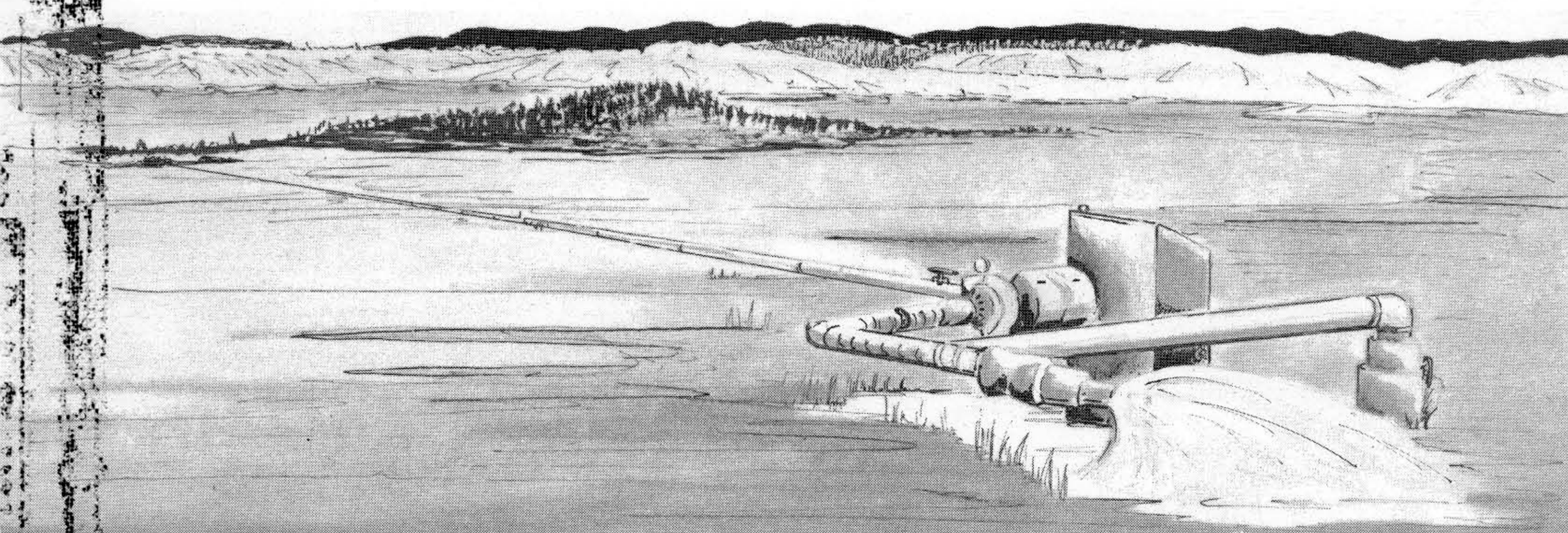
Special Report 19

ARTESIAN WATER, MINNELUSA AND PAHASAPA FORMATIONS, SPEARFISH — BELLE FOURCHE AREA

by

Earl J. Cox



STATE OF SOUTH DAKOTA ARCHIE GUBBRUD, GOVERNOR

SOUTH DAKOTA STATE GEOLOGICAL SURVEY

Allen F. Agnew, State Geologist

Science Center, University Vermillion, South Dakota

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PRELIMINARY REPORT ON THE ARTESIAN WATER SUPPLIES FROM THE MINNELUSA AND PAHASAPA AQUIFERS IN THE SPEARFISH-BELLE FOURCHE AREA

by
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State Geological Survey
Belle Fourche

Science Center, University
Vermillion, South Dakota
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Plate 1.--Location of Homestake Hydroelectric Plant should be 6-2-15ddb instead of 6-2-15a.

Plate 2.--Under EXPLANATION it should be "Morrison through Opeche" instead of "Morrison to Opeche".

Abstract

Tentative studies in the Spearfish-Belle Fourche area show that at least 34,000 acre-feet of water is being withdrawn annually by springs and artesian wells from the Minnelusa and Pahasapa aquifers.

The area studied has an annual recharge to the Minnelusa of about 5,760 (?) acre-feet. The Minnelusa Formation is apparently being partly recharged by water from the Pahasapa Formation.

The sketchy recharge information and the rather meager pressure data suggest that a serious overdraft of the Minnelusa aquifer exists, and has been accelerated in the past year (1961). The study also shows that the Pahasapa hydrostatic head is decreasing.

It is recommended that approval to drill wells for irrigation use be held in abeyance until the extent of the overdraft can be determined by additional studies.

It is further recommended that pumping tests be conducted on several of the nonflowing artesian wells in the area to determine the transmissibility and storage coefficients of the Minnelusa sands.

INTRODUCTION

Present Investigation

This report contains the results of an investigation by the South Dakota Geological Survey during 1961, and the early part of 1962 in the southwestern part of Butte County, the northern part of Lawrence County, South Dakota, and a small part of adjoining Crook County, Wyoming (fig. 1). Many large-flowing, low-pressure artesian wells are located in this area and are causing a decline in pressure (or water level) of the artesian aquifers. Consequently, in December of 1960, the South Dakota Water Resources Commission requested that the State Geological Survey prepare a preliminary report on the artesian aquifers in the area.

Specific information was requested on recharge, discharge, pressure, temperature, and location and depth of all producing aquifers.

An inventory was made of all wells in the area checking particularly on the flows and pressures. Periodically the flows and pressures were rechecked. Twelve water samples were collected from wells and springs for quality of water analyses. A map of the area showing the surface geological formations was made.

The preparation of this report was under the supervision of Dr. Allen F. Agnew, State Geologist. Information on many wells in this area was obtained from the State Water Resources Commission in Pierre, from the District Office of the U. S. Geological Survey in Huron, and from the Geology Department of the South Dakota School of Mines and Technology in Rapid City. Residents and water-well drillers of the Spearfish-Belle Fourche area have given much information and have been most cooperative during the field investigation.

Special thanks is due Mr. Charles Dyer of the U. S. Geological Survey for providing the photographs for this report.

Previous Investigations

In 1890 and 1891, E. S. Nettleton, of the U. S. Department of Agriculture, made a general investigation of the artesian conditions in North and South Dakota. Apparently, at that time there were no artesian wells in western South Dakota. In 1895 the South Dakota Agricultural College and Experiment Station published a report by J. H. Shepard, which dealt with the chemical quality of artesian waters, mainly in eastern South Dakota.

