SOUTH DAKOTA

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 26

ARTESIAN CONDITIONS IN WEST CENTRAL SOUTH DAKOTA

GEOLOGY
E. P. Rothrock

HYDROLOGY
T. W. Robinson, Jr.

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GEOLOGY

E. P. Rothrock

Foreword

As part of a plan for furnishing a permanent and reliable water supply for parts of South Dakota west of the Missouri River, where water supplies have been a problem during the recent drouth, the Legislature of 1934 appropriated the sum of fifteen hundred dollars, for investigating the artesian possibilities of the region. This sum was matched by the United States Geological Survey and the investigation carried out as a cooperative project by the State and Federal Geological Surveys.

The hydrologic work was done by Mr. Thomas W. Robinson, Jr., Assistant Engineer of the United States Geological Survey, and his conclusions are contained in this report. The data on the depth and number of artesian sands was obtained by the State Geologist from well records selected from the files of the Survey.

The funds allotted were sufficient to determine the hydrostatic head, and the sea level elevation of the artesian sand. This data together with the sea level elevations at the surface in areas where wells are needed, will be sufficient to show whether flowing wells can be obtained. It will also show how far water must be pumped to raise it to the surface in those areas where wells will not flow. Though much useful detail had to be omitted, the survey has been sufficiently inclusive to furnish the information requested by the State Legislature.

The cooperation of Dr. O. E. Meinzer, Chief of the Ground Water Division of the United States Geological Survey, is especially appreciated. His interest in the State's problem and the fund of information which he made available from his wide experience with ground water problems made the present report possible. The careful and thorough field work of Mr. Thomas W. Robinson, Jr. is hereby recognized. His analysis of the hydrologic problems was done with a detail and accuracy far greater than was thought possible at the beginning of the undertaking. Recognition should also be made of the contribution of the members of the Twenty-third Session of the State Legislature, whose foresight made possible this beginning in the attack on one of the State's most serious problems, namely, the conservation of its water supplies.

Previous Work

In the early days of artesian exploitation in South Dakota, Dr. N. H. Darton published a series of extensive reports dealing with the location of artesian flows from the upper aquifers in

South Dakota and the surrounding states.[1] No work has been done on artesian water in western South Dakota since his last report in 1918. This report presents only detail which has been added to his classic work by the drilling of recent wells.

The Cause of Artesian Flow

Artesian waters flow because the reservoirs from which they come hold water under pressure. It is relieved wherever a well is drilled into the reservoir. The force is somewhat similar to that which is obtained in city water supplies. The water in the city pipes is under pressure held by the column of water in the stand-pipe. When a faucet is opened or a hose is turned on, water squirts upward to a height which is controlled by the height of the water tower and the friction of the pipes through which the water flows.

Though this simple comparison does not account for all the details of artesian flow, it will suffice to illustrate the generally accepted principle upon which such flow is based. The water pipe of the artesian supply consists of sheets of porous sandstone, separated and overlain by thick beds of impervious shale through which water cannot flow. These great sheets of porous sandstone separated by hundreds of feet of impervious shale and clay underlie most of the state. The beds have been elevated to the westward so that their western edges come to the surface about the Black Hills and in the foothills of the Rocky Mountains, some three thousand feet above their position along the Missouri River. The uplifted sandstones form the "stand-pipe" from which the artesian water is to flow.

Water finds its way into these sandstones at their outcrops, and has worked through the pores of the rock until the entire aquifer has become filled and a pressure is developed at the lower end, so that water rises to the surface when a well or other opening is made into it in the lower lands.

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1. Geology and water resources of the southern half of the Black Hills and adjoining regions of South Dakota, U. S. Geol. Survey 21st Ann. Rept., pp. 489-599, 1901.

   Preliminary Report on the geology and underground water resources of the Central Great Plains, U. S. Geol. Survey Prof. Paper 32, 1905.

   Geology and water resources of the northern Black Hills and adjoining regions in South Dakota and Wyoming, U. S. Geol. Survey Prof. Paper 65, 1909.

   Geology and underground waters of South Dakota, U. S. Geol. Survey Water Supply Paper 227, 1909.

   Artesian waters in the vicinity of the Black Hills, U. S. Geol. Survey Water Supply Paper 428, 1918.

The weight of the overlying rocks tends to compress the artesian formation when the pressure of the water in the formation is relieved by wells. Although the resulting compression must be slight, it is apparently sufficient to squeeze out through the wells a considerable volume of artesian water that would otherwise remain in dead storage. To the extent that such compression has occurred, and to the extent that the formation has been drained by lowering of the water table near the outcrops, the water that has been discharged through the artesian wells is derived by depletion of the supply in storage rather than from perennial recharge with surface water at the outcrops.

Variations in atmospheric pressure produce small fluctuations in the water levels in the artesian wells that do not overflow and comparable fluctuations in the pressure and discharge of the flowing wells. These fluctuations are too slight to be ordinarily noticeable but in wells in which the water rises just about to the surface they may cause the well to stop flowing during fair weather and to begin to overflow on the approach of rainy weather. The spouting of artesian wells sometimes observed during the passage of a tornado is due to the great and sudden decrease in the atmospheric pressure at such times.

In the geological section of this report an attempt will be made to set forth the meager data on the character of these artesian sandstones, the number of them that may be productive, and the depth at which they lie in different parts of the area.

THE RAPID CANYON SECTION

The best place to see these aquifers is in the canyon of Rapid Creek at the east side of the Black Hills. The succession of rock strata which may be seen here underlies the Great Plains having been raised to the surface by the uplift of the Black Hills. The artesian sandstones and other rocks of the succession have been exposed by the erosion of Rapid Creek as follows.

Formation	Thickness in feet	Remarks
Dakota sandstone (Fall River)	119	Sandstone; an important aquifer
Fuson formation	125	Shale and fire clay
Lakota sandstone	112	Sandstones separated by clays; an important aquifer
Morrison formation	0-121	Clay and shale; some fine sandstone; reported an acquifer.
Unkpapa sandstone	218	Fine grained sandstone, separated by clays; not sufficiently continuous to be an aquifer.
Sundance formation	307	Sandstone and shale; an aquifer
Spearfish formation	320	Red sandy shale and shaly sand.
Minnekahta limestone	36	Dense limestone
Opeche formation	124	Red beds like Spearfish formation
Minnelusa sandstone	554	Upper 300 feet massive sandstone: a good aquifer.
Pahasapa limestone	204	Cavernous limestone: an aquifer in places.
Englewood limestone	60	Limestone; not cavernous.
Deadwood formation	319	Two heavy sandstones separated by shale; a good acquifer.

Seven of these formations have been identified as the horizons which furnish artesian water in South Dakota. The Dakota sandstone is perhaps the most widely productive and best known. The Lakota sandstone has also furnished large supplies. Water was reported from a sandstone in the Hunter well which was identified as Morrison. A large flow was encountered near Pierre in a sandstone corresponding to the Sundance formation in stratigraphic position. The Minnelusa sandstone is an excellent water bearer where it has been penetrated but portions of it are too fine grained and calcareous to be productive. The Pahasapa limestone furnished an artesian flow fifty miles east of Rapid City. The Deadwood formation furnishes an artesian flow at Rapid City and at Edgemont south of the Black Hills. The other sandstone formations appear to be either too discontinuous or to be too "tight" to permit easy flow of water and therefore have not been recognized as artesian aquifers.

A detailed description of the formations as they occur in and near Rapid Canyon will serve to give a clearer picture of the nature of these aquifers and their associated formations, which can be used for comparison with the well logs which follow.

Formations Overlying the Dakota Sandstone

East of the water gap at Rapid City a series of formations are exposed which are of interest here because they overlie the artesian aquifers and will have to be penetrated in any wells which reach the artesian sands in west-central South Dakota. They are all part of the Upper Cretaceous system. The uppermost of these is the Pierre shale which makes the bed rock over the entire area. It is approximately 1200 feet thick and is composed of dark shales which are characteristically sticky and make the gumbo clays which are prevalent over much of the surface of the area. Most drillers log this formation simply as black shale.

Beneath the Pierre lies the Niobrara chalk, a formation composed of chalk rock with some shale. On the outcrops along the Missouri and about the Black Hills its color and composition are very distinctive but the drillers note it only as shale. Cuttings from wells show it to be a grey shaly material with white specks through it and very calcareous. For this reason it is not easy to identify from most drill records. Its thickness on the outcrops is about 200 feet.

Beneath the Niobrara lies the Carlile shale, a black sticky shale much like the Pierre in appearance. Concretionary layers are encountered in it which usually are reported as limestones. Its thickness is about 700 feet.

The Carlile formation rests on the Greenhorn limestone, a formation of shelly limestone and shale. It makes prominent escarpments in its outcrops east of Rapid City but is usually unrecorded or noted only as a thin zone of "shells" in most well records. It is 60 feet thick in its outcrops.

The Graneros formation directly overlies the first aquifer, the Dakota sandstone and is mostly an impervious black shale. It outcrops along the eastern side of the hogback through which Rapid Creek has cut a water gap at Rapid City. It is a persistent formation, outcropping as far east as the Big Sioux valley at the extreme eastern boundary of the state. It forms an impervious cover for the Dakota sandstone over most of the state, effectively confining water in the sandstone and thus causing the development of artesian pressures.

Dakota Sandstone

(Cretaceous)

The Dakota or Fall River sandstone[1] as it has been called is the first recognized artesian horizon and is overlain by some thirty-three hundred feet of Cretaceous shales and limestones according to the figures given by Dr. N. H. Darton.[2] These overlying formations which have been described above are so largely impervious that they maintain the pressure of the water in the Dakota sandstone in the country east of the Black Hills.

The sandstone itself is composed of a shelly upper part of thin sandstone beds separated by dark shale partings, below which lies a massive sandstone of variable thickness. The section measured in roadcuts and in the water gap at Rapid City revealed the following:

Section of Dakota sandstone at Rapid Water Gap at west side of Rapid City, S. Dak.

Upper part measured on south side of gap east side of hogback below Hangman Hill; massive sandstone measured at cliff on north side of gap.

Feet	
3	Massive blocks of Dakota sandstone
7	Sandstone, fine grained, white, soft
20	Top 2 ft. shelly limonitic sandstone. Beds 1/8--1/4 inch thick. Ledge maker. Lower 18 ft. sandstone, buff, shelly and shale.

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1. Ruby, W. W., Lithologic studies of sedimentary rocks of the Black Hills Region, U. S. Geol. Survey Prof. Paper 165, p. 5.
2. Darton, N. H., Central Black Hills folio, U. S. Geol. Survey, Folio 219, Columnar Section.

9	Top makes a little ledge; sandstone, white shelly, fine grained; weathers buff with some limonitic spots.
1	Sandstone ledge maker; prominent beds 1 to 3 inches thick; color buff.
1	Sandstone, shelly, buff
15	Sandstone, shelly, light grey
14	Sandstone; bluish-black, weathers very light grey; fine grained; bedding indistinct.
10	Alternating brown shale and inch beds of buff sandstone; the sandstone weathers into limonitic chunks. Where washed clean down the dip, sand makes pavements of little rectangular blocks.
22	Brown sticky shale
20	Shale, light grey; weathers in little blocks
44½	Massive buff sandstone; makes cliffs and dip slope of hogback near Water Gap; cementation poor.
163½	Total thickness

Fuson Formation

(Lower Cretaceous)

The Fuson formation as exposed in the water gap at Rapid City is mostly a clay which on drying breaks into little blocks a somewhat characteristic feature. It separates the water-bearing Dakota and Lakota sandstone by 125 feet of impervious material.

Section of Fuson formation on the north bluff of the gap at Rapid City

Massive sandstone cliffs of Dakota formation

Feet	
100	Partly covered slope containing brown sticky and maroon clays, some mottled when fresh. Red iron concretions and iron veins are common in the joints.
25	Fire clay

Massive sandstone of Lakota formation

A more detailed section was exposed in a road cut on the south side, one-half mile south of the gap.

Section of Fuson formation in road cut one-half mile south of Hangman Hill near Rapid City.

Feet	
1	Block clay; light grey; some buff streaks on joints; blocks $\frac{1}{2}$ to $\frac{1}{4}$ inch.
$1\frac{1}{2}$	White sand, soft
$1\frac{1}{2}$	Block clay, grey and much like above
8	Buff sandstone; beds $1\frac{1}{2}$ to 3 feet
1	Grey-white sand like white sand above
$4\frac{1}{2}$	Maroon block clay soft; easily dug with pick; not brittle.
6	Dark clay; blue-black when wet; weathers with bluish cast; soft and not brittle; much like above except in color.
$\frac{1}{2}$	Buff, hard clay; looks like bed of limonite; conchoidal fracture having brownish surface.
2	Light grey brittle block clays, weathering reddish-brown; break into small blocks 1/8 to 1/4 inch on weathering.
$4\frac{1}{2}$	Light grey, brittle block clays; weathering with silver grey surface; blocks small like those above.
7	Massive block clays very brittle; makes cliff in road cut; clay is very light grey, but joints are all buff; contact between this and above is very sharp.
$37\frac{1}{2}$	Total thickness

Lakota Sandstone

(Lower Cretaceous)

The Lakota sandstone at the water gap at Rapid City consists of two cliff-making sandstones separated by forty feet of shale. Although this is one of the important aquifers massive sandstones are not conspicuous, the thickest measuring twenty-one feet. As in the case of the Dakota sandstone, shelly zones composed of thin sandstone layers separated by dark shale make a considerable portion of the formation.

Section of the Lakota sandstone on the north side of the water gap at Rapid City, South Dakota

Feet	
10	Covered slope; "float" indicates shelly sandstone
41	Upper cliff-maker, which forms the top of the hogback

21 ft. Massive, buff, cross-bedded sandstone.
20 ft. Shelly sandstone; ripple marks and cross bedding very conspicuous.

43 Slope largely covered, maroon shales outcropping here and there; and prominent outcrop in valley farther east show entire section to be shale.

1/3 Massive grey limestone. No fossils observed.

18 Lower cliff-maker.

13 ft. Massive sandstone much like upper cliff, except color is grey instead of buff.

5 ft. Shelly sandstone.

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112 1/3 Total thickness

Morrison Formation

(Lower Cretaceous?)

The Morrison formation outcrops in the water gap at Rapid City, but is not well exposed. It occupies 121 feet stratigraphically, between the lowermost Lakota sandstone cliff and the upper sandstone of the underlying Unkpapa. The upper twenty feet and the lower thirty feet show outcrops of gray green shale characteristic of the Morrison formation elsewhere in the Black Hills.

Though this formation furnished artesian water in the Hunter well near Wall it is not probable that it will serve as an important artesian reservoir. Its shale is impervious and but little sandstone is included. Moreover, it is not a continuous sheet; only a short distance north of the gap it is entirely missing while to the south it disappears and reappears again in small patches. From this it appears probable that it may not be continuous under the plains to the east.

Unkpapa Sandstone

(Jurassic)

This formation is characterized by its very soft, medium to fine-grained, white or brightly colored sandstone. In the outcrop at Rapid Gap it is very white, so white in fact that it appears like drifts of snow among the dark evergreen trees on the west side of the hogback.

The outcrop at the gap at Rapid City shows two thick sandstones separated by ninety feet of shale. These sandstones should make excellent aquifers, but apparently the formation is not sufficiently continuous to develop an artesian head. A short distance north of the gap, the upper sandstone cuts out the Morrison formation completely, while at other places the Unkpapa itself is extremely thin. In the gap, however, the following strata are exposed.

Section of Unkpapa sandstone in north wall of water gap at Rapid City, South Dakota

Feet	
47	White, soft sandstone; sufficiently indurated to make a cliff.
62	Covered; "float" indicates shale.
27	Shale, blocky, varicolored; maroon and grey-green bands predominate; weathering shows purple, orange and pink colors also.
82	White sandstone, very soft; lower part weathers white; upper part weathers into light buff and yellow. The characteristic color of the outcrop is very light and the striking colors and lack of induration differentiate it readily from other sandstones. The rock in the lower part of this interval is very calcareous.
218	Total thickness

Sundance Formation

(Jurassic)

The Sundance formation does not outcrop well at Rapid Gap, as it makes the lower grass covered slopes of the hogback. Seven miles south of Rapid City, however, there is an excellent exposure on the east side of Highway 40. At this place the same divisions which persist throughout the Black Hills north of Rapid City are found so that this section is fairly representative.

