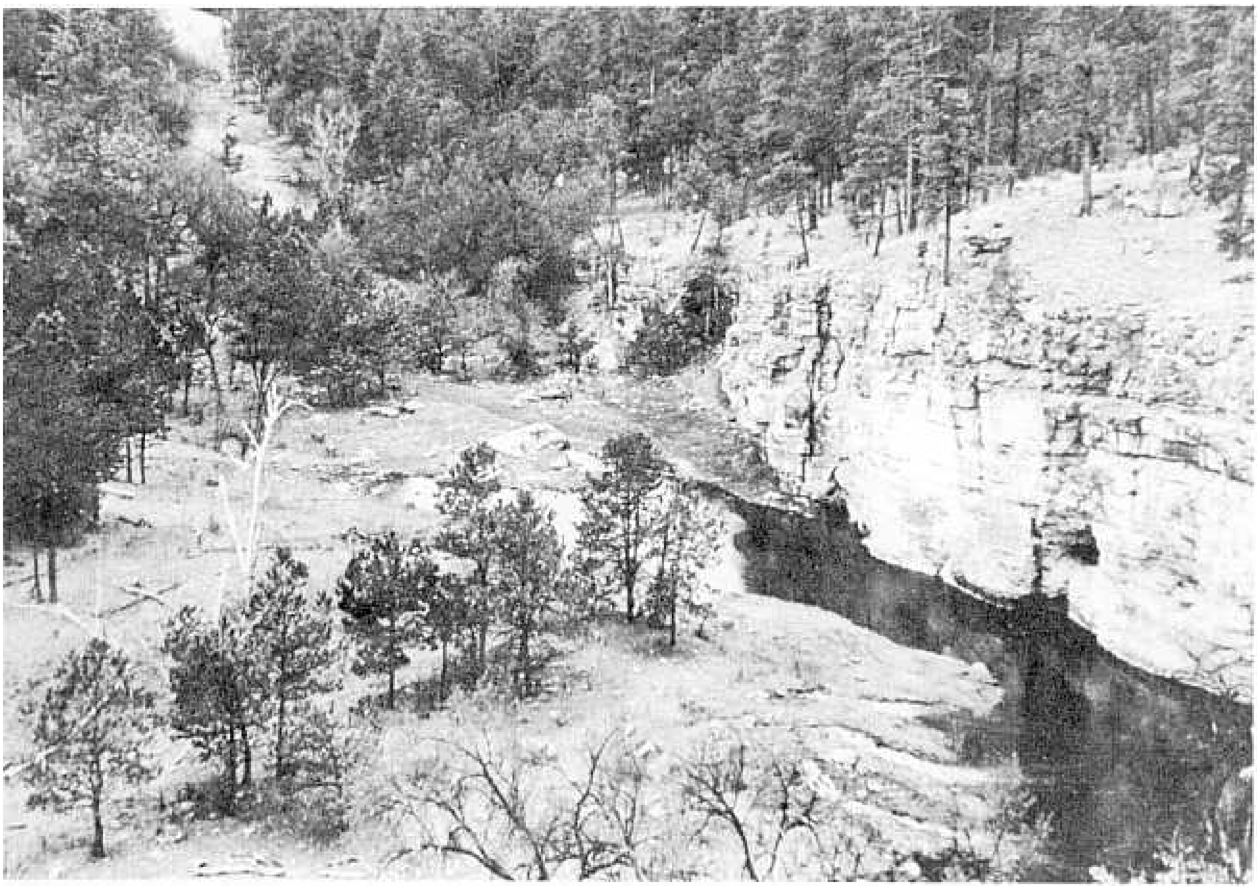
Report of Investigations No. 107

Large Springs in the Black Hills, South Dakota and Wyoming



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Water Resources Research Institute
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S. Dak. State University Brookings, S. Dak.

S. Dak. Geological Survey Vermillion, S. Dak.

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CONTENTS

ABSTRACT

Between 1966 and 1971, monthly stream gagings were conducted on most large streams and springs in the Black Hills of South Dakota and Wyoming. Streams draining the impermeable Precambrian core of the Hills lose an average of 44 cfs to sinkholes where these streams cross the Paleozoic limestone belt flanking the Precambrian core. At the outer edge of the limestone large springs occur where the Triassic Spearfish Formation acts as an impermeable dam to ground water. The average discharge of these springs is at least 190 cfs. The difference between the stream flow loss and the spring discharge is due to precipitation recharge falling directly on the limestone. Since there is probably little deep ground-water loss from this system, precipitation recharge and evapotranspiration rates on the limestone can be established. In general, the northern Hills has a precipitation recharge of at least 6.8 inches/year, and the southern Hills at least 0.6 inches/year.

Ground-water flow directions, based on dye tests, piezometric levels, and discharge measurements show a generally southernly flow of ground water in the eastern flank of the limestone from the Rapid City area towards Hot Springs.

INTRODUCTION

The purpose of this investigation is to measure and determine the origin of large springs in the Black Hills. Because the origin of these springs is related to the same limestone beds into which numerous streams disappear, this investigation also includes a study of these disappearing streams, the so-called "sinkhole problem."

This investigation was initiated in 1966 by J. P. Gries, Professor of Geology, South Dakota School of Mines and Technology, and D. W. Niven, graduate student, South Dakota School of Mines and Technology, and was initially funded by the South Dakota Water Resources Research Institute at Brookings, South Dakota. Funding was continued for three years as a study of water losses to sinkholes in the Pahasapa Limestone. Most of the data and some detailed maps of these gagings are found in the project completion reports and other reports by Gries and Niven (1967), Gries and Crooks (1968), Crooks (1968b), Gries and others (1968), Gries and Rapp (1969), Rapp (1969), and Gries (1971).

During the summers of 1968 and 1969 the South Dakota Geological Survey sponsored P. H. Rahn to work on this project. At this time the scope was enlarged to include the origin of all large springs in the Black Hills.

In general, this report describes only the large springs in the Black Hills, that is, springs whose flow is greater than 1 cubic foot per second (cfs). Many of the springs that appear on topographic and highway maps are, in fact, seeps or small springs with discharges of less than 1 cfs.

ACKNOWLEDGMENTS

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Thanks also to the directors of the Black Hills Conservancy Sub-District and to Lenord Yarger of the United States Geological Survey for their encouragement and helpful suggestions. Victor Myers of the Remote Sensing Institute in Brookings, South Dakota, kindly supplied aerial photographs of some critical areas.

The writers particularly acknowledge the counsel of Dr. Duncan J. McGregor, State Geologist, during the course of the field work and preparation of this report. Fred V. Steece of the South Dakota Geological Survey critically reviewed the manuscript.

Many local residents aided the writers by allowing access to their land and extending other courtesies. Special thanks to the following people: Jack Paulton, Elmer Iverson, Thomas Callan, John McFarland, Larry Jacobson, Henry Schmitz, Kirk Dahn, James Thomson, Charles Hall, Dr. Eugene Ittzes, and Virgil Williams.

PREVIOUS INVESTIGATIONS

Water loss by streams crossing the Paleozoic limestones in the Black Hills was first noted by Newton and Jenny (1880). Detailed description of ground waters in western South Dakota was made by Darton (1896, 1901, 1905, 1909a, 1909b, 1918). The study of artesian aquifers in this area was further studied by Rothrock and Robinson (1936). Brown (1944) made a study of the water losses of streams flowing east from the Black Hills. A detailed investigation of discharge of Battle Creek relating to losses and gains in the Paleozoic and lower Cretaceous rocks was conducted by Shortridge (1953). Cox (1962) conducted a similar investigation in the northern Hills and related recharge to the artesian pressure in wells. Gries (1943) and Adolphson and LeRoux (1971) studied artesian pressure in wells in the Paleozoic limestones flanking the Black Hills.

Swenson (1968), using data by Brown (1944), estimated that a minimum of 54 cfs enters the Paleozoic limestone beds ". . . without any sign of rejected recharge" (Swenson, 1968, p. 175). He concluded that this water migrates eastward down the dip of the limestone and later moves upward into the

Cretaceous "Dakota Sandstone." Schoon (1971) took exception to Swenson's theory in view of subsurface stratigraphic data. White (1969) used Swenson's concepts to classify the Black Hills carbonate aquifers into an artesian aquifer system.

GEOLOGY

The general geology of the Black Hills is described by Darton and Paige (1925). The Black Hills uplift is about 100 miles long and about 60 miles wide, measured from the lower Cretaceous sandstone hogback which surrounds the Hills (see pl. 1). The long axis of the uplift trends north-northwest. The uplift is Laramide in age, and the central part of the Black Hills has been eroded down to the Precambrian. The highest point in the Black Hills is Harney Peak in the Precambrian core whose elevation is 7,242 feet above sea level.

The gently dipping Paleozoic and Mesozoic rock sequences flanking the Black Hills are remarkably complete. The major systems are summarized below in descending order from youngest to oldest.

Sedimentary Rocks:

Tertiary

White River Group. 0 to 600 feet of gently dipping clays with local sandstone channel fillings and limestone beds are separated by an angular unconformity from the older sedimentary rocks.

Cretaceous

Graneros Group, Greenhorn Formation, Carlile Formation, Niobrara Formation, and *Pierre Shale.* These sediments include over 2,000 feet of black fissile shale, with some thin interbedded limestone chalk, bentonite, and sandstone.

Jurassic-Lower Cretaceous

Inyan Kara Group (Cretaceous), *Morrison Formation* (Jurassic), and *Unkapapa Sandstone* (Jurassic). These deposits are predominantly sandstones, with some interbedded clay. The thickness is from 200 to 1,000 feet.

Permian-Triassic-Jurassic

Spearfish Formation (Permo-Triassic) and *Sundance Formation* (Jurassic). The bright red, sandy shale beds of the Spearfish Formation range from 250 to 700 feet thick, and contain some gypsum lenses. The Sundance Formation consists of 250 to 450 feet of glauconitic sandstones and greenish-gray shale.

Permian

Minnekahta Limestone. It consists of 40 feet of massive thinly laminated limestone. The *Opeche Formation* is a 90-foot thick red shale.

Permo-Pennsylvanian

Minnelusa Formation. It consists of three units: an upper red to white sandstone, up to 200 feet thick; a middle dolomite, sandstone, and shale with much anhydrite in subsurface, 200 to 300 feet thick; and lower sandstones and dolomites with basal red shale, 0 to 300 feet thick.

Mississippian

Pahasapa (Madison) Limestone. This massive cavernous limestone and dolomite is 300 to 650 feet thick (fig. 1). It thins out 30 miles southeast of the most southerly outcrop (Gries, and Mickelson, 1964).

Ordovician-Devonian-Mississippian

Englewood Formation. This thin-bedded pink limestone is 30 to 40 feet thick. The *Whitewood Formation* is a buff limestone up to 60 feet in the northern Black Hills.

Cambrian-Ordovician

Winnipeg Formation. This dense green shale is up to 60 feet thick in the northern Black Hills. *Deadwood Formation.* This formation is generally a massive sandstone, with some green shale and flaggy limestone, and conglomerate locally at the base. It ranges from 400 feet thick in the northern Black Hills to 10 feet thick in the southern Hills.

Igneous Rocks:

Tertiary

Tertiary intrusive rocks are found as dikes, sills, and laccoliths in the northern Black Hills. The composition varies from rhyolite to andesite.

Precambrian

Granite and granite pegmatite dikes and stocks are found in the Harney Peak area. *Metamorphic rocks* of varying lithologies make up the bulk of the Precambrian core of the central Black Hills. The predominant rock types are slate, phyllite, schist, and quartzite.

Because of the relative permeabilities of the

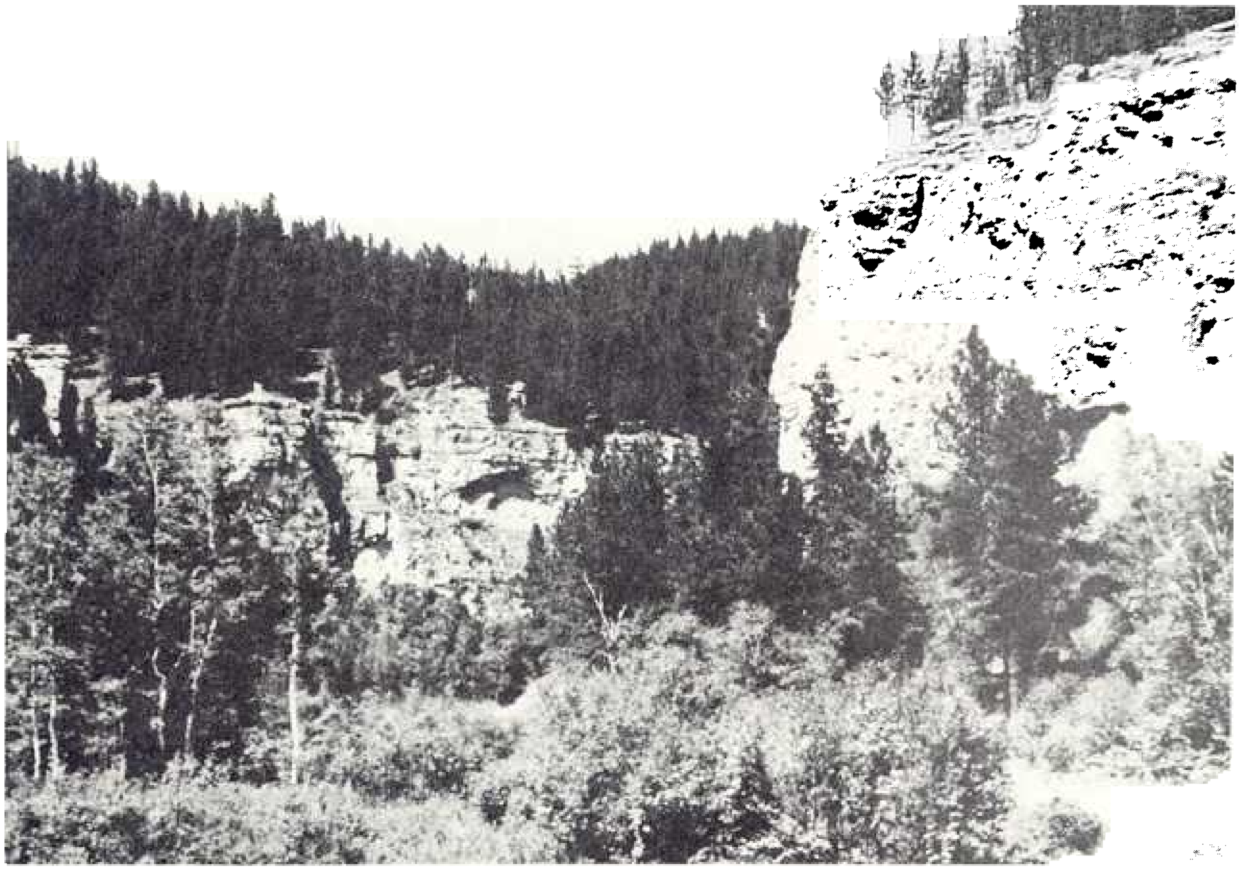


Figure 1. Cliffs of the Pahasapa Limestone, exposed in Spearfish Canyon.

bedrock units, it is convenient to consider the rocks described above into five major groups.

a. *Cretaceous aquitard*. The relatively impermeable Cretaceous black shales.
b. *Sandstone aquifer*. Permeable Cretaceous and Jurassic Sandstones and interbedded shales.
c. *Triassic-Jurassic aquitard*. The relatively impermeable Triassic Spearfish Formation and Jurassic Sundance Formation.
d. *Carbonate aquifer*. Permeable Paleozoic limestones and sandy dolomites.
e. *Precambrian aquitard*. Relatively impermeable lower Paleozoic Winnipeg and Deadwood Formations and the underlying Precambrian rocks.

The carbonate aquifer (shown in blue, pl. 1) is the main object of this study, because all large springs are related to this aquifer.

HYDROLOGY

General precipitation and runoff characteristics of the Black Hills are described by Orr (1959). Average annual precipitation ranges from 26 inches in the high parts of the northern Hills to 16 inches in the lower elevations. Most of the precipitation occurs during the months from April to August.

Streamflow records have been collected for many years, by the U.S. Geological Survey. These data are published in the Geological Survey's Water Supply Paper series for the streams of the Upper Missouri Basin. Some of these data have been incorporated into this report. Because the U.S. Geological Survey is mainly concerned with the discharge of major rivers, it was necessary for the purpose of this report to make many additional measurements of springs and streams above and below sinkholes.

Streamflow is generally highest during April through July when precipitation is also highest. Another source of streamflow is the many small seeps and springs in the central Precambrian core. These normally freeze in winter, build ice accumulations, and melt in the spring.

Figure 2. Beaver Creek at Buffalo Gap (Site 15) is being gaged with the pigmy current meter. Twenty readings of the average velocity, as determined by a spinning wheel in the current, is multiplied by the cross-sectional area to determine the total discharge.

STREAM GAGING PROCEDURE

In order to understand the hydrology of the Paleozoic carbonate aquifer, it is necessary to measure the streamflow loss into it as well as the spring discharge from it. This is why there is a clustering of gaging stations on or near the carbonate aquifer as shown on plate 1. A total of 63 different gaging stations were gaged periodically in this investigation. These stations are located on plate 1 and described in detail in appendix A.

Gagings were measured with the Gurley pigmy current meter (fig. 2) where the discharge exceeded 2 cfs, or with 3-inch Parshall flumes where the discharge was less than 2 cfs. These techniques are discussed by Corbett (1962).

In general, gagings were taken at each site once each month for as long as 4 years, but many of the less significant sites have less gagings. It is believed that one gaging each month gives an accurate indication of the discharge of a spring, because most springs have either a constant or only slightly variable discharge that follows a yearly cycle. For instance, if the average flow of the spring-fed Fall River, as determined by the continuous recordings of the U.S. Geological Survey Gaging Station is compared to monthly data, there is a difference of only 2 percent.

Information derived from the monthly discharge measurements of streams draining the Precambrian core of the Black Hills is not as accurate as the spring measurements. The reason is that the Precambrian streams are subject to flooding after heavy rain or snowmelt (fig. 3). For example, there is a 17 percent error between the monthly gaging data and the U.S. Geological Survey Gaging Station data on Grace Coolidge Creek at Custer Park Zoo between October 1968 and January 1969. Because of the variable discharge of the Precambrian streams, they were gaged during a normal streamflow day during the month rather than during an exceptionally high or low streamflow day.