N. H. Darton (1901, 1905, 1909a, 1909b, 1918), and Darton and C. C. O'Harra (1905 and 1909), and Darton and Sidney Paige (1925), of the U. S. Geological Survey published a series of extensive reports dealing with South Dakota and the surrounding states.

A report by South Dakota State Engineer (Derr, 1916), lists valuable basic data regarding artesian wells in the State.

Two guidebooks (1929, 1952) give some information on artesian conditions in the Black Hills.

Rothrock and Robinson (1938) made a study of artesian conditions in west-central South Dakota.

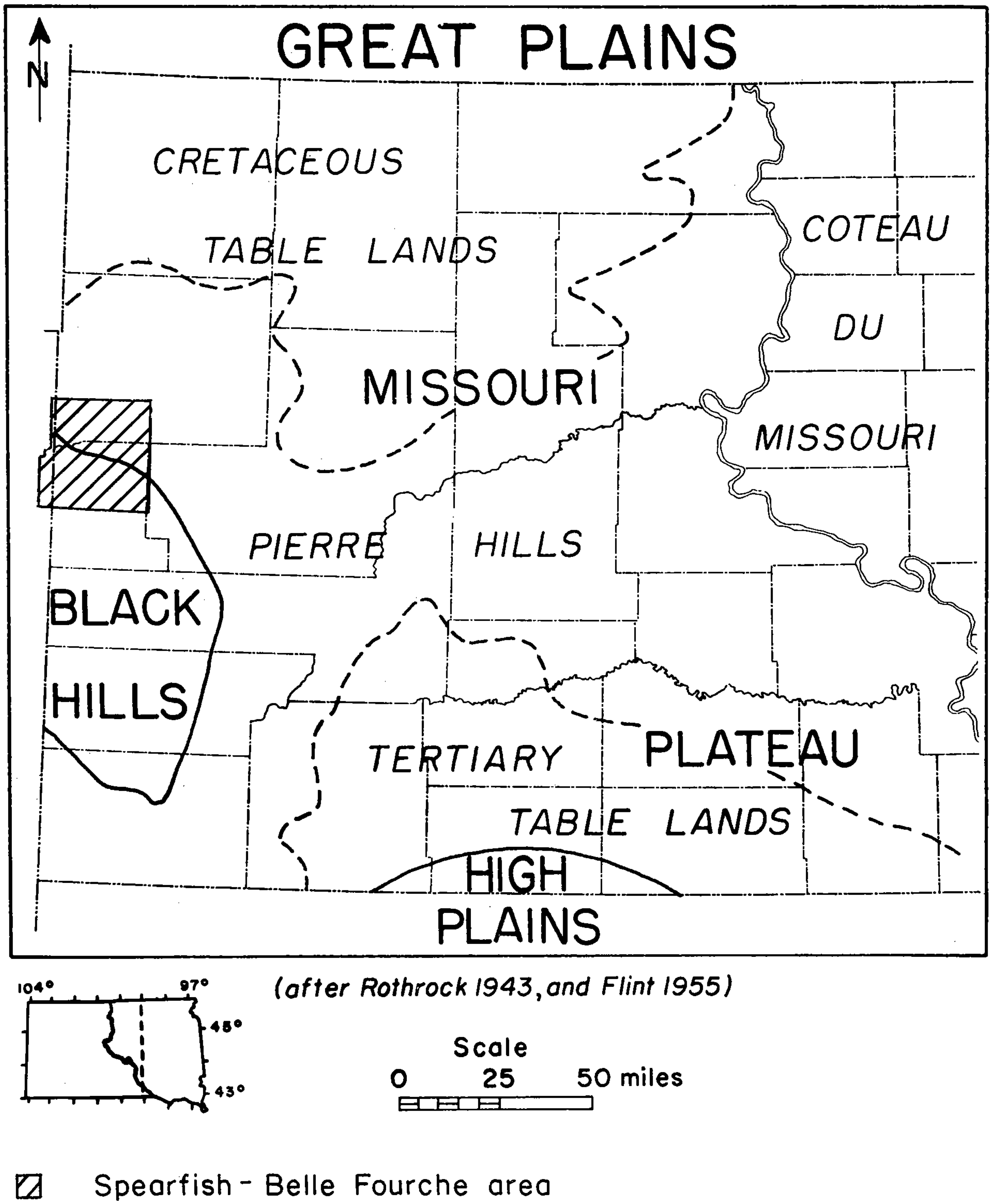


Figure I. Major Physiographic Divisions of Western South Dakota.

Rosier (1951) made a reconnaissance study of the geology and ground water hydrology of the Belle Fourche irrigation project.

Orr (1959) made a study of the precipitation and streamflow in the Black Hills.

Davis, Dyer, and Powell (1961) made a progress report on wells penetrating artesian aquifers in South Dakota.

Location and Extent of Area

The area studied is in the southwestern quarter of Butte County and the northern one-half of Lawrence County, plus a small area in Wyoming along Sand Creek. Spearfish (pop. 3682, 1960 census) and Belle Fourche (pop. 4087, 1960 census), are the main centers of commerce in the area.

The area is in the northern Black Hills division and extends into the Missouri Plateau division of the Great Plains physiographic province.

Climate

The climate is similar to the continental climate of the surrounding plains, except that it is modified by the prominence of the Black Hills uplift. Precipitation is higher and temperatures are generally lower closer to the Black Hills (table 1). Rapid fluctuations in temperature occur frequently.

Topography and Drainage

The main drainages of the area are Spearfish Creek and the Redwater River. Spearfish Creek flows north from the town of Spearfish and joins the easterly flowing Redwater River about six miles north of town. From the confluence of the streams the Redwater River flows east and then north until it enters the Belle Fourche River at the town of Belle Fourche.

The Redwater River Valley generally consists of wide floodplains which grade into small knolls or flat topped ridges that are sometimes capped by terrace gravels. On the east and north sides of the area studied the Fall River Formation forms a prominent ridge.

