	3600	32	16	Qa									
10aa	SG	Pure #1 Govt. E	O	3659	1747			1070	1525							
11ca	I	D. Hunter	SW	3600	30	10	Qa									
13bb	I	Don Henry	SW	3625	39	14	Qa									Clay and gravel 12-18
13db	I	Don Henry	SW	3625	35	20	Qa									
16dc	SG	Gary #16-15 State	O	3615	2916			975	1410	1810	2290	2580				
12-6- 6ca	SG	Osage Trust #1 Moody	O	3740	3029?			1690	2213	2608						
8ac	SG	Amerada #1 Moody	O	3625K	4988			1689	2136	2560				3670	3770	PC 4865
12-8- 2ab	SG	Gary #1 Kimblem	O	3594K	3105			2339	2720							

APPENDIX D

SELECTED POTENTIOMETRIC DATA

Well Number: Location, see appendix C.

Elevation: Surface elevation above sea level.

Interval Tested: Feet below ground surface of zone tested.

Formation: Formation tested. *Kf,* Fall River Formation; *Kl,* Lakota Formation; *Js,* Sundance Formation; *Cml,* Minnelusa Formation; *Cp,* Pahasapa Formation.

Estimated Test Depth: Estimated depth below ground surface of pressure bomb.

Shut-in pressure (SIP): Expressed in pounds per square inch (psi).

$\frac{\textbf{SIP}}{\textbf{0.45}}$: Conversion of SIP to feet of water.

Potential Elevation: Estimated elevation of the potentiometric surface above sea level.

$$\text{Estimated elevation} = \frac{\text{SIP}}{0.45} - (\text{Est. test depth - surface elevation}).$$

Remarks: All pressures given in pounds per square inch.

IHP	Initial hydrostatic pressure
FHP	Final hydrostatic pressure
IF	Initial flowing pressure
FF	Final flowing pressure
ISI	Initial shut-in pressure
FSI	Final shut-in pressure
BHP	Bottom hole pressure
TDS	Total dissolved solids

APPENDIX D. SELECTED POTENTIOMETRIC DATA

Well No.	Elevation	Interval Tested	Formation	Est. Test Depth	SIP (psi)	SIP / 0.45	Potential Elevation	Remarks
7-1-15dd	3576		Js					20 gpm flow Kf, 10 gpm flow @ 809 ft, Js
7-1-21da	3526	2315-2333	Cml	2324	27	60	1262	
7-1-21da	3526	2390-2400	Cml	2395	1026	2280	3411	temperature = 84° F., H_2S
7-2-21ad	3821		Js					flowed 3 gpm
8-3-17ab	3671	2151-2303	Cml	2230?	966	2142	3583	IHP 1134, FHP 1123, IF 202, FF 684, ISI 993, FSI 966
8-9-32bd	3241	2553-2580	Kf	2560			3630	received 970 ft water
9-2- 1ac	3455		Cp	surface	100	222	3677	tested in 1955, flow 130 gpm
9-2-15cc	3586	2692-2701	Cml	2697	1170	2500	3389	IHP 1547, FHP 1557, IF 220, FF649, ISI 1196, FSI 1170
9-7-25ad	3413	4027-4042	Cml	4035	1380	3070	2248	IHP 1975, FHP 1925, ISI 1380, FSI 1380, BHT 138° F.
10-2- 3dd	3655		Kf	1085	360	778	3358	measured static level 405 ft, potable
10-2- 3dd	3655		Kl	1271	360	778	3172	measured static level 610 ft, potable
10-2- 3dd	3655		Js	1728	600	1332	3269	measured static level 465 ft, brackish
10-2- 3dd	3655		Js	1904	1000	2210	3971	artesian flow, TDS 7380
10-2- 3dd	3655		Js	1964	975	2160	3861	artesian flow
10-2- 3dd	3655		Cml	2609	160	356	1412	small amount of brackish water
10-2- 3dd	3655		Cp	3642	1800	4000	4023	TDS 1308
10-2- 3dd	3655		Cp	3780	1975	4390	4252	TDS 2804, final flow 165 gpm
11-1-10cb	4260	3540-3562	Cml	3600			1935	BHP 750
11-1-10cb	4260	3926-4080	Cp	4000			4040	BHP 1700
11-1-29bb	4171	3579-3607	Cml	3595	727	1615	2191	IHP 1660, FHP 1600, ISI 234, FSI 727
11-1-29bb	4171	3681-3704	Cml	3690	1335	2970	3451	IHP 1730, FHP 1707, ISI 1311, FSI 1335
11-1-29bb	4171	4036-4060	Cml	4050	1451	3222	3342	IHP 1916, FHP 1916, ISI 1497, FSI 1451
12-1- 6bb	4009	3660-3739	Cml	3700	640	1420	1729	ISI 609, FSI 640, FHP 1885
12-1- 6bb	4009	4000-4055	Cml	4025	1566	3480	3464	IHP 2107, FHP 2097, IF 2097, FF 1158, ISI 1572, FSI 1566
12-6- 8ac	3381		Cp	4900?			3041?	received 4620 feet fresh water

APPENDIX E

SELECTED WATER QUALITY DATA

Sample: Well number, see appendix C.