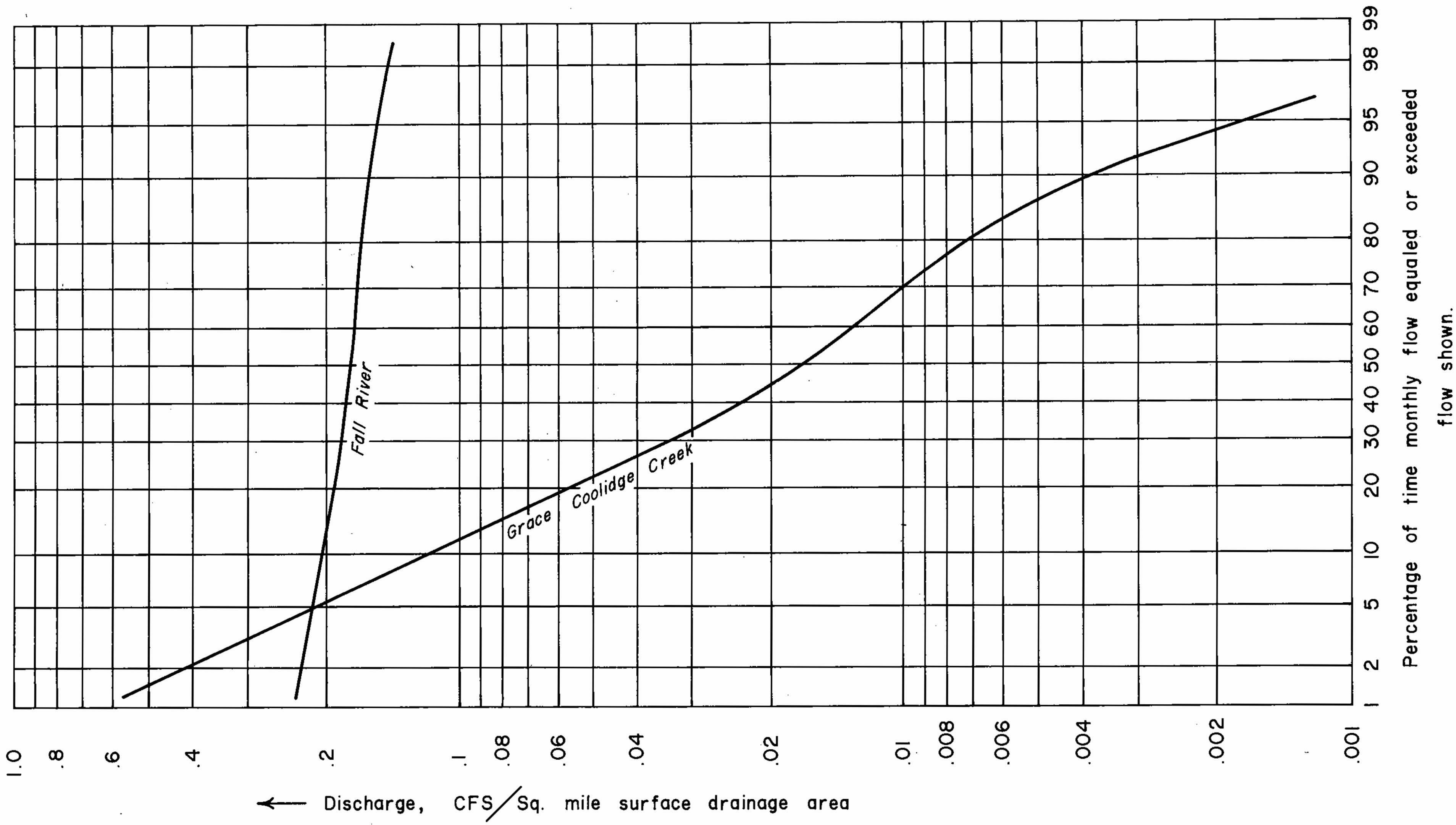


Figure 3. Flow duration curves for Fall River at Hot Springs (site 18) and Grace Coolidge Creek at Custer Park Zoo (site 7).

ORIGIN OF BLACK HILLS SPRINGS

Hydrogeologic Classification Of Springs

Based on the reconnaissance inventory of large springs in the Black Hills described in appendix A, it is apparent that their origin is related to certain geologic controls. Therefore, the following sixfold classification of springs is proposed, based on their hydrogeologic position. Three types of springs yield large flows and are referred to in this report as major springs (fig. 4); the other three types of springs yield only small flows and are referred to as minor springs (fig. 5).

The three types of major springs are described below:

Type 1 are springs wholly confined to the carbonate aquifer. Springs such as Gravel Spring (Site 54) and Cold Brook (Site 16) occur in deep ravines in the Paleozoic carbonate aquifer. The water usually sinks back into the aquifer within a short distance downstream. Although they may have large discharges during certain parts of the year, they may dry up. Some of these springs, such as along Boxelder Creek, are clearly related to each other and to a master disappearing stream; that is, they are resurgent springs (fig. 6). It is believed that these springs originate simply because the stream valley has been cut down locally to the water table. Small fluctuations in the water table may cause large changes in spring discharge. For instance, Observation Well No. 2 in Sioux Park, Rapid City, maintained by the U.S. Geological Survey, has a seasonal fluctuation of only about 12 feet from 1965 to 1969 (Adolphson and LeRoux, 1971). During this time the Type 1 spring along Boxelder Creek at Site 56 (Dome Spring) varied as much as zero to 10.8 cfs.

Type 2 are springs at the Minnekahta-Spearfish contact. Springs such as Cleghorn Spring (Site 62), Fall River (Site 18), Cascade Spring (fig. 7) (Site 19), etc., occur at a low elevation near the outer edge of the Paleozoic carbonate aquifer. This is usually at the Spearfish-Minnekahta contact, but may be at the Minnelusa-Opeche contact. These springs do not dry up and serve as points of permanent discharge from the carbonate aquifer.

Type 3 are springs draining the carbonate aquifer in the western Black Hills. Along the limestone escarpment in the western Black Hills, springs along Rhoad's Fork (Site 26) and Headwater Spring (Site 27) originate when precipitation falls on the permeable carbonate plateau, percolates downward to the relatively impermeable Deadwood and Precambrian aquitard, and then moves laterally to some convenient discharge point, usually along a major ravine. In the western Black Hills, most of these springs issue from fractured Englewood Limestone.

The three types of minor springs are described below:

Type 4 are many small springs in the northern Black Hills which are related to Tertiary intrusives, such as Jones' Spring (Site 47) and Railroad Spring (Site 44). These springs occur because some precipitation percolates through the carbonate rocks and encounters relatively impermeable crystalline Tertiary intrusive rock (sills, dikes, laccoliths, etc.), and moves laterally until it discharges at some low point (fig. 5). These springs may discharge water from a perched water table; however, their flow seemed to be constant during the period of this investigation.

Type 5 are many small springs located at the contact of the Minnelusa Formation where it lies on the Pahasapa Limestone. A thin red paleosol occurs at the base of the Minnelusa Formation at most places. Water apparently percolates downward through the Minnelusa, encounters the relatively impermeable paleosol, and moves laterally to some discharge point. Usually the water from the spring sinks back into the underlying Pahasapa Limestone a short distance downstream. Yield from these springs is small (usually less than 0.01 cfs) but serves as valuable watering places in the otherwise dry limestone plateau of the western Black Hills; examples are "Compton Spring," "Barrel Spring," and "Gooseberry Spring."

The importance of the basal Minnelusa paleosol and other thin relatively impermeable beds within the Paleozoic carbonate aquifer is not known with certainty. The basal Minnelusa paleosol may act as an aquiclude, separating Pahasapa water from Minnelusa water. Similarly, the Opeche Formation may act as an aquiclude between the Minnelusa Formation and the Minnekahta Limestone. Apparently at some places where the large Type 2 springs come out at the outer edge of the Minnelusa Formation, as Cleghorn Spring, the Opeche does play an important role. At other places, such as Cascade Spring, the Opeche Formation does not significantly inhibit the movement of ground water within the Paleozoic Limestone. Small springs on the outer edge of the dip slope of Minnekahta Limestone, as Site 45, may only be draining the Minnekahta Limestone, with the Opeche Formation preventing deeper penetration of the ground water.

Type 6 are springs draining alluvium. Many small springs are recharged by precipitation falling on deposits of alluvium. The springs near Sturgis are a good example (Sites 40, 41, and 43). Such springs occur in abundance throughout the Precambrian core of the Black Hills; they are more properly called seeps, and serve as discharge points for much of the ground water that maintains the base flow of the streams in the Precambrian area. Similar small springs also occur locally at the base of gravel terraces flanking particularly the eastern Black Hills. These

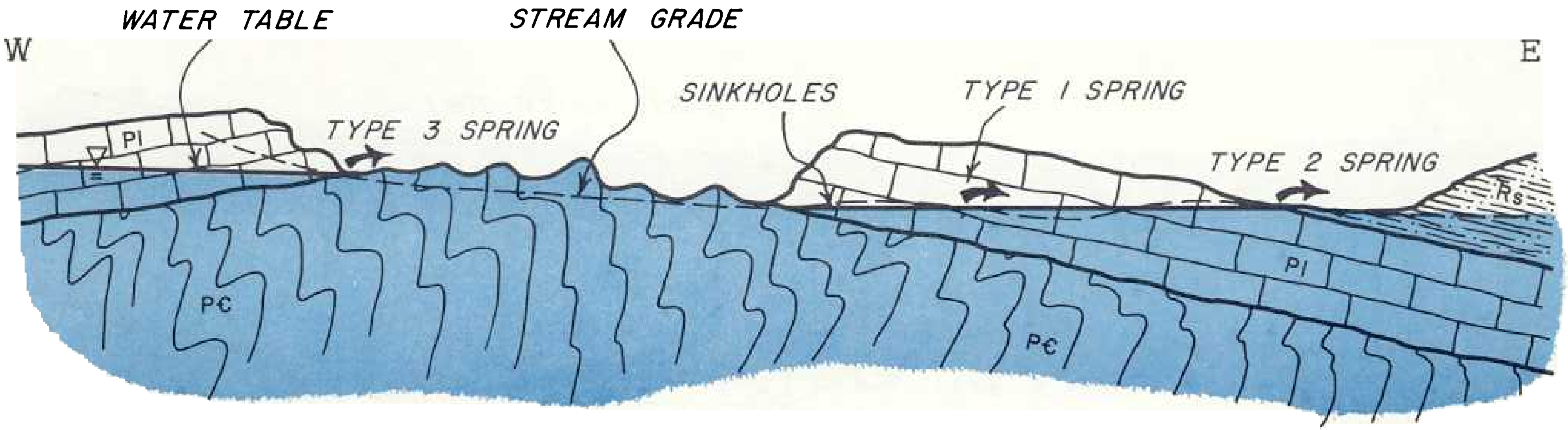


Figure 4 Idealized sketch showing origin of the three types of major springs in the Black Hills.

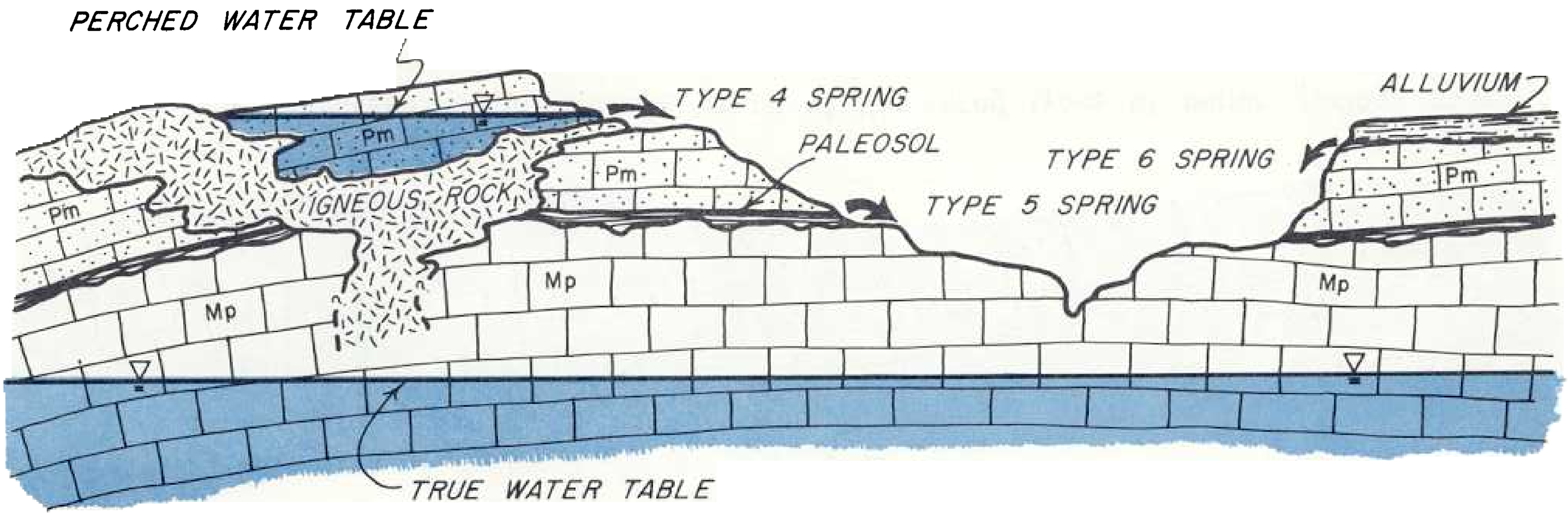


Figure 5. Idealized sketch showing origin of the three types of minor springs in the Black Hills.

Figure 6. Boxelder Creek disappearing into the alluvium overlying sinkholes in the Pahasapa Limestone just below Site 53. Note whirlpool.

small springs are too numerous to describe in this report; however, they form an important source of water for ranchers.

Plate 2 shows the location and discharge of all three known types of major springs in the Black Hills. According to Meinzer's (1927) classification of springs based on discharge (table 1), none of the springs in the Black Hills are of first magnitude (discharge greater than 100 cfs). However, there are six second order springs having discharge between 10 to 100 cfs: Sand Creek (23.91 cfs), Cascade Spring (23.65 cfs), Fall River (22.92 cfs), the sum of the springs on Spearfish Creek (39.83 cfs), McNenny Fish Hatchery (17.47 cfs), and Cleghorn Spring (10.24 cfs).

Dye Tests

Dye tests were used to determine the interconnection of sinkholes and springs. The five following tests are of significance in understanding the hydrogeology of the carbonate aquifer.

November, 1966

On November 22, 1966, 10 gallons of 15 percent Rhodamine B dye were injected into a sinkhole 100 yards above School Section Bridge (Site 53) by D. W. Niven, a graduate student at South Dakota School of Mines and Technology. Because a high rate of water movement was not anticipated, the springs downstream were not monitored until long after the crest of the dye flood had passed. Traces of the dye were detected from packets of activated charcoal which had been inserted in the springs beforehand.

Table 1. Meinzer's (1927) classification of springs

Magnitude	Average Discharge
First	100 cfs or greater
Second	10 to 100 cfs
Third	1 to 10 cfs
Fourth	0.223 to 1 cfs
Fifth	0.022 to 0.223 cfs
Sixth	0.002 to 0.022 cfs

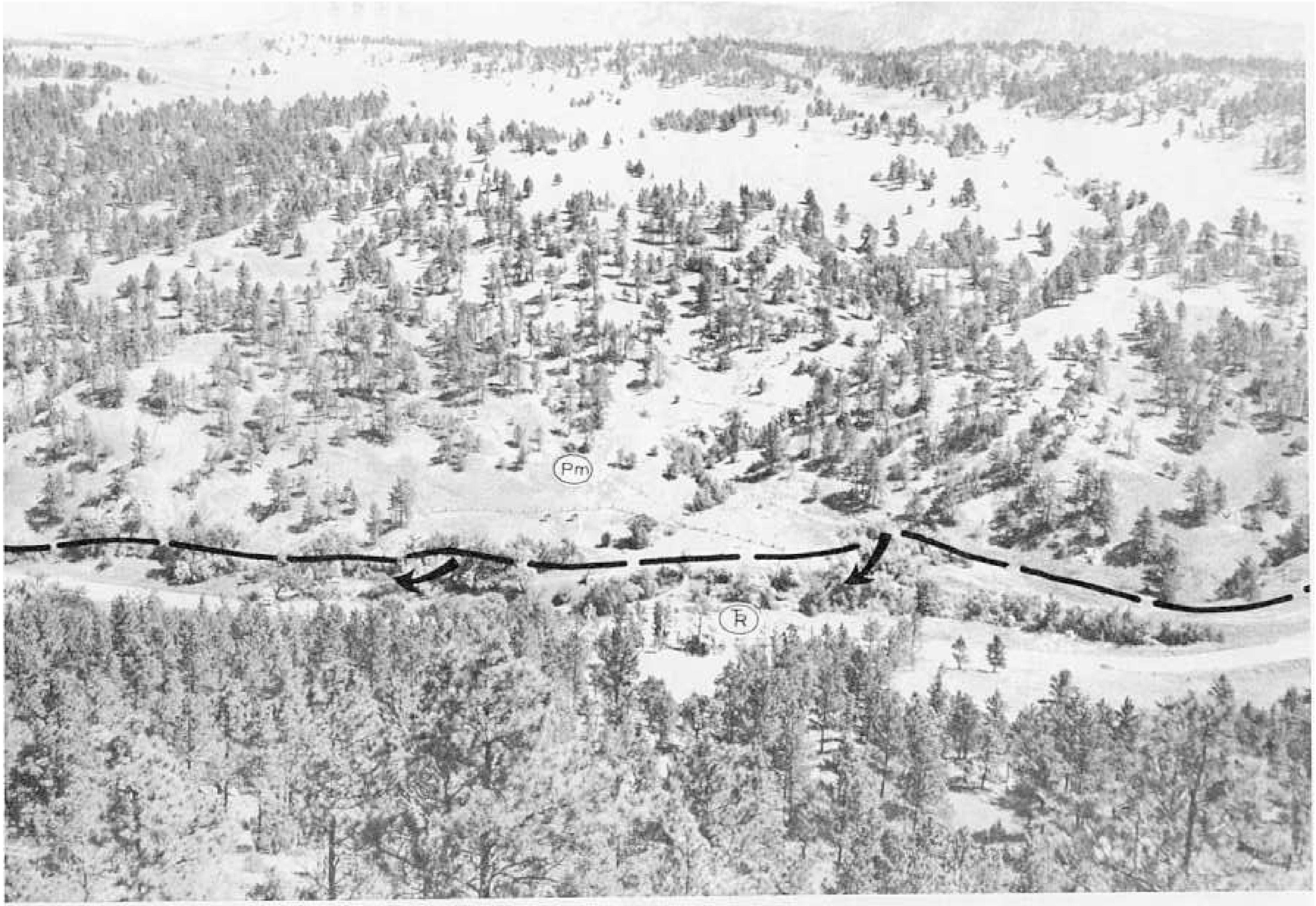


Figure 7. Location of Cascade Spring. Arrows indicate points of discharge at the contact of the Minnekahta Limestone and Spearfish Formation.

Figure 8. Dumping dye into the sinkhole in the Pahasapa Limestone along Boxelder Creek.

April, 1968

On April 11, 1968, Crooks (1968, 1968b) injected 1 pound of fluorescein dye in 2½ gallons of water into the same sinkhole (fig. 8). One hour and eight minutes later visible dye suddenly appeared at Gravel Spring (Site 54). Since the airline distance between two points is 2,200 feet, the water moved through the Pahasapa Limestone at greater than 0.37 miles per hour! The water undoubtedly travels as an underground stream along a large crack, probably following a joint and/or bedding plane. Such avenues of ground-water movement are easily visible in the many caves in the Pahasapa Limestone (Gries, 1938; Conn, 1966). Most of the water from Gravel Spring usually sinks back into the limestone within a few hundred yards. Visible dye showed up at Doty Spring (Site 55) three hours and two minutes after the original injection at the sinkhole. At this time the small trickle of surface overflow from Gravel Spring had not yet reached Doty Spring. A much diluted fluorescence was noted at Dome Spring (Site 56) six hours and thirty-five minutes after the original injection.

July, 1968

On July 9, 1968, the above test was repeated, using 1 gallon of red Rhodamine WT dye. The dye was injected in the same sinkhole, and reappeared at Gravel Spring in one hour and seven minutes. It showed at Doty Spring in two hours and fifty minutes, and at Dome Spring six hours and twenty-five minutes after the original injection.

These three dye tests prove that the Boxelder Springs are directly related to Boxelder Creek where it disappears into the sinkholes. It should be pointed out that these springs are all Type 1 springs, and all lie in the same drainage basin as the disappearing master stream that feeds them.

November, 1968

There is no Type 2 spring on Boxelder Creek. The lowermost spring on Boxelder Creek is Lang Spring (Site 57) which sinks back into the limestone. The question of the final destination of Boxelder Creek water remains unanswered.

On November 9, 1968, 15 gallons of Rhodamine WT dye were dumped into the same Boxelder Creek sinkholes (Site 53). Wells and springs as far away as Rapid City were monitored. Figure 9 shows the test area. Because Boxelder Creek generally sinks into the limestone for the last time at Dome Spring at an elevation of 3,920 feet and because the elevation of Cleghorn Spring is 3,390 feet there is reason to believe that at least some of the Cleghorn Spring water comes from Boxelder Creek, each lying in a different surface drainage system.

No measureable amounts of dye came out immediately at Cleghorn Spring or at any of the wells sampled (fig. 9). But the dye did show up, 34 days later, at City Spring (Site 63). The record of the dye concentration at City Spring is shown in figure 10.