Well-numbering System

Wells in this report are numbered in accordance with the U. S. Bureau of Land Management's system of land subdivision. The first numeral of a well designation indicates the township, the second the range, and the third the section in which the well is situated. Lowercase letters after the section number indicate the well location within the section. The letters a, b, c, and d are assigned in counterclockwise direction, beginning in the northeast corner of each tract. The first letter denotes the 160-acre tract, the second the 40-acre tract, the third the 10-acre tract, and the fourth the $2\frac{1}{2}$-acre tract. To distinguish between two or more wells situated within the same tract,

Table 1.--Average precipitation and temperature at or near Spearfish and Belle Fourche 1950-1961.

	Spearfish (Homestake Sawmill)		Belle Fourche (Bureau of Reclamation Diversion Dam)	
Year	Precipitation (inches)	Temperature (degrees F.)	Precipitation (inches)	Temperature (degrees F.)
1950	13.75	43.9	11.31	42.8
1951	21.50	42.6	14.57	43.2
1952	13.00	--	9.91	46.9
1953	19.10	49.9	15.28	48.4
1954	15.75	49.3	8.77	47.7
1955	20.15	46.7	12.47	45.1
1956	20.78	--	10.19	--
1957	21.72	--	16.68	45.7
1958	19.70	--	12.75	46.6
1959	11.89	47.4	9.50	48.1
1960	11.93	46.7	9.91	46.4
1961	13.77	--	10.28	47.5
Ave.	20.97* 19.13**	--	14.09* 13.07***	46.6

*The averages were obtained in oral conversation from H. Orr, U. S. Forest Service. Orr had arrived at these averages after a comprehensive check of all information available. Some of the records used were for the 1890's.

**Twenty year average, 1942-1961.

***Thirty-six year average, 1926-1961.

consecutive numbers beginning with 1 are added as a suffix to each well designation. Well 7-2-10cda2 is the second well described in the NE$\frac{1}{4}$ SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 10, T. 7 N., R. 2 E; the method of designation is shown by Figure 2.

GENERAL GEOLOGY

Bedrock

Stratified sedimentary rocks of Cretaceous, Jurassic, Triassic, Permian, Pennsylvanian, and Mississippian age are exposed in the area studied. These include the Inyan Kara, Morrison, Sundance, Spearfish, Minnekahta, Opeche, Minnelusa, and Pahasapa Formations (fig. 3). Of these formations only the last five mentioned above are involved in the production of water in the area studied. The Spearfish Formation is overlain to the north and northeast by the northeastward dipping Sundance Sandstone, Morrison Shale, Lakota Sandstone, Fall River Sandstone, and overlying shales.

The Spearfish in this area has a maximum thickness of about 640 feet. It consists mainly of red sandy or silty shale. Gypsum stringers occur throughout the formation and may locally thicken to twenty feet.

The Minnekahta Limestone ranges in thickness from 33 to 45 feet and is a massive gray to pink laminated limestone. Solution caverns or sinks may occur in the formation.

The Opeche Formation varies in thickness from 100 to 120 feet and is made up of red silty and sandy shales and may have streaks of gypsum. The top few feet of the formation are characteristically purple.

The Minnelusa Formation has a thickness of from 400 to 500 feet. It consists of pink and white granular sandstones with limestone lenses and layers. Red shales, white sandstone and interbedded limestone occur near the base. Locally a thick permeable sand is found at the top of the formation.

The Pahasapa Limestone is about 630 feet thick in this area and is light colored. The formation contains many solution caverns. The Pahasapa is underlain by about 70 feet of Ordovician limestone, shale, and sandstone, and about 450 feet of Cambrian Sandstone.

Structure

The general dip of the beds in the area is northeast and varies from one to three degrees. The Belle Fourche Anticline is on the east side of the area studied and the major axis can be traced from Belle Fourche to a point about three miles east of Spearfish.

OCCURRENCE OF GROUND WATER

Principles of Occurrence

Practically all ground water is derived from precipitation. Rain and meltwater from snow enters the ground by direct percolation or by percolation from streams and lakes that lie above the general water table. Ground water generally moves downward and laterally from areas