There are six divisions of the formation, which differ considerably in thickness from place to place. South of Rapid City we find the following members:

Feet	
40	Upper sandstone member
113	Upper shale member
43	Sandy, belemnite member
98	Red and white sandstone member
14	Lower shale member
2	Basal sandstone member

Details of the section are as follows:

Section of Sundance formation seven miles south of Rapid City, S. Dak. on east side of Highway 40.

Feet	
40	Upper sandstone member; color on outcrop, yellow.
	15 ft. Sandstone, soft, thinbedded, yellow
	6 ft. Limestone
	5 ft. Sandstone, cliff maker, yellow, massive
	6 ft. Sandstone, like above but shelly
	2 ft. Limestone
	4 ft. Sandy limestone, shelly
113	Covered slope; probably shale
43	Soft sand, light buff, very fine grained, carrying abundant belemnites.
12	Sandstone
	6 ft. Massive sandstone, white; makes small cliff.
	6 ft. Sandstone, shelly
64	Sand, fine, red.
22	Sandstone; ripple marked, cliff maker, grey to buff.
14	Grey shale
2	Sandstone
310	Total thickness

Spearfish Formation

(Triassic)

The Spearfish formation does not outcrop in Rapid Canyon so that it can be measured but forms the floor of the Red Valley just west of the Dakota hogback. The best information on its thickness was found just east of Stage Barn Canyon, 11 miles north of Rapid City, where 320 feet were measured. The formation is composed of red sandy shales and fine grained red sandstones with scattered beds and stringers of gypsum.

Red beds of this character have been found in deep borings nearly as far east as the Missouri River, but apparently do not give artesian flows. Whether this is due to the fineness of grain or lack of continuity of the coarser beds is not known. It is certain that some of the sands are very "tight" because of clay which occupies space between the grains.

Minnekahta Limestone

(Permian?)

The Minnekahta is a thin limestone which separates the two red bed formations (Spearfish and Opeche) in the Black Hills. It outcrops along Rapid Creek on the west side of the Red Valley opposite Rapid City and is the first formation outcropping in Rapid Canyon proper. The limestone has a remarkably uniform thickness about the north end of the Black Hills. In Rapid Canyon it measured 36 feet.

This limestone is not an aquifer. It is dense, and while it breaks in slabby pieces there are few caverns or solution cracks along which water can flow.

Opeche Formation

(Permian?)

Lying beneath the Minnekahta limestone in Rapid Canyon is the Opeche formation, a series of red beds which appear much like the Spearfish, except that the color, especially at the top, is more nearly maroon, while the Spearfish is in most places a brick red. Gypsum beds are absent in the outcrops of the Opeche formation in Rapid Canyon.

Section of Opeche formation on north wall of Rapid Canyon opposite the state fish hatchery.

Feet

8 Upper contact

1 ft. 6 in.	Shelly Minnekahta limestone
6 in.	Sandy shale, purplish-red, calcareous, banded
2 in.	Limestone, grey, sandy, dense.
7 in.	Sandy shale, like above; calcareous, smooth surface, much very fine sand.
3 in.	Limestone, dense, grey
4 ft.	Sandy shale or shaly sandstone. Very sandy and very fine grained. Brick red. Top 6 in. finer laminations. Some thin limestone beds and lenses (1/8 inch).
10 in.	Limestone, dense, bluish-grey weathering to buff. Some sand very fine.
6 in.	Shale, light green, very calcareous.

106 Red beds of Opeche. Most of it in covered slope.
10 Lower contact; sandstone, massive, brick red, uniformly fine to medium grained; resembles underlying Minnelusa sandstone but can be separated by sharp change in color; becomes shelly on longer weathering and crumbles into slope while Minnelusa holds its cliff.

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124 Total thickness

Minnelusa Formation

(Pennsylvanian)

The Minnelusa formation is of considerable interest as an artesian aquifer because the top half is a very thick, massive, medium to coarse grained sandstone. In Rapid Canyon this sandstone was 319 feet thick. Beneath the massive sandstone lies a zone of sandstones with shale partings. This zone is 138 feet thick in Rapid Canyon and under it lies 111 feet made up largely of limestones separated by thin shales. The base of the formation is marked by 23 feet of red shale which seems fairly persistent in the outcrops about the Black Hills.

No single outcrop exposes the entire formation in Rapid Canyon, but by piecing together the information obtained from several outcrops the following section was obtained.

Section Minnelusa sandstone in Rapid Canyon

Feet

102 Buff sandstone; appears massive in places, but in others it is soft and thin bedded; 3 to 6 inch bedding prominent. Supposed to correlate with the Tensleep sandstone in Wyoming.
4 Limestone, dense, grey
124 Red calcareous member; outcrop shows strata with contorted appearance in some parts and well bedded in others.
3 Limestone
3 Sandstone
3 Limestone
80 Massive, cliff making sandstone; this is the bottom member of the upper sandstone.
60 Alternating limestones and sandstones; most sections show four limestones from one to twenty-three feet thick.
78 White sandstone zone

33 ft. Massive white and buff sandstone
24 ft. Alternating limestones, sandstones and shales.
21 ft. Massive white sandstone.
Note: Both sandstones are prominent cliff makers.

121	Limestone zone; upper part contains alternating limestones, sandstones and shales; lower part nearly all limestone.
23	Covered interval with red shales showing at the base. More than 15 ft. of this shale is exposed.
601	Total thickness

Pahasapa Limestone

(Mississippian)

This formation is a massive limestone which forms prominent cliffs in that part of Rapid Canyon known as Dark Canyon. The limestone is fine grained, massive, light grey to dove colored. It is very cavernous and takes a large percentage of the water of many of the streams which flow across it. In Rapid Canyon 300 feet are exposed according to Darton.[1] It cannot be proved that the caverns are continuous, but it is of interest to note that the artesian water in a well fifty miles east of Rapid City came from limestone apparently of this formation.

Englewood Limestone

(Mississippian)

The Englewood limestone is not over 61 feet thick in Rapid Canyon. It is not of interest as an aquifer as it is not cavernous, but it might be possible to identify it in well cuttings as its purplish color and abundant fossils are characteristic.

Section of Englewood limestone in upper end of Dark Canyon, Rapid Canyon, S. Dak.

Feet	
10	Limestone, buff colored; in well defined beds about a foot thick; supports cliff above less resistant purple limestone. Not placed in Pahasapa because of change in bedding. Fossil stromatapora found here and below in purple limestone.
15	Massive appearing purplish limestone; weathers into round surfaces; tends to conceal itself below more resistant buff beds. Contains fossils.
26	Purplish limestone in massive one foot beds. Looks like overlying member except that it is more prominent on weathering and the bedding is more pronounced.

1. Darton, N. H., U. S. Geol. Survey Folio 219, p. 7

Feet	
10	Covered Top cliffs of sandstone of Deadwood formation.
61	Total thickness

Deadwood Formation

(Cambrian)

This formation is of interest because it is the lowest of the unmetamorphosed sedimentary strata and since it does furnish excellent artesian water south of the Black Hills. The formation is largely sandstone, the top and bottom being made of massive beds with some thin layers of conglomerate. Immediately below the upper sandstone lies a "flaggy" zone in which thin sandstones are separated by shale. The "flaggy" zone is separated from the lower massive sandstone by a zone of green shales which contain limestone beds. Thus, in Rapid Canyon, we have two sandstones in the formation which might act as aquifers.

Section of Deadwood Formation in Rapid Canyon on north wall seven miles above Rapid City, S. Dak.

Feet	
10	Upper Massive Sandstone Sandstone, red, medium grained; in beds from 1 to 3 feet thick. This is all there is to show for the upper massive sandstone here.
110	Slabby Sandstone Sandstone, red; grades from the 1 foot beds above into thin flaggy sandstones; this is the upper flaggy member.
136	Green shale member Mostly covered by grassy slope; conspicuous in all outcrops in this vicinity. Float and small exposures of red sandstone, green shale and some limestone conglomerate. Some float carries trilobite and brachiopod fragments.
72	Lower Massive sandstone Sandstone; red, medium to coarse grained. Some conglomerate near base and at top but no continuous zone. Massive, but much cross-bedded; makes prominent cliffs.
328	Total thickness

CORRELATION OF WELL RECORDS

It is not possible to follow the formations which have been described with certainty beneath the plains between the Black Hills and the Missouri River. Canyons and stream valleys expose only Pierre shale and younger rocks, so that the only sources of information are the records of deep wells. Only a few deep borings have been drilled in the area and these are widely scattered. The only record available for most of them is the drillers' log supplemented in some cases by the memory of persons who lived in the vicinity or who worked on the well. The problem is still further complicated by the fact that many of the wells were drilled with jetting tools and this method does not afford easy examination of the materials penetrated, especially when they are all as poorly consolidated as those through which wells in western South Dakota must pass. With such information as can be gathered from these wells, however, a correlation will be attempted.

The red beds of the Spearfish and Opeche formations are easily distinguished in such drillings as they redden the mud noticeably. The dense limestone of the Pahasapa is also easily recognized because it is difficult to drill. With these two formations as markers the correlation of the rest of a log can be made with a fair assurance of accuracy though it is impossible to recognize details of the stratigraphy. Red beds have been reported in all wells drilled deep enough to encounter them from Rapid City to Standing Butte, 20 miles northwest of Pierre, and from 8 miles south of Red Elm in Ziebach County as far south as the White River south of Kadoka.

Only two wells in the entire area have been drilled deep enough to encounter the Pahasapa limestone but as one of them was the Standing Butte well, and the other lay between it and Rapid City, it is a fairly safe assumption that this formation underlies most of the area under discussion.

Hunter, Zeal and Tanburg Wells

Three wells, drilled as oil tests carried a correlation from the Black Hills toward the northwest for nearly 100 miles with considerable accuracy. They are designated as the Hunter, Zeal and Tanburg wells. Two of these wells were drilled with cable tools, and cuttings from all three were carefully saved, and studied by the geological staffs of the companies which drilled them. The following logs are available through the courtesy of these oil companies. The well nearest Rapid City is known as the Hunter No. 1 and lies about 20 miles north of Wall and 50 miles directly east of Rapid City. It was drilled by the Gypsy Oil Company in 1931 giving the following record.

Log of the Hunter No. 1, of the Gypsy Oil Company, in S.W. ¼, sec. 28, T. 3 N., R. 16 E. in Pennington County, South Dakota

Feet	
0 - 1900	Shale, gray
1900 - 2120	Shale, gray, chalky
2120 - 2170	Chalk, gray to white
2170 - 2390	Shale, gray; sandy shale and thin fine sands
2390 - 2563	Shale, dark gray to black; chalky below 2470 ft.
2563 - 2575	Limestone, brown, soft
2575 - 2610	Shale, dark gray, limy
2610 - 2690	Shale, greenish-gray, silty
2690 - 2875	Shale, dark gray to black, chalky
2875 - 3024	Shale, greenish-gray to black; silty shale; sandy shale; thin fine sands
3024 - 3054	Sand, medium fineness, porous. Drill stem tester showed 1400 ft. of fresh water in one hour at 3041 ft.
3054 - 3077	Shale, greenish-gray
3077 - 3082	Sand, coarse
3082 - 3145	Shales, gray, drab, maroon; layers of sandy shale
3145 - 3154	Shale, dark gray, silty
3154 - 3178	Shale, dark gray, thin limestones, gray brown
3178 - 3313	Shale, gray, silty to sandy
3313 - 3323	Shale, dark gray; thin limestones, gray brown
3323 - 3325	Sand, pyrite cement
3325 - 3420	Sand, medium fineness, porous; layers of shale toward base; drill stem tester showed 2300 ft. fresh water in one hour at 3325 ft.
3420 - 3445	Shales and siltstones, green
3445 - 3460	Shales and clays, red, white, brown and green
3460 - 3488	Sand, coarse, porous; drill stem tester showed 3000 ft. fresh water in fifteen minutes at 3461 ft.
3488 - 3495	Shales, gray to green, sandy
3495 - 3530	Sand, fine, varicolored
3530 - 3767	Shales, siltstones and fine sands, green
3767 - 3836	Sand, fine, and sandy shale, pink to red
3836 - 3950	Shale, red, gypsiferous
3950 - 3980	Limestone, dense, pink to white
3980 - 4080	Shales, red; lower part silty to sandy
4080 - 4082	Anhydrite
4082 - 4121	Limestone, dense, white to pink
4121 - 4520	Interbedded anhydrite, red shale, green shale, sandy shale, thin sands and thin limes.
4520 - 4600	Limestone, brown; with thin fine sands and rare anhydrite. Drilled with cable tools below 4573 ft. Nine inch casing cemented at 4513 ft. One bailer of dilute water per hour at 4520 to 4580 ft.
4600 - 4660	Interbedded limy sand and sandy lime, brown

4660 - 4693	Shale, red brown, with thin white limestones
4693 - 4735	Limestone, dense, white to pink
4725 - 4734	Shales, red, green, yellow and purple
4734 - 4780	Limestone, white to brown
4780 - 4785	Shales, red, yellow and green
4785 - 4812	Limestone, bright red at top, light brown below
4812 - 4830	Shales and fine sands, interbedded with variegated clays
4830 - 4934	Limestone, dense to crystalline; white, cream, and light brown. Oolitic at base; fresh water rose 3850 ft. from porous zone at 4855 to 4872 ft.
4934 - 5001	Dolomite, finely crystalline, porous; fresh water rose 4000 ft. from porous zone at 4934 ft.
5001	Total depth

From a study of the cuttings of the Gypsy Oil Company geologists made the following correlation:

0 - 1900	Pierre
1900 - 2200	Niobrara
2200 - 2560	Carlile
2560 - 2590	Greenhorn
2590 - 3020	Graneros
3020 - 3120	Dakota
3120 - 3320	Fuson
3320 - 3425	Lakota
3425 - 3600	Morrison
3600 - 3700	Unkpapa
3700 - 3860	Sundance
	Uncorrelated hiatus
4490	"Top Pennsylvanian"
4490 - 4820	Minnelusa
4820 - 5001	Pahasapa

Thirty-eight miles north of the Hunter Well, the J. S. Cosden Company drilled an oil test in the bottom of Cherry Creek near the old Zeal Post Office. As this well was drilled with cable tools and the cuttings saved and examined by the company geologists, it gives an excellent correlation of the formations seventy miles away from the outcrop in the Black Hills, even though it does not penetrate the formations below the Lakota.