This dye test is very important in terms of understanding the Black Hills hydrogeology. It shows that water that disappears into sinkholes in one drainage basin may reappear as springs - namely Type 2 springs - in a completely different drainage area. Ground water can and does travel through the Paleozoic carbonate aquifer with little regard for the surface topography.

September, 1969

On September 9, 1969, 12 gallons of Rhodamine WT dye were poured into the sinkholes along Grace Coolidge Creek at Custer Park Zoo (Site 7). Samples were collected at the springs 2 miles downstream, at the well at Ritteberger's Ranch 2 miles east of Site 7, and at the flowing artesian well at Callan's Ranch near Site 8. No detectable dye was observed in any of these localities during the following 3 months, using a fluoroscope capable of detecting less than 0.1 ppb (part per billion) dye. Apparently there is not **direct** connection between these sinkholes and springs.

On November 7, 1969, an 8,000-gallon gasoline truck overturned and spilled its contents just above the Custer Park Zoo (Site 7) on Grace Coolidge Creek. The State released some water from Center Lake to help flush the pollutant away. Although the spring's discharge downstream (near Site 8) reportedly increased slightly a few days later, no detectable gasoline was reported in the springs or wells downstream.

A possible explanation for the unsuccessful September, 1969 dye test is that the dyed waters of Grace Coolidge Creek became so diluted with ground water that the dye was not detectable where it emerged at the springs. An alternative hypothesis is that Grace Coolidge Creek waters migrate southward towards Hot Springs and the other large springs in the southeastern edge of the limestone.

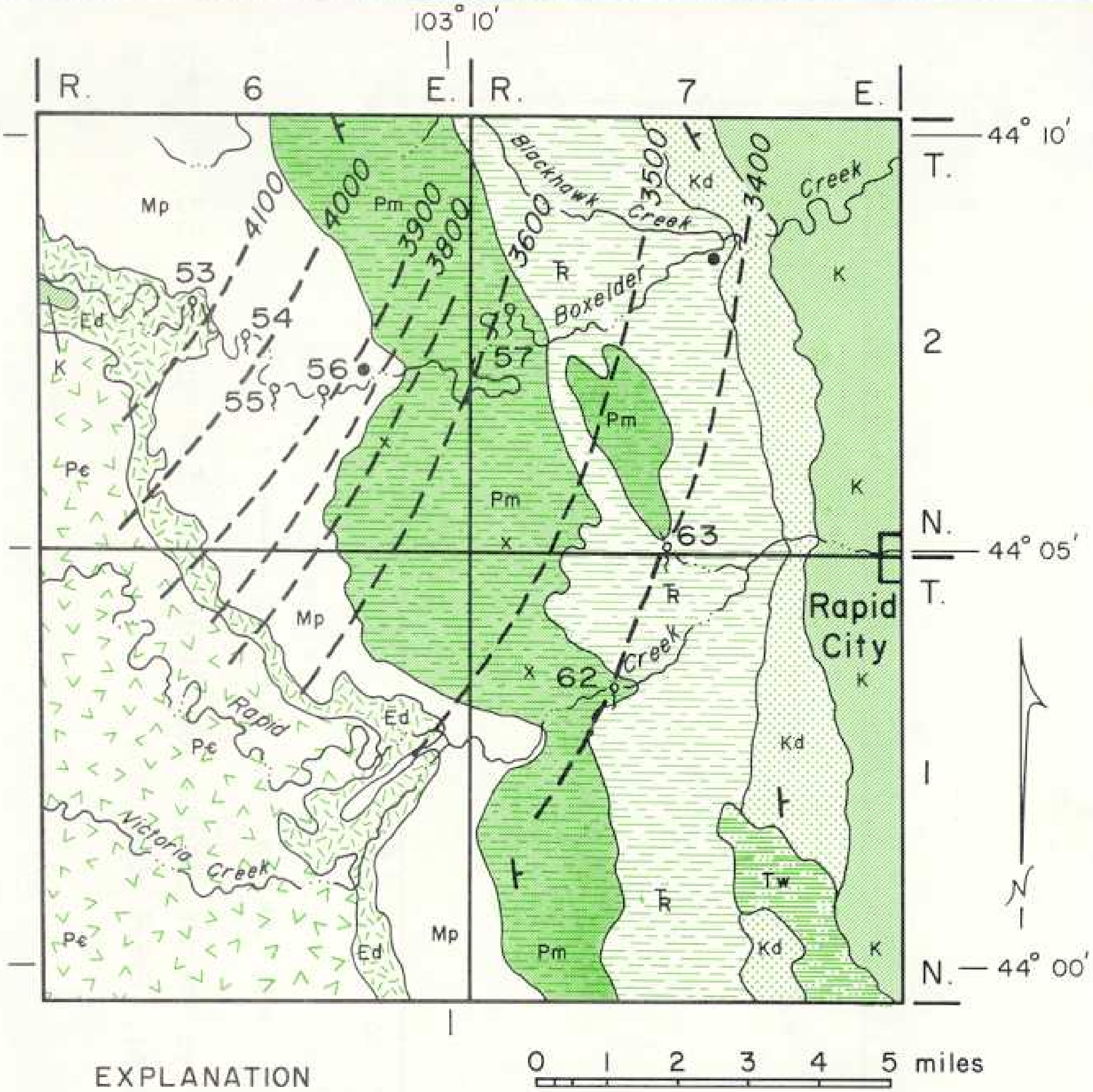
In general, the dye tests indicate that perhaps all the ground water in the carbonate aquifer is interconnected, moving laterally from one surface drainage basin to the next. The disappearing streams serve as places of ground-water recharge and the Type 2 springs serve as places where ground water discharges, much as water overflows a dam at the lowest places on the top of the dam. The "dam" in this case is the impermeable Spearfish Formation. The water table slopes gently to the spring elevation, cutting across the various limestone beds.

Quantitatively, the data from the November, 1968 dye test shows that probably only a small percentage of the 15 gallons of dye injected ever came out. Feuerstein and Selleck (1963) show curves for the calibration of Rhodamine B dye in fluorescent units as a function of concentration in parts per billion dye. The maximum dye detected at City Spring was 2.95 fluorescent units (on 30X scale), which is equivalent to approximately 5.90 ppb dye. Since the average flow of City Spring during the period of dye outflow was 0.65 cfs, the total volume of dye outflow can be computed (Keeley and Scalf, 1969). It equals approximately 0.816 gallons, or about 5.4 percent of the 15 gallons of 20 percent dye that was injected (Rahn, 1971). What became of the remainder of the dye? It may have become so diluted that it was undetectable and came out at Cleghorn Spring or elsewhere. Possibly some of the dye migrated farther southward towards Hot Springs. Possibly some migrated eastward to become part of the ground water of the great artesian system of the Dakota. Undoubtedly much of the dye became absorbed by clays in the rock (Buchtela and others, 1968).

TOTAL WATER BUDGET

The Paleozoic carbonate aquifer around the Black Hills receives a certain amount of recharge from streams. Data on stream loss and spring discharge are shown on table 2 and plate 3. These data are not necessarily the same as the average flows at these points because some of the flood flows go beyond the sinkholes and out into the prairie. For instance, the average flow of Spring Creek (Site 1) is 7.53 cfs. Because flows greater than 25.4 cfs generally go beyond the carbonate aquifer (past Site 2), the average recharge rate to the carbonate aquifer is only 7.00 cfs. Other streams, such as Beaver Creek (Site 14), apparently never flowed completely across the carbonate aquifer during the period of this investigation. Thus the average flow of Beaver Creek at Site 14 is the same as the recharge rate to the carbonate aquifer. The total stream recharge rate to the carbonate aquifer in the Black Hills is 43.87 cfs.

Table 2 and plate 3 also show the average discharges of springs whose flow leaves the carbonate aquifer (Type 2 and 3 springs). The total spring discharge rate is 190.01 cfs. This is a minimum rate, because there are probably some springs and flowing



EXPLANATION

Tw — Tertiary White River Group.

K — Cretaceous rocks, mainly Pierre Shale.

Kd — Cretaceous "Dakota Sandstone".

Ŧ — Triassic Spearfish Fm.

Mp Pm — Paleozoic Limestones.

Ed — Cambrian Deadwood Fm.

Pє — Precambrian Schists.

Strike and Dip.

× Water well.

• Sampled water well.

55 — Spring, number is gaging station.

4100 — Piezometric surface on limestone in feet above sea level.

Figure 9. Map of the Boxelder Creek dye test area.

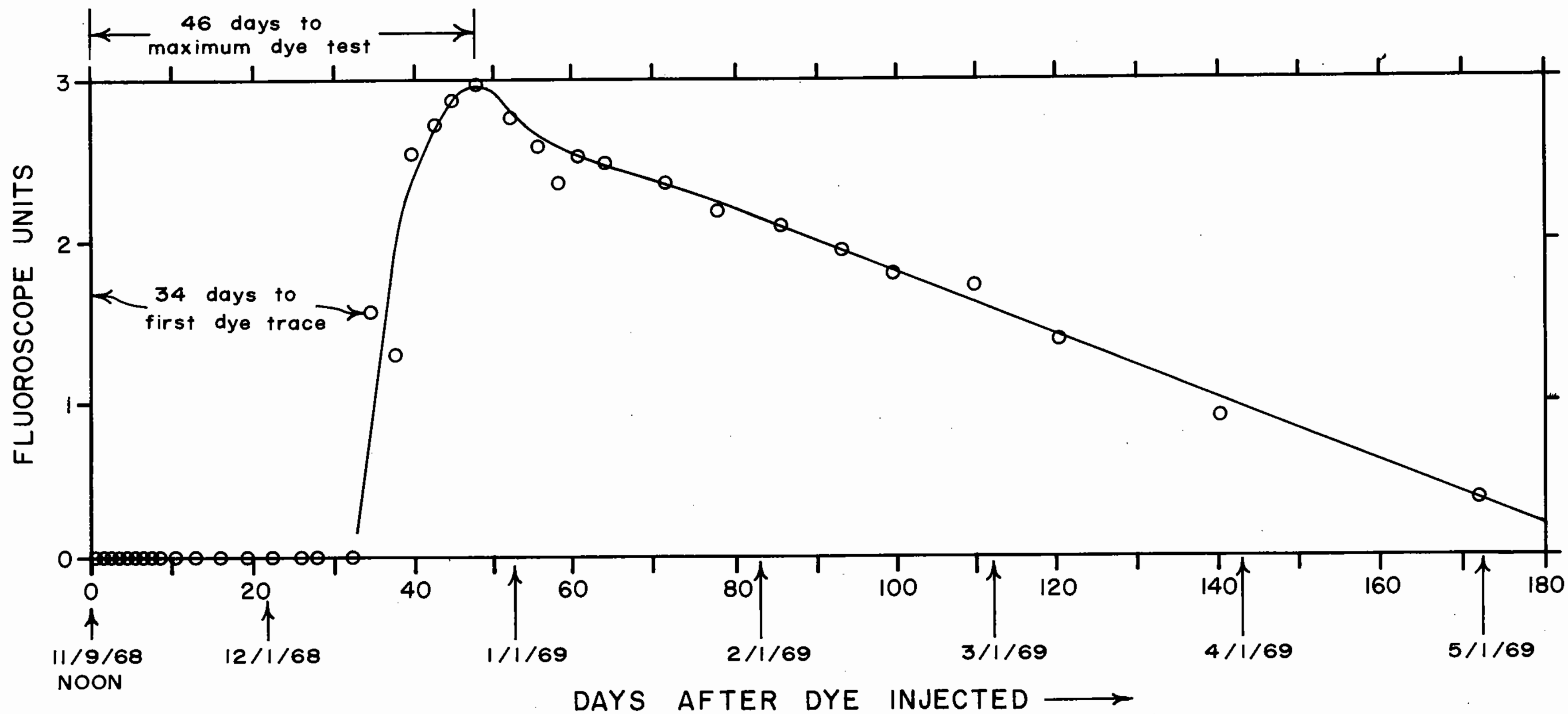


Figure 10. Record of dye which discharged from City Springs (site 63) during the November, 1968 dye test.

Table 2. Summation of average flows of Type 2 and 3 Springs and Disappearing Streams in the Limestone Belt around the Black Hills.

Discharge from Limestone (Type 2 & 3 Springs)

Site No.	Name	Flow (cfs)
4	Battle Creek	1.39
5	Deadman Gulch	0.83
8	Grace Coolidge Creek	1.03
15	Beaver Creek	8.56
17, 18	Fall River	24.90
19	Cascade Spring	23.65
20	Stockade Beaver Creek	12.84
21	Upper Stockade Beaver Creek	1.76
22	Spring Creek	0.24
23	South Fork of Castle Creek	1.08
24	Ditch Creek	3.20
25	Castle Creek	4.39
26	Rhoad's Fork	4.28
27	Headwater Spring	3.00
28	Tilson Creek	1.8
29	Soldier Creek	0.38
31	Sand Creek	23.81
32	McNenny Fish Hatchery	17.47
36	Spearfish Creek	39.83
40	Bear Butte Creek	0.60
41, 43, 45	Cattle, Alkali, Morris Creek	2.13
49	Elk Creek	1.73
62	Cleghorn Spring	10.24
63	City Spring	0.87
		Sum = 190.01 cfs

* * * * * * * *

Recharge to Limestone (Disappearing Streams)

Site No.	Name	Flow (cfs)
1	Spring Creek	7.00
3	Battle Creek	4.16
6	Spokane Creek	0.44
7	Grace Coolidge Creek	1.61
9	French Creek	4.95
10, 11, 12	Lame Johnny Creek	0.63
13	Highland Creek	0.70
14	Beaver Creek	0.60
37	False Bottom Creek	0.57
39	Bear Butte Creek	1.68
46	Elk Creek	6.00
50	Little Elk Creek	0.89
53	Boxelder Creek	10.95
59	Victoria Creek	0.29
60	Rapid Creek	3.4
		Sum = 43.87 cfs

* * * * * * * *

artesian wells in the Black Hills that were overlooked during the project.

Since there is an interconnection between sinkholes and springs between drainage basins through the limestone, as evidenced by the dye tests, water that enters the sinkholes is not "lost" in Brown's (1944) and Swenson's (1968) sense, but serves as part of the recharge of the many springs. Heretofore the significance of the large spring discharge has been overlooked.

The basic hydrologic budget for the carbonate aquifer can be expressed as:

Recharge = Discharge

Recharge can be thought of as the sum of precipitation falling directly on the carbonate aquifer and streamflow loss. Discharge is the sum of spring flow and possible loss to a deep artesian system:

Precipitation onto Limestone (A) + Disappearing Streams (B) =

Spring Discharge (C) + Deep Ground Water Recharge (D)

Since only B and C of this equation are known, this one equation is unsolvable. However, if the deep ground-water recharge is called X, then the equation can be rewritten as:

$$\underset{(146.14\ \text{cfs} + X)}{(A)} + \underset{43.87}{B} = \underset{190.01\ \text{cfs}}{C} + \underset{X}{D}$$

Thus 146.14 cfs is the **minimum** amount of water recharge to the limestone by precipitation falling directly on it. Figure 11 is a diagrammatic sketch of the limestone hydrologic budget.

The data for this report does not cover the same exact period of time for all the stations. It may be argued that there is a lag of several years between recharge and discharge. However, the discharge of the Type 2 and 3 springs did not vary much during the period of this investigation. Furthermore, the sinkhole losses were roughly the same for each year.

Plate 3 shows the probable directions of

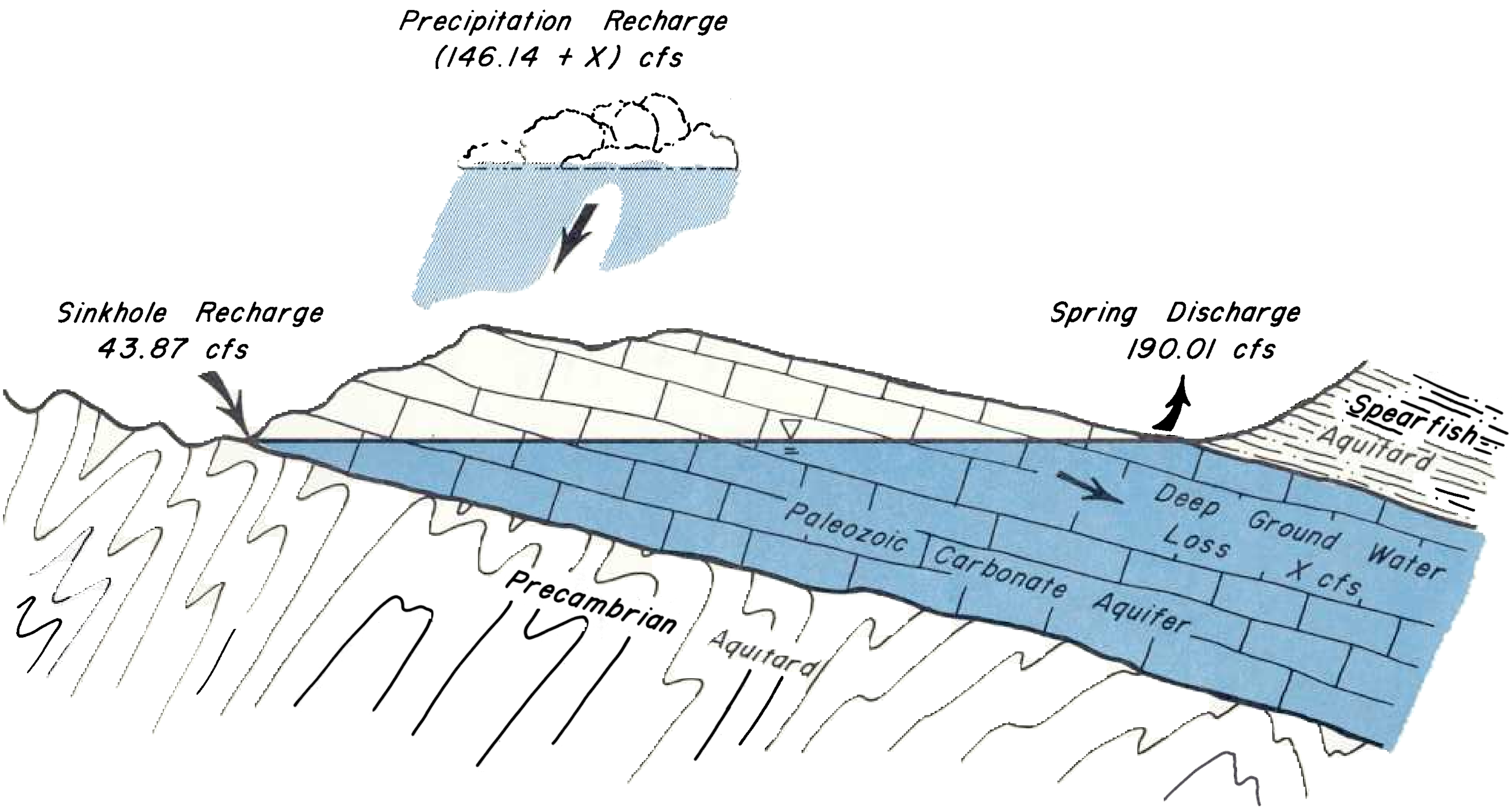


Figure General hydrogeologic model for the Black Hills.

ground-water flow in the carbonate aquifer. These directions are based on dye tests, topographic and geologic data, spring and sinkhole flow data, and some water well (piezometric head) information. Because direct surface water runoff resulting from precipitation falling directly on the carbonate aquifer was never observed during the period of this investigation, the assumption can be made that the precipitation that did fall on the carbonate aquifer either was returned to the atmosphere by evapotranspiration, or percolated downward and became ground water. Therefore, some estimates of evapotranspiration can be made.