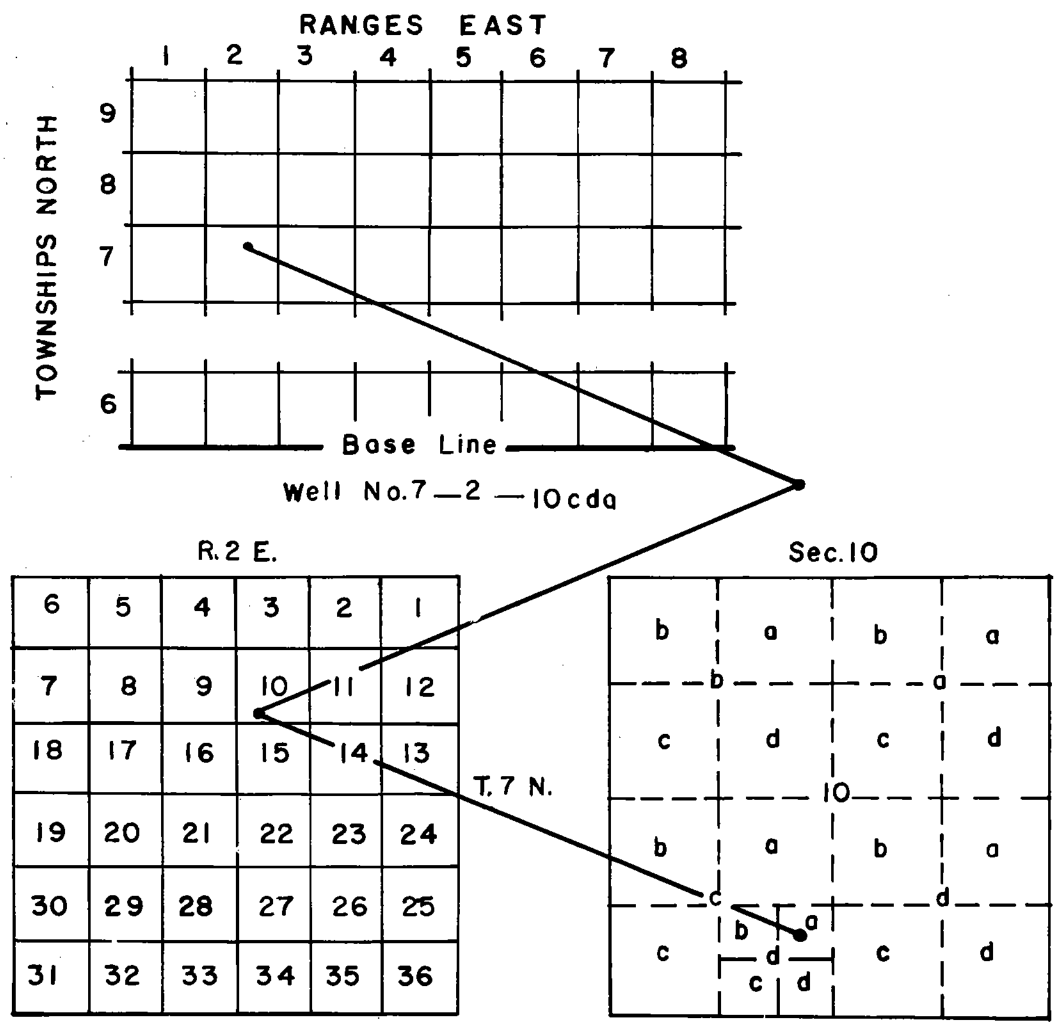
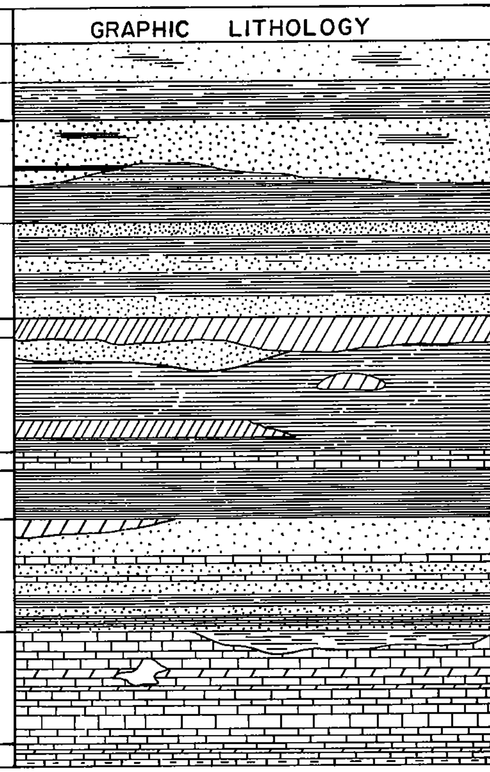


Figure 2. Well-numbering system.



SERIES		FORMATION	Thickness, feet	DESCRIPTION
LOWER CRETACEOUS	INYAN KARA	FALL RIVER [DAKOTA (?)] SS.	10-200	Massive to slabby sandstone.
	INYAN KARA	FUSON SHALE	10-188	Gray to purple shale. Thin sandstone.
	INYAN KARA	LAKOTA SANDSTONE	25-485	Coarse, hard, crossbedded sandstone mostly buff to gray. Conglomerate locally and coal at base.
JURASSIC		MORRISON FORMATION	0-220	Green to maroon shale. Thin sandstone.
		SUNDANCE FORMATION	250-450	Greenish-gray shale, thin limestone lenses Glauconitic sandstone; red ss. near middle.
		GYPSUM SPRING FORMATION	0-45	Red siltstone, gypsum, and limestone.
TRIASSIC		SPEARFISH FORMATION	300-700	Red sandy shale, soft red sandstone and siltstone with gypsum and thin limestone layers. Gypsum locally near the base.
PERMIAN		MINNEKAHTA FORMATION	30-50	Massive gray laminated limestone.
		OPECHE FORMATION	50-135	Red shale and sandstone.
PENNSYLVANIAN		MINNELUSA SANDSTONE	300-850	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite. Red shale with interbedded limestone and sandstone at base.
MISSISSIPPIAN		PAHASAPA (MADISON) LIMESTONE	300-630	Massive light-colored limestone. Dolomitic in part. Cavernous.
		ENGLEWOOD LIMESTONE	30-60	Pink to buff limestone. Shale locally at base.

Figure 3. Generalized Columnar Section of the Northern Black Hills Area.

of recharge to areas of discharge. The ground water in the area studied is under artesian conditions as it is confined in the aquifer by overlying impermeable stratas. Under artesian conditions, hydrostatic pressure will raise the water in a well or other conduit that penetrates the aquifer, above the top of the aquifer.

The amount of water that is available from an artesian system depends on the amount of water entering the aquifer and the porosity and permeability of the aquifer. Porosity is a measure of the number of voids in a rock and is expressed as the ratio of pore space to the total volume of rock.

Porosity is dependent on (1) the shape and arrangement of individual particles, (2) the degree of sorting of the particles, (3) the degree of cementation and compaction of the particles, and (4) the amount of material which has been removed by percolating ground water. Sands usually have a porosity from 20 to 40 percent depending on the above conditions, whereas sandstones have porosities of 15-20 percent. Sandstones have lower porosities owing to their higher degree of compaction and cementation.

Permeability is a measure of the rate at which a fluid will pass through a material. A material that has a high percentage of interconnected pores likewise has a high permeability, whereas a material that is high in porosity but in which the pores are not connected will have low permeability. Porosity and permeability are not synonymous but are related. Favorable porosity and permeability is of little value unless the ground water is adequately recharged at the outcrop.

The most common method of estimating ground water recharge has been to determine the quantity of water that falls annually as rain or snow and then to approximate what percentage of this reaches the zone of saturation. This method is of little value, unless there is a reliable basis for the percentage that is approximated to reach the zone of saturation. Commonly the approximated percentage and therefore also the computed recharge is much too large (Tolman, 1937).

Ground Water in the Spearfish Formation

The Spearfish Formation is generally not very permeable. In much of the Black Hills area it yields only limited amounts of mineralized water. Northwest of the town of Spearfish wells produce up to 1000 gallons per minute (gpm) from caverns in the basal part of the formation. The caverns are probably the result of dissolved gypsum beds. Water from lower formations, primarily the Minnelusa and Pahasapa, probably reaches the lower Spearfish Formation by way of channels, solution caverns or faults. The springs in the area probably have the same source.