Log of the Zeal Well in the SE¼, NW¼,
section 16, T. 9 N., R. 17 W.,
Meade Co., South Dakota

Feet

1 - 50	Brown shale
50 - 100	Dark shale
100 - 117	Light shale

117 - 145	Dark shale
145 - 864	Brown shale
864 - 1090	Blue shale
1090 - 1240	Gray shale
1240 - 1290	Light gray shale
1290 - 1445	Gray shale
1445 - 1985	Brown shale
1985 - 2047	Brown shale with a little sand
2047 - 2060	Lime shell
2060 - 2075	Black shale
2075 - 2077	Lime shell
2077 - 2310	Dark gray shale
2310 - 2313	Lime shell
2313 - 2544	Dark gray shale and at bottom some sand. At 2544 ft. struck water sand, possibly was in sand a couple of feet.
2544 - 2551	Water sand and water raised within 300 ft. of top.
2551 - 2565	Sand and lime in formation, mixture formation
2565 - 2570	Gray shale at 2566 ft., cemented casing to shut off water.
2570 - 2578	Gray shale; or near the Dakota sand
2578 - 2600	Gray sand
2600 - 2672	White sand, Dakota sand and artesian water flow, tasted salty and warm water
2672 - 2681	Blue shale
2681 - 2752	Blue shale
2752 - 2820	Black shale and just going into a sand, the Dakota
2820 - 2822	Sand, and very hard; very large flow of artesian water, very warm
2822 - 2925	Sand, total thickness of sand 105 ft. Called the Lakota; large flow of water
2925 - 2970	Gray shale and the formation at bottom was sandy.
2970	Total depth

The following correlation of this well was determined by Mrs. E. R. Applin and published in the Journal of Paleontology.[1]

Correlation of Zeal Well

0 - 440	No record
440 - 1198	Pierre
1198 - 1720	Niobrara
1720 - 2015	Carlile
2015 - 2331	Greenhorn
2331 - 2544	Graneros
2544 - 2672	Dakota
2672 - 2820	Fuson
2820 - 2970	Lakota

1. Applin, E. R., Journal of Paleontology, Vol. VII, No. 2, pp. 215-220, 1933.

The same company drilled a second well twenty-five miles northeast of the Zeal Well and about ten miles south of Red Elm in Ziebach County. This well penetrated red beds well beneath the Lakota formation, and so gives a longer section than the Zeal Well. Unfortunately it was drilled with a jetting machine, which does not allow as clear cut a set of samples as does the cable tool rig. Samples were saved, however, and identified by the company geologists, who were able to obtain a satisfactory correlation from them.[1]

Log of Ole Tanberg No. 1 (Red Elm) in the N.W.¼, section 9, T. 11 N., R. 19 E., in Ziebach County, South Dakota

Feet	
0 - 45	Surface clay (yellowish sand)
45 - 155	Shale
155 - 275	Shale and boulders
275 - 409	Shale
409 - 432	Gumbo and boulders
432 - 857	Hard shale and boulders
857 - 861	Rock
861 - 1131	Hard shale and boulders
1131 - 1171	Lime rock and gumbo
1171 - 1186	Hard shale and boulders
1186 - 1308	Lime and shale
1308 - 1340	Shale and boulders
1340 - 1460	Sticky shale
1460 - 1490	Gumbo
1490 - 1640	Shale and shell
1640 - 1660	Shale and boulders
1660 - 1730	Hard shale
1730 - 1754	Limestone and shale
1754 - 1770	Lime
1770 - 1785	Shale and lime
1785 - 1805	Hard lime
1805 - 1819	Sandy lime
1819 - 1870	Lime and shale
1870 - 1895	Shale and boulders
1895 - 1927	Gumbo
1927 - 1933	Gypsum
1933 - 1945	Lime
1945 - 1961	Gumbo
1961 - 2000	Sticky shale
2000 - 2040	Shale and boulders
2040 - 2114	Gumbo
2114 - 2164	Sticky shale
2164 - 2174	Shale and boulders
2174 - 2265	Lime
2265 - 2281	Lime and shale

1. Applin, op. cit., pp. 215-220

2281 - 2339	Lime
2339 - 2356	Lime and shale
2356 - 2388	Sticky shale
2388 - 2400	Gumbo and boulders
2400 - 2459	Shale and gumbo
2459 - 2465	Gumbo
2465 - 2570	Shale
2570 - 2571	Lime
2571 - 2615	Shale
2615 - 2619	Lime
2619 - 2635	Shale
2635 - 2658	Shale and boulders
2658 - 2668	Broken lime and shale
2668 - 2673	Limy shale
2673 - 2683	Sticky shale
2683 - 2697	Limy shale
2697 - 2713	Lime
2713 - 2715	Limy shale
2715 - 2724	Lime
2724 - 2733	Shale
2733 - 2738	Lime and shale
2738 - 2740	Shale
2740 - 2747	Sand
2747 - 2767	Sandy shale
2767 - 2771	Hard shale
2771 - 2787	Sandy shale and lime
2787 - 2789	Lime
2789 - 2795	Shale
2795 - 2810	Gypsum and gumbo
2810 - 2882	Sticky shale
2882 - 2887	Lime and gypsum
2887 - 2930	Shale
2930 - 2943	Shale and shells
2943 - 2961	Shale and gypsum
2961 - 2964	Rock
2964 - 2967	Lime rock
2967 - 2976	Hard shale and sand
2976 - 2986	Sandy lime and shale
2986 - 3000	Sand and shale
3000 - 3045	Hard sand
3045 - 3057	Sand and broken shale
3057 - 3100	Sandy shale
3100 - 3108	Hard shale
3108 - 3120	Sandy shale
3120 - 3161	Black shale
3161 - 3180	Black shale and sand
3180 - 3182	Rock
3182 - 3220	Sandy shale
3220 - 3231	Sandy shale
3231 - 3267	Sand and shale
3267 - 3287	Shale
3287 - 3348	Red bed

3348 - 3358	Red bed and shale
3358 - 3365	Limy shale
3365 - 3387	Shale and lime
3387 - 3389	Sandy lime
3389 - 3396	Broken sand
3396 - 3402	Broken sand and shale
3402 - 3405	Broken lime and shale
3405 - 3465	Red bed
3465 - 3503	Flinty red rocks
3503 - 3528	Red bed
3528 - 3536	Broken red bed
3536 - 3543	Broken red bed and rock
3543 - 3550	Broken red bed
3550 - 3556	Lime
3556 - 3575	Lime and red bed
3575 - 3584	Broken red rock and lime
3584 - 3587	Broken red bed
3587 - 3588	Hard sandy lime
3588 - 3593	Broken lime
3593 - 3600	Soft shale
3600 - 3604	Anhydrite and gypsum

The following correlation by Mrs. Applin has one notable feature in that the Dakota is very thin and furnishes no water.

Correlation of Ole Tanberg No. 1 (Red Elm)

Feet	
0 - 40	No record
40 - 280	Fox Hills
280 - 1640	Pierre
1640 - 1840	Niobrara
1840 - 2177	Carlile
2177 - 2380	Greenhorn
2380 - 2745	Graneros
2745 - 2765	Dakota (no water)
2765 - 2971	Fuson
2971 - 3039	Lakota
3039 - 3220	Morrison
3220 - 3505	Sundance (red calcareous at 3430 ft.; 3483-3485 ft. pink limestone)
3505 - 3581	Spearfish; non-calcareous red beds.

Standing Butte Well

Another well west of the Missouri from which a fairly accurate drillers' log is available has penetrated the formations below the Dakota-Lakota zone. It was drilled in Stanley County 25 miles northwest of Pierre and about 60 miles southeast of the Tanberg Well at Red Elm. It is usually known as the Standing Butte Well because of the butte which lies a short distance east of it. The well was drilled by a local company who engaged several different drillers before it was completed. Only the drillers' logs are at present available but they throw considerable light on the character of the formations penetrated since it was required that they should be kept in considerable detail.

Log of Standing Butte Well in section 9, T. 7 N., R. 27 E., in Stanley county, South Dakota

Feet	
1 - 927	Pierre Shale
927 - 933	Gray shale rock
933 - 963	Gray sandy shale carrying dry gas
963 - 1400	Shale
1400 - 1450	Sand and water
1450 - 1735	Shale
1735 - 1905	Dakota sandstone carrying water, with gas and oil showing.
1905 - 1940	Fuson shale
1940 - 1976	Lakota stone
1976 - 2190	Morrison shale
2190 - 2270	Base of the Morrison or Upper Sundance
2270 - 2279	Lime rock, penetrating lower sandstone
2279 - 2290	Water sand
2290 - 2292	Lime rock
2292 - 2294	Pyrites iron shell
2294 - 2307	Loose white sand
2307 - 2325	Gray shale
2325 - 2350	Water sand, with great water flow
2350 - 2356	Coal
2356 - 2382	Sandstone
2382 - 2385	White sand
2385 - 2392	Sandstone
2392 - 2402	Fuller's earth
2402 - 2405	Sandstone
2405 - 2412	Clay
2412 - 2559	Red beds carrying streaks of gypsum and sand
2559 - 2560	Oil sand carrying large quantity of oil
2560 - 2564	Red beds
2564 - 2570	Tar sands carrying oil
2570 - 2615	Red beds
2615 - 2620	Sand showing tar

2620 - 2625	Black sand
2625 - 2657	Hard sand rock, showing gas and tar
2657 - 2659	Black flakey shale
2659 - 2660	Gypsum
2660 - 2665	Broken formation of sand and shale, more gas
2665 - 2670	Broken formation, some gypsum
2670 - 2680	Sand rock
2680 - 2685	Broken formation
2685 - 2727	Tough gray shale
2727 - 2730	Pink formation showing lime
2730 - 2755	Pink rock
2755 - 2764	Limestone shells, conglomerate between
2764 - 2771	Pink sticky formation
2771 - 2781	Conglomerate
2781 - 2787	Gray shale
2787 - 2798	Conglomerate
2798 - 2830	Conglomerate, gas showing
2830 - 2840	Broken formation, gypsum and lime
2840 - 2848	Lime and gypsum
2848 - 2873	Red shale
2873 - 2877	Black shale
2877 - 2880	Red shale
2880 - 2910	Lime, gypsum, black shale
2910 - 2920	Tough yellow clay
2920 - 2930	Red shale
2930 - 2935	Hard sandstone, shell
2935 - 2940	Sand, small flow of water
2940 - 2967	Sand, very sharp
2967 - 2990	Light sandy shale
2990 - 3010	Gray sandy shale
3010 - 3027	Sandy, heavy water flow
3027 - 3090	White lime, medium hard
3090 - 3160	Lime, very hard
3160 - 3170	Lime, medium hard
3170 - 3508	Lime with hard, medium and soft layers.

Correlation of this log with those that have been described above cannot be done with as much confidence as would be desirable. The drillers' descriptions, however, indicate certain formations which could hardly be confused with anything else. The thick limestone in the bottom 470 feet of the well, for instance; (3027 to 3508) can be assigned to the Pahasapa formation since it is the only one in this position with this thickness in this part of the great plains.

The 160 feet of red beds carrying streaks of gypsum lying between 2412 - 2615 feet seems to indicate the Spearfish-Opeche group of the Black Hills. The fact that no hard limestone corresponding to the Minnekahta was recorded in this interval might be interpreted as indicating either that the two red bed formations of the Black Hills had merged into one formation by the pinching out of the limestone, or that either the Triassic-Spearfish or the Permian-Opeche formation had disappeared. From the information at hand there is no way of identifing these formations more accurately. In either case the red bed group has become much thinner than in their outcrops in the Black Hills.

Between the red beds and the limestone at the bottom of the hole, lies 411 feet of alternate sand and shale with some limestones. This seems to correspond in position and general character with the Minnelusa formation as it appears in the Black Hills and in the ~~Hunter well.~~ It is noteworthy that the thick massive sandstone which made the top member of this formation in Rapid Canyon is represented by only 40 feet of sand in the Standing Butte well. The base of the Minnelusa is placed at the top of a white, hard, limestone, leaving the alternations of sand, shale, and limestone found in the outcrop, represented by a zone of thin sands and sandy shales.

It is 70 miles from the Hunter well to the Standing Butte well and while this is a long distance over which to correlate on lithological evidence alone, the persistence of the formation in the west and the lack of conflicting data to the east, seems to warrant placing these two intervals in the same formation. The gypsum reported at the depth of 2665 feet to 2670 at Standing Butte may correspond to the gypsum zone noted in the upper part of the Minnelusa in the Hunter Well.

The sediments lying above the red beds are not so easily separated and the correlation has to depend upon the position of the various sands and other hard members and on small details in the shales which separate them. The 36 feet of grey shale and grey sandy shale with dry gas, lying between 933 and 963 feet, correspond to the position in which the Niobrara formation should lie and corresponds fairly well with the position in which lime is reported from some of the water wells not very far away.

Below this horizon lies 437 feet of shale underlain in turn by 50 feet of sandstone which carries water. In other wells in this vicinity lime shells and some water are reported at this horizon and this seems to indicate the Greenhorn formation. Without cuttings from any of these wells, these suggestions are open to some question. It is certain, however, that the Greenhorn underlies this part of South Dakota since it occurs with undiminished thickness in the Black Hills and the Big Sioux Valley. It seldom is reported in wells except as limy shells or hard sandy streaks.

The Dakota-Lakota zone seems to be indicated by the sands lying between 1735 and 1980 feet. This sand zone is separated into two parts, the upper one a 170 foot sandstone and the lower one a 36 foot sandstone. Between the two lies 35 feet of shale. Water and gas were encountered in the upper sandstone but no mention was made of either in the lower.

Between the Dakota-Lakota zone and the top of the red beds lies 346 feet of sediments which should correspond to the Jurassic formations in the Black Hills outcrops namely the Morrison and underlying Sundance. This interval corresponds closely to the 435 feet assigned to these formations in the Hunter Well north of Wall and the 466 feet assigned to them in the Ole Tanberg Well near Red Elm. The upper 200 to 300 feet of this interval has been reported as shale without any further description, while the lower 242 feet is reported as sandstone, sandy shale, clay shale. One thin limestone and a 6-foot coal seam also occur. There is nothing in the description of either of these portions on which to base a correlation, except that the sands are mentioned as white in a number of cases, and the association of thin limestones and sands, and beds of shallow water sediments, such as the coal, are similiar to those found in the Sundance outcrop. In view of these facts the final correlation will, of course, have to be held in abeyance till more definite information is available, but it seems reasonable, to assign this interval in the well log to the Morrison and Sundance formations.

The following correlation is therefore suggested for the Standing Butte Well.

Correlation of Standing Butte Well

0 - ?	Pierre
? - ?	Niobrara--top uncertain; first hint of formation at 927 feet.
? - 1400	Carlile
1400 - 1450	Greenhorn
1450 - 1735	Graneros
1735 - 1905	Dakota
1905 - 1940	Fuson
1940 - 1976	Lakota
1976 - 2190	Morrison
2190 - 2270	?
2270 - 2412	Sundance
2412 - 2559	Spearfish
2559 - 2570	Minnekahta
2570 - 2615	Opeche
2615 - 3027	Minnelusa
3027 - 3508	Pahasapa

Conclusions From Four Deep Wells

It has long been known from outcrops and data from wells drilled through the Dakota, that the Cretaceous formations outcropping about the Black Hills extended across the entire state. The evidence of these four deep wells indicates that many of the formations below the Dakota are also quite persistent, at least as far eastward as the Missouri river. Variations in detail from the exposures in Rapid Canyon are, of course, to be expected, but the general stratigraphic succession seems to be much the same.

The Pahasapa limestone and the overlying Minnelusa sandstone seem to extend through very effectively. The red beds can also be recognized, though it is not certain which of the red formations exposed in Rapid Creek Canyon, extend as far east as the Standing Butte Well. Of the Jurassic formations the Sundance formation seems to be the most persistent. Shales tentatively classified as Morrison are to be found in all logs but their thickness seems to vary greatly.

The Dakota-Lakota group of sands have been penetrated by many wells near the Missouri River and a number on the western plains. The general practice has been to call the first sand from which flowing water was obtained the Dakota horizon and the next flow the Lakota. There is some basis for this distinction since the different flows offer water of different quality, but it remains to be seen whether this correlation can be followed from the Black Hills to the Missouri River.

In 1925 Dr. W. T. Lee pointed out that the sands of the Dakota seem to be large lenses rather than a continuous bed.[1]

In 1930 Dr. W. W. Rubey diagramed the encroachment of the Cretaceous Sea across South Dakota as an oscillating advance which left long fingers or wedges of sand extending westward and interfingering with the eastward pointed shales.[2]

Recent work by Mr. Bruno Petsch in plotting the artesian sands from Mitchell to the Missouri River and along the James Valley where wells are very abundant, showed a similar fingering, three artesian sands, one above the other, extending westward, from the quartzite ridge which lies in eastern South Dakota.[3]

In the correlation of these wells, however, it has been assumed that the separation did exist, and such sands were assigned to the Dakota and Lakota formations, separated by Fuson shales. It is noteworthy, however, in these logs and in other logs of water wells drilled in western South Dakota that the thicknesses of these sands vary greatly. In comparing the Dakota in the Zeal and Ole Tanberg wells, Mrs. E. R. Applin states: "The fine grained, light gray sandstones found in the State School Lands No. 1 (Zeal) appear to be missing in this (Tanberg) well, and we include in this formation only the beds represented by cores from 2,745 to 2,765 feet, showing a coarse-grained, angular, clear quartz sand carrying no water."[4] In the Zeal Well

1. Lee, W. T., Continuity of some oil bearing sands of Colorado and Wyoming, U. S. Geol. Survey Bulletin 751, Part II, 1925.