Consider the ground-water drainage for Cascade Spring (Site 19); the average discharge of Cascade Spring is 23.65 cfs. If all of this water accumulates because of precipitation on the carbonate aquifer in the area shown on plate 3, then the drainage area involved is about 332 square miles. The recharge rate by precipitation can be calculated as follows:

$$\textit{Precipitation Recharge} = \frac{\textit{Spring Discharge}}{\textit{Drainage Area}}$$

$$\frac{23.65 \text{ cfs}}{332 \text{ sq. miles}} = 0.62 \text{ inches/year}$$

Thus, if the average precipitation on this drainage area is 17 inches/year, and the average recharge to ground water is 0.61 inches/year, then the evapotranspiration rate is 16.4 inches/year. Because there is very little or no seasonal fluctuation in flow of Cascade Spring or any other Type 2 or 3 spring, there is probably a long lag between precipitation recharge and spring discharge. Water dripping through the darkness of Jewel Cave, for example, may take dozens of years before it finally flows out into the sunlight at Cascade Spring.

In the high rainfall region of the northwestern Black Hills, there is more recharge. The average discharge of Sites 26 and 27 is 7.68 cfs, and (from pl. 3) this drains only about 11 square miles:

$$\textit{Precipitation Recharge} = \frac{\textit{Spring Discharge}}{\textit{Drainage Area}}$$

$$\frac{7.68 \text{ cfs}}{11 \text{ sq. miles}} = 6.77 \text{ inches/year}$$

The difference between the average yearly precipitation in the northwestern Black Hills (22 inches) and the ground-water recharge (6.8 inches/year) is consumed by evapotranspiration (15.2 inches/year).

Thus it can be seen that the southern and northern Black Hills have about the same evapotranspiration rates, but that the average yearly ground-water recharge varies from 0.6 inches in the southern Hills to 6.8 inches in the northern Hills. These ground-water recharge rates are minimum estimates, because there may be some deep ground-water seepage out of the Hills, and because of possible ungaged artesian wells and springs as previously explained.

These evapotranspiration rates agree closely with published data by Orr (1959), who based his estimation on streamflow in the Precambrian rocks where there is no ground-water loss.

According to the model established in plate 3, there is little or no deep ground-water underflow away through the carbonate aquifers towards the prairie basins as envisioned by Swenson (1968), and X in the general hydrological budget equation approaches zero. X is assumed to be equal to zero for the sake of simplicity, in that the hydrogeologic facts presented in this report can be adequately explained without the addition of this unknown parameter. Instead, a simple system is envisioned whereby precipitation recharge and sinkhole recharge supplies water that moves through the carbonate aquifer and discharges as springs. There is reasonableness to this theory because the quantities of water that would naturally migrate under the prairie and perhaps leak upwards into the Dakota Sandstone (Swenson, 1968) would be small in comparison to the flow rates shown on table 2. A supporting bit of evidence is the very low gradients on the piezometric surface on the limestone. The gradient from Rapid City eastward is only a few feet per mile (Gries, 1971). Additional limitations to the theory of upward leakage from the carbonate aquifer to the Dakota Formation are presented by Schoon (1971).

Since the Black Hills is a typical domal uplift, similar to other mountain ranges in the Central Rockies, where Paleozoic limestones flank these uplifts, an analogous hydrogeologic situation may exist in these areas too. This is probably particularly true of the Bighorn and Wind River Mountain. Marsell (1969) reports similar hydrogeologic conditions around the Uinta Mountains in Utah.

THERMAL SPRINGS

Stream and spring temperatures were usually recorded at each gaging site (see app. A). The spring temperatures do not vary systematically with the seasons, and thus are not helpful in determining the travel-time of water from disappearing stream to emerging spring. However, the temperature data is informative in that ecological conditions of the flowing waters are dependent upon the water temperature. For instance, trout will not naturally reproduce at Cascade Spring (Site 19) because of the relatively warm (67°F) water; but they will reproduce at Rhoad's Fork (Site 26) where the temperature is 43°F.

Plate 4 shows the distribution of warm and hot springs. The temperature of most Type 2 and 3 springs do not vary seasonally. Small differences in temperatures from month to month probably owe their origin to instrument error or the fact that some springs only seep gradually out of gravel or from under a pond, allowing adjustment for atmospheric temperature. Some of the Type 1 springs, such as Gravel Spring (Site 54), are not shown on plate 4 because their temperature is directly related to the daily temperature of the disappearing stream.

The cause of the high temperatures in the springs at the southeastern edge of the Black Hills (pl. 4) is not known. The springs in the northern Hills, especially the shallower springs, such as South Fork of Castle Creek (Site 23), correspond closely with the mean annual air temperature of 44°F. City Spring (Site 63) in Rapid City has a temperature of 51°F. This is 4 degrees above the mean annual air temperature at Rapid City (Johnson, 1949). The 4 degree warming can be attributed to the natural warming within the earth by the geothermal gradient. In the Black Hills, as judged by temperatures in the bottom of the Homestake Mine, the geothermal gradient is approximately 1.1°F per hundred feet depth. Adolphson and LeRoux (1968) attribute the hot water found in the artesian wells in west central South Dakota to deep ground-water flow through the Dakota Sandstone and other formations.

The unusually warm springs near the town of Hot Springs (Site 18) are too warm to be explained by a normal geothermal gradient. It is unlikely that ground water will circulate below the base of carbonate aquifer prior to flowing upward and discharging at the Minnekahta-Spearfish contact at Hot Springs. Thus ground-water heating by normal geothermal gradient should not be more than: (1,000-foot thick carbonate section) (1.1°F/100 feet) = 11°F. Since the mean annual air temperature of Hot Springs is 48°F, this could heat the water from about 48°F to 59°F, at most. How then does the water get heated to 87°F?

There are at least four other possibilities to explain the high temperature. The first is that residual or partially cooled magma lies at shallow depth under the southeastern Black Hills, creating a geothermal anomaly. This could be an intrusive igneous body such as the Tertiary intrusives in the northern Black Hills, such as Bear Butte or Devil's Tower. Since the youngest age of the known intrusives is 30 million years, the probability of a new intrusion in the southern Hills seems remote. Additionally, there is no geological or geophysical evidence for such an intrusion.

Another possibility is that ground waters become warmed by the chemical weathering reactions that take place as they flow through the rocks. All oxidation and hydration weathering reactions are exothermic. The chemical weathering of anhydrite to gypsum, for instance, is shown by the reaction:

$$CaSO_4 + 2\ H_2O = CaSO_4 \cdot 2\ H_2O$$

At a temperature of 20°C, 142 calories/mole are released in this reaction. Subsurface drilling in the prairie shows that as much as 300 feet of anhydrite is present in the Minnelusa Formation. None is present in the outcrop except near Sundance, Wyoming. The weathering of this anhydrite and other minerals may account for the thermal springs. Support for this hypothesis is gained by the observation that there is a general correlation between spring temperature, the distance the ground water has traveled prior to discharge, and the total dissolved solids in the spring water (table 3). For instance, Cascade Spring (Site 19) is quite warm (67°F). The ground waters producing this spring have traveled tens of miles, and the spring water has such a high mineral content that it precipitates calc-tufa over its streambed. Support for this theory is the fact that breccia pipes are found in outcrops of the Minnelusa Formation (Brobst and Epstein, 1963; Post, 1967). These breccia zones apparently formed where anhydrite was dissolved away. Another chemical reaction that could account for high temperatures is the fact that heat is evolved when gas goes into solution with water. Such a mechanism could account for hot water in the Dakota Formation (Schoon, 1971), but is considered unlikely at Hot Springs.

The third possibility may be due to heat generated by radioactive decay. There are naturally radioactive deposits in the Black Hills, especially in the Cretaceous sandstones near Edgemont. Keene (in preparation) noted that the water from the flowing artesian well at Provo is 139°F. It is difficult to explain the origin of all thermal springs in the Black Hills by radioactive decay, however, because the thermal spring waters do not flow through known radioactive rocks, and the thermal spring waters are not particularly radioactive.

A fourth possibility is that the rocks underlying Hot Springs could have a higher conductivity. Thus, perhaps a highly heat-conductive rock within the Precambrian conducts more heat up from the depths of the earth's crust, creating a high geothermal gradient under the town.

WATER MANAGEMENT

There has been a lot of local interest expressed about "plugging the sinkholes." This is a plan especially promoted by ranchers downstream from disappearing streams, whereby bentonite or concrete would be emplaced in the loss zone to prevent water from sinking into the carbonate aquifer. Attempts to plug the sinkholes have not worked in the past. They

Table 3. Selected Water Analyses, Western South Dakota

	Evans' Plunge (spring) Sec. 13, T. 7 S., R. 5 E.	Cascade Spring Sec. 20, T. 8 S., R. 5 E.	Cleghorn Spring Sec. 8, T. 1 N., R. 7 E.	Jackson Spring Sec. 8, T. 1 N., R. 7 E.	Rapid Creek above sinkholes Sec. 18, T. 1 N., R. 7 E.	City Well No. 1 (Minnelusa) Sec. 9, T. 1 N., R. 7 E.	Black Hills Ordnance Depot Well (Pahasapa) Sec. 3, T. 10 S., R. 2 E.	Edgemont No. 2 Well (Pahasapa) Sec. 1, T. 9 S., R. 2 E.	Bar N Well (Pahasapa) Sec. 31, T. 5 N., R. 24 E.	Spring No. 21 above LAK, Wyoming (From Brobst and Epstein, 1963) Sec. 31, T. 45 N., R. 60 W.
Calcium	295.0	568.0	48.5	49.4	46.9	47.6	138	49.3	342.0	472.0
Magnesium	49.1	92	19.3	19.8	25.0	19.1	43.0	16.9	72	78.0
Sodium	99.1	60	4.8	5.2	3.3	5.2	263.0	898.4	82	5.5
Silica	16	22	9.5	9.5	5.0	12.0	------	9.0	30	14.0
Iron	1.1	0.3	tr.	tr.	tr.	tr.	------	0.5	7	0.4
Fluoride	------	0.9	------	------	------	------	------	------	------	0.4
Carbonate	123	0.0	114	107.4	107.8	104.8	------	91.6	108	0.0
Bicarbonate	------	235	------	------	------	------	177	------	------	227.0
Sulfate	736.3	1540	33	28	27	30	400	1894.3	990	1260.0
Chloride	120	62	------	4.0	3.0	2.5	377	22.1	182	5.0
Loss on Ignition	101.8	------	31.9	6.8	30.0	8.5	------	7.9	249	------
pH	------	7.0	7.3	7.4	8.1	7.7	------	8.2	6.9	7.5
Hardness (as $CaCO_3$)	------	------	197.6	201.6	218	199	------	192.5	1230	------
Total Dissolved Solids	1553	2530	252	232	260	230	1308	2980	2087	2110.0

will probably never work because, in general, the streams meander on floodplains underlain by permeable alluvium which is in turn underlain by limestone. It would be impractical to cover a several mile reach of the channel and the floodplain with bentonite or concrete. In addition, the first large flood would erode the sealing materials.

Aside from the practical feasibility, the advisability of this undertaking is questionable, based on the total water budget. Plugging the sinkholes may not significantly lower the level of water in wells because there is still ample recharge from precipitation falling directly on the carbonate aquifer. But the springs serve as critical overflow areas from the carbonate ground-water reservoir. Hence any diversion of a stream would ultimately deplete recharge and thus the discharge of the spring flow proportionally. These springs serve as major sources of fresh water for ranchers, fish hatcheries, city water supplies, and sewage dilution. No water would be gained by plugging the sinkholes; there would only be a change in its distribution.

Rather than attempt to plug a sinkhole, two alternative methods of useful water management are:

(1) Flume diversion. The 1-foot metal pipe flume at French Creek (Site 9) usually carries about 3 cfs beyond the sinkholes to recharge alluvium downstream. Flows greater than 4.5 cfs still flow beyond the diversion dam at the flume entrance, allowing natural recharge to take place in the carbonate aquifers. Flood flows still scour the channel, enabling debris to be swept from the sinkholes and alluvium in the channel bottom, so that recharge can take place. The ecological balance of the canyon has been changed very little since the flume was installed in 1958.

(2) Dam construction. Any flood causes large amounts of water to leave the Black Hills. This wasted resource could be prevented by dam construction, either in the Precambrian rocks, or in limestone itself. A dam in the Precambrian rocks could be regulated in its discharge so as to permit calculated amounts of recharge to the carbonate aquifer downstream, such as Rapid Creek. A dam in the carbonate aquifer has the advantage of allowing water to recharge the carbonate aquifer through the bottom of the reservoir area itself. The reservoir would probably leak rapidly because in the hydrogeologic situation where the water table is well below the bottom of the lake, the rate of recharge is directly proportional to the lake depth (Rahn, 1968). Thus, the reservoir would not be very useful as a recreational site. It is interesting to note that this is exactly what will happen in the case of the newly constructed Cottonwood Dam, above Hot Brook (Site 17) on the Fall River. When a (rare) flood on the limestone catchment area puts water into the Cottonwood Reservoir, it will quickly sink into the carbonate aquifer, and Cascade Spring will probably gain in discharge accordingly. The Fort Meade Veterans Administration Dam in Deadman Canyon, 3 miles southwest of Sturgis, is another example of a dam which leaks water to the carbonate aquifer.

CONCLUSIONS

The substance of this report concerning the distribution and discharge of large springs in the Black Hills is shown on plate 2 and in appendix A. In the course of this investigation it was observed that the location of the largest springs is controlled by the geology; the large springs are located where the permeable Paleozoic carbonate aquifer abuts against relatively impermeable rocks (aquitards). The two major aquitards are the Precambrian-Cambrian rocks and the Triassic-Jurassic formations.

Plate 3 shows the location of sinkholes, springs, and the probable direction of ground-water flow in the carbonate aquifer surrounding the Black Hills. Large amounts of water are recharged to the inner edge of the carbonate aquifer where streams draining the Precambrian core of the Black Hills cross it. Even larger quantities of water discharge from the outer edge of the carbonate aquifers. The water spills out at topographic lows in the ground-water dam caused by the thick sequence of shales of Triassic and Jurassic age. The difference between the total streamflow loss (44 cfs) and the average spring discharge (190 cfs) must be due to precipitation falling directly on the carbonate aquifer.

Water management should take into consideration the concept of a single interconnected ground-water reservoir in the carbonate rocks surrounding the Black Hills. If the sinkholes at one disappearing stream are plugged, then recharge to one or more springs will be prevented, because springs are the sensitive indicators of the ground-water level in the carbonate aquifer. Spring discharge will vary directly, over a period of years, to recharge. Hence no gain in water will ultimately be accomplished by plugging sinkholes. There would only be a change in the distribution of the water.

The carbonate aquifer has a surface area of over 1,500 square miles. Assuming an average saturated thickness of 500 feet and an average porosity of 10 percent, then the aquifer contains over 15 cubic miles of water. This is over twice as much as Oahe Reservoir! Probably 10 percent of the total ground water contained in the carbonate reservoir would be available to wells.

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APPENDIX A – GAGING DATA FOR 63 SITES

DESCRIPTION OF APPENDIX A

Appendix A lists data for all 63 gaging sites. In addition to discharge, the temperature of the water was measured where it was felt this data would be helpful in correlating time of sinkhole recharge to spring discharge. The appendix describes the location of these 63 sites; detailed data on the precise location of the sinkholes and springs are available from the Geology Department at the South Dakota School of Mines and Technology, or from the annual reports to the South Dakota Water Resources Research Institute. The appendix also lists the average flow of each site, and where applicable, the flow of the springs alone (with no contribution from downvalley surface streamflow).[1] Pertinent information about each site is summarized in the paragraph preceding the data. The number refers to the site locations as shown on plate 1. The following symbols are used:

F	Flowing; but no measurement made
I	Iced over; no flow
D	Dry; no flow
Cfs	Cubic feet per second
°F	Temperature

1. Spring Creek at Stratobowl

This gaging site is located near the Precambrian-Cambrian contact. Although Sheridan Lake is upstream, there is no flood control storage regulations on the reservoir. During the 4 years of record, Spring Creek had an average flow of 7.53 cfs. Measured 500 feet downstream from Jacobson's, NE¼SW¼NE¼ sec. 12, T. 1 S., R. 6 E.

1. Spring Creek at Stratobowl -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	28	42.06	----
1967	8	7	23.61	----
1967	9	5	14.08	68
1967	9	22	12.21	60
1967	10	21	4.62	45
1967	11	7	1.39	33
1967	12	21	3.13	32
1968	1	24	3.84	32
1968	2	3	5.14	32
1968	3	15	6.22	33
1968	4	12	F	----
1968	5	10	5.84	50
1968	6	----	17.81	----
1968	7	----	17.15	----
1968	8	1	7.39	----
1968	9	2	2.34	----
1968	10	18	.78	43
1968	11	10	1.01	37
1968	12	7	.76	33
1969	1	28	I	----
1969	2	28	I	----
1969	3	31	4.01	----
1969	4	----	11.50	----
1969	5	11	6.89	----
1969	6	9	6.05	61
1969	7	16	2.95	----
1969	7	28	24.23	----
1969	8	12	6.19	----
1969	9	28	1.96	----
1969	10	10	3.20	----
1969	11	26	I	----
1969	12	11	I	----
1970	1	23	I	----
1970	2	28	I	----
1970	3	31	5.10	----
1970	4	24	23.83	----
1970	5	20	20.38	----
1970	6	26	26.66	----
1970	7	----	F	----
1970	8	7	15.18	----

[1]Every individual measurement of discharge is not necessarily included in the calculation of the average flow because some measurements, especially flood flows, were deliberately taken during unusual conditions.

1. Spring Creek at Stratobowl -- continued.

1970	9	30	.23	----
1970	10	31	.12	----
1970	11	30	I	----
1970	12	21	I	----

Average flow = 7.53 cfs
Average recharge to limestone = 7.00 cfs

2. Spring Creek at Route 16

Within a few miles downstream from Site 1, Spring Creek usually disappears into sinkholes in the Pahasapa Limestone. The stream is usually dry at Site 2.

The maximum amount of water that the carbonate aquifer can absorb in Spring Creek Canyon is probably related to the position of the water table. On July 28, 1967, the loss from Site 1 to 2 was 42.06 - 14.94 = 27.12 cfs. On July 28, 1968, the loss from Site 1 to 2 was 24.23 - 0.29 = 23.94 cfs. On June 6, 1970, the loss from Site 1 to 2 was 26.66 - 0.71 = 25.95 cfs. Measured under bridge at Reptile Gardens; NW¼NE¼SW¼ sec. 3, T. 1 S., R. 6 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	28	14.94	----
1967	8	7	D	----
1969	7	25	4.95	----
1969	7	28	.29	----
1969	7	29	D	----
1970	4	24	F	----
1970	5	20	F	----
1970	6	26	.71	----
1970	7	----	D	----
1970	8	7	D	----

Average flow = 0.53 cfs

3. Battle Creek at Hayward

This gaging site is located near the Precambrian-Cambrian contact, just

3. Battle Creek at Hayward -- continued.

above the sinkholes. The average flow is 4.16 cfs, which is slightly larger than the new U.S. Geological Survey Gaging Station just above Site 3. Measured at 4,500 feet downstream from Hermosa-Hayward county road crossing; SE¼SW¼SE¼ sec. 19, T. 2 S., R. 7 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	26	12.82	52
1967	8	22	3.55	----
1967	9	20	5.33	61
1967	10	18	2.19	51
1967	11	29	F	----
1967	12	7	2.05	32
1968	1	24	2.75	35
1968	2	3	2.39	33
1968	3	8	3.57	----
1968	4	20	3.71	51
1968	5	7	3.00	----
1968	6	----	10.59	----
1968	7	2	15.44	----
1968	8	6	1.71	79
1968	9	4	3.51	----
1968	10	18	.71	45
1968	11	10	.78	36
1968	12	7	.48	----
1969	1	28	I	----
1969	2	28	.42	----
1969	3	31	.31	----
1969	4	----	3.48	----
1969	5	11	2.06	----
1969	6	9	4.75	70
1969	7	30	16.69	----
1969	8	21	3.40	----
1969	9	----	----	----
1970	7	22	2.36	----

Average flow = 4.16 cfs
Average recharge to limestone = 4.16 cfs

4. Battle Creek 5 miles west of Hermosa

Shortridge (1953) observed that Battle Creek sinks into the upstream exposures of limestone below Hayward, but springs appear farther downstream at the outermost carbonate exposures.