Ground Water in the Minnekahta-Opeche Formations

In most of the Black Hills area the Minnekahta and Opeche Formations are not considered to be aquifers; however, in the area studied, the Minnekahta may yield large amounts of water under artesian conditions. The producing area is rather limited and the water probably originates in lower formations and moves upward along fissures or channels. The area studied has at least seven wells producing from the Minnekahta, with one well (No. 33, Appendix A) flowing between 500 and 800 gpm.

Ground Water in the Minnelusa Formation

Nearly all the ground water in the Minnelusa aquifer is derived from rainfall and melting snow, which enters the outcrop and moves down-dip away from the Black Hills. It is believed that the principal area of recharge for the area studied is the Minnelusa outcrop between Spearfish Creek in Lawrence County and Sand Creek in Crook County, Wyoming (pl. 1). This area contains about 54 square miles of Minnelusa outcrop of which two-thirds (34 square miles) is in South Dakota. The porosity and permeability of the Minnelusa Sandstone is such that it absorbs about as much water from the base of streams crossing the outcrop as the stream gains by seepage from the valley walls above water level.

The annual precipitation on the Minnelusa outcrop is estimated at 21 inches per year. This would result in 59,880 acre-feet of water annually falling on the 54 square miles of Minnelusa outcrop. The percentage of the annual precipitation entering the Minnelusa outcrop could not be determined. However, if as much as two inches of precipitation entered the Minnelusa aquifer it would represent a recharge of only 5,760 acre-feet per year for the area studied (or 10 percent of the total annual precipitation).

No attempt was made to estimate the amount of ground water in transient storage in the Minnelusa aquifer.

Withdrawal from the Minnelusa artesian aquifer in the area studied is estimated at 9,680 acre-feet per year by flowing and pumped wells, and 24,205 acre-feet per year by springs, or a total of 33,885 acre-feet. The springs feeding Sand Creek (pl. 1), are flowing from the Pahasapa aquifer, and are not included in this estimate.

If the estimated Minnelusa recharge of 5,760 acre-feet is correct, then the outcrop recharge cannot equal the total withdrawal of 33,885 acre-feet. For this reason, it is believed that the Minnelusa aquifer is being partially recharged in some other manner. The most logical possibility would seem to be channeling or seepage upward from the underlying Pahasapa Formation.

Ground Water in the Pahasapa Formation

The Pahasapa Formation outcrop probably receives more precipitation per square mile than the Minnelusa outcrop, because of its greater elevation. Because of the porous and cavernous nature of the Pahasapa Limestone, it may be recharged mainly by streams. These cavernous aqueducts may be nearly parallel to the strike of the bed which makes it difficult to determine the recharge zone for a given area. As these aqueducts may capture much of the runoff of a drainage basin, the recharge to the Pahasapa Formation is not necessarily in direct relation to the amount of outcrop in a given area. Future studies of stream flow loss across the Pahasapa outcrop may allow reasonable estimates of recharge to be made.

The recharge zone of the Pahasapa Formation is at a higher elevation than the recharge zones of the overlying Minnelusa and younger formations, and thus the Pahasapa has a greater hydrostatic head. The ascending Pahasapa water probably recharges the younger formations as it channels or seeps upward.

Springs

The city of Spearfish obtains about 650 gallons of water per minute from springs that rise at 6-2-33d (pl. 1) from the lower part of the Pahasapa or the underlying Englewood Limestone. The city utilizes all the water from these springs during the summer months. The upper part of the Pahasapa and the Minnelusa do not produce large springs in Spearfish Canyon.

Numerous large springs exist in the area studied. These include the Spearfish Trout Farm Spring, the Crow Creek Springs, and springs in and near the city of Belle Fourche water collection gallery (pl. 1). Lakes in the area that are fed by springs are Cox Lake, Mirror Lake, and Montana Lake (pl. 1). During the irrigation season when the wells flow unrestricted, the springs feeding Montana Lake dry up entirely, and the springs feeding Mirror Lake decrease as much as 25 percent.

The surface bedrock at and in the vicinity of all the above springs is the Spearfish Formation.

These springs are of artesian origin. The primary source of the spring water is thought to be the Pahasapa Formation, and it is believed that faulting or channeling has allowed the water to reach the surface. Several facts would tend to back up the above statement: (1) the Minnelusa recharge, if it is near the estimated 5,760 acre-feet, could not sustain the flows obtained from the various springs; (2) the permeability of the formations above the Minnelusa is so low that they could not transmit the volume of water that issues from the springs; and (3) the annual precipitation on the outcrops of these younger formations is less than that on the Pahasapa Formation.

The Minnekahta Limestone contains solution caverns which are natural channel-ways for the passage of water. A sink at the Cole Quarry, located at 6-3-35a, is shown on photographs in Appendix B. This sink was first seen at the top of the Minnekahta Formation and has not changed in size downward through the 20 feet of limestone that has been quarried. Springs in the area studied probably reach the surface through comparable channel-ways.

The springs that are the main source of water for Sand Creek in Wyoming are fed by artesian flows from the Pahasapa Formation. The Pahasapa Formation is exposed in the bed of the Creek for several miles (pl. 2). This zone of springs rises in 52-61-13 and 52-60-18 and the section to the west, and extends for about a mile to the north along the bottom of Sand Creek.

During the 1930's, large Pahasapa springs flowed into Sand Creek about a mile south of the present spring. These springs have long since ceased to flow, apparently because of a drop in the Pahasapa hydrostatic head. Should the hydrostatic head continue to drop, the flows of the present springs will, of course, decrease. A drop of about 125 feet in head will cause the Sand Creek Springs to cease flowing and Sand Creek will therefore become an intermittent stream.

The reason for this drop in the hydrostatic head of the Pahasapa is not clear. A possible cause might be an overdraft by Minnelusa wells in Lawrence County, which lowers the hydrostatic head in the Minnelusa Formation and allows the ascending Pahasapa spring water to recharge the Minnelusa at a faster rate than normal, thus causing an overdraft on the Pahasapa.