2. Rubey, W.W., Lithologic studies of fine-grained upper Cretaceous sedimentary rocks of the Black Hills Region, U. S. Geol. Survey Prof. Paper 165, p. 49, 1930

3. Petsch, Bruno, Water resources of South Dakota. Preliminary report, State Planning Board Report, pp 1-20, June, 1935.

4. Applin, E. R., Journal of Paleontology, A micro-fossiliferous Upper Cretaceous section from S. Dak.", Vol. 7, p. 218, 1933.

the Dakota was 128 feet thick and carried a strong flow of water, estimated at 5,000 barrels a day.

It will also be noted that in the Standing Butte Well the Lakota is very thin as is also the separating Fuson shales; no water was reported from the Lakota in this well. Whether these formations are two entirely separate sand horizons which vary greatly in thickness from place to place, or whether they are modifications of a single sand zone, marking the base of the Cretaceous section, will make but little difference in the matter of artesian water, since at least one flow and sometimes several are encountered in this zone.

Though quite a number of deep wells, aside from those described, have been drilled in various parts of the area, few have gone below the Dakota-Lakota sandstone zone. In most cases they were drilled to the first good flow of water and thus depths to the main flow are all that were recorded so that in many cases it is not known whether the Lakota was present. By considering records of wells close to the four which are described above, it is possible to extend these two formations over most of the area. Graphic logs of some of these wells are given in the accompanying sheet of columnar sections.

Though wells are too far apart to carry the Dakota-Lakota succession with certainty, a shale dividing two sands has been found in all the deeper wells, which is assumed to be the Fuson. It may be significant that the upper waters in the west-Missouri country have a salty taste while the lower ones are fresher. In nearly all wells, however, waters from two or more flows are mixed either by corrosion of the casing or by purposely perforating casing at all water horizons to get the maximum flow. Analyses of the separate waters, therefore, are not available and little more than the above generalization can be made with the present information.

POSITION OF ARTESIAN FLOWS

Hunter Well

A study of the reported water flows from artesian wells and oil tests brings out the fact that there are at least seven formations which yield artesian water, some of them from more than one horizon. In the Hunter Well at Wall, six flows were reported, the artesian formations being the Dakota, Lakota, Morrison, Minnelusa, and Pahasapa. All but the last reported only one water horizon. The Pahasapa, however, gave two strong flows.

Water Sands Reported from the Hunter Well

Formation	Position of flow below top of formation.	Depth	Sea level elevation of flow.	Height of water column	Sea level elevation of top of water column
Dakota	20 ft.	3041	-84	1400 ft.	1316
Lakota	5 ft.	3323	-366	2300 ft.	1934
Morrison	36 ft.	3461	-507	3000 ft.	2500
Minnelusa	30 ft.	4520	-1563	1 Bailer per hour	
Pahasapa	35 ft.	4855	-1898	3850 ft.	
Pahasapa	140 ft.	4934	-1977	4000 ft.	2023

While none of these sands furnishes flowing water in the Hunter Well, the pressures were strong enough to raise water above the surface when the elevation was less than 1900 ft. and the strongest flow would have reached 2500 ft. As reported, the Dakota flow was under the least pressure for it raised the water only 1400 ft. above the sandstone or to an elevation of 1316 ft. The Lakota flow was under greater head for water rose 2300 feet above the sandstone to an elevation of 1932 feet. Water from deeper sands was under greater pressure, with the exception of that from the Minnelusa. The pressure in the lower Pahasapa flow, the strongest reported was sufficient to raise water 4000 ft.

Zeal Well

The Zeal Well reported two water sands in the Dakota sandstone and one at the top of the Lakota sandstone. The first Dakota "sand" was struck at a depth of 2544 feet raising a water column 2244 feet to within 300 feet of the surface. The second flow, encountered in a white sand 56 feet lower at a depth of 2600 feet, raised water to the surface. The Lakota sandstone furnished a heavy flow of very warm water from a depth of 2800 feet.

Water Horizons in the Zeal Well

Formation	Depth	Sea level elevation of flow	Height of water column	Sea level elevation of top of water column
Dakota	2544	-366	2244	1879
Dakota	2600	-422	2600 plus	2178 plus
Lakota	2820	-642	2820 plus	2178 plus

Unfortunately no pressure records were kept on this well so that it is impossible to give further data than that water flowed from the two lower horizons.

Tanberg Well

The log of the Tanberg Well, south of Red Elm, contained no statement on water sands except that the Dakota carried no water.[1]

Standing Butte Well

The Standing Butte Well reported six water sands but little information was recorded except that they flowed. The first water was struck at 1400 feet. The driller reported that it came from a sand. It may be a stray sand in the Graneros formation, but it is noteworthy that it is present at the position occupied by limy shells of the Greenhorn formation in other wells in this part of the state. The Dakota at a depth of 1735 feet reported water but none was reported from the Lakota. The big flow in this well apparently came from sands which perhaps can be correlated with the Sundance formation.

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1. Applin, E. R., op. cit., p. 218

Water Sands of the Standing Butte Well

Formation	Position of flow below top of the formation	Depth	Sea level elevation of flow
Greenhorn		1400	558
Dakota	0 ft.	1735	223
Lakota			
Sundance	9 ft.	2279	-321
Sundance	55 ft.	2325	-367
Minnelusa	320 ft.	2935	-977
Minnelusa	395 ft.	3010	-1052
Pahasapa	No water reported		

Other deep wells all draw from the Dakota-Lakota group of sands. As many as two or three flows are reported from these sands in most of the wells and it has been difficult in many instances to determine which of the two formations furnishes the water. In most cases it has been customary to call the first sand the Dakota and the second sand, the Lakota, but some wells have reported at least two flows in the Dakota. The positions of these flows are indicated on the accompanying well log sheet.

STRUCTURE AND DEPTH OF ARTESIAN SANDS

Depth necessary to reach the artesian sands depends on the elevation of the surface and the structure of the artesian formations. The surface forms a continuous down slope from the foot of the Black Hills to the Missouri River. Its elevation at the western end is about 3300 feet above sea level while at the Missouri River it is approximately 2000 feet. The total fall, therefore, is about 1300 feet or about 7 feet per mile.

If the artesian sands sloped uniformly, parallel to the surface of the Great Plains it would be a simple matter to set an approximate figure for the depth at which they would be encountered. They have flexed, however, into a great northward-plunging trough known as the Lemmon Syncline which parallels the axis of the Black Hills. This trough is the major structural feature of western South Dakota. Its axis passes through the city of Lemmon, extends southeastward near Philip and is lost beneath the younger formations south of the White River. It was mapped by Darton[1] and later by Ward.[2] It may be likened to a deck of cards, the various formations which have been described forming individual cards in the pack. If the center of the deck is bent into a trough each layer will conform to the curve of the others.

From the outcrops in the Black Hills all the formations slope rapidly eastward and northward to the axis of the syncline and then slope gently up from the axis as the Missouri River is approached. This curvature is best ascertained from the position of the Dakota sandstone since its elevation is known at more places than any other formation of the succession. In the outcrops in the Black Hills, this formation lies at about 3500 feet above sea level. From this point it slopes eastward at a rate of about 70 feet per mile and lies 63 feet below sea level in the Hunter Well. In the Zeal Well farther east it lies 366 feet below sea level. At Cherry Creek, 25 miles farther east, it has risen to 15 feet below sea level. In the Standing Butte Well it has risen still further to 223 feet above sea level, a total rise of 589 feet above its position in the lowest part of the syncline or at a rate of about 10 feet to the mile. At the Cheyenne Agency the elevation of the Dakota is 226 feet above sea level, at Pierre it is 480 feet and at Chamberlain it attains its highest elevation between the Missouri and the Black Hills namely 834 feet.

The top of the Pahasapa Limestone shows a similar structure. It lies 1863 feet below sea level in the Hunter Well, nearly a mile below the elevation of its outcrops in the Black Hills. From this point it rises on the eastern flank of the syncline toward

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1. Darton, N. H., Geology and Underground waters of South Dakota U. S. Geol. Survey, Water Supply Paper No. 227, pl. XIII, 1909.
2. Ward, Freeman, The structure of western South Dakota, S. Dak. Geol. Survey, Circular No. 25, 1925.

the Missouri River and in the Standing Butte Well, the easternmost point at which it has been observed, it lies 829 feet higher or at an elevation of 1069 feet below sea level.

Other formations have somewhat a similar relation but our information on them is not sufficiently detailed to afford further information on the structure.

Minor structures are doubtless superimposed on this big syncline which will change the elevation of the artesian sands locally. These minor structures have not been worked out in detail, however. The general structure outlined above gives the position of the artesian sands with sufficient accuracy to guide the driller in making contracts for deep wells.

Since the surface of the great plains is so nearly a plane it will be seen that the deepest drilling would be in the vicinity of the axis of the Lemmon Syncline. Wells in the vicinity of Wall will have to go deeper for artesian water than will wells either to the east or west. The depth to which wells must be drilled to reach the top of the Dakota Sandstone on the divides between the large rivers in eastern Pennington and Meade counties is approximately 3000 feet over large areas. It will vary between 2000 and 2500 feet on the highlands and 1700 to 2000 feet in the lowlands. These depths obtain to within a few miles of the Black Hills where the formations rise sharply to the surface.

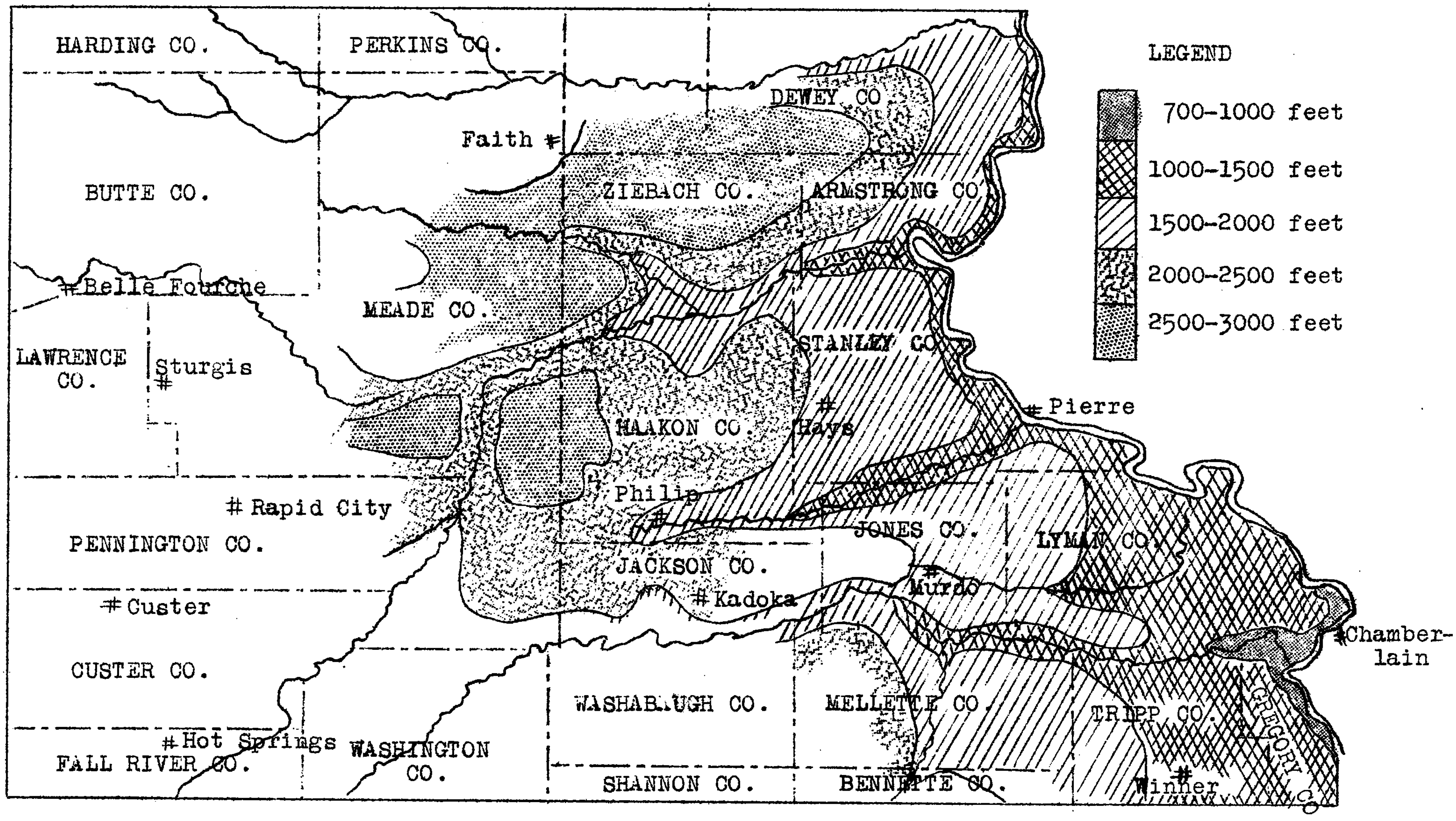
In Ziebach and Dewey Counties the top of the Dakota lies 2500 feet below the highlands between the Cheyenne and Moreau River valleys and from 1600 to 1800 feet below the bottom of these valleys. In the Haakon and Jackson County uplands 2500 foot wells will be necessary to reach the top of the sandstone on the highlands while in the valleys 1600 feet will be sufficient.

In the counties bordering the Missouri River the sandstone lies about 2000 feet below the higher parts of the divides but as the Missouri is approached, these divides lower until 1400 feet will be sufficient to reach the sandstone. Wells in the valley of the Missouri itself will have an average depth of about 1300 feet, from the Cheyenne Agency south to Pierre. South of Pierre, however, the sandstone begins to rise on a structural uplift which carries it to within 700 feet of the surface at Chamberlain.

Depths to the top of other artesian formations can be determined for any locality by adding to the depth of the Dakota in that locality the thickness of the formations between the top of the Dakota and the desired aquifer indicated in the nearest well on the cross section sheet.

It is obviously impossible to predict accurately the position in the formation at which artesian flows may be encountered since they are not always at the top of the formation. Though records show considerable variation in the position of these flows, in all wells they occur under the shale partings at the top of the various sandstone members. Drillers frequently report increasing flows in the deeper parts of the sandstone members. This is doubtless due to the existence of layers of coarser materials which make the sands more pervious. The practice of reporting the main flow only, makes it appear that water occurs well down in formations which sometimes yield lesser amounts nearer their upper surfaces. A study of the maps and the sections accompanying this report will make it clear that nowhere in the area do artesian horizons go more than 5000 feet below surface and that they are all within 3500 feet in the shallower parts of the area. It should be possible, therefore, to supply ample water from flowing wells or by shallow pumping in any part of the area under consideration as the need for it arises.

DEPTH OF TOP OF DAKOTA SANDSTONE BELOW THE SURFACE
IN WEST-CENTRAL SOUTH DAKOTA



ARTESIAN CONDITIONS IN WEST-CENTRAL SOUTH DAKOTA

HYDROLOGY

By Thomas W. Robinson

INTRODUCTION

Location of area

This report presents the results of a study of the artesian conditions in the west-central part of South Dakota and of the artesian water supply of the semiarid plains region between the Black Hills uplift and the Missouri River, in which the Pierre shale is at or very near the surface. (See pl. 1.) In general the area studied includes all of western South Dakota except the Black Hills uplift and the northern and southern rows of counties. The Black Hills uplift, with its numerous streams and springs, does not present any serious water-supply problem. Although in the northern and southern counties there has not been much development of the artesian water, there are over most of their area deposits of permeable sands, which so far have generally yielded an adequate supply of water to wells of moderate depth. In the area studied there are no extensive bodies of shallow ground water, and local residents for the most part are forced to rely on the deeper artesian waters or on surface water.