There is a series of springs along Battle Creek on the property belonging to Mr. Elmer Iverson. The springs are somewhat variable in discharge, but average 1.39 cfs. The temperature measurements of these springs are not very accurate as they are affected by air temperature. Only on rare occasions does Battle Creek flow continuously across the limestone belt from Site 3 to 4. The average flow at this point, including the spring flow and the rare flood, is about 1.58 cfs. Measured 3,200 feet above Hermosa-Hayward county road turnoff; NW¼NW¼NW¼ sec. 34, T. 2 S., R. 7 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	26	2.95	----
1967	8	22	1.68	56
1967	9	20	1.46	52
1967	10	18	1.14	46
1967	11	29	.93	40
1967	12	7	.71	40
1968	1	24	.44	44
1968	2	3	.43	43
1968	3	8	.42	----
1968	4	20	.27	49
1968	5	7	.17	----
1968	6	----	2.70	----
1968	7	2	2.23	----
1968	8	6	1.59	61
1968	9	4	----	----
1968	10	18	1.50	54
1968	11	10	1.74	51
1968	12	11	.71	----
1969	1	28	1.42	----
1969	2	28	.87	43+
1969	3	31	1.59	50
1969	4	----	1.11	----
1969	5	11	1.61	----
1969	6	9	.63	61
1969	7	16	.91+	----
1969	7	25	34.45+	----
1969	8	21	1.25	58
1969	9	28	1.01	----
1969	10	10	.95	----
1969	11	26	.78	----
1969	12	----	.71	----
1970	1	25	.58	----
1970	2	14	.63	----
1970	3	20	.68	----
1970	4	29	8.89	----
1970	5	13	1.02	----
1970	6	29	1.53	----
1970	7	22	1.92	----
1970	8	25	1.39	----

Average flow = 1.58 cfs
Average spring discharge = 1.39 cfs

5. Deadman Gulch

Springs occur in the Spearfish Formation along this tributary to Battle Creek. The water undoubtedly leaks upward from the limestone. The average discharge is 0.83 cfs and average temperature is 51°F.

Located 4 miles west of Hermosa in NE¼NE¼NW¼ sec. 27, T. 2 S., R. 7 E. Measured 8,300 feet above junction with Battle Creek.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	30	.85	52
1969	9	28	1.26	53
1969	10	10	1.09	----
1969	11	26	.84	----
1969	12	11	.81	----
1970	1	25	.74	50
1970	2	14	.62	----
1970	3	20	.54	----
1970	4	29	1.24	----

5. Deadman Gulch -- continued.

1970	5	13	1.08	52
1970	6	29	F	----
1970	7	22	.44	----
1970	8	25	.40	----

Average spring discharge = 0.83 cfs

6. Spokane Creek at Route 16A

This small stream discharges about 0.44 cfs into the limestone at this site. No flow was observed beyond the limestone.

Located in SE¼NE¼NE¼ sec. 2, T. 3 S., R. 6 E. Measured at Precambrian-Cambrian contact 3,500 feet east of Route 16A.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	22	.44	----

Average flow = 0.44 cfs

7. Grace Coolidge Creek at Custer Park Zoo

The average flow of this stream is 1.61 cfs. Although Center Lake is located upstream, it has no flood storage capability and hence does not significantly affect the flow at this point. The discharge determined by the permanent U.S. Geological Survey Gaging Station is slightly less than the measurements in this report because the U.S. Geological Survey Station is located in alluvium where some stream loss to the limestone occurs. The entire flow of Grace Coolidge Creek is usually lost to the limestone within a mile downstream of Site 7.

Located in SE¼SW¼NE¼ sec. 26, T. 3 S., R. 6 E. Measured 1,200 feet below Route 36 crossing.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	24	5.89	72
1967	8	21	2.39	63

7. Grace Coolidge Creek at Custer Park Zoo -- continued.

1967	9	13	1.38	52
1967	10	3	1.29	60
1967	11	28	.78	32
1967	12	7	.95	33
1968	1	10	I	----
1968	2	2	I	----
1968	3	1	1.11	36
1968	4	12	.99	44
1968	5	3	.89	51
1968	6	----	4.24	----
1968	7	3	3.05	----
1968	8	1	1.68	----
1968	9	4	2.25	53
1968	10	1	1.11	----
1968	11	11	1.94	33
1968	12	19	1.85	33
1969	1	25	.07	----
1969	2	15	I	----
1969	3	31	I	----
1969	4	----	.52	----
1969	5	13	.82	----
1969	6	12	.90	51
1969	7	18	10.86	68
1969	8	7	2.71	62
1969	9	28	.67	----
1969	10	10	1.04	----
1969	11	26	1.42	----
1969	12	11	1.39	----
1970	1	25	I	----
1970	2	7	I	----
1970	3	20	I	----
1970	4	11	1.70	----
1970	5	13	2.54	----
1970	6	29	F	----
1970	7	22	1.52	----
1970	8	25	1.69	----

Average flow = 1.61 cfs

8. Grace Coolidge Creek 3 miles west of Hermosa

Many small springs and seeps occur in the alluvium along this stream. Since there is no single spring source, accurate temperature measurements cannot be made. The average discharge, measured at the Inyan Kara hogback where the floodplain constricts and shallow ground water leaks out of the alluvium, is 1.03 cfs. The springs undoubtedly initially originate by the upward percolation from deep limestone, because wells drilled to the limestone in this area are flowing artesian wells.

The discharge of these springs is less during the summer. This is probably because of evapotranspiration in the spring area.

Where the floodplain widens near the town of Hermosa, Grace Coolidge Creek water normally disappears into the alluvium to become shallow ground water. These areas of shallow ground water are commonly referred to as areas of "sub-irrigation."

Located in SW¼NE¼SW¼ sec. 1, T. 3 S., R. 7 E. Measured 11,200 feet above junction of Routes 36 and 79.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	24	F	----
1967	8	21	F	----
1967	9	13	2.35	----
1967	10	3	1.98	----
1967	11	28	1.73	----
1967	12	7	1.43	----
1968	1	10	1.37	----
1968	2	2	1.15	----
1968	3	1	1.23	----
1968	4	12	1.14	----
1968	5	3	1.21	----
1968	6	4	1.03	----
1968	7	3	.92	----
1968	8	1	1.15	----
1968	9	4	1.74	----
1968	10	1	F	----
1968	11	11	F	----
1968	12	----	F	----
1969	1	25	F	----
1969	2	----	F	----

8. Grace Coolidge Creek 3 miles west of Hermosa -- continued.

1969	3	31	F	----
1969	4	----	F	----
1969	5	13	F	----
1969	6	12	.42	----
1969	7	18	.90	----
1969	8	7	.64	----
1969	9	4	.31	----
1969	9	28	.77	56
1969	10	10	1.16	----
1969	11	20	1.10	----
1969	12	11	1.01	----
1970	1	25	.49	----
1970	2	7	.46	----
1970	3	20	.79	----
1970	4	11	.53	----
1970	5	13	1.02	----
1970	6	29	.55	----
1970	7	22	.61	----
1970	8	25	.26	----

Average flow = 1.03 cfs

9. French Creek at Custer Park

The average flow at this site is 5.25 cfs, of which approximately 4.95 cfs recharges the limestone.

French Creek is gaged just above "low-head dam." This dam diverts some water through a pipe of 1-foot diameter around the limestone sinkhole area. It is capable of diverting about 4.5 cfs. This diversion is a successful way to permit water to pass beyond sinkholes.

Located in NW¼NW¼SE¼ sec. 11, T. 4 S., R. 6 E. Measured just above "Low Head Dam" 7,200 feet west of Custer Park Zoo airport "red mountain" road.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	24	12.97	71
1967	8	25	F	----

9. French Creek at Custer Park -- continued.

1967	9	13	F	----
1967	10	3	F	----
1967	11	28	I	32
1967	12	6	1.12	34
1968	1	10	1.36	32
1968	2	2	.56	33
1968	3	1	1.39	34
1968	4	12	2.18	46
1968	5	3	1.92	50
1968	6	10	30.06	----
1968	8	1	13.1	----
1968	9	4	13.6	----
1968	10	1	2.1	----
1968	11	11	2.8	----
1968	12	19	1.96	----
1969	1	26	I	----
1969	2	28	1.45	----
1969	3	12	13.53	----
1969	4	----	8.10	----
1969	5	13	4.0	----
1969	6	12	3.7	52
1969	7	29	9.0	----
1969	8	7	10.5	----
1969	9	21	1.6	----
1969	10	10	2.36	----
1969	11	26	2.52	----
1969	12	26	1.35	----
1970	1	25	1.50	----
1970	2	7	2.73	----
1970	3	30	2.92	----
1970	4	11	9.65	----
1970	5	13	12.76	----
1970	6	29	4.0	78
1970	7	22	1.0	----
1970	8	25	.6	----

Average flow = 5.25 cfs

Average recharge for limestone = 4.95 (assuming all 1-foot pipe diversion eventually leaks through alluvium into limestone).

10 to 12. Lame Johnny Creek at Custer Park

These stations are on small tributaries of Lame Johnny Creek. All streams lose their flow to the limestone at the Precambrian contact. Their combined flow averages 0.63 cfs.

10. North Fork of Lame Johnny Creek at Custer Park. Located in SW¼NE¼ sec. 22, T. 4 S., R. 6 E.; measured at Precambrian-Cambrian contact.

Year	**Month**	**Day**	**Discharge** (cfs)	**Temperature** (°F)
1968	8	1	.14	----
1969	8	7	.10	----

Average flow = 0.12 cfs

11. South Fork of Lame Johnny Creek in Custer Park. Located in SW¼NE¼ sec. 32, T. 4 S., R. 6 E.; measured at Precambrian-Cambrian contact.

Year	**Month**	**Day**	**Discharge** (cfs)	**Temperature** (°F)
1969	8	1	.11	----
1969	8	7	.09	----

Average flow = 0.10 cfs

12. Flynn Creek in Custer Park. Located in SW¼SE¼ sec. 32, T. 4 S., R. 6 E.; measured at Precambrian-Cambrian contact.

Year	**Month**	**Day**	**Discharge** (cfs)	**Temperature** (°F)
1968	8	1	.72	----
1969	8	7	.1	----

Average flow = 0.41 cfs

13. Highland Creek in Custer Park

Located in SW¼NW¼ sec. 8, T. 5 S., R. 6 E.; measured at Precambrian-Cambrian contact.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	1	.84	----
1969	8	7	.56	----

Average flow = 0.70 cfs

14. Beaver Creek at Wind Cave

Beaver Creek completely disappears into the limestone at this point. Its average flow is 0.06 cfs.

Located in SE¼SW¼SW¼ sec. 25, T. 4 S., R. 5 E.; measured 3,300 feet below Route 385 bridge.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	24	F	62
1967	8	21	.71	----
1967	9	11	.89	54
1967	10	3	.80	57
1967	11	15	.87	58
1967	12	6	.51	38
1968	1	12	.70	33
1968	2	2	.60	----
1968	3	1	.85	----
1968	4	12	.36	50
1968	5	3	.60	57
1968	6	----	1.56	----
1968	7	3	2.04	----
1968	8	1	.87	----
1968	9	5	.50	58
1968	10	1	.61	----
1968	11	11	.26	----
1968	12	19	.14	----

14. Beaver Creek at Wind Cave -- continued.

1969	1	26	I	----
1969	2	----	I	----
1969	3	----	I	----
1969	4	----	I	----
1969	6	12	1.18	52
1969	7	25	.72	----
1969	8	7	.56	----
1969	10	26	.60	----
1969	11	19	.53	----
1969	12	19	.47	----
1970	1	20	.45	----
1970	2	14	.47	----
1970	3	30	.50	----
1970	4	29	.59	----
1970	5	22	.36	----

Average flow = 0.60 cfs
Average recharge to limestone = 0.60 cfs

15. Beaver Creek at Buffalo Gap

A large spring issues forth at the easternmost contact of the Minnekahta and Spearfish Formations, along a small anticline in the Beaver Creek Valley. It discharges a fairly steady 8.56 cfs, and has a constant temperature of 64°F.

Located in SE¼SW¼ sec. 14, T. 6 S., R. 6 E.; measured in Buffalo Gap.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	24	7.48	67
1967	8	21	5.97	67
1967	9	11	5.86	63
1967	10	3	5.54	65
1967	11	15	6.84	63
1967	12	6	5.92	62
1968	1	12	6.27	64
1968	2	2	6.14	64
1968	3	1	5.96	66
1968	4	12	6.04	64

15. Beaver Creek at Buffalo Gap -- continued.

1968	5	3	F	64
1968	6	----	9.25	----
1968	7	3	9.31	----
1968	8	1	15.73	----
1968	9	5	8.78	67
1968	10	1	8.35	----
1968	11	11	7.92	65
1968	12	19	11.85	----
1969	1	25	10.82	----
1969	2	28	10.85	63
1969	3	23	13.49	62
1969	4	----	11.16	----
1969	5	19	10.36	----
1969	6	11	7.78	62
1969	7	9	8.35	66
1969	8	8	8.26	63
1969	9	21	8.46	65
1969	10	26	10.85	64
1969	11	19	8.64	64
1969	12	17	8.27	64
1970	1	20	7.86	64
1970	2	14	8.87	64
1970	3	19	7.74	64
1970	4	29	F	64
1970	5	22	7.82	64
1970	6	30	7.10	64
1970	7	23	7.72	----
1970	8	14	10.38	64

Average flow = 8.56 cfs

16. Cold Brook at Cold Brook Reservoir

A small spring appears just above Cold Brook Reservoir, and is responsible for the maintenance of the constant reservoir level. The spring discharges water at the rate of 0.66 cfs. The temperature is hard to measure because the spring seeps out in a small pond, and is affected by the air temperature.

All this water sinks back into the limestone within the reservoir area.

Located in SW¼NW¼NE¼ sec. 11, T. 7 S., R. 5 E.; measured 100 feet above Cold Brook Reservoir.

16. Cold Brook at Cold Brook Reservoir -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	9	5	.8	64
1968	10	13	.82	64
1968	11	19	.66	----
1969	1	25	.92	----
1969	2	15	.43	----
1969	3	23	.57	----
1969	4	----	.77	----
1969	5	19	.62	52
1969	6	11	0.5	61
1969	7	9	.81	67
1969	8	8	.4	67

Average flow = 0.66 cfs

17. Hot Brook above the Fall River

Springs in Hot Brook Canyon discharge about 1.98 cfs; the water temperature is a constant 75°F. The water probably is derived from the Pahasapa Limestone, because the spring is located on the axis of the Cascade anticline where the Pahasapa is exposed along the canyon. The water does sink into the limestone at Site 16, but the stream is continuous to the town of Hot Springs.

Located in NW¼SE¼NE¼ sec. 14, T. 7 S., R. 5 E.; discharge measured 5,700 feet above Route 87; temperature measured at spring originating 8,700 feet above Route 87.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	7	1.95	75
1968	9	5	2.54	74
1968	10	16	3.20	75
1968	11	19	1.80	74
1968	12	15	1.55	75
1969	1	25	.99	----
1969	2	15	1.03	74
1969	3	23	3.46	75

17. Hot Brook above the Fall River -- continued.

1969	4	----	1.43	75
1969	5	19	4.09	----
1969	6	11	1.4	75
1969	7	9	1.90	74
1969	8	8	1.9	75
1969	9	21	2.3	75
1969	10	26	1.5	76
1969	11	19	1.7	68?
1969	12	17	1.6	74
1970	1	20	1.7	74
1970	2	14	1.8	74
1970	3	19	1.8	72
1970	4	29	1.5	74
1970	5	22	1.8	74
1970	6	30	1.4	75
1970	7	23	3.27	----
1970	8	14	1.8	75

Average flow = 1.98 cfs

18. Fall River at Hot Springs

There are several large springs in the town of Hot Springs; the largest is Evans' Plunge which has a constant temperature of 87°F. The total average discharge of all the springs, exclusive of Hot Brook, is 22.92 cfs, and does not vary throughout the year (fig. 3). Site 18 gaging values are about 2.2 cfs higher than the U.S. Geological Survey gage located in downtown Hot Springs during the period of October 1968 to January 1969, probably because Site 18 gage includes sewage effluent discharge.

Located in SE¼NW¼NW¼ sec. 24, T. 7 S., R. 5 E.; discharge measured at U.S. Geological Survey Gaging Station 300 feet below Route 18 bridge in Hot Springs; temperature measured under Route 87 bridge at Evans' Plunge.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	7	23.13	85
1968	9	5	25.28	84
1968	10	16	21.14	83

18. Fall River At Hot Springs -- continued.

1968	11	19	21.27	----
1968	12	15	24.55	----
1969	1	25	26.31	----
1969	2	15	27.09	----
1969	3	23	23.22	----
1969	4	----	22.82	----
1969	5	19	34.61	----
1969	6	11	24.49	84
1969	7	9	----	85
1969	8	8	----	85
1969	9	21	----	86
1969	10	26	----	84
1969	11	19	----	84
1969	12	17	----	82
1970	1	20	----	84
1970	2	14	----	84
1970	3	19	----	81?
1970	4	29	----	82
1970	5	22	----	84
1970	6	30	----	85
1970	7	----	----	----
1970	8	14	----	85

Average flow = 24.90 cfs
Average flow exclusive of Hot Brook = 24.90 - 1.98 = 22.92 cfs

19. Cascade Spring below Cascade

Cascade Spring is the largest single spring in the Black Hills of South Dakota. It issues forth dramatically at the contact of the Minnekahta and Spearfish Formations. It has a steady discharge and constant temperature of 67°F. One mile north of Cascade Spring itself is a smaller spring called "Cold Spring," which has a discharge of about 1.1 cfs and a temperature of 64°F. The discharge of Cascade Spring and Cold Spring together averages 23.65 cfs, Because of the large volume of water discharge by this spring, and because of the small surface drainage basin above the spring, it is obvious that Cascade Spring is recharged by water entering the limestone underlying other surface drainage basins; namely, the expanse of limestone to the northwest towards Jewel Cave. Based on water quality data and piezometric levels of wells in the

Edgemont area, Keene (in preparation) suggests that Cascade Spring is derived from ground water in the Minnelusa Formation. Because of the high dissolved solids in this spring water (table 3), the vegetation and stream bed become coated with limestone. The waterfalls 3 miles downstream from the spring are caused by these deposits called calc-tufa.

The clear, briskly-flowing waters make Cascade Creek one of the most scenic locales in the Black Hills. The narrows at the Inyan Kara hogback would make an ideal dam site. The recreational value of such a reservoir would be great because the surface drainage area into Cascade Spring is small (less than half a square mile), and hence the reservoir would not be subject to floods and siltation.

Located in SE¼SE¼SE¼ sec. 19, T. 8 S., R. 5 E.; discharge measured 2,500 feet below the old town of Cascade; temperature was measured at Cascade Spring.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	8	24.69	66
1968	9	5	23.36	66
1968	10	13	24.69	67
1968	11	19	26.49	66
1968	12	15	19.72	66
1969	1	25	29.66	----
1969	2	15	22.32	67
1969	3	23	21.05	68
1969	4	----	23.00	67
1969	5	19	25.11	----
1969	6	11	21.43	67
1969	7	9	23.62	66
1969	8	8	23.95	66½
1969	9	21	23.24	67
1969	10	26	22.13	67
1969	11	19	23.59	68
1969	12	17	22.63	67
1970	1	20	24.81	67
1970	2	14	22.94	67
1970	3	19	23.77	67
1970	4	29	27.36	67
1970	5	22	23.83	----
1970	6	30	21.68	67
1970	7	23	23.21	----
1970	8	14	22.93	66

Average flow = 23.65 cfs

20. Stockade Beaver Creek above LAK Reservoir

This stream was gaged at a permanent 8-foot Parshall flume located just above the LAK Reservoir. Most of the springs occur at several places along the Minnekahta-Spearfish contact, within a few miles upstream. The spring's temperature is a constant 53°F, and the discharge (exclusive of Site 21 upstream) is a fairly constant 12.84 cfs. Fluctuations in discharge are probably due to withdrawals for irrigation and phreatophyte transpiration upstream.