Another possibility may be the manner in which the forests and grazing lands are handled in the outcrop areas. Along with a decreased hydrostatic head in the aquifers, a downward trend in runoff is published by Mr. H. K. Orr (1959) of the U. S. Forest Service. In evaluating the runoff records (1915-42) of Rapid Creek he writes:

> "Reasons for the downward trend in runoff, if it is real, cannot be precisely pinpointed, but there are several possible explanations. It may be that some long-term carryover effect or cycle of low precipitation is still influencing ground water storage. Or it may be that more moisture is held on agricultural land by changed tillage and cropping practices and lost to evaporation and transpiration. Another possibility is the change from mature, old-growth, virgin ponderosa pine forest to a more dense second-growth forest that may draw more heavily on available moisture. Improved fire protection and reduction of burned-over area may also mean that more acres are occupied by vegetation, primarily ponderosa pine, and a greater total amount of moisture is utilized."

Temperatures and Pressures of the Artesian Aquifers

The following generalized temperature-depth correlations apparently exist in wells in the area:

Depth of well (feet)	Temperature (degrees F.)
0- 700	49-55
700-1200	55-61
1200-2000	61-75
over 2000	75 plus

The mean annual temperature in the area studied ranges from 45.3° to 47.2°. A smooth temperature gradient for wells in this area does not exist. Several possibilities may account for this. Most of the wells produce from uncased holes, which allows the mixing of water from several aquifers. A well may bottom in a poor producing zone of the Minnelusa, thus resulting in the higher (and cooler) aquifers producing most of the water. This gives a cooler temperature than would be expected for the depth of the well. An example of this may be Well 41 (Appendix A).

A warmer temperature than would be expected for the depth of the well can occur when a well is bottomed in the Spearfish Formation and the water is being fed by channels from the Pahasapa Formation. An example of this may be Well 29 (Appendix A). This well produces from a lower Spearfish gypsum cavern at a depth of 576 feet (and should have a temperature of about 54° F.), but the temperature of the water (63° F.) indicates that it is probably coming from about 1300 feet, which would be near the top of the Pahasapa Formation.

Pressure records of area wells are few and incomplete (Appendix A). In all cases where periodic pressures or water levels have been taken during the irrigation season, they show a continuous decrease and the rate of decrease has accelerated in the last year. The flows and pressures of some wells taken in May, 1962, before irrigation started, showed an increase in flow and pressure. This is due to some of the wells being shut in during the winter months and to recharge of the aquifer by melting snow. It is expected that future flow and pressure readings will show a decline. The increased number of wells drilled recently is presumed to be responsible for the decreased pressure. This pressure decrease is indicative of an overdraft.

With the exception of one well (No. 16, Appendix A), the wells in the different formations have similar pressures. The numerous uncased wells in the area, and the Pahasapa water that presumably channels to the surface, should tend to equalize the pressures in the different formations. The above exception may be due to water from the Lower Pahasapa Formation, with greater hydrostatic head, channeling to the Minnelusa Formation at this location.

Faulting Related to Ground Water

The numerous springs in the area suggest the possibility of fault zones which could allow artesian water to migrate to the surface along fault planes. Air photos and surface examination located a sink hole at 53-60-28da, northeast of Montana Lake. According to a local resident, the sink appeared about 15 years ago. The sink is about 20-30 feet square, and water stands in it about 15 feet below the land surface. The north side of the sink appears to be a hanging wall with a northerly dip of about 60-70 degrees. This sink may be on a fault that caused Montana, Mirror, and Cox Lakes. The sink is at an approximate elevation of 3515 feet which is near the top of the Minnelusa hydrostatic head in the area, and at approximately the same elevation as the springs that feed Montana Lake. The lowering of the hydrostatic head in the area in recent years may have reduced the support under this unstable zone and allowed the sink to form.

Seismic information obtained in connection with the local Minuteman Missile Sites shows a north-south fault in 7-1-19dddd. The west side of the fault is down-thrown 15 feet. The dip and length of the fault are unknown.

Quality of Water

Precipitated water is nearly pure before it reaches the ground. However, all ground water contains minerals which are obtained: (1) from the atmosphere as the water vapor condenses and falls, (2) from soil and underlying deposits as the water percolates downward to the water table, and (3) from deposits below the water table, in which the water is circulating.

In general, it can be said the more minerals a water contains, the poorer its quality, and also as a general rule, the farther from the outcrop the well is, the more minerals the water contains.

Chemical analyses were obtained on the water from three springs and nine Minnelusa wells in the area (table 2). All the water samples contain over 200 parts per million (ppm) calcium carbonate and are

Table 2.--Chemical analyses of water samples in the Belle Fourche-Spearfish area.*

Well No. (see App.B)	Date collect-ed	Parts Per Million									Sodium percent-age of Cations	Source	Depth of well
		Iron	Calcium	Mag-nesium	Sodium	Sulfate	Chloride	Fluoride	Total Solids	Hard-ness $CaCO_3$			
1	2/59	2	765.5	211.4	28	2,350	50	--	--	2,780	--	Minne-lusa	3200
3	8/60	0.74	582	92	58	1,610	61	2.6	2,530	1,830	6	Minne-lusa	2225
4	8/61	0.17	164	23	7.8	308	1.3	0	658	502	3	Minne-lusa	2340
9	8/61	8.1	564	142	24	1,780	4	0.9	2,630	1,990	3	Minne-lusa	825
14	8/60	0.05	80	31	2.5	119	0.6	0.4	410	328	2	Minne-lusa	985
20	10/56	0	579.1	46.17	13.11	1,422	3	0.6	--	1,636	--	Spring	
21	6/61	--	225	28	2	487	0	--	956	676	--	Spring	
31	8/61	0.08	408	73	4.9	1,060	0.6	0.7	1,680	1,320	1	Minne-lusa	845
35	6/61	--	274	42	2	732	0	--	1,262	858	--	Spring	
36	6/61	--	154	28	2	275	Tr.	--	678	501	--	Minne-lusa(?)	?
38	8/60	0.17	325	51	2.5	781	1.4	0.4	1,300	1,020	1	Minne-lusa	1218
45	11/54	0	63.33	20.53	6.69	8.23	4	0.1	--	242.6	--	Minne-lusa	565

*samples from Well Nos. 20, 45 analyzed by State Department of Health, Pierre, South Dakota
samples from Well Nos. 3,4,9,14,31,38 analyzed by U. S. Geological Survey, Quality of Water Branch, Lincoln, Nebraska
samples from Well Nos. 21,35,36 analyzed by State Chemical Lab., Vermillion, South Dakota
sample from Well No. 1 analyzed by State Agriculture Exp. Sta., Brookings, South Dakota

considered very hard. For those samples tested for manganese, boron, and bicarbonate, none of the samples exceeded .03, .23, and 283 ppm respectively.