Source: Source of data. *I,* water analysis obtained during interview; *A,* Atomic Energy Commission, Lucius Pitkin Inc., prime contractor; *U,* USGS, Rapid City, South Dakota; *S,* Files, South Dakota School of Mines and Technology; *P,* Post (1967); *B,* Bowles (1968).

Aquifer: Producing formation. *Qt,* Quaternary terrace deposit; *Qa,* Quaternary alluvial deposit; *Kp,* Pierre Formation; *Kn,* Niobrara Formation; *Kf,* Fall River Formation; *Kl,* Lakota Formation; *Js,* Sundance Formation; *Cml,* Minnelusa Formation; *Cp,* Pahasapa Formation.

Chemical ions: Expressed in parts per million (ppm).

Specific Conductance: Microhms at 25° C.

Hardness: Expressed as $CaCO_3$ in ppm.

Total Dissolved Solids (TDS): Expressed in ppm.

APPENDIX E. SELECTED WATER QUALITY DATA

Sample	Source of Data	Aquifer	Calcium	Magnesium	Sodium	Silica	Iron	Flouride	Carbonate	Bicarbonate	Sulfate	Chloride	Hydrogen Sulfide	Sodium Absorption Ratio	Specific Conductance	pH	Hardness	Total Dissolved Solids
9-2-10dc	I	Qt	436	84	451					555	1854			5.1	3750	7.8	1442	3480
10-3-25dd	I	Qa	501	668	1050						4950	300		7.1	11,000		334	6969
10-4-19cc	I	Qa	196	585	1370					310	1806	30		11		7.5		4297
10-4-20cc	M	Qa	222	195	1224		55				3366	37		14		3.2	1383	5596
12-4-11ca	M	Qa	128	39	18	20	.03		220		493	23		<1		7.6	478	941
10-1-27	M	Kp	280	281	2391	8	1.0		8		5506	410		24			1598	9344
10-1-27	M	Kp	535	212	509	18			1105		1352	52		4.7		7.6		4561
10-2-25da	M	Kp-Kn	475	156	231	30	96				2457	8		2.3		4.5		3674
10-3-20aa	M	Kn	382	126	198	15	18		149		1615	15		2.2		3.5		2940
7-1-17	A	Kf	26	10	290	15	.25	1.3	0	238	500	.17		12		8.0		1080
8-2- 6midl	A	Kf	9	6.5	396	12	.08	2.2	60	952	11	86	5+	24	1700	8.8	55	1540
8-2- 8ac	A	Kf	8	4.5	385	12	.10	2.4	60	952	8	76	5	26		8.6		1513
8-2-17db	A	Kf	4.5	2.9	383	10	.13	2.0	60	878	41	58	5+	33				1445
8-2-20da	U	Kf	2.8	0.7	489	5.4	2.9	0.6	39	306	655	72		67	3200	8.9	10	1450
8-2-28dd	A	Kf	37	11	584	12	.25	1.0	0	531	832	286		21	5100	8.0		2284
8-2-36a	U	Kf	104	37	167	17	.19	0.7	0	315	430	48		3.5	1410	7.7	412	1010
10-3-15ba	M	Kf	14	8	1064				226		1790	47		55		8.1	68	3189
7-1-3bb	A	Kl	80	18	179	10	.92	0.8	0	207	468	11	0.1	4.6		7.9		975
7-1-11cc	A	Kl	260	125	120	10	1.3	0.1	0	294	1014	.15		1.5		7.4		1825
7-1-16dd	A	Kl	62	22	262	10	.18	0.4	0	279	552	11		7.1	1690	7.7		1198
8-1-30dc	M	Kl	4.6	2.4	446	5.7	.34		21	492	495	37	2	42		8.4	21	1506
8-2- 5ac	A	Kl	134	80	355	10	.02	0.3	0	400	1102	10	<1	6.0	2600	7.7		2091
9-2- 1aa	S	Kl	104	30	107		1.6	.95		246	204	135		2.3	1098	7.0	382	829
7-2-12ca	S	Js	61	10	512	26	1.5	0.7	0	212	1000	65		11.3	2540	7.6	213	1790
7-4-29dc	I	Js	275	326	282	12	3		210	653	653	26		3.1		8.3	602	1470
Cascade Sp.	P	Cml	568	92	60	22	0.3	0.9	0	235	1540	62		9	2700	7.0		2530
Average	B	Cml	396	103	34					69	438	26		<1				1066
9-7-25ad	S	Cml	695	94	468		56			1145	1932	151						4545
9-2- 1ac	S	Cp	117	33	161		.04	1.0		219	239	241		3.2		7.1		1134
10-2- 3ac	S	Cp	114	31	213	27	.25	1.2		197	315	270		4.5	1720	7.5	411	1070
10-2- 3dd	M	Cp	138	43	263					177	400	377		5.1			521	1439