Purpose of investigation

In this study the United States Geological Survey has cooperated with the South Dakota Geological Survey. The study was made as a result of the severe drought of 1933 and 1934, during which the surface-water supply was depleted to such an extent that an acute water shortage existed in this area, as well as in other sections of the State. Recognizing this water shortage, the South Dakota legislature at the session of 1935 passed Senate Bill 23, appropriating $1,500 for "making a survey of the need for drilling artesian wells and the construction of reservoirs to store and conserve water flowing from such wells and * * * making a survey and report of the various artesian-well basins throughout the State and in gathering facts and statistics to enable the State geologist and the governor to determine whether or not such wells should be drilled." The bill further provided that "the State geologist and the governor are * * * empowered to accept and use any funds provided by an agency of the United States or from any other or private sources" to carry out this survey. As a result an agreement was made with the United States Geological Survey in the spring of 1935, whereby $1,275 of the regular Federal appropriation for the investigation of the water resources of the United States was provided for this survey.

This report deals primarily with the artesian water from the Dakota sandstone, which is the most widely extended artesian aquifer in South Dakota. Some attention, however, was given to deeper artesian aquifers, chiefly the Lakota sandstone and the Minnelusa sandstone. The purpose of these studies was to determine (1) the static level of the artesian water, or height above sea level to which the water would rise in tightly cased wells; (2) the rate and amount of decline of the static water level in the past; (3) the possibility of developing deeper artesian aquifers as a source of water supply; and (4) the temperature and quality of the water.

Field work was begun on June 21, 1935, and was continued until September 4, 1935. The funds and consequently the time available for this investigation and report were virtually only sufficient to carry out the program of measuring the head at the readily accessible wells and determining the altitude above sea level at some of the wells. A detailed study of any particular locality was not possible. Consequently this report covers only in a general way the artesian conditions of the area. All the hydrologic studies were made by Thomas W. Robinson, assistant engineer, of the United States Geological Survey, under the supervision of O. E. Meinzer, geologist in charge of the division of ground water. The geologic studies embodied in this report were made by E. P. Rothrock, State geologist.

Previous investigations

During 1890 and 1891 E. S. Nettleton,[1] of the United States Department of Agriculture, made a general investigation to determine the depths of artesian wells, their pressures and flows, in the artesian basin of North and South Dakota. Apparently at that time there were no artesian wells in the western part of South Dakota. In 1895 the South Dakota Agricultural College and Experiment Station published a report by J. H. Shepard,[2] which had to do chiefly with the chemical character of the artesian water, mainly in the eastern part of the State. The first really comprehensive study of the artesian basin in South Dakota was made by N. H. Darton,[3] of the United States Geological Survey, and published in 1896. This report also related largely to the eastern part of the State. At that time, according to Darton, there was very little development of the artesian basin west of the Missouri River. The few wells that had been drilled in the western part of the State were mainly in the Missouri River Valley, altho

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1. Nettleton, E. S., Artesian and underflow investigation: 52d Cong., 1st sess., S. Ex. Doc. 41, pt.2, 1892.
2. Shepard, J. H., The artesian waters of South Dakota: South Dakota Agr. Coll. and Exper. Sta. Bull. 41, 1895.
3. Darton, N. H., Preliminary report on artesian waters of a portion of the Dakotas. U. S. Geol. Survey 17th Ann. Rept., pt. 2, p. 609, 1896.

drilling was then in progress on a well in the Rosebud Indian Reservation, on the highlands at the head of Oak Creek on the divide between the White River and the Keyapaha River. In 1898 J. E. Todd,[4] then State geologist, published a report of his geologic studies made in 1895 and 1896. This report dealt in part with the artesian conditions of the State. The most extensive and somewhat detailed investigations of the geology and hydrology of the artesian basin in western South Dakota were made under the direction of N. H. Darton, of the United States Geological Survey, and numerous reports[5] on the subject have been published. All these reports relate to the geology and artesian conditions in the adjacent to the Black Hills, and Water-Supply Paper 227, in addition, covers the entire State. In 1915 the State Legislature passed Senate Bill 128, which provided for investigating the conservation of artesian water and recommending to the governor such legislation as should be found advisable. The State engineer, H. M. Derr, was empowered to make a detailed and exhaustive investigation of the use and control of all public and privately owned artesian wells in the State. The funds provided for the investigation were insufficient to visit all the wells in the State, but a large number of wells were visited and recorded. Much valuable information was obtained regarding the size and amount of casing, altitude depth, pressure and flow, both former and existing, temperature, use of water, and condition of the well. The results of this investigation and the recommendations for the conservation of artesian water are presented in a report by the State engineer.[6] Two later reports by the office of the State engineer[7] give in some detail the number, yield, and pressure of artesian wells throughout the State. They also contain general data on the decrease in artesian head and recommendations for the conservation of the artesian-water supply.

Acknowledgments

Grateful acknowledgment is made to O. E. Meinzer, for constructive suggestions during the period of the investigation and preparation of the report; to E. P. Rothrock, State geologist, for well data and other information furnished by his office; to Beyer Aune, superintendent of the Belle Fourche field station, for copies of water analyses made by the United States Department of Agriculture; to H. E. Walden, city auditor of Philip, William Mussman, city auditor of Chamberlain, and F. E. Pohle, of Philip, for copies of water analyses and well data. The Norbeck Co., Anton Sather, Lawerence Wagner, Peter Vallery, O. B. Smith, and Paul Gruble, water-well drillers, furnished information on the

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4. Todd, J. E., Geology of South Dakota: South Dakota Geol. Survey Bull. 2, 1898.
5. The following publications of the United States Geological Survey relate to artesian conditions in western South Dakota; Geol. Atlas, Folios 85, 107, 108, 128, 164, 209, and 219; Water-Supply Papers 227 and 428.
6. Derr, H. M., Report on artesian wells; South Dakota State Engineer 6th Bienn. Rept. for 1915-16, pp. 145-282.
7. Artesian waters in South Dakota: South Dakota State Engineer, 9th Bienn. Rept., 1922; South Dakota State Engineer Conservation Bull., 1924.

original water levels and pressures, discharge, temperature, depth, and location of artesian wells; and many residents of the area furnished information and were helpful in many ways.

The writer is also indebted to the operators of the Black Hills sugar plant of the Utah-Idaho Sugar Co. for the use of their special equipment in calibrating the altitude gage used to measure the head on flowing wells.

METHODS OF DETERMINING THE STATIC WATER LEVELS IN OBSERVATION WELLS

The static water level in nonflowing wells was obtained by measuring down to the water level in the well from the top of the casing or some other permanent point, with a steel tape weighted on the end. It was not possible to make a measurement of the water level in some of the wells visited, because of the smaller diameter of the casing and the type of pump installation. Most of the wells were constructed with 3-inch casing, although a few had 4 inches or larger. Many of the 3-inch wells had been recased inside once, and some of the larger ones two and even three times. Thus the inside diameter of the recased wells was only about 2 inches. As practically all the nonflowing wells were equipped with lift pumps, there was in the recased wells very little space between the inside of the casing and the discharge pipe of the pump, through which the tape could be lowered to the water level. In such wells it was virtually impossible to make a measurement of the water level without first removing the entire pump, a difficult and costly operation. In many of the nonflowing wells the pump rested on top of the casing or was screwed directly into it. In order to make a measurement of the water level in wells where the pump rested on the casing it was first necessary to raise the pump off of the casing. This was usually done by means of a block and tackle, which required the services of two men. The amount of labor and equipment necessary to unscrew and raise the pumps screwed to the casing was so great that no attempt was made to make a measurement of water level in these wells.

The pressure head in flowing wells -- that is, wells whose static water levels are above the ground surface -- was obtained by measuring the shut-in pressure with an altitude gage. An altitude gage is a pressure gage that has been calibrated to read in feet the distance to which the water would rise in a tight pipe, above the center of the gage. The flow of the well was first shut off by closing all the valves, and then the altitude gage was attached to the discharge pipe of the well. In some wells having a head of only 5 feet or less, the static level was obtained by attaching a 5-foot length of ordinary garden hose to the well and raising the open end until the water just ceased to flow. The vertical distance from the open end of the hose to the measuring point was measured with a steel tape.

As the altitude gage is a delicate instrument, it may become inaccurate as a result of jars and bumps received in handling and transportation. Thus in order to obtain accurate readings it was necessary to calibrate the gage. The calibration was done at the Black Hills sugar plant of the Utah-Idaho Sugar Co. at Belle Fourche, with a special device known as the "dead-weight pressure-gage tester."

Measurements of the static water level of flowing wells were confined for the most part to new wells that were in good condition and equipped with valves for closing off the flow. Many of the old wells were suspected of having corroded or defective casing, which would allow the water to escape underground and so not give a true measure of the static level.

In order to study the relation of the static water level in the wells throughout the area it was necessary to refer the measuring points of the wells to sea-level datum. This was done by determining the altitude of the measuring point in nonflowing wells and of the altitude gage in flowing wells, by instrumental leveling by a sensitive aneroid barometer known as an "altimeter," or from a topographic map. Level lines were run to wells that were at a considerable distance from a bench mark, but for most of the wells the altitude was determined by the altimeter or from a topographic map. The longest level line was about 17 miles, to well 26, at Whitehorse, in the Cheyenne River Indian Reservation. It would be desirable and much more satisfactory to have the altitude at all the observation wells determined by instrumental leveling. However, the running of level lines is expensive, and the funds available for the investigation were not adequate for this work. The altitude of 43 wells was determined by an altimeter or from topographic maps except for 9 wells.

In any artesian well that is yielding water, whether by pumping or by discharge through artesian pressure, there is invariably a draw-down,[8] or a reduction in pressure of the water in the well. As soon as a well ceases to yield water there is a decrease in the amount of draw-down and an equivalent increase in the pressure of the water. This increase in pressure is very rapid at first and then continues at a gradually diminishing rate until the normal static pressure of the water is reached. The theory of this recovery of pressure is best explained by Meinzer.[9] In any well that discharges by artesian pressure this increase in pressure can be measured by means of a pressure gage. The length of time required for complete recovery of the pressure will vary according to the permeability of the aquifer, the length of time the well has been yielding water, and other factors such as an elasticity factor. In some flowing wells the static pressure appears to be reached

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8. Meinzer, O. E., Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, P. 61, 1923.
9. Meinzer, O. E., Compressibility and elasticity of artesian aquifers: Econ. Geology, Vol. 23, pp. 277-280, May 1928.

almost immediately after the well is closed; in others it may require several hours, days, or even weeks. Repeated measurements made in nonflowing wells after the pump has been stopped and in flowing wells after the flow has been shut off indicate that in wells drawing water from the Dakota sandstone recovery is relatively rapid.

In making measurements of the static water level of flowing wells it was not always feasible to leave the altitude gage attached until the normal static pressure of the water was reached. Under such conditions the normal or total static head was estimated from the available pressure readings. This was done by making periodic readings of the pressure and recording the elapsed time over a period of several hours. From these data a recovery curve was drawn, usually at the time of the test. When it became evident from the shape of the curve that the initial rapid rise had passed and that the pressure was increasing only slowly the test was discontinued. The shape of the curve was then projected, and the point of approximate complete recovery estimated. A typical recovery curve for a well of this type is shown in figure 1. This well (No. 24) is at Cherry Creek post office on the Cheyenne River Indian Reservation.

Water-level measurements of all flowing wells having a high pressure head were made in this manner. The estimated total static head of these wells is shown in the appended table of well records.

Under certain conditions water will rise higher in a well than its pressure head, because of the presence of bubbles of gas in the water. The resulting water and gas mixture has a lower specific gravity than water alone, and hence the water rises higher than it would under the same pressure if the column contained no gas. In practically all the wells in the north-central and northeastern part of the area moderate to large amounts of gas were mixed with the water. Thus the observed static level for these wells is higher than in wells that do not yield gas. However, as the primary purpose of the investigation was to determine the altitude of the water level in the wells, no attempt was made to correct for the effect of the gas lift.

Changes in atmospheric pressure will affect the water level in artesian wells. An increase in atmospheric pressure will cause a lowering of the water level, and a decrease in atmospheric pressure will cause a rise of the water level. No attempt was made to correct the measurements of water level for changes in atmospheric pressure, as the investigation did not warrant this degree of refinement. Repeated measurements of water level in nonflowing observation wells, however, indicate that changes in atmospheric pressure caused the water level to fluctuate as much as 2.5 feet.

Figure 1. - Recovery curve of pressure head in well 24 at Cherry Creek, S. Dak.

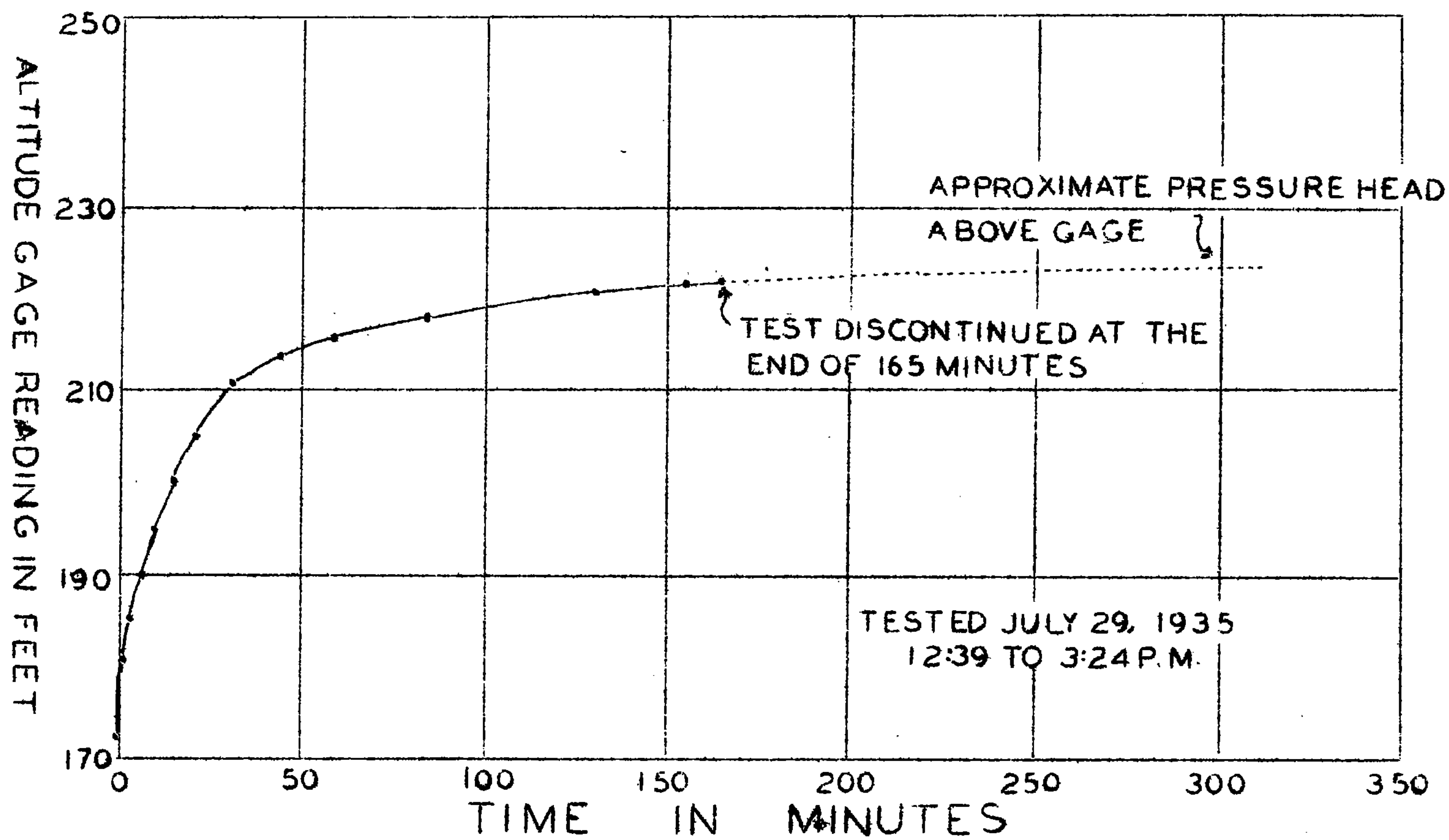

FIGURE 1 - RECOVERY CURVE PRESSURE HEAD IN WELL NO. 24
AT CHERRY CREEK, S. DAK.