Located in NE¼NE¼SW¼ sec. 31, T. 45 N., R. 60 W.; discharge measured at old 8-foot Parshall Flume 9,500 feet above Route 16; temperature measured at a spring 1,400 feet above flume.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	22	13.16+	56
1968	10	13	16.46	53
1968	11	19	14.10	53
1968	12	15	13.79	53
1969	1	25	13.34	----
1969	2	15	13.79	53
1969	3	23	16.87	----
1969	4	----	12.27	----
1969	6	12	12.05	53
1969	7	18	15.41	57
1969	8	13	14.56+	45?
1969	9	26	13.2	53
1969	10	20	10.0	54
1969	11	21	11.3	54
1969	12	11	16.2	54
1970	1	23	16.5	50?

20. Stockade Beaver Creek above LAK Reservoir -- continued.

1970	2	28	17.5	49?
1970	3	31	18.5	52
1970	4	24	16.5	----
1970	5	19	15.8	----
1970	6	----	F	----
1970	7	8	17.0	53
1970	8	6	12.8	54

Average flow = 14.60 cfs
Average flow exclusive of Station 20 upstream = 14.60 - 1.76 = 12.84 cfs

21. Beaver Creek above Beaver Creek campground

A small (1.76 cfs), cold (43°F) spring occurs near the Pahasapa-Minnelusa contact there and flows continuously down to Site 20.

Located in NE¼SE¼SW¼ sec. 5, T. 1 N., R. 1 E.; measured 2 miles east of South Dakota-Wyoming border, 200 feet above Beaver Creek campground.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	6	12	----	44
1969	8	13	1.76	43

Average flow = 1.76 cfs

22. Spring Creek above Medicine Mountain Ranch

Springs at Sites 22 to 28 seem to have a common origin. Precipitation falls onto the high limestone plateau of the western Black Hills. Some precipitation is returned to the atmosphere by evapotranspiration and some percolates downward until it hits the relatively impermeable Deadwood and Precambrian Formations. It then moves laterally, discharging along some ravine at the contact between the overlying carbonate aquifer and the underlying Deadwood Formation. These springs serve as the headwaters of Spring, Castle, and Rapid Creeks.

Bear Spring, located on the upper drainage of Hell Canyon, has a similar origin, but sinks back into the limestone. It is only a small spring and was not gaged.

22. Spring Creek above Medicine Mountain Ranch -- continued.

Measured at Precambrian-Deadwood contact. Located in SW¼SW¼SW¼ sec. 2, T. 2 S., R. 3 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	6	2	.24	42

Average flow = 0.24 cfs

23. South Fork of Castle Creek just below Pole Creek

Cold (44°F) springs discharge just above here. They average 1.08 cfs, of which springs on Pole Creek contribute 0.14 cfs. Located in NE¼SE¼NE¼ sec. 10, T. 1 S., R. 2 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	21	.50	44
1970	7	3	1.65	44

Average flow = 1.08 cfs

24. Ditch Creek

Ditch Creek is the main tributary of South Fork of Castle Creek. Ditch Creek has an average flow of 3.3 cfs and the temperature of the main spring on Ditch Creek is 41°F. This is the coldest known spring in the Black Hills.

Located in SE¼NW¼NE¼ sec. 11, T. 1 S., R. 2 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1970	7	8	3.2	41

Average flow = 3.20 cfs

25. Castle Creek 1 mile northwest of Deerfield

Castle Creek, which has an average flow of about 4.39 cfs, originates from springs upstream.

Downstream from Deerfield, there is a permanent U.S. Geological Survey gaging site where South Fork of Castle Creek joins Castle Creek. The average flow for this gage, including all Sites 23, 24, and 25 for the period of October 1968 to September 1969, including floods, was 11.10 cfs.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	21	4.39	----

Average flow = 4.39 cfs

26. Rhoad's Fork

Large springs cascade down a cliff at the base of the Pahasapa Limestone at this point. The flow seems to be a constant 4.28 cfs and 43°F.

Discharge measured at Black Fox Campground; temperature measured at 2 miles above Black Fox Campground.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	6	3	----	43
1969	7	19	4.23	42½
1970	7	9	4.33	44

Average flow = 4.28 cfs

27. South Fork of Rapid Creek

"Headwater Spring" on South Fork of Rapid Creek discharges a fairly constant 3.00 cfs and has a temperature of 43°F. Measured 4,000 feet above Black Fox Campground.

27. South Fork of Rapid Creek -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	6	3	----	43
1968	8	21	3.27	44
1969	7	19	2.32	43
1970	7	9	3.40	44

Average flow = 3.00 cfs

28. Tilson Creek

Sites 28, 32, 34, 35, 36, and 37 are affected by diversions related to the Homestake Mining Company and the towns of Lead and Deadwood.

Tilson Creek discharges 0.8 cfs, plus about 1.0 cfs which is diverted to Lead. Measured at 2 miles below Besant Park located SW½NE½ sec. 26, T. 3 N., R. 2 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	19	.80+[1]	----

Average flow = 1.8 cfs?

[1] Plus some water diverted above here to Lead, South Dakota (probably 1 cfs)

29. Soldier Creek

Small springs discharge 0.38 cfs from the Pahasapa Limestone. The water flows into Wyoming.

Measured 1 mile below Route 85. Located in SW¼NW¼NE¼ sec. 20, T. 48 N., R. 61 W.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	1	.38	----

Average flow = 0.38 cfs

30. Cold Spring Creek, tributary of Sand Creek

A spring discharge of 1.63 cfs above Buckhorn, Wyoming, from the

30. Cold Spring Creek, tributary of Sand Creek -- continued.

Pahasapa Limestone. The temperature of the water is 42°F. This water sinks back into gravels overlying the Pahasapa Limestone several miles downstream.

Measured at 1 mile east of South Dakota-Wyoming boundary, 3 miles east of Buckhorn, Wyoming. Located in NE¼NE¼NE¼ sec. 7, T. 2 N., R. 1 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	1	1.63	42

Average flow = 1.63 cfs

31. Sand Creek 2 miles south of Beulah, Wyoming

Large springs discharge from the Pahasapa Limestone at the U.S. Department of Interior Fish Genetics Research Station (Ranch A). The average flow of the springs is about 23.81 cfs, and the temperature is a constant 54°F.

Discharge measured at 2 miles south of Route 14; temperature measured at U.S. Department of Interior Fish Genetics Laboratory. Located in SW¼NE¼NW¼ sec. 8, T. 52 N., R. 60 W.

31. Sand Creek 2 miles south of Beulah, Wyoming -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	28	27.52	54
1968	10	5	22.98	----
1968	11	12	20.74	----
1968	12	8	26.61	----
1969	1	26	19.16	----
1969	2	8	18.78	----
1969	3	22	16.33	----
1969	4	13	32.02	----
1969	5	10	40.37	----
1969	6	16	21.08	----
1969	7	20	24.95	54
1969	8	1	24.83	54½
1969	9	13	24.06	55
1969	10	20	25.32	54
1969	11	21	18.00	55
1969	12	15	19.42	54
1970	1	29	19.41	52
1970	2	28	20.52	52
1970	3	31	19.40	52
1970	4	24	72.78	55
1970	5	19	70.09	55
1970	6	----	F	----
1970	7	10	34.75	54[1]
1970	8	6	F	57

Average flow = 28.14 cfs

Average flow of spring only = 23.81 cfs

[1] Flood flow

32. Crow Creek at McNenny Fish Hatchery

Many springs occur at the U.S. Department of Interior Fish Hatchery along Crow Creek. Although the springs discharge from the Spearfish Formation, the water probably comes from the underlying limestones, because of the presence of flowing artesian wells at the fish hatchery. The springs themselves cause unusual sand boils along Crow Creek, and at places have eroded out large areas such as Cox Lake and Mirror Lake. Although the discharge of 17.47 cfs was only measured once, the springs are reportedly constant in discharge and have a constant temperature of 52°F.

Discharge below is difference between flow of Crow Creek at Route 14 and flow of Crow Creek a quarter of a mile below fish hatchery.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1971	4	8	17.47	42

Average flow = 17.47 cfs

33 to 36. Spearfish Creek

Springs occur over a considerable reach of Spearfish, Little Spearfish, and East Fork of Spearfish Creeks, and there are many diversions. The total flow of Spearfish Creek at the U.S. Geological Survey gaging site in Spearfish (Site 36) is 52.43 cfs, of which about 39.83 cfs is spring discharge by base flow. Of this spring flow, about 11.60 cfs comes from Little Spearfish Creek (Site 33), 9.12 cfs from upper Spearfish Creek (Site 34), and 9.51 cfs from East Fork Spearfish Creek (Site 35). The total of these three sites is 30.23 cfs. The difference between the 39.83 cfs base flow at Spearfish (Site 36) and 30.23 cfs is 9.60 cfs, which comes from springs along Spearfish Canyon below Cheyenne Crossing.

33. Little Spearfish Creek, tributary of Spearfish Creek. Discharge measured 1 mile above Savoy; temperature measured at spring 4 miles above Savoy. Located in NE¼NE¼SW¼ sec. 36, T. 5 N., R. 1 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	14	11.60	43

Average flow = 11.60 cfs

34. Spearfish Creek, measured 50 feet above junction of East Fork of Spearfish Creek, 1,000 feet above Cheyenne Crossing. Located in SW¼SW¼NW¼ sec, 31, T. 5 N., R. 2 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	19	9.12+[1]	----

Average flow = 9.12 cfs
[1] Plus water diverted by Homestake Mining Company

35. East Fork Spearfish Creek, tributary of Spearfish Creek. Measured 50 feet above junction of Spearfish Creek, 1,000 feet above Cheyenne Crossing. Located in SW¼SW¼NW¼ sec. 31, T. 5 N., R. 2 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	19	9.51±[1]	----

Average flow = 9.51 cfs
[1] ± Homestake pumping station contribution at Hanna

36. Spearfish Creek at Spearfish, measured at U.S. Geological Survey Gage Station in Spearfish. Located in NW¼SE¼SW¼ sec. 10, T. 6 N., R. 2 E.

Average base flow (spring discharge) from 10/68 to 9/69 is 39.83 cfs

37. False Bottom

False Bottom Creek contributes about 0.57 cfs to sinkholes in the limestone below Maitland.
Measured at Maitland. Located in SE¼SE¼NW¼ sec. 18, T. 5 N., R. 3 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	6	16	.57	----

Average flow = 0.57 cfs

38. Whitewood Creek at Whitewood

Whitewood Creek is extemely polluted and carries a large sediment load from the Homestake Mine; its discharge varies considerably. For these reasons no systematic gaging was conducted. A reasonable estimate of its flow is 15 cfs. Probably little flow is lost or gained in the limestone belt.
Measured at Route 14. Located in NE¼NE¼NW¼ sec. 27, T. 6 N., R. 4 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	28	5.	----
1968	10	4	3.	----
1968	11	12	6.	----
1968	12	8	4.	----
1969	2	8	10.	----
1969	3	22	10.	----
1969	4	----	10.	----
1969	5	----	25.	----

38. Whitewood Creek at Whitewood -- continued.

1969	6	16	4.	----
1969	7	20	8.	----
1969	9	13	28.	----

Average flow = 10. cfs (Assume no recharge or springs).

39. Bear Butte Creek at Galena

Like most streams whose waters head in Precambrian rocks, the discharge of Bear Butte Creek varies considerably. It averages 6.70 cfs. Experience has shown that only those discharges greater than 5 cfs will flow completely across the carbonate aquifer along Bear Butte Creek without sinking in; this amounts to an average sinkhole loss of 1.68 cfs.

Measured at Double Rainbow Mine. Located in NW¼NW¼SW¼ sec. 3, T. 4 N., R. 4 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	28	1.22	----
1968	10	4	1.56	----
1968	11	12	1.59	33
1968	12	8	1.30	----
1969	1	26	I	----
1969	2	8	I	----
1969	3	22	I	----
1969	4	30	23.86	----
1969	5	----	61.85	----
1969	6	16	4.69	67
1969	7	2	9.60	70
1969	8	18	1.48	----
1969	9	13	.94	----
1969	10	31	1.85	----
1969	11	16	1.56	----
1969	12	12	.78	----
1970	1	24	I	----
1970	2	24	I	----
1970	3	17	I	----
1970	4	25	F	----

39. Bear Butte Creek at Galena -- continued.

1970	5	20	26.13	----
1970	6	----	F	----
1970	7	10	6.51	----
1970	8	24	2.39	----

Average flow = 6.70 cfs
Average sinkhole loss = 1.68 cfs

40. Bear Butte Creek east of Sturgis

Small springs occur along Bear Butte Creek just east of Sturgis, along the City Park. These springs probably originate by recharge on the alluvium under Sturgis, which serves as a collecting place for local precipitation and irrigation waters. A less likely explanation is that the spring originates by upward leakage from the underlying carbonate aquifer.

The gaging site used is opposite the Veterans Hospital and above the Sturgis sewage outlet. The average flow of the springs is 0.60 cfs, but varies considerably.

Located in NW¼NE¼NW¼ sec. 11, T. 5 N., R. 5 E.; discharge measured adjacent to Fort Meade Veterans Administration Hospital; temperature measured at spring in Park at east side of town.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	8	29	.69	56
1968	10	4	.19	55
1968	11	12	.86	50
1968	12	8	1.22	43
1969	1	26	.53	----
1969	2	8	.66	----
1969	3	22	.84	----
1969	4	----	23.76	----
1969	5	10	29.76	50
1969	6	16	6.89	49
1969	7	2	1.88	52
1969	8	26	.41	55
1969	9	13	.33	56
1969	10	20	.52	55

40. Bear Butte Creek east of Sturgis -- continued.

1969	11	16	.50	52
1969	12	12	.34	48
1970	1	29	I	----
1970	2	24	.20	----
1970	3	17	.20	46
1970	4	24	F	52
1970	5	19	58.61	52

Average flow = 6.42 cfs
Average flow springs only = 0.60 cfs

41. Cattle Creek near Fort Meade Cemetery

This small spring has an origin and setting similar to the spring at Site 40. Located in NE¼SE¼NE¼ sec. 14, T. 5 N., R. 5 E. Discharge measured 3,000 feet south of Fort Meade Cemetery; spring is 500 feet southwest of I-90.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	2	.10	----

Average flow = 0.10 cfs.

42. Alkali Creek above Sturgis Reservoirs

Ground water drains from the Pahasapa Limestone and Tertiary intrusive rocks in this area and supplies the Sturgis Reservoirs with a base flow of about 0.23 cfs. This water is diverted from the reservoirs directly to the town of Sturgis. The U.S. Veterans Administration Hospital at Fort Meade has a similar water supply in Deadman Canyon.

Located in NE¼NE¼SW¼ sec. 33, T. 5 N., R. 5 E.; measured above Davenport's Dam No. 4.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	26	.23	----

Average flow = 0.23 cfs

43. Alkali Creek near Black Hills Cemetery

Small springs appear here, and are similar in origin to those at Sites 40 and 41. Discharge measured at BLM recreational area, 2,500 feet northeast of I-90; temperature measured at spring 2,500 feet southeast of Black Hills National Cemetery. Located in NW¼SW¼SW¼ sec. 24, T. 5 N., R. 5 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	2	.58	48

Average flow = 0.58 cfs

44. "Railroad Spring" on Tilford Gulch

This spring is located high on a hill in the Pahasapa Limestone. It is probably caused by the contact of the Limestone with the relatively impermeable Vanocher intrusive, an andesite of Tertiary age. The spring has a 3-inch pipe built to supply steam engines at Tilford in the 1890's. It is now only used by local ranchers.

Located in SE¼SE¼SE¼ sec. 14, T. 4 N., R. 4 N.; measured 2 miles west of Tilford at I-90.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	20	.01+[1]	47

Average flow = 0.02 cfs
[1] Plus pipe diversion estimate at .01 cfs

45. Morris Creek

This small spring at the Minnekahta-Spearfish contact discharges about 0.45 cfs. Located in SW¼ sec. 20, T. 4 N., R. 6 E.; measured at spring 50 feet west of I-90.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	6	18	.38	----

45. Morris Creek -- continued.

1969	8	18	.51	----

Average flow = .45 cfs

46. Elk Creek at Thomson's Ranch

The drainage area above this point is entirely in the Precambrian; hence the flow is quite variable, similar to Sites 1, 7, 31, and 53. The average flow is 7.88 cfs. Since flows greater than 10 cfs do not generally sink into the limestone but flood on through it, the average recharge rate to the limestone is therefore 6.00 cfs. The stream is generally dry below this point to Site 48.

Located in NW¼SE¼NW¼ sec. 24, T. 4 N., R. 4 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	7	25	9.44	74
1967	8	23	3.90	60
1967	9	28	F	----
1967	10	13	3.43	49
1967	11	8	4.08	32
1967	12	16	I	----
1968	1	26	I	----
1968	2	9	I	----
1968	3	15	3.90	44
1968	4	23	10.68	48
1968	5	11	4.88	55
1968	6	----	7.44	----
1968	7	17	5.84	----
1968	9	1	3.19	----
1968	10	5	2.28	53
1968	11	12	7.38	33
1968	12	8	2.48	33
1969	1	26	I	----
1969	2	8	I	----
1969	3	22	6.38	----
1969	4	----	34.00	----
1969	5	6	54.98	----
1969	6	18	6.11	----

46. Elk Creek at Thomson's Ranch -- continued.

1969	7	2	6.76	----
1969	8	18	3.13	67
1969	9	14	2.28	----
1969	10	31	3.85	----
1969	11	16	4.39	----
1969	12	18	I	----
1970	1	24	I	----
1970	2	24	I	----
1970	3	17	I	----
1970	4	25	13.52	----
1970	5	20	40.90	----
1970	6	23	F	----
1970	7	14	9.95	----
1970	8	24	4.73	----

Average flow = 7.88 cfs
Average recharge to limestone = 6.00 cfs

47. "Jones' Spring"

This small spring is similar in origin to Sites 42 and 44. Water discharges from a point where permeable Pahasapa Limestone lies over relatively impermeable igneous intrusive rock.