The analyses of the Minnelusa well water in this area vary considerably so that increasing mineral content could not be equated to the general rule of distance from the Minnelusa outcrop. Water from the springs in this area also showed a variable mineral content and showed no correlation with the well water. Further testing, however, may result in a pattern being established.

Reports have been received that the quality of the water from wells bottoming in the lower part of the Spearfish Formation has improved during the last 20 years. If this is true, it would indicate that the Spearfish water-bearing zones are being recharged by open-hole Minnelusa wells, or by wells that have been improperly cased, or wells that have deteriorated casing. Unverified reports have also been received that about 60 old Minnelusa wells in the valley of Spearfish Creek have now ceased to flow, presumably because of casing failure, and thus may be recharging the formations above the Minnelusa.

Surface Water in Spearfish Creek

The water in the northern part of Spearfish Canyon is being used by the Homestake Mining Company from a dam located in 5-2-17a. The water from the dam enters a tunnel and flows by gravity six or seven miles to the Homestake Hydroelectric Plant in 6-2-15ddb. The bottom of the tunnel is lined with concrete to prevent seepage. The purpose of the tunnel was to keep the water high enough to maintain the static head of 670 feet which exists at the hydroelectric plant. The intake dam captures all the water in Spearfish Creek and consequently the water does not cross the Pahasapa or Minnelusa outcrops, which occur between the intake dam and the town of Spearfish. The Homestake Mining Company has supplied the following figures which show the intake in second-feet at the dam for the high and low months for each of the last five years.

Table 3.--Intake in second-feet for the high and low months from 1957-61 at the Homestake Mining Company Dam in Spearfish Canyon.

Year	Low Month	Average second-feet	High Month	Average second-feet
1957	January	27.0	May	93.9
1958	December	24.8	May	51.9
1959	January	23.2	May	40.3
1960	November	22.7	April	45.1
1961	August	18.45	March	25.1
Average for the 5 yrs.		23.23		51.3

CONCLUSIONS AND RECOMMENDATIONS

The customary method of completing artesian water wells in the Belle Fourche-Spearfish area has been to put in a short length of surface casing and produce "open-hole", or to completely case the well and cement the casing only near the top. In most wells, the Spearfish, Minnekahta, Opeche, and the Minnelusa Formations are not cased or are not cemented off. These methods of completing the wells allow water from the different formations to mix. It seems certain that the formation waters, in some areas at least, have mixed via sinks, channeling, or faults.

A more immediate result of the "open-hole" completion practice is to cause a reduction in the artesian flow. The reduction is caused apparently by caving of the sides which bridge the uncased hole. In some cases, this has resulted in as much as a 42 per cent reduction in flow within a year after the well was drilled; this happens even in wells where the pressure is as great as 85 pounds per square inch (Well 3, Appendix A).

Some of the flow reductions shown in Appendix A are probably the result of an overdraft of the aquifer but some reductions are due to improper well completion practices. If surface casing is properly cemented before a large, high-pressure flow is encountered, no problem is presented in placing and cementing adequate casing to the producing formation. Many people would undoubtedly protect their expensive investment by cementing casing all the way to the producing zone if they were aware of the problems that can arise from "open-hole" completions.

It is recommended that approval to drill wells for irrigation use be held in abeyance until the extent of the overdraft can be determined by additional studies.

In recognition of the importance of careful observation of the Minnelusa artesian water pressure, the State Water Resources Commission has approved a bid to drill and case an observation well to the Minnelusa Formation, to be located in 7-2-10bad. The drilling is to be completed by June 30, 1962, and the completed well will contain a permanent pressure gage and chart.

The location of the test well was selected so that it would not be influenced by fluctuations of outcrop recharge, so that it would be reasonably close to the large-flowing Minnelusa irrigation wells, and so that it would be at the top of the Minnelusa Formation in the thick sand zone which produces the large flows in this area.

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APPENDIX A

Records of Wells

No.	Name & Location	Temp. Degrees F.	Total Depth	Surf. Elev.*	Elev. top Minn.*	Date Comp.	Flow date	Flow gpm	Pressure date	Pressure psi	Deepest Formation Penetrated
1	Geisinger 56-60-4b		3200	3310	227	1958	1958 10/62	100r 5e	1958	68r	Minnelusa
2	Olson 9-3-27ad	125.5	4016	3000	690	1952	10/61	1194			Pahasapa
3	Dusing 8-3-2bd	103	2225	2990	861	1960	8/60 8/61 5/62	75 43 24	8/61 5/62	85 80	Minnelusa
4	McElroy 8-3-33cc	72	2340	3260	1325	1960	8/61 5/62	47 50	8/61 5/62	60 60	Minnelusa
5	Broadhurst 8-3-31ac	71	1853	3200	1180	1960	8/60 8/61 5/62	800 667 545	5/62	78.2	Minnelusa
6	McKay 8-1-33ac		1450	3493	2258	1953	1961	25r			Minnelusa
7	Fishel 8-1-19cb	64	1585	3390	2235	1953	1961	75r			Minnelusa
8	Montana Lake 53-60-28c	51	3515								
9	Papousek 7-1-19bc	53	825	3525		1961	8/61 5/62	1e ½e			Minnelusa
10	Papousek 7-1-19dc	53	640	3510		55&60	7/56 2/62 5/62	800r 500r 523	7/56 5/62	7.8r 9.0	Opeche (?)