GENERAL GROUND-WATER CONDITIONS

There are in western South Dakota seven recognized artesian aquifers. In the order of their depth below the surface, they are the Dakota sandstone, the Lakota sandstone, the Morrison formation, the Sundance formation, the Minnelusa sandstone, the Pahasapa limestone, and the Deadwood formation. These artesian aquifers crop out in wide zones encircling the Black Hills uplift and have a steep outward dip that within short distances carries them far beneath the adjoining plains, where they are buried under a thick body of sedimentary beds consisting chiefly of relatively impermeable shales. Because of this steep dip it is only along the edge of the Black Hills, close to the outcrop zones, that the Minnelusa sandstone and the Deadwood formation lie near enough to the surface to be economically utilized as sources of water supply.

In the region lying between the Black Hills and the Missouri River there is need for ground water in most localities, as the surface waters are inadequate or of bad quality. The principal source of ground water in this region is the artesian water from the Dakota sandstone. The only well drilled for water supply that is known to penetrate the Lakota sandstone in this area east, is the municipal well at Philip (No. 18). Two oil prospects yielding water and known to have penetrated the Lakota sandstone are No. 17, drilled by the Weaver Oil Co. in Jackson County, and No. 27, the Standing Butte well, in Stanley County. In two other oil prospects, now abandoned and plugged, water was reported from the Lakota sandstone. These are the Zeal well, in the NW$\frac{1}{4}$ sec. 16, T. 9 N., R. 17 E., Meade County and the Gypsy No. 1, in the SW$\frac{1}{4}$ sec. 28, T. 3 N., R. 16 E., Pennington County. The Zeal well yielded artesian flows from both the Dakota and Lakota sandstones.

According to Darton [10] the intake area of the Dakota, Lakota, and Minnelusa sandstones and the Deadwood formation is in their high outcrop zones in the Black Hills. The outcrop zones of the Dakota and Lakota sandstones occur for the most part at altitudes of 3,100 to 3,500 feet, and those of the Minnelusa sandstone and the Deadwood formation are still higher. Here these sandstones receive water, part of which comes from rainfall and part from streams that flow across the outcrops. The water thus absorbed by the sandstone percolates down the dip through the interstices of the rock and passes far beneath the surface. In general the direction of movement of this water is outward from the Black Hills and thence eastward across the State. The accompanying map shows the approximate head of the artesian water in the Dakota sandstone in 1935 in all parts of west-central South Dakota. The contour lines show the shape and position of the piezometric surface -- that is, the surface to which the water will rise in tightly cased wells that tap the Dakota sandstone.

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10. Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Water-Supply Paper 227, pp. 60-61, 1909; Artesian Water in the vicinity of the Black Hills: U. S. Geol. Water-Supply Paper 428, p. 28, 1918. Darton, N. H., and Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Central Black Hills folio (No. 219), p. 33, 1925.

The piezometric surface is above the land surface in places where flowing wells can be obtained. The movement of the artesian water is always in the direction that the piezometric surface slopes -- that is, at right angles to the contours of that surface. Thus, on the accompanying map it is possible to trace the direction of movement of the water.

Because of the similarity in structure of the other three sandstones, artesian water in them is inferred to move in the same general direction.

Differences in static level

As water enters the Dakota sandstone at an altitude of 3,100 to 3,500 feet and is confined by relatively impermeable shale in its eastward extension, it would be expected to have great pressure, or head, in the plains to the east. This pressure was determined in many wells in the central and eastern part of the area. The greatest surface pressure, that of 120 pounds to the square inch, indicating a head of 276 feet with reference to the measuring point near the surface, was found in well 25, at Red Scaffold, in the Cheyenne River Indian Reservation. The depth of the well was 2,385 feet, indicating a pressure at the bottom of about 1,160 pounds to the square inch. Owing to the friction or resistance offered to the water in its passage through the strata, there is a decrease in pressure to the east. Thus from the accompanying map it may be seen that the altitude to which the water would rise in tightly cased wells decreases from about 3,200 feet in the vicinity of the Black Hills to about 1,700 feet near Chamberlain. The 1,500-foot loss of head is due to the frictional resistance offered to the water. The loss in head is doubtless greatest in localities of extensive withdrawal of artesian water in the central and eastern part of the State. Before there was extensive artesian development in South Dakota the pressure of the water, and the resulting altitude to which the water would rise, was much greater than that represented on the accompanying map.

In some artesian aquifers the water from different depths will rise to different levels. Such a condition appears to exist in the Dakota sandstone. Although the writer has not had an opportunity to verify this difference in static water level, reports from well owners and drillers indicate it to occur. As drilling progresses from the top to the bottom of the aquifer, the flow of the well will increase. Many well owners who do not desire a large flow of water take advantage of this condition, and have their wells drille into the aquifer only a few feet. Reports indicate that with increased depth and flow there is also an increase in pressure. Such an increase in pressure would explain apparent discrepancies in the static level of wells close together but penetrating the aquifer to different depths.

So far as the writer is aware, no one has ever attempted to measure this apparent increase in pressure. Possibly this omission is due to the method of drilling. Commonly the hydraulic rotary method of drilling is used, in which mud-laden fluid is circulated through the well and drilling operations are carried on without interruption until the well is completed. Accurate measurements of pressure or of depth to the water level as the sandstone is penetrated would be difficult under these conditions. Moreover, the results would be unreliable unless the water in the well were clear when the measurements were made, because muddy water is heavier than clear water and will accordingly not rise as high in the well.

Piezometric surface

The location and numbers of all artesian wells for which information was collected are shown on the accompanying map. The numbers on the map correspond to the numbers in the appended table of well records. No attempt was made to obtain a record for all the wells in the area, but only for those where it was possible to obtain a measurement of water level or to collect other significant information. The map of the piezometric surface was prepared from the data collected on these wells. It shows the height to which the water from the Dakota sandstone will rise above sea level. The contours on the piezometric surface are based on measurements of the static water level and the altitude of the measuring points at the wells.

In many parts of the region there were no artesian wells or none that penetrated the Dakota sandstone. This is true of the area along the east edge of the Black Hills, from the vicinity of Sturgis south to Buffalo Gap and east as far as the west line of the Cheyenne River Indian Reservation and the town of Philip. No artesian wells could be found in northern Stanley and Ziebach Counties, in Armstrong County, or in western Jones and Mellette Counties. Necessarily in these areas the contours are more or less generalized. However, because of the fairly uniform slope of the piezometric surface in areas for which data are available it is believed that the contours, as a whole, depict the form of the piezometric surface rather closely.

From the contours on the map it may be seen that the piezometric surface slopes eastward from the outcrop area bordering the Black Hills. It is steepest along the edge of the Black Hills, becomes somewhat less steep toward the east, and is almost flat west of the Missouri River. Between well 1, north of Belle Fourche, and well 26, at Whitehorse, the average slope is 8.4 ft. to the mile; between well 14, near Sturgis, and well 39, near Fort Pierre, it is 9.6 feet to the mile; and between well 16, at Buffalo Gap, and well 69, at Iona, it is 7.6 feet to the mile. Interpolations from Darton's map of the piezometric surface, published in 1908, indicate that the average hydraulic gradients in these three sections were then respectively 6.8, 8.0, and 7.6 feet to the mile. Thus in the period since the early work by Darton the hydraulic gradient in the northern and central parts of the area has increased about 1½ feet to the mile, while in the southern part it has remained nearly the same.

The downstream or eastward bulge of the contours immediately east of the Black Hills is due to the curving trend of the outcrop or intake area of the sandstone. There appears to be an unusually steep hydraulic gradient between well 25, at Red Scaffold, and well 24, at Cherry Creek, in the Cheyenne River Indian Reservation, and between well 21, at West Fork, and well 24, the gradient between wells 25 and 24 being 14.8 feet to the mile and that between wells 21 and 24 20.1 feet to the mile. As it was not possible to measure the pressure of well 25, the driller's report of 120 pounds to the square inch, which there is no reason to question, was used in constructing the map. It is possible that the large difference in pressure is due to the different depths to which the aquifer was penetrated. The well logs indicate that the Dakota sandstone was penetrated about 75 feet in well 25 and to the bottom of the sandstone in well 21, but only about 30 feet in well 24.

Because of the conditions just described, a distinct westward or upstream bulge of the 2,000-foot, 2,100-foot, and 2,200-foot contours of the piezometric surface is indicated in southern Ziebach County and northern Haakon County. Other than this there does not appear to be any major irregularity in the eastward-sloping piezometric surface. The contour interval of 100 feet is too great to indicate minor irregularities, which doubtless occur in the form of local cones of depression in the vicinity of flowing wells.

Decline in head

There has been a pronounced decline in the artesian head since the first wells were drilled in the area. The decline has not proceeded uniformly but has varied from place to place, depending upon the local draft. It has been greatest in the eastern part of the area, especially in eastern Stanley County in the vicinity of Pierre and in eastern Lyman County in the vicinity of Chamberlain. No periodic measurements of artesian head have been made on any wells in this area, but a few records of head at different times are available, from which some conclusions as to the rate of decline can be reached.

The earliest record of artesian head was obtained from the city auditor of Chamberlain. An article by Scott Hayes, then city engineer of Chamberlain, in the Chamberlain Register of August 30, 1900, gives the following information: The first well to supply the city with water was finished in May 1891. It was started at an altitude of 1,547 feet[11] and drilled to a depth of 785 feet. At that depth it yielded a flow of 529 gallons a minute, and the water had a temperature of 74°F. The hydrostatic pressure at the end of a 24-hour test was 122 pounds to the square inch, which is equivalent to a head of 280 feet. This statement agrees with the record given in the early report by Nettleton.[12] In April 1900 the flow was not more than 40 gallons a minute. Hayes states that "the decrease in flow is accounted for by the drawing away of the supply by six power wells in the city, sunken at altitude 170 to 210 feet lower." Another well drilled in August 1900 to a depth of 966 feet and started at a point 10 feet higher had a hydrostatic pressure of 55 pounds to the square inch. In regard to a third well Hayes states, "In the Fountain well (altitude 1,744 feet) the flow ceased and the surface of the water receded until now (August 1900) it is more than 50 feet below top of pipe."

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11. Altitudes used by Hayes are taken from the United States Missouri River Commission surveys.
12. Nettleton, E. S., Artesian and underflow investigation: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 2, pp. 52, 53, 1892

From these data it is concluded that the altitude of the piezometric surface at Chamberlain was 1,828 feet in May 1891, as recorded in the first well, and 1,684 feet in August 1900, as recorded in the second well. In the Fountain Well the water level in August 1900 may have been a few feet higher than the 1,684-foot level. Thus in the period from May 1891 to August 1900 there was a total drop in head of about 140 feet, or at the average rate of 15 feet a year. This rapid rate of decline was no doubt caused largely by the power wells referred to by Hayes. Under the high head that prevailed in the early years the discharge was large, which of itself tended to produce rapid decline in head. During the present investigation it was not possible to obtain comparable measurements on these wells, and therefore the amount of decline up to the present time is not known.

On October 13, 1915, observations were made by H. M. Derr,[13] State engineer, on the town well at Oacoma, about 3 miles west of Chamberlain. This well was drilled in 1912 to a depth of 1,180 feet on land 1,388 feet above sea level. The pressure recorded on October 13, 1915, was 95 pounds to the square inch, giving a head of 1,607 feet with reference to sea level. Some notion of the amount of decline between 1900 and 1915 is afforded by a comparison of the piezometric surface between this well and the wells at Chamberlain. Thus a direct comparison shows that the decline as recorded by the well at Oacoma amounted to 77 feet. However, as the well at Oacoma is up the slope of the piezometric surface, that surface stands higher at Oacoma than at Chamberlain, and the decline would be greater by an amount equal to the difference in head between the two wells. From the accompanying map this difference in head is estimated as between 10 and 20 feet. Accordingly the amount of decline between 1900 and 1915 is about 90 feet, or at the average rate of 6 feet a year. The total decline between 1891, when the first well was drilled at Chamberlain, and 1915 was about 230 feet, and in 1935 it was undoubtedly greater.

Another record that affords data on the decline in head is obtained from the McClure well, in sec. 31 or 32, T. 108 N., R. 78 E., in northwestern Lyman County, which is described by Darton.[14] According to Darton the altitude of the well was 1,917 feet and the pressure 20 pounds to the square inch, which indicates that the water had sufficient head to rise 1,963 feet above sea level. It is not known in what year this pressure was determined, but presumably in 1908 or earlier. A later report by Derr[15] indicates that the well stopped flowing about 1911. The writer visited the locality in July 1935 but found that the well had been destroyed and that there were no other nearby wells that

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13. Derr, H. M., Report on artesian wells: South Dakota State Engineer 6th Bienn. Rept., for 1915-16, p. 237, 1916.
14. Darton, N. H., Geology and underground waters of South Dakota: U.S. Geol. Survey Water-Supply Paper 227, p. 120, 1909
15. Derr, H. M., op. cit., p. 244.

could be measured. Between the year in which Darton's reported pressure of 20 pounds to the square inch was measured and the year in which the well ceased to flow the decline amounted to 46 feet. By interpolating from the contours on the accompanying map of the piezometric surface, it was estimated that in 1935 the head at the locality of the McClure well was between 1,790 and 1,800 feet with reference to sea level. Thus in the 24-year period since the well ceased to flow the decline in head has apparently amounted to about 120 feet, or at the average rate of about 5 feet a year.

According to Todd[16] the pressure of one of the first wells drilled at Pierre for the Pierre Natural Gas & Power Co. was 210 pounds to the square inch. It is not clear in what year the well was drilled, but it was either 1895 or 1896. Todd reports that the top of the well was 3 or 4 feet below the depot. (This refers to the old depot; a new one was built in 1906 at a different location.) From Todd's description, the altitude at the well is estimated as about 1,440 feet, and the head when the well was drilled as about 1,920 feet with reference to sea level. In 1930 well 44, owned by the city of Pierre, was drilled by the Norbeck Co. on ground at an altitude of 1,440 feet. The original shut-in pressure of this well was reported by the driller as 80 pounds to the square inch, making the altitude of the static water level about 1,620 feet. Thus in the 35-year period the decline in head amounted to about 300 feet, or at the average rate of $8\frac{1}{2}$ feet a year.

Some idea of the regional decline in head over the area is afforded by a comparison of Darton's map of the piezometric surface,[17] published in 1908, with the map in this report. Such a comparison, however, yields only general information, as the data for Darton's map were drawn from various sources over several years. Thompson,[18] in a discussion of Darton's map, states:

> "Here again it becomes necessary to consider the data from which the piezometric lines on Darton's map were drawn. This subject is not discussed in the report that contains the map, but the writer is informed by Dr. Darton that the available data in regard to head were unavoidably of various degrees of reliability. Some were obtained during the course of his own investigations in the period from 1895 to 1903, but many of them were taken from a report by Nettleton based on work done in 1890-91,[19] Some of the pressures in Nettleton's report are quite evidently those existing several years prior to the time of his investigation and possibly as far back as the completion of the first wells in 1882."