Located in SW¼NW¼SE¼ sec. 23, T. 4 N., R. 5 E.; measured along Bethlehem ("Crystal") Cave road, 2,000 feet north of Elk Creek.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	7	17	.13	----
1968	9	1	.08	53
1969	8	18	.05	----
1970	7	14	F	52

Average flow = 0.09 cfs

48. Elk Creek above Steckle's Ranch

A spring occurs at this point, and sinks back into the limestone within a few hundred yards downstream. It has an average discharge of 4.91 cfs and a fairly constant temperature of 45°F. Located in NW¼NE¼ sec. 26, T. 4 N., R. 5 E.; measured at "Pansy Park," 1,600 feet above Steckle's Ranch.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	8	23	7.88	49
1967	9	28	7.04	48
1967	10	13	6.20	48
1967	11	8	5.36	42
1967	12	16	3.36	44
1968	1	26	2.31	45
1968	2	9	1.96	44
1968	3	15	1.89	47
1968	4	23	2.22	46
1968	5	11	2.39	49
1968	7	17	6.02	----
1968	9	1	2.76	48
1968	10	5	1.65	47
1968	11	12	.17	----
1968	12	8	I	----
1969	1	26	I	----
1969	2	----	I	----
1969	3	22	I	----
1969	4	----	I	----
1969	5	10	44.72	----
1969	6	18	5.22	47
1969	7	2	F	48
1970	7	14	12.58	49

Average flow, springs only = 4.81 cfs

49. Elk Creek at Piedmont

A spring discharges from alluvium overlying the Spearfish Formation at this point. Because of known high artesian pressure in the underlying limestone as demonstrated by local wells, and the limited capacity of the alluvium to collect large amounts of precipitation, it is believed that this

spring water has its origin in the underlying carbonate aquifer. Located in SW¼NE¼NW¼ sec. 11, T. 3 N., R. 6 E.; discharge measured at turnoff to Miller's ranch, 1 mile east of Piedmont; temperature measured at spring 4,000 feet northeast of Piedmont.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	27	.63	51
1969	9	13	1.93	51
1969	10	20	2.24	----
1969	11	16	2.07	50
1969	12	15	2.17	50
1970	1	29	1.41	----
1970	2	24	1.32	48
1970	3	17	1.53	50
1970	4	24	2.24	56
1970	5	19	44.28	56
1970	6	23	F	----
1970	7	14	9.4	52
1970	8	24	6.59	52

Average flow = 6.32 cfs
Average flow, springs only = 1.73 cfs

50. Little Elk Creek

The average discharge of the stream is approximately 0.89 cfs. The water usually all sinks into the limestone. Located in SW¼NE¼NE¼ sec. 12, T. 3 N., R. 5 E.; measured at Precambrian-Cambrian contact 3 miles west of I-90.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	7	30	1.50	----
1968	8	29	.53	----
1969	7	11	.63	----

Average flow = 0.89 cfs

51. South Fork of Stagebarn Canyon ("Botany Canyon")

Small springs occur where the Englewood Limestone is exposed in this deep canyon. The water sinks back into the Englewood and Pahasapa Limestone within a mile downstream. Located 2 miles southwest of I-90; discharge measured in NW¼ sec. 27, T. 3 N., R. 6 E.; spring temperature measured at NW¼NE¼ sec. 33, T. 3 N., R. 6 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	7	11	.12	46

Average flow = 0.12 cfs

52. Blackhawk Creek

A small spring originates under the railroad trestle at Blackhawk. It is probably recharged by local precipitation on surrounding alluvium. Located in NE¼NE¼NW¼ sec. 8, T. 2 N., R. 7 E.; measured 1,500 feet east of I-90.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	18	.14	----

Average flow = 0.14 cfs

53 to 58. Boxelder Creek

The average discharge of Boxelder Creek where it exits from the Precambrian rocks (Site 53) is 13.23 cfs. It loses almost all its flow to some large caves and deposits of alluvium overlying the Pahasapa Limestone. According to Gries and others (1968), it is possible to crawl into these caves to a point under the stream bed where water still flows above! Farther downstream there are several large ephemeral springs; they flow when the water table is high. Water usually sinks back into the limestone within a few hundred yards below each of these ephemeral springs. Boxelder Creek hydrogeology has been described in some detail by Crooks (1968a, 1968b). The interconnection of waters at Sites 53, 54, 55, and 56 was proved by a dye test (see other sections of this report). Dye was observed to flow from

the primary sinkholes at Site 53 to "Gravel Springs" (Site 54) in 67 minutes. This type of spring, having a direct subsurface connection with the disappearing stream, is called a resurgent spring.

The average flow of Site 58, where the stream valley leaves the limestone, is 2.28 cfs. Therefore the average recharge to the limestone by Boxelder Creek is 10.95 cfs. This is the largest disappearing stream in the Black Hills.

Small ungaged springs occur within a few miles upstream from Site 53 where buttes of limestone (Steamboat Rock, etc.) lie on top of the Deadwood Formation.

53. Boxelder Creek at Custer Gap, located in SW¼SW¼NW¼ sec. 16, T. 2 N., R. 6 E.; measured 50 feet above gap.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1966	9	5	4.3	66
1966	10	2	5.1	54
1966	11	3	5.0	37
1966	12	6	4.6	32
1967	1	31	4.7	33
1967	3	9	10.6	33
1967	4	15	15.7	46
1967	5	21	32.0	58
1967	6	----	122.6	56
1967	7	27	47.38	----
1967	8	18	16.40	58
1967	9	21	13.71	57
1967	10	26	10.26	35
1967	11	30	7.56	32
1967	12	16	4.38	33
1968	1	25	12.64	33
1968	2	23	6.77	32
1968	3	22	11.83	33
1968	4	11	13.88	46
1968	5	27	8.82	61
1968	6	----	8.41	----
1968	7	5	7.14	----
1968	8	12	5.60	60

53. Boxelder Creek at Custer Gap -- continued.

1968	9	3	3.51	53
1968	10	6	3.21	44
1968	11	7	2.80	37
1968	12	9	6.60	33
1969	1	26	1.4	----
1969	2	8	1.70	----
1969	3	22	6.50	----
1969	4	30	38.59	----
1969	5	----	33.45	----
1969	6	18	11.09	68
1969	7	11	5.05	75
1969	8	10	2.75+[1]	70
1969	9	5	.90+[2]	----
1969	10	31	1.35	----
1969	11	23	2.58	----
1969	12	18	I	----
1970	1	24	I	----
1970	2	24	I	----
1970	3	30	3.05	----
1970	4	25	21.81	----
1970	5	20	59.90	----
1970	6	23	58.00	62
1970	7	14	19.34	----
1970	8	24	9.31	----
1970	9	30	1.21	----
1970	10	31	1.28	----
1970	11	30	I	----
1970	12	21	I	----

Average flow = 13.23 cfs
Average recharge to limestone = 10.95 cfs
[1] Plus Merchen's pump = 1.2 cfs
[2] Plus Merchen's pump = 1.2 cfs

54. **"Gravel Spring" along Boxelder Creek,** located 2,000 feet southeast of sinkholes near Nemo Road bridge below Custer Gap; in SE¼NW¼SE¼ sec. 16, T. 2 N., R. 6 E.; discharge measurement is from spring only, and does not include Boxelder Creek flow (if any) from above.

54. "Gravel Spring" along Boxelder Creek -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1966	9	5	1.5	62
1966	10	2	2.8	50
1966	11	3	2.0	39
1966	12	6	1.6	35
1967	1	31	1.1	35
1967	3	9	6.0	34
1967	4	15	9.9	48
1967	5	21	10.7	57
1967	6	----	13.3	58
1967	7	27	2.56	60
1967	8	18	13.86	59
1967	9	21	11.80	54
1967	10	26	8.03	40
1967	11	30	3.63	34
1967	12	16	2.04	37
1968	1	25	7.77	35
1968	2	23	4.29	----
1968	3	22	2.80	36
1968	4	11	9.36	----
1968	5	27	6.55	36
1968	7	5	5.43	----
1968	8	12	4.43	61
1968	9	3	2.18	55
1969	8	11	.88	63
1969	9	5	D[1]	----

Average flow = 5.60 cfs
[1] Some standing water in hole; no flows

55. **"Doty Spring" along Boxelder Creek,** located 1,600 feet southeast of Gravel Spring, in SW¼SE¼SE¼ sec. 16, T. 2 N., R. 6 E.; discharge measurement does not include any flow of Boxelder Creek coming into Doty Spring from above, if any.

55. "Doty Spring" along Boxelder Creek -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1966	9	5	2.9	58
1966	10	2	3.2	51
1966	11	3	3.1	----
1966	12	6	3.1	41
1967	1	31	2.6	39
1967	3	9	3.9	36
1967	4	15	4.6	46
1967	5	21	7.8	----
1967	7	27	10.86	58
1967	8	18	6.28	59
1967	9	21	3.94	50
1967	10	26	3.63	43
1967	11	30	3.12	37
1967	12	16	2.75	38
1968	1	25	3.29	38
1968	2	23	2.31	----
1968	3	22	1.37	40
1968	4	11	2.90	----
1968	5	27	2.29	49
1968	7	5	.92	----
1969	8	11	2.89	61
1969	9	5	F	----

Average flow = 3.53 cfs

56. "Dome Spring" along Boxelder Creek, located 3,400 feet southeast of Doty Spring, in SE¼SW¼NW¼ sec. 22, T. 2 N., R. 6 E.; discharge measurement does not include any flow of Boxelder Creek coming into Dome Spring from above, if any.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1966	9	5	.6	58
1966	10	2	1.1	53
1966	11	3	.8	46
1966	12	6	.5	42
1967	1	31	D	----
1967	3	9	3.0	43
1967	4	15	7.8	46
1967	5	21	10.8	58
1967	7	27	8.29	66
1967	8	18	6.59	60
1967	9	21	6.26	52
1967	10	26	5.73	44
1967	11	30	1.79	40
1967	12	16	1.79	40
1968	1	25	3.46	38
1968	2	23	2.33	----
1968	3	22	1.71	39
1968	4	11	4.52	----
1968	5	27	4.43	49
1968	7	5	4.98	----
1969	8	11	1.5	----
1969	9	5	D	----

56. "Dome Spring" along Boxelder Creek -- continued.

Average flow = 3.54 cfs

57. "Lang Spring" or Boxelder Creek, located in NE¼SW¼ sec. 18, T. 2 N., R. 7 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1970	8	24	1.5	53
1970	8	26	1.6	----
1970	12	29	D	----

Average flow = 1.03 cfs

58. Boxelder Creek at Route 79, located in NE¼NW¼SE¼ sec. 17, T. 2 N., R. 7 E.

58. Boxelder Creek at Route 79 -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	1	31	.9	36
1967	3	9	1.1	36
1967	4	15	1.0	50
1967	5	21	3.2	----
1967	6	----	65.3	----
1967	7	27	F	----
1967	8	18	3.53	----
1967	9	21	3.16	49
1967	10	26	2.73	40
1967	11	30	2.55	35
1967	12	16	2.38	33
1968	1	25	3.31	40
1968	2	23	2.02	----
1968	3	22	1.79	----
1968	4	11	F	----
1968	5	27	1.09	58
1968	6	----	.29	----
1968	7	----	D	----
1970	5	20	F	----
1970	6	23	30.99	----
1970	7	----	----	----
1970	8	24	D	----
1970	9	----	D	----
1970	10	----	D	----
1970	11	----	D	----
1970	12	----	D	----

Average flow = 2.28 cfs

59. Victoria Creek at Victoria Dam

Victoria Creek drains a small area of Precambrian rocks and contributes approximately 0.58 cfs to the limestone within a short distance downstream. Measured 100 feet above Victoria Lake; located in NW¼SW¼NW¼ sec. 27, T. 1 N., R. 6 E.

59. Victoria Creek at Victoria Dam -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1969	8	12	.08	45
1970	7	27	.49	----

Average flow = 0.29 cfs

60 and 61. Rapid Creek

Rapid Creek drains a large area of Precambrian rocks above Site 60. There are two large flood control reservoirs which regulate the discharge: Deerfield and Pactola. Site 60, located just upstream from the carbonate aquifer, has an average discharge of 41.49 cfs. Probably because of this large discharge, Rapid Creek flows continuously across the limestone; apparently this was true even before the construction of the reservoirs.

During 1967 and 1968, the U.S. Geological Survey Gaging Station at Site 61, near where Rapid Creek leaves the carbonate aquifer, had an average flow that was 3.40 cfs less than the flow during the same days at Site 60. Rapp (1969) pointed out that a loss does occur in Rapid Creek in this limestone reach, and suggested that at least part of this loss provides recharge to Cleghorn Spring (Site 62).

60. Rapid Creek at Curt Dahn's house in Dark Canyon, located 6,500 feet west of Route 40 crossing at U.S. Geological Survey Gaging Station in NE¼SW¼ sec. 13, T. 1 N., R. 6 E.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1967	8	14	83.86	56
1967	9	8	62.89	67
1967	10	25	24.09	38
1967	11	16	23.07	38
1967	12	22	15.38	32
1968	1	26	22.53	32
1968	2	24	21.54	----
1968	3	15	38.57	37

60. Rapid Creek at Curt Dahn's house in Dark Canyon -- continued.

1968	4	5	40.60	----
1968	5	29	50.13	43
1968	6	----	51.84	----
1968	7	----	52.61	----
1968	9	2	34.02	----
1968	10	6	27.23	45
1968	11	10	18.17	34
1968	12	10	27.29	33
1969	1	28	8.64?	----
1969	2	10	24.76	----
1969	3	18	17.18	----
1969	4	----	50.26	----
1969	5	11	105.36	----
1969	6	18	74.05	59
1969	7	7	65.65	64
1969	8	12	56.26	----

Average flow = 41.49 cfs

61. Rapid Creek at U.S. Geological Survey Gaging Station located in NE¼NE¼NE¼ sec. 18, T. 1 N., R. 7 E.; measured at Route 40 crossing 4,000 feet west of Cleghorn Spring's fish hatchery.

Year	Month	Day	Discharge (cfs)	Temperature (°F)

(See U.S. Geological Survey records.)

62. Cleghorn Spring

This spring has a steady discharge of about 10 cfs and the water has a constant temperature of 53°F. The gaging site, just below the fish hatchery, is handicapped to some degree because of the presence of a nearby well belonging to the Rapid City Water Department, the so-called "Jackson Spring" well. This well is a shallow, high-capacity (2.8 cfs) well developed in alluvium, which undoubtedly takes some water from Cleghorn Spring. The mineral content of water from the two sources is almost the same (see table 3). The pump in the well is triggered automatically, and the discharge of Cleghorn Spring can be visually observed to fluctuate accordingly. Thus the

62. Cleghorn Spring -- continued.

natural discharge of Cleghorn Spring is probably slightly in excess of 10.24 cfs.

Located in SE¼NW¼SE¼ sec. 8, T. 1 N., R. 7 E.; discharge measured 1,300 feet east of South Dakota Fish Hatchery, where Cleghorn Spring discharges into Rapid Creek; temperature measured at spring 100 feet north of caretaker's house.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	9	2	9.61	52
1968	11	15	9.72	----
1968	12	10	10.60	52
1969	1	28	11.73	----
1969	2	10	10.35	52
1969	3	18	10.32	----
1969	4	----	9.48	----
1969	5	11	10.57	52
1969	6	18	9.72	52
1969	7	7	9.38[1]	53
1969	8	12	8.10	----
1969	9	25	11.35	54
1969	10	31	10.77	54
1969	11	23	11.52	54
1969	12	18	9.06	----
1970	1	24	10.84	54
1970	2	27	7.84	56?
1970	3	31	9.74	54
1970	4	25	10.99	54
1970	5	25	11.88	54
1970	6	----	F	----
1970	7	9	11.57	52
1970	7	25	10.57	52
1970	8	----	F	----
1970	9	30	11.83	----
1970	10	31	9.14	----
1970	11	30	F	----
1970	12	29	9.32	53

62. Cleghorn Spring -- continued.

Average flow = 10.24 cfs
[1]Discharge less than normal because Rapid City's valves at "Jackson Spring" are on, and high evapotranspiration is taking place on Cleghorn Spring fish hatchery pond.

63. City Spring (Lime Creek)

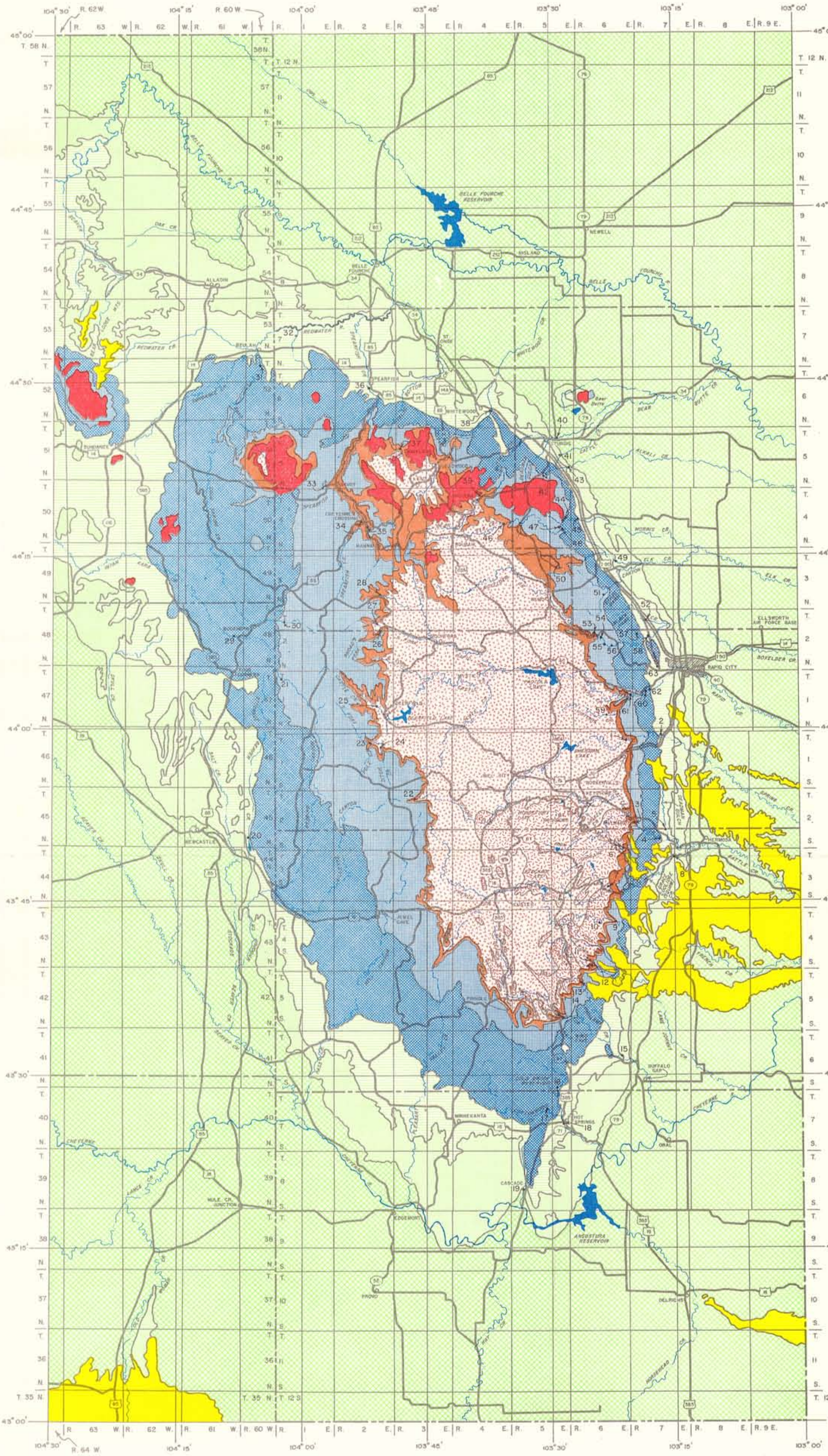
This spring occurs at the Minnekahta-Spearfish contact along the lowest point in a small anticline north of Rapid City. The spring flowed continuously during the period of this investigation at a temperature of 53°F and a discharge averaging 0.87 cfs. Some artesian wells in the vicinity of the cement plant nearby also tap into this water and discharge about the same amount. Although the cement plant wells only extend down to the Minnelusa Formation, both City Spring and the cement plant wells probably take water from the entire Paleozoic limestone aquifer, because a dye test (see other sections of this report) showed that City Spring contains some water from Boxelder Creek at Site 53.

Located in SE¼SE¼NE¼ sec. 32, T. 2 N., R. 7 E.; measured 1,600 feet north of intersection of 44th and West Chicago Streets in Rapid City.

63. City Spring (Lime Creek) -- continued.

Year	Month	Day	Discharge (cfs)	Temperature (°F)
1968	7	25	.86	50
1968	9	2	.62	51
1968	11	7	F	50
1968	12	10	.72	51
1969	1	28	.62	----
1969	2	----	.42	----
1969	3	18	.35	----
1969	7	7	.84	51
1969	8	15	.98	51
1969	9	28	.79	51
1969	10	31	.94	52
1969	11	23	.62	52
1969	12	12	.55	52
1970	1	24	.40	53
1970	2	27	.56	52
1970	3	17	.70	52
1970	4	25	1.28	52
1970	5	25	1.91	52
1970	6	----	F	----
1970	7	25	1.95	50
1970	8	----	F	----
1970	9	30	1.17	----
1970	10	31	1.53	----
1970	11	30	.73	----
1970	12	21	.63	----

Average flow = 0.87 cfs



TERTIARY

White River Group. *Consists of 0 to 600 feet of clays with local sandstone channel fillings and limestone beds.*

Tertiary intrusive rocks are found as dikes, sills, and laccoliths in the northern Black Hills. The composition varies from rhyolite to andesite.