*feet above sea level. **water level below (-) or above (+) land surface (feet).

a-about b-before e-estimated r-reported

No.	Name & Location	Temp. Degrees F.	Total Depth	Surf. Elev.*	Elev. top Minn.*	Date Comp.	Flow date	Flow gpm	Pressure date	Pressure psi	Deepest Formation Penetrated
11	Giltner	53	402	3510		1952	1952	800	1952	9.1	Minnekahta
	7-1-30bd1						7/56	700r	8/60	5.9	
							8/60	470	8/61	5.0	
							5/62	461	4/62	6.75	
12	Giltner	54	406	3510		1951	7/56	408			Minnekahta
	7-1-30bd2						8/60	390			
13	Giltner		498	3540		1943	b1952	30	8/60	+0.9**	Minnelusa
	7-1-30ca						7/56	5	8/61	-1.4**	
							5/62	4	5/62	+0.27**	
14	Tullock	56.5	985	3510	3012	1960	8/60	90			Minnelusa
	7-1-30dd						5/62	133			
15	Papousek		397	3480		a1916					
	7-1-29aa1										
16	Papousek	52	555	3480	2940	1961	5/62	800	5/62	40.0	Minnelusa
	7-1-29aa2										
17	Papousek	52	430	3480		1955	7/56	150	1955	18.3r	Minnekahta
	7-1-29aa3						5/62	550	5/62	14.0	
18	SDGFP	51.5	400	3480			7/56	43			Minnelusa
	7-1-21cc						8/60	40e			
19	USFWS	52	220	3379		1943	7/56	1600r			Spearfish
	7-1-21bb						4/60	934			
							8/60	1000	8/60	29.1	
									5/61	28.1	
									4/62	26.6	
20	Mirror Lake	52	3470				6/61	620			
	7-1-20ab						10/61	462			

*feet above sea level. **water level below (-) or above (+) land surface (feet).

a-about b-before e-estimated r-reported

No.	Name & Location	Temp. Degrees F.	Total Depth	Surf. Elev.*	Elev. top Minn.*	Date Comp.	Flow date	Flow gpm	Pressure date	Pressure psi	Deepest Formation Penetrated
21	Cox Lake 7-1-16d			3405			6/61 10/61	2429 2496			
22	Cunningham 7-1-9bc		785	3423	2727	1958					Minnelusa
23	Schenk 7-1-22ba	52				a1914	7/56	128			Minnelusa (?)
24	Anderson 7-1-14cc	54		3464		1914	8/61 5/62	150 306	8/61 5/62	3.5 6.75	Spearfish (?)
25	Sleep 7-1-23bc	53	585			1954	7/56 5/62	1.5e 0.0	8/61 5/62	-8.0** 0.0**	Minnelusa
26	Sleep 7-1-23cb	52.5	465	3470		1955	7/56	1100r			Minnekahta
27	Edwards 7-1-26ac		270	3524	3327	1960			8/60 5/61 8/61 4/62	-29.28** -29.08** -35.25** -29.08**	Minnelusa
28	Evans 7-1-24ac	54	360	3400		1960	8/60 8/61 5/62	300 188 210			Minnekahta
29	Bryant 7-1-13ac	63	576	3340		1958		1600r		60r	Spearfish
30	Schuft 7-2-8bc	61	982	3305	2375	1951	5/62	172			Opeche (?)

*feet above sea level. **water level below (-) or above (+) land surface (feet).

a-about b-before e-estimated r-reported

No.	Name & Location	Temp. Degrees F.	Total Depth	Surf. Elev.*	Elev. top Minn.*	Date Comp.	Flow date	Flow gpm	Pressure date	Pressure psi	Deepest Formation Penetrated
31	Crago Bros. 7-2-18ca	59	845	3405	2613	1960	8/61 5/62	610 732			Minnelusa
32	Redwater Ditch*** 7-2-19ac	55	700	3405	2764	1960	8/60 10/61	1500 756			Minnelusa
33	Evans 7-2-19cc	54	426	3435		1954	8/56 8/61 5/62	850 570 741			Minnekahta
34	Riley 7-2-20cb	54.5		3435		1962	5/62	316	5/62	21.3	Minnekahta
35	Trout Farm Spring			3395							
36	Evans 7-2-29aa										Minnelusa (?)
37	Redwater Obs. Well No. 1 7-2-10bad	57	1306	3205		5/62	5/62	70e	5/62	100.0	Opeche
38	Perkins 7-2-15cc	59.5	1218	3437	2320	1960	8/60 8/61	630 522	8/61	19	Minnelusa
39	Henwood 7-2-22cc	53	681	3415		1955	8/60 8/61 5/62	225 150 150			Spearfish
40	Johnson 7-2-23bc	56	1088	3378		1958	8/56 5/62	110 86			Minnelusa
41	Johnson 7-2-23ca	54.5	1303	3360	2566	1960	8/61 5/62	138 158			Minnelusa

*feet above sea level. **water level below (-) or above (+) land surface (feet).
a-about b-before e-estimated r-reported
***also known as the U. and I. Sugar Co. Well.

No.	Name & Location	Temp. Degrees F.	Total Depth	Surf. Elev.*	Elev. Top Minn.*	Date Comp.	Flow date	Flow gpm	Pressure date	Pressure psi	Deepest Formation Penetrated
42	Tetrault 7-2-33dd		555	3500	3355	1960	1960	25r			Minnelusa
43	Homestake 6-2-9bb		622	3681	3368				10/39	-25.0**	Minnelusa
44	BHTC 6-2-9d		300	3660	3400	b1918	b1918	115	b1918	15	Minnelusa
									9/56	-17.74**	
									3/57	-16.90**	
									5/57	-15.93**	
									8/57	-18.21**	
									8/59	-22.43**	
									8/60	-25.03**	
									5/61	-29.35**	
									6/61	-29.9 **	
									8/61	-31.1 **	
									5/62	-32.2 **	
45	Spearfish City 6-2-10da		565	3720	3355	1950					Minnelusa
46	Homestake 6-2-23bb		415	3700		a1904	a1904	50	9/56	-74.15**	Minnelusa
									3/57	-75.65**	
									5/57	-75.00**	
									8/57	-75.92**	
									6/59	-76.73**	
									8/60	-79.89**	
									5/61	-82.44**	
									8/61	-83.3 **	
									5/62	-85.55**	
47	Helmer 7-2-12bb	61		3210			8/61	130e			(?)
48	Ryther 7-3-7aa	64	1620	3320	1740	1962	2/62	275e			Minnelusa
							5/62	333			
49	Sankey 7-2-15dc		1250	3410(?)		5/62	5/62	600e			Minnelusa

*feet above sea level. **water level below (-) or above (+) land surface (feet).
a-about b-before e-estimated r-reported

Appendix B

Photographs of Sink Hole in the Cole Quarry

(located 6-3-35a)