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16. Todd, J. E., Geology of South Dakota: South Dakota Geol. Survey Bull. 2, pp. 93-94, 1898.
17. Darton, N. H., op. cit., pl. 11.
18. Thompson, D. G., The origin of artesian pressure: Econ. Geology, vol. 24, p. 765, November 1929.
19. Nettleton, E. S., op. cit.

Thus it appears that Darton's map is really a composite map covering a period of several years. However, a comparison of the contours on the two maps shows that in the eastern and east-central parts of the area there has been a total decline in head ranging from a possible minimum of 50 feet to a maximum of at least 250 feet.

In the western part of the area well 9, at Vale, affords some data on the decline in head. According to Darton [20] the reported head of this well was 50 feet with reference to the land surface. The year in which this measurement was made is not given but must have been some time between 1909, when the well was drilled, and 1917, when the text of the folio was prepared. A measurement on August 7, 1935, gave a head of 29.5 feet with reference to the land surface. The decline has therefore amounted to 20.5 feet in the period since the well was first measured.

No records could be obtained as to the amount of decline of the water table in the intake area. However, measurements of head in wells 1 to 13 miles from the outcrop zone, compared with data of head reported by Darton, [21] indicate that it is not large--at least not as large as the decline in the eastern part of the area. This may be due partly to the fact that records in the intake area do not extend back to such early years as those farther east. The longest record, that of well 9, at Vale, about 13 miles from the intake area, shows only a decline of 20.5 feet in a period that may have been as long as 26 years or as short as 18 years. Interpolation from the contours on Darton's map indicate that the decline at some wells may have been as much as 80 feet.

During the present investigation an effort was made to obtain the available data concerning the decline of the artesian head since the beginning of artesian development. Accurate records of the head in former years in the part of the State west of the Missouri River are very scarce, and generalizations must largely be based on the memories of well owners and drillers as to the pressure or the height to which the water would rise in certain flowing wells at the time they were completed or in some later year, or the year in which certain wells ceased to flow, indicating a water level at the top of the well.

The data collected on the decline in head have been arranged according to counties and are presented in the following table.

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20. Darton, N. H., U.S. Geol. Survey Geol. Atlas, Newell folio No. 209, p. 7, 1919.
21. Darton, N. H., Artesian waters in the vicinity of the Black Hills, South Dakota: U.S. Geol. Survey Water-Supply Paper 428, 1918.

Decline of artesian head in wells drawing

from the Dakota sandstone

Well No. or location	Period	Amount of decline in feet[a]	Well No. or location	Period	Amount of decline in feet[a]	Well No. or location	Period	Amount of decline in feet[a]
	Butte County			Hughes County			Lyman County cont'd	
1	1932[b]–1935	8.5	Pierre[c]	1895–1930	300	60	1918–1935	19
9[c]	Between 1909 &							
	1917–1935	20.5		Lyman County		61	1916–1935	50
	Haakon County		McClure	1911–1935	120 ±	64	1918–1935	75 ±
21	1925–1935	18	48	1918–1935	32	66	1919–1935	35
	Stanley County		50	1931[b]–1935	7	69	1914–1935	45 ±
28	1918–1930	60?	51	1922–1935	14		Tripp County	
30	1912–1934	125 ±	54	1915–1935	64[e]	71	1931[b]–1935	3
33	1912–1915	36[d] ±	55	1907–1915	69[e]	74	1927–1935	8
	1915–1935	92[d] ±		1915–1935	51[e]		Brule County	
	1912–1935	125[d] ±		1907–1935	120[e]	Chamberlain[c]		
							1891–1900	140
34	1912[b]–1934	75	57	1925[b]–1935	16		1900–1915	90 ±
37	1911–1934	84 ±	58	1914–1935	40		1891–1915	230 ±
39	Between 1923 &							
	1925[b]–1935	55						

a. Based on reports of well owners, well drillers, or local residents of water level at the time well was drilled, cleaned, recased or year it ceased to flow, unless otherwise indicated.
b. Ceased to flow.
c. See text pages 45–50
d. Based on report by Derr, H. M., Report on artesian wells: South Dakota State Engineer Sixth Beinn. Rept., for 1915–16 p. 265.
e. Based on report by Derr, H. M., idem, p. 238.

A report by John Berg [22] gives general information concerning the pressure and flows of wells by counties. That part of the information which pertains to the area covered by the present report may be summarized briefly as follows: There is considerable waste of water in nearly all the counties, with pressures and flows decreasing fast. In Butte, Gregory, Meade, and Stanley Counties flows are obtained only on the lower lands. In Hughes County the artesian head is falling about 4 feet a year, and in Stanley County from 3 to 5 feet a year.

A table given by Berg [23] shows that in 1921-22 there were in the area covered by this report 220 artesian wells, of which 203 were flowing. These 203 wells flowed about 5,900 gallons a minute, according to assessors' reports. In 1910-12, according to the same table, there were 122 artesian wells having a combined flow of about 5,300 gallons a minute. Although the number of wells was nearly doubled in the 10-year period, the combined flow remained nearly the same. Thus the average flow of the wells in 1910-12 must have been reduced to nearly one-half by 1921-22.

From the data just presented it is apparent that there has been a persistent decline of the artesian head. The decline has occurred in all parts of the area, but the amount and rate of decline have differed from one locality to another. The greatest decline recorded is in the Missouri Valley, along the east margin of the area--more than 230 feet at Chamberlain and 300 feet at Pierre. This is partly explainable by the lack of definite records of the head in other parts of the area for the early years of the artesian development, but doubtless also by the much greater draft in the Missouri Valley and the part of the artesian basin east of the river. The decline has proceeded at a much slower rate in recent years, because it has caused a decrease in yield of flowing wells and a consequent decrease in draft from the artesian basin.

The importance of measurements on the artesian wells in South Dakota was recognized by Todd [24] as early as 1898. At that time he recommended in part that "a careful record be kept of the pressure in the various artesian wells in the different parts of the State." It is to be regretted that systematic measurements of pressure or water-levels have not been made in the past. Provision should be made to obtain accurate and systematic records of the head in a number of carefully selected and controlled wells, in order to accumulate definite information on which to base conclusions as to the rate of depletion of the artesian supply and as to whether there is appreciable replenishment of the supply. A groundwork of such basic data is essential for making sound and comprehensive plans in regard to the use and conservation of the artesian water supply, which sooner or later must be taken under consideration.

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22. Berg, John, Artesian wells: South Dakota State Engineer 9th Bienn. Rept., for 1921-22, pp. 51-56, 1922.
23. Idem, pp. 51, 56.
24. Todd, J. E., Geology of South Dakota: South Dakota Geol. Survey Bull. 2, p. 11, 1898.

ARTESIAN WATER IN THE LAKOTA SANDSTONE

Beneath the Dakota sandstone and separated from it by an impermeable layer of clay known as the Fuson shale lies the La-Kota sandstone. As a source of artesian water in the western part of the area it is at least equal to and perhaps better than the Dakota sandstone, largely because of its greater thickness and greater water-yielding capacity. In the outcrop area along the northern edge of the Black Hills its average thickness is about 150 feet,[25] but it thickens to more than 400 feet in the region south of Fairburn. In contrast, the Dakota sandstone in most of the region from Whitewood to Hermosa is less than 50 feet thick but it increases in thickness south of Fairburn and reaches a maximum of 200 feet at Buffalo Gap. Because the Lakota sandstone lies at greater depth than the Dakota sandstone, relatively few wells penetrate it except along the edge of the Black Hills, close to its outcrop area. It seems to be the rule that wells which penetrate the Lakota sandstone yield larger flows of water under a greater head than those which draw from the Dakota sandstone. This may be due in part to the smaller draft from the Lakota sandstone and a consequently smaller reduction in pressure head. However, if the porosity and permeability of the Lakota sandstone are equal to those of the Dakota sandstone, and there is no reason to believe that they are materially less, the Lakota, because of its greater thickness, especially in the outcrop area, should contain a larger volume of water and should yield a larger flow than the Dakota. The areal extent of the Lakota sandstone is not definitely known, but according to the log of the Standing Butte well (No. 27), it is present as far east as northeastern Stanley County. Probably it underlies all or most of the area covered by this investigation.

Some idea of the difference between the Dakota sandstone and the Lakota sandstone in both yield and pressure is afforded by wells that have been drilled through the Dakota to the Lakota in search of additional water supplies. (See the table at the end of this report.) The most easterly well for which a record is available is the 2,293-foot municipal well at Philip (No. 18) drilled in 1934. According to Mr. Junkman, caretaker for the well, the first flow amounted to about 1 gallon a minute at a depth of about 1,980 feet. The flow increased to 4 or 5 gallons a minute when the well had reached a depth of about 2,080 feet, presumably near the base of the Dakota sandstone. The third flow, which is inferred to come from the Lakota sandstone, near the bottom of the well, amounted to 10 gallons a minute. On June 30, 1935, the measured flow amounted to 14 gallons a minute. According to F. E. Phole, of Philip, the pressure of the water when the well had reached a depth of about 2,080 feet was about 6 pounds to the square inch.

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25. Darton, N. H., and Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Central Black Hills folio (No. 219), p. 12, 1925.

It was not possible to measure the head when the writer visited the well, in June 1935, because of the pump installation, but two reported measurements of pressure after the well had been completed are available. The Norbeck Co., which drilled the well, reported a pressure of about 25 pounds [25] to the square inch, and Mr. Junkman reported a pressure of 14 or 15 pounds to the square inch. Mr. Junkman questioned the accuracy of his measurement, as the gage he used was old and in poor condition. The report by the Norbeck Co. has, therefore, been accepted as the more accurate of the two. Thus in this well there was between the Dakota sandstone and the Lakota sandstone an increase in yield of about 10 gallons a minute and an increase in pressure of about 19 pounds to the square inch, or an increase in head of about 44 feet.

The 558-foot well of Frank Gruble (No. 14), drilled in 1931, also penetrated both the Dakota sandstone and the Lakota sandstone. This well is within 3 or 4 miles of the outcrop area of the two sandstones. At the time the well was drilled the flow from the Dakota sandstone was only about 1 gallon in 5 minutes, but the flow from the Lakota sandstone was about 50 gallons a minute. No measurement of pressure was made at that time, but Paul Gruble, the driller, stated that the pressure of the water from the Dakota sandstone was "very small", and he estimated the static level as not more than 10 feet above the land surface. A measurement made on August 1, 1935, gave the static level of the water in the Lakota sandstone as 110 feet above the land surface. Thus the head of the Lakota sandstone is about 100 feet more than that of the Dakota sandstone.

A well (No. 8) drilled at the Belle Fourche field station of the United States Department of Agriculture in 1935 penetrated both the Dakota sandstone and the Lakota sandstone. On passing through the Dakota between the depths of 2,400 and 2,450 feet, the water level rose within about 250 feet of the top of the well. Drilling was continued through the Lakota sandstone from 2,540 feet to about 2,595 feet, and the water level then rose within about 75 feet of the top of the well. After casing off the water from the Dakota sandstone the water level was about 65 feet from the top. Thus there was an apparent difference in head of 185 feet between the two sandstones. On February 13, 1935, after the well had been bailed for about 10 hours and about 22,000 gallons of water had been removed, it began to flow at the rate of 25 gallons a minute. A measurement on February 14, 1935, showed a pressure of 4 pounds to the square inch. On March 4, 1935, after the flow had been shut off for 6½ days, the pressure was 9 pounds to the square inch before the well was opened. The flow, measured immediately after the well was opened, was 33 gallons a minute. It seems evident, therefore, that the bailing operations removed the muddy water and cleared up the well. As muddy water has a higher specific gravity than clear water, the water level evidently did not rise to its normal position until the water in the well became clear. Had this operation been carried on when the Dakota

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25. Norbeck, George, written communication.

sandstone was penetrated, the water level would no doubt have stood closer to the top of the well than it did. As the result of the bailing, the level of the water from the Lakota sandstone rose about 85 feet.

It seems evident that the Lakota sandstone will yield larger flows under greater pressure than the Dakota sandstone, at least as far east of the Black Hills as Philip and probably as far as the Missouri River. If this condition does persist to the Missouri River, the Lakota sandstone forms a potential supply of artesian water that hitherto has been but slightly developed. It is of great importance to residents within the area, especially in localities where wells drawing from the Dakota sandstone have ceased or nearly ceased to flow. In these localities it would generally be possible to drill new wells or deepen existing wells to the Lakota sandstone, and thereby again to obtain artesian flows. In future development of water supplies in the central and eastern parts of the area the Lakota sandstone offers possibilities that should not be overlooked. A statement in regard to the character of the water is given under the heading "Quality of water."

Locally, at least, there has been a decline in head of the water in the Lakota sandstone. The only measure of this decline was obtained from the municipal well at Belle Fourche (No. 3). This well, except in emergencies, is no longer used as a water supply and has been shut off for several years. Darton[26] gives a reported pressure of 45 pounds to the square inch on this well, equivalent to a static level of about 104 feet above the land surface. A measurement of the pressure on August 22, 1935, gave a static level of only 32 feet above the land surface. As the water supply of the Lakota sandstone has not been developed extensively, it is believed that the decline in head that has occurred up to the present time is largely confined to more or less local areas in which there has been development. The principal area in which the Lakota has been tapped borders the outcrop zone along the northeastern edge of the Black Hills, from the vicinity of Belle Fourche to the vicinity of Fort Meade. Many wells are reported to draw water from the Lakota sandstone in the district around Belle Fourche.

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26. Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 78, 1909.

ARTESIAN WATER IN THE MINNELUSA SANDSTONE AND THE DEADWOOD FORMATION

Beneath the Lakota sandstone and separated from it by about 1,000 feet of shale, sandstone, and limestone lies the Minnelusa sandstone. As a source of water supply the Minnelusa can probably be considered only in a relatively narrow strip close to its outcrop area along the edge of the Black Hills, where it can be reached at moderate depths. Where it occurs in other parts of the State it lies so deep that it cannot be developed as a source of water except at very heavy cost. Wells that penetrate it along the edge of the Black Hills yield water copiously. The Bear Butte well (No. 12), about 5.5 miles north and east of Sturgis, is perhaps the best example. This well was originally drilled as an oil test hole but was abandoned because of the large flow of water encountered in the Minnelusa sand. According to reports the flow was about 3,000 gallons a minute at the time the well was drilled. Various unsuccessful attempts have been made to control the well. When the writer visited it on July 31, 1935, the flow was estimated as between 700 and 800 gallons a minute, coming through an opening in the side of the casing.

The 1,225-foot well of St. Martin's Academy (No. 13) in Sturgis, at an altitude of 3,465 feet, drilled in 1935, is too high to afford a flow, the water standing about 288 feet below the land surface. (See table of well records) The well is pumped and yields water of good quality and in quantity more than sufficient for the needs of the academy. Many flowing wells in the vicinity of Spearfish and some in the vicinity of Rapid City draw water from the Minnelusa sandstone.

A comparison of the water-yielding capacity of the Minnelusa sandstone and the underlying Deadwood formation is afforded by the Rapid City municipal well (No. 15) drilled in 1935 to a depth of 1,463 feet. According to E. M. Sneckenberger, city manager, the well passed through the Minnelusa sandstone at about 920 feet and penetrated the Deadwood formation. Mr. Sneckenberger reported that the Minnelusa sandstone at first yielded a flow of about 300 gallons a minute and the shut-in pressure of the water was about 11 pounds to the square inch, but the Deadwood formation yielded only about 160 gallons a minute, although the shut-in pressure was about 62 pounds. The static level of the water from the Minnelusa sandstone was about 25 feet above the land surface, or about 3,425 feet above sea level, and that of the Deadwood formation about 143 feet above the land surface, or about 3,543 feet above sea level. Water from the Minnelusa sandstone had a temperature of 52°F. and that from the Deadwood formation 64°F.

On completion of drilling operations, with the Minnelusa sandstone cased off, the well was shot at a depth of 1,460 feet with 160 quarts of nitroglycerine, and the flow of the Deadwood formation then decreased to about 60 gallons a minute. After the shooting the well was cleaned out and the casing perforated, so that the water comes from both formations. The combined flow of the two formations was about 340 gallons a minute in February 1935, but it had decreased to about 250 gallons a minute by July 1935.

E. M. Sneckenberger, city manager of Rapid City, reported the following results of a pumping test made on well 15 in July 1935:

Draw-down (feet)	Discharge (gallons a minute)	Specific capacity (gallons per foot of draw-down)
27	315	11.7
37	430	11.6
42	460	11.0
44.5	496	11.1
64	640	10.0

When the draw-down exceeded 64 feet the specific capacity began to decrease notably, and therefore the test was not carried further.

TEMPERATURE OF THE ARTESIAN WATER

There was no opportunity in this brief investigation to make an adequate study of the temperature of the artesian water and its geologic and hydraulic interpretation. However, the temperature data that were obtained are recorded in the table of well records for future use. Except as otherwise indicated the recorded temperatures were obtained by the writer at the mouth of the well after it had been discharging for some time.

In general the temperature of the artesian water from the Dakota sandstone increases eastward from the Black Hills for a distance ranging from 100 to 150 miles and then decreases irregularly toward the Missouri River. The computed depth-temperature gradient, or number of feet in depth for each increase of 1° F. in temperature of the water is not at all uniform. It ranges from about 9 feet in the vicinity of Chamberlain to about 23 feet at the Whitehorse well (No. 26), in the Cheyenne River Indian Reservation. Except in well 26 the depth-temperature gradient appears to decrease from the Missouri River toward the west. At the J. T. Singleton well and the Bierwagon well (No. 21), near West Fork, and the Red Scaffold well (No. 25), in the Cheyenne River Indian Reservation, the temperature increases 1° F. for about each 20 feet of depth.

The highest temperature recorded for water coming from the Dakota sandstone was 120° F., at well 25.

The highest temperature noted in the area was 130° F., at the deep well of the Weaver Oil Co. (No. 17), south of Kadoka. The formations from which this water was coming is not certainly known but is believed to be the Lakota sandstone.

QUALITY OF WATER

During the course of the investigation numerous inquiries were made of well owners as to the quality of the artesian water, especially as to its potability and hardness. It was learned that the water from all the wells along the edge of the Black Hills is considered potable and is generally soft. A few well owners reported hard water. Analyses of water from wells 8 and 25 (below) show more fluoride than is considered desirable in water to be used by children. The dental defect known as "mottled enamel" has been definitely associated with the regular drinking by children of water with as much as 2 parts per million of fluoride. Additional analyses would probably show excessive amounts of fluoride in other well waters that have been considered acceptable for human use.

In the northeastern part of the area most of the water was found to be not potable though generally soft. In the southeastern part it is used for drinking and domestic supply, although the water is hard except that a few well owners reported soft water. So far as could be learned during the course of the investigation all the water was suitable for livestock use.

All the reported nonpotable water carries varying quantities of inflammable gas and is very saline. The high degree of salinity renders it unfit for culinary use. As a general rule the test by which the local residents determine potability is whether or not the water can be used to make coffee. In the area of nonpotable water the residents depend chiefly upon surface water or rain and snow water collected during storms and stored in cisterns. In some localities there are shallow wells that obtain water from deposits of sand and gravel. These wells are usually located in the gravel terraces along streams or in the alluvium of the stream valleys. The quality of the water from some of these wells is good and that from others bad. Many of these shallow wells became dry during the drought of 1933-34.

In the southeastern part of the area wells yielding soft water were found only a few miles distant from wells yielding hard water. Both the hard and soft water wells were apparently supplied from the Dakota sandstone. It was noted also that practically all the wells in the eastern part of the area yielded water containing a considerable amount of iron. Red and reddish-brown deposits and stains were common in the tanks and stock troughs and on plumbing fixtures.

No samples of water were collected for chemical analysis during the course of the investigation. However, the records were obtained by several chemical analyses which have been made from time to time by other agencies. In addition chemical analyses of the artesian water have been published in early reports.[27] The analyses that were collected are given below.

Well 8, 2,600 feet deep, 12-½ inches in diameter, in the NE¼ sec. 24, T. 9 N., R. 5 E., Belle Fourche field station, U. S. Department of Agriculture.

8a. Sample collected from Pierre shale at 50 to 60 feet.
8b. Sample collected at depth of 2,200 feet (200 feet above top of Dakota sandstone) after the well had penetrated the Lakota sandstone.
8c. Sample from Lakota sandstone at depth of 2,580 feet.
8d. Sample from Lakota sandstone at 2,600 feet.

Analysts: 8 a, L. V. Wilcox; 8 b, 8 c, Wilcox and Hatcher; 8 d, Wilcox, Higgins, and Hatcher, U. S. Department of Agriculture.

12. Bear Butte well, 690 feet, 10 inches in diameter, in the SW¼ sec. 18, T. 6 N., R. 6 E. Water from Minnelusa sandstone. Because of the small amount of casing in the well it is possible that some water from overlying formations may be mixed with water from the Minnelusa sandstone.

15. Municipal Park well, 1,463 feet deep, 10 inches in diameter, in the NW¼ sec. 9, T. 1 N., R. 7 E., owned by Rapid City. Water from Minnelusa sandstone and Deadwood formation.

18. Well 2,293 feet deep, 6 inches in diameter, in the SW¼ sec. 13, T. 1 N., R. 20 E., owned by city of Philip. Water from Lakota sandstone.

19. Well 1,842 feet deep, 3 inches in diameter, in the NW¼ sec. 13, T. 1 N., R. 23 E., at Nowlin. Owned by Chicago & North Western Railway Co. Water from Dakota sandstone.

Analysts: 12, Higgins, Hatcher, and Wilcox, U. S. Department of Agriculture; 15, Wilcox and Nelson, U. S. Department of Agriculture; 18, B. A. Dunbar, South Dakota State College; 19, Guy G. Frary, State chemist.

21. Well 2,090 feet deep, 4 inches in diameter, in the NW¼ sec. 11, T. 6 N., R. 21 E., owned by Dan Bierwagon estate. Water from Dakota sandstone.

25. Norbeck well, 2,385 feet deep, 6¼ inches in diameter, in the SE¼ sec. 6, T. 9 N., R. 19 E., 30 miles southeast of Fair, on Cheyenne Indian Reservation. Water from Lakota sandstone.

46. Well 1,836 feet deep, 8 inches in diameter, in the SW¼ sec. 25, T. 41 N., R. 27 W., at Wood, owned by Chicago & North Western Railway Co. Water from Dakota sandstone.

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27. Shepard, J. H., The artesian waters of South Dakota: South Dakota Agr. Coll. and Exper. Sta. Bull. 41, 1935. Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, 1909; Artesian water in the vicinity of the Black Hills, South Dakota: U. S. Geol. Survey Water-Supply Paper 428, 1918.

47. Well 1,681 feet deep, 8 inches in diameter, in the NW$\frac{1}{4}$ sec. 12, T. 40 N., R. 25 W., at Mosher, owned by Chicago & North Western Railway Co. Water from Dakota sandstone.

Analysts: 21, Smith-Emery Co.; 25, Wilcox and Nelson, U. S. Department of Agriculture; 46, 47, H. D. Browne, Chicago & North Western Railway Co.

A, Well in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 14, T. 8, R. 4, near Nisland, owned by Peter Vallery. Water from Dakota sandstone.

B, Well in the SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 11, T. 8, R. 4 near Nisland, owned by William Burke. Water from Dakota and Lakota sandstones.

C, Fort Meade well, 360 feet deep, 4 inches in diameter, at junction of highway 24 and entrance road to Fort Meade from the west, on the south side of the road, C.C.C. camp 1728. Water from Lakota sandstone.

D, Zeal well, 2,970 feet deep, in the NW$\frac{1}{4}$ sec. 16, T. 9 N., R. 17 E., Meade County. Water from Lakota sandstone.

E, Well owned by South Dakota State cement plant at Rapid City. Water from Minnelusa sandstone.

Analysts: A, B, C, E, U. S. Department of Agriculture; D, Guy G. Frary, State Chemist.

Analyses of water from wells in the west-central part of South Dakota. (Numbers at heads of columns correspond to numbers in table of well records)

	Parts per million			
	8 a	8 b	8 c	8 d
Date (1934)	July 12	Oct. 3	Oct. 3	Nov. 26
Silica (SiO_2)	--	--	--	--
Iron (Fe)	--	--	--	--
Calcium (Ca)	--	0.8	0.4	4.0
Magnesium (Mg)	--	2.4	2.0	2.0
Sodium (Na)	5,055	261	393	410
Carbonate (CO_3)	51	124	50	24
Bicarbonate (HCO_3)	467	321	528	589
Sulphate (SO_4)	--	87	337	361
Chloride (Cl)	2,816	39	14	8.9
Fluoride (F)	--	2.2	4.0	4.2
Nitrate (NO_3)	--	.62	.62	Trace
Boron (B)	--	.48	.34	.28
Sum of constituents reported	8,152	676	1,061	1,104
Total hardness as $CaCO_3$	--	12	9.2	18

Analyses of water from wells in the west-central part of South Dakota - continued.

	Parts per million			
	12	15	18	19
Date	10/16/34	4/2/35	--	--
Silica (SiO_2)	--	--	38	28
Iron (Fe)	--	--	--	--
Calcium (Ca)	288	43	8.8	6.4
Magnesium (Mg)	61	19	2.0	1.5
Sodium (Na)	2.3	7.8	720	385
Carbonate (CO_3)	0	0	54	13
Bicarbonate (HCO_3)	210	225	1,305	231
Sulphate (SO_4)	752	18	8.1	23
Chloride (Cl)	5.3	--	259	410
Fluoride (F)	.6	.2	--	--
Nitrate (NO_3)	.62	--	--	--
Boron (B)	.07	.04	--	--
Sum of constituents reported	1,213	199	1,733	981
Total hardness as $CaCO_3$	970	185	30	22

Analyses of water from wells in the west-central part of South Dakota - continued.

	Parts per million			
	21	25	46	47
Date	--	3/13/35	--	--
Silica (SiO_2)	11	--	26	20
Iron and Aluminum oxides (Fe_2O_3-Al_2O_3)	2.4	--	3.6	.5
Calcium (Ca)	70	9.6	10	71
Magnesium (Mg)	23	4.5	4.9	9.8
Sodium (Na)	2,512	2,197	687	516
Carbonate (CO_3)	0	0	--	--
Bicarbonate (HCO_3)	127	1,696	1,033	451
Sulphate (SO_4)	4,554	1.4	172	768
Chloride (Cl)	632	2,417	362	120
Fluoride (F)	--	2.8	--	--
Nitrate (NO_3)	--	1.9	--	--
Boron (B)	--	7.7	--	--
Sum of constituents reported	a/ 7,870	5,477	1,774	1,727
Total hardness as $CaCO_3$	269	42	45	218

a/ Includes 3.4 parts of ammonium (NH_4)

Analyses of water from wells in the west-central part of South Dakota - continued.

	Parts per million				
	A	B	C	D	E
Date	10/34	10/34	3/21/35	--	10/23/34
Silica (SiO_2)	12	15	--	8.5	--
Iron (Fe)	--	--	--	1.5	--
Calcium (Ca)	7.2	40	245	14	45
Magnesium (Mg)	2.1	14	75	4.9	21
Sodium (Na)	250	111	84	776	3.2
Carbonate (CO_3)	0	0	0	--	0
Bicarbonate (HCO_3)	291	240	345	465	231
Sulphate (SO_4)	300	208	795	705	22
Chloride (Cl)	19	5.3	7.8	444	3.6
Fluoride (F)	.7	.2	.2	--	.2
Nitrate (NO_3)	Trace	Trace	1.9	--	1.9
Boron (B)	.18	.06	.11	--	.04
Sum of constituents reported	734	512	1,379	2,183	211
Total hardness as $CaCO_3$	27	157	920	55	199

UNDERGROUND LEAKAGE

Causes of leakage

The chief causes of underground leakage of wells are defective construction and corrosion. Defective construction is usually the result of using inadequate equipment or of hiring incompetent or inexperienced drillers who are not familiar with the ground-water conditions of the area. It is not known to what extent defective construction has caused underground leakage in wells in South Dakota, but, especially in recently drilled wells, it is believed to be small.

The principal cause of underground leakage and often complete failure of the well is corrosion of the metal casing -- essentially an electro-chemical process accomplished through the agency of water and resulting in deterioration and destruction of the casing in wells. In many of the wells examined the surface pipe and fittings were so badly corroded that they were unfit for further use. Owing to the corrosive action of the water many of the wells have been recased once and some two or three times. With the possible exception of a narrow strip along the edge of the Black Hills none of the area appeared to be entirely free from corrosion of the casing. The corrosive action was much worse in the areas of nonpotable water -- that is, water carrying gas and having a high salt content -- than in the area of potable water. It is a significant fact that the casings of flowing wells deteriorate sooner than those of nonflowing wells. This may be due, to some extent, to the mechanical wearing away of the casing by flowing water, but it is believed to be due in greater part to the larger amounts of corrosive salts or acids that are brought into contact with the casing. Thus to reduce the flow of the well would increase the life of the casing.

The history of well 41, used to supply gas to the city of Fort Pierre, indicates that cast-iron casing lasts longer in wells in this territory than wrought-steel casing. This well was drilled in 1905. In 1909 it was recased with 6-inch wrought steel casing. In 1920, because of the failure of the 6-inch casing, it was recased a second time with 4-inch cast-iron casing having wrought-steel couplings at the joints. The lengths of casing were not screwed far enough into the couplings to form a tight butt joint, and therefore a small space was left between the ends of each two lengths. In August 1935 the yield of the well had decreased to about one-half its normal yield and Anton Sather, well driller, was hired to recondition it. Mr. Sather attempted to pull out the string of 4-inch cast-iron casing, but found that the wrought-steel couplings were so badly corroded that they would not hold together. The couplings apparently were corroded where they came into contact with the water in the narrow space left between the ends of the lengths of casing. It was possible, however, to remove about 200 feet of 4-inch casing. As the well was found to be clogged near the bottom, it was cleaned out to its original depth. The cleaning operations were difficult, because splinters and scale from the top 200 feet of the 6-inch wrought-steel casing, which was badly corroded, continually fell into the well. After being cleaned the 200 feet of 4-inch cast-iron casing was replaced, and the yield of the well returned to its former flow. The cast-iron casing after 15 years of service was still in good condition. The type of casing best suited to combate the corrosive action of the water presents a problem that should not be overlooked in future development. A relatively small amount wisely spent when a well is finished may save much in the future.

In view of the general character of the formations overlying the Dakota sandstone it would appear that there is little opportunity for underground leakage. There are, however, in these overlying formations thin strata of permeable sandstone that carry water under a low head. The largest and most persistent of these strata is reported to occur from 100 to 300 feet above the top of the Dakota sandstone. According to Mr. Sather, who has drilled extensively in the eastern part of the area, the water from this stratum of sandstone has a higher head now than the decade 1900 to 1910. Such a condition suggests underground leakage of water from the Dakota sandstone into this upper sandstone and possibly into other permeable strata.

Well 40, in Fort Pierre, is suspected to leak underground, as its static water level is considerably below that of nearby wells.

Additional work and examination of wells by means of a deep-well current meter[28] would be necessary before the extent and amount of underground leakage could be determined.

Wild wells

Throughout the western part of the State, and doubtless in the eastern part also, there are numerous "wild wells" --that is, wells which flow unrestricted or only partly restricted the year around and whose water is not put to beneficial use. The largest of these are the Standing Butte well (No. 27) and the Bear Butte well (No. 12). When visited during the summer of 1935 the Standing Butte well was flowing about 1,000 gallons a minute and the Bear Butte well between 700 and 800 gallons a minute. There are numerous others throughout the area, especially in the lowlands along the Missouri River and in the valleys and along tributaries of the Bad and White Rivers.

No attempt was made to visit and record all the reported wild wells, but some information in regard to them was collected. Several such wells in Chamberlain were drilled between 1890 and 1900 as power wells and were