CRETACEOUS

Graneros Group, Greenhorn Limestone, Carlile Formation, and Pierre Shale. *These sediments include over 2,000 feet of black fissile shale, with some thin interbedded limestone chalk, bentonite, and sandstone.*

TRIASSIC–JURASSIC

Inyan Kara Group (Cretaceous), **Morrison Formation** (Jurassic), and **Unkpapa Sandstone** (Jurassic). *These deposits are predominantly sandstone, with some interbedded clays. The thickness is from 200 to 1,000 feet.*

TRIASSIC–JURASSIC–PERMIAN

Spearfish Formation (Permo-Triassic), and **Sundance Formation** (Jurassic). *The bright red, sandy shale beds of the Spearfish Formation range from 250 to 700 feet thick, and contain some gypsum lenses. The Sundance Formation consists of 250 to 450 feet of glauconitic sandstones and greenish-gray shale.*

PALEOZOIC CARBONATE AQUIFER

PERMIAN

Minnekahta Limestone. *Consists of 40 feet of massive thinly laminated limestone.*

Opeche Formation. *This is a 90 foot thick red shale.*

PERMO–PENNSYLVANIAN

Minnelusa Formation. *Consists of three units: an upper red-to-white sandstone up to 200 feet thick, a middle dolomite, sandstone, and shale, with much anhydrite in subsurface, 200 to 300 feet thick, and lower sandstones and dolomites with basal red shale, 0 to 300 feet thick.*

MISSISSIPPIAN

Pahasapa (Madison) Limestone. *This massive cavernous limestone and dolomite is from 300 to 650 feet thick. (See Figure 1). Thins out 30 miles southeast of the southernmost outcrop (Gries and Mickelson, 1964).*

ORDOVICIAN–DEVONIAN–MISSISSIPPIAN

Englewood Formation. *Thinly bedded pink limestone from 30 to 40 feet thick.*

Whitewood Formation. *A buff limestone up to 60 feet thick in the northern Black Hills.*

CAMBRIAN–ORDOVICIAN

Winnipeg Formation. *Dense green shale up to 60 feet thick in the northern Black Hills.*

Deadwood Formation. *This formation is generally a massive sandstone with some green shale and flaggy limestone and conglomerate locally at the base. It ranges from 400 feet thick in the northern Black Hills to 10 feet thick in the southern Black Hills.*

PRECAMBRIAN

Granite and granite pegmatite dikes and stocks are found in the Harney Peak area. Metamorphic rocks of varying lithologies make up the bulk of the Precambrian core of the central Black Hills. The predominant rock types are slate, phyllite, schist, and quartzite.

10• Gaging site, numbers refer to Appendix. See appendix and text for complete description.

Source of data:
Base map – U. S. Geological Survey
Geology – Darton 1901 and 1909a

Compiled by Perry H. Rahn, South Dakota School of Mines and Technology – 1972.

Drafted by D. Johnson

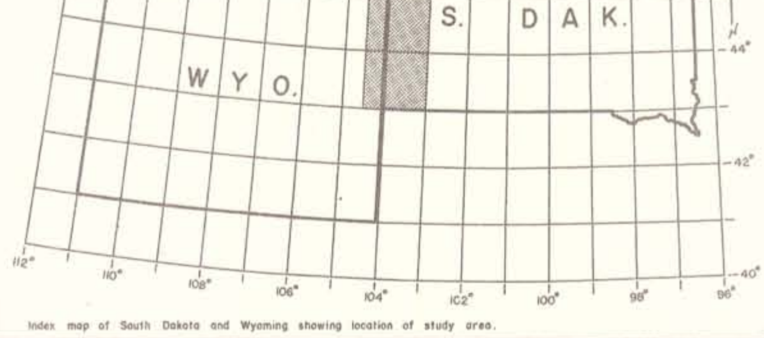
SCALE

0 5 10 15 20 miles

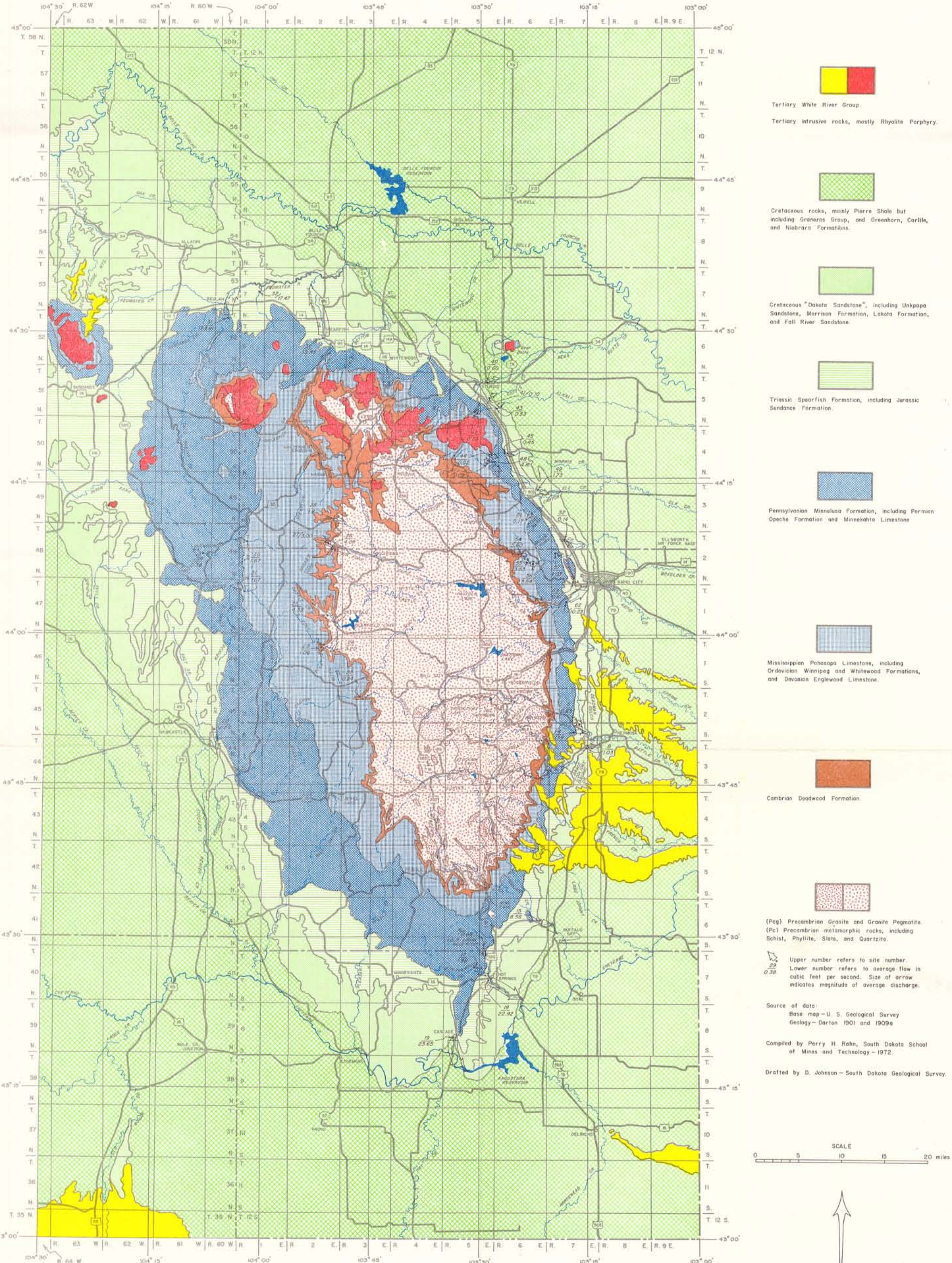
South Dakota Geological Survey

Report of Investigations No. 107

Plate 1. Generalized geologic map of the Black Hills, South Dakota and Wyoming, showing location of gaging sites.



Index map of South Dakota and Wyoming showing location of study area.



South Dakota Geological Survey

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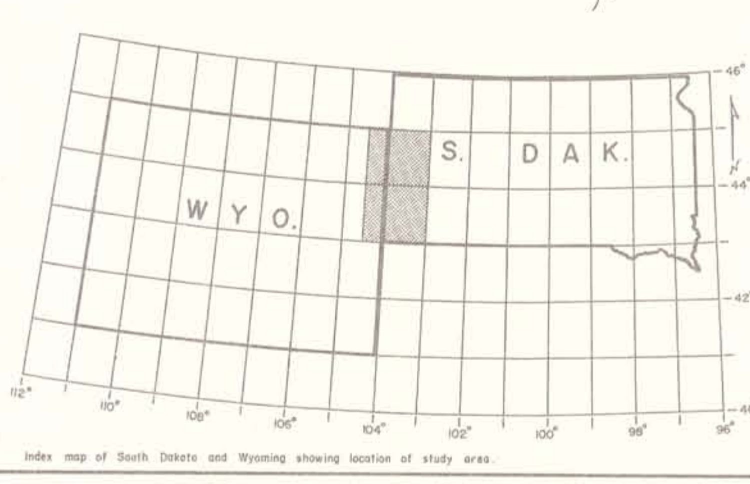
Plate 2. Large springs of the Black Hills, South Dakota and Wyoming.



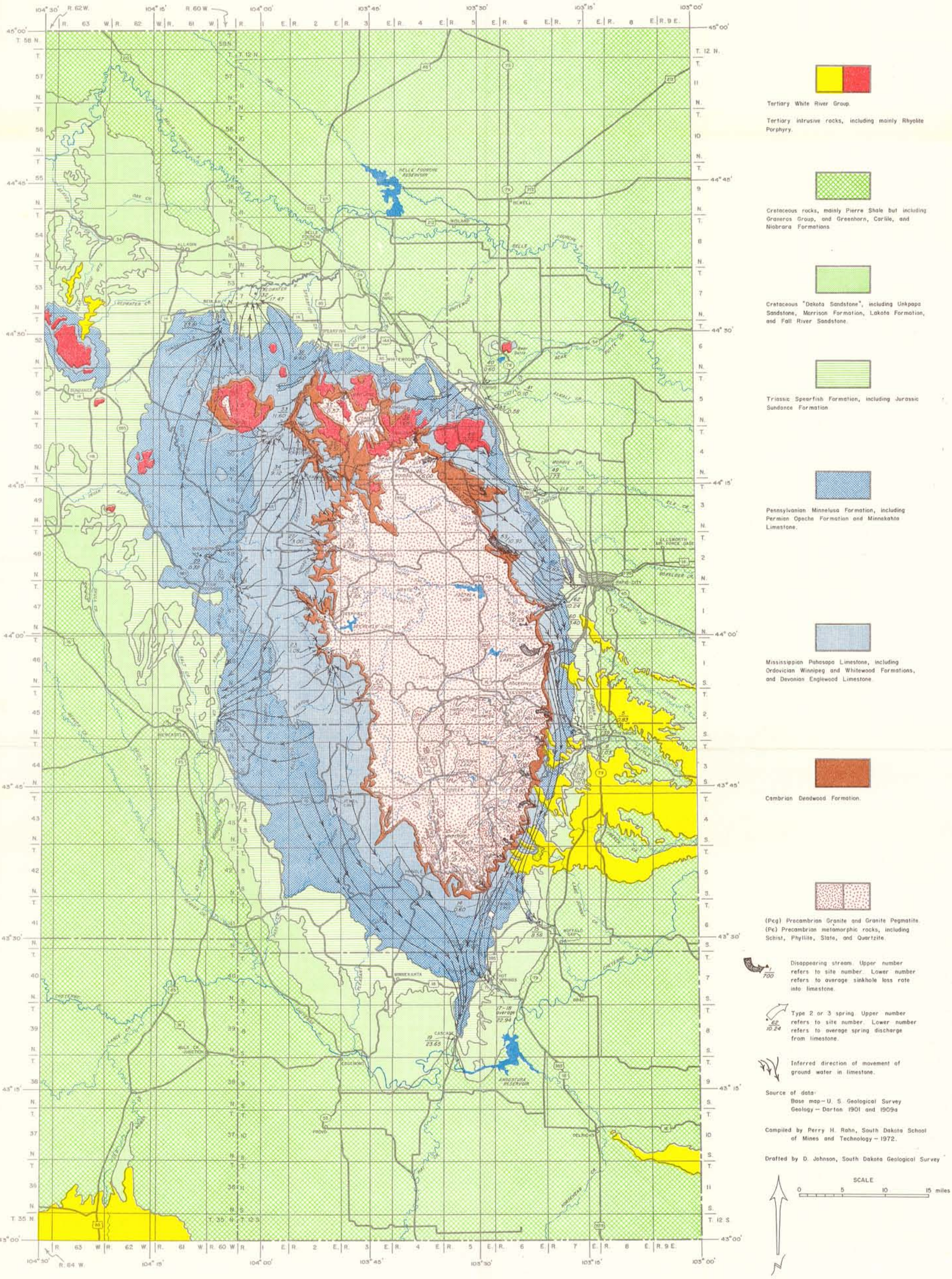


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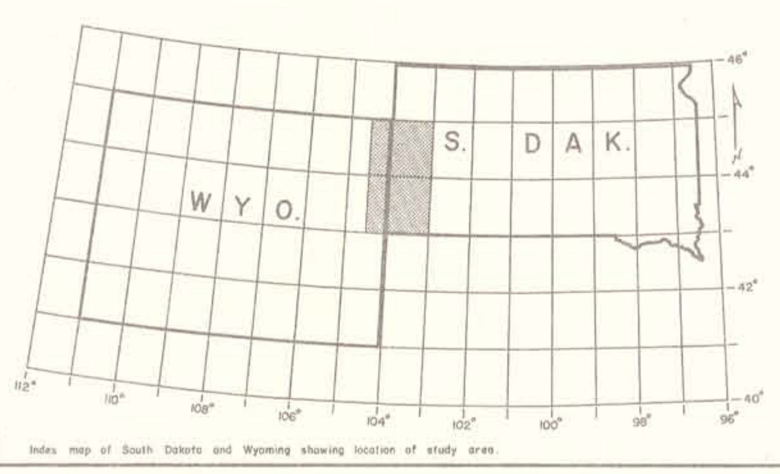
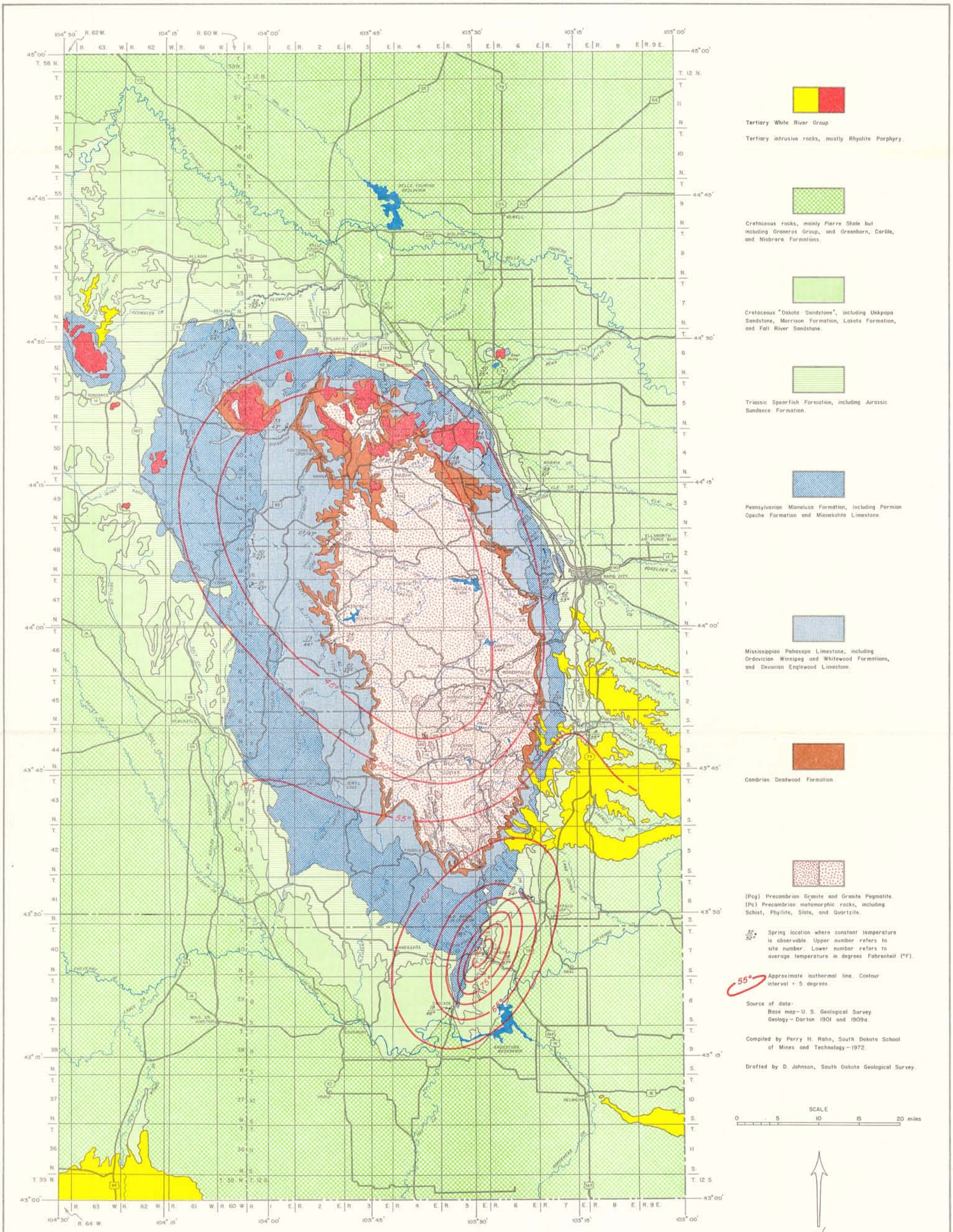
Plate 3. Hydrogeologic map of the carbonate aquifer, Black Hills, South Dakota and Wyoming.



Index map of South Dakota and Wyoming showing location of study area.



South Dakota Geological Survey

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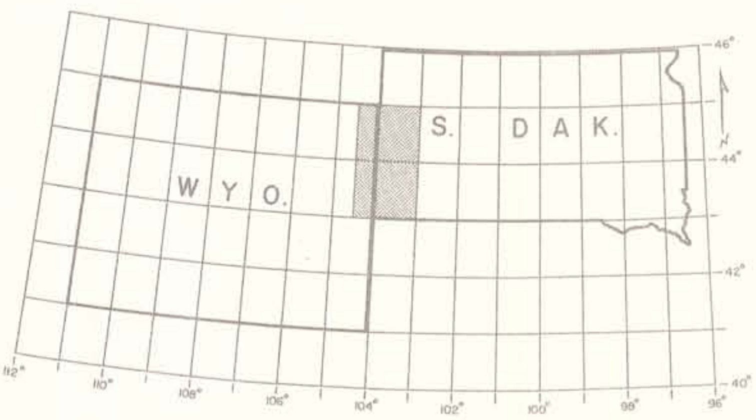
Plate 4. Temperature map of springs of the Black Hills, South Dakota and Wyoming.



Index map of South Dakota and Wyoming showing location of study area

About the South Dakota Geological Survey

The South Dakota Geological Survey is a research and public service agency for the State of South Dakota. Since 1893 the State Geologist has been authorized to "make an actual geological survey of the lands, the earth, and the area beneath the surface of the lands . . . . " of the State. The purpose of the State Geological Survey is to conduct field and laboratory studies of South Dakota's geology and mineral deposits, which are the metals and non-metals, the mineral fuels including oil and gas, and ground water. The results of these studies are published in reports such as this.

The work of the South Dakota Geological Survey is continuous – its research and services are adjusted to the changing economy in order to serve South Dakota most effectively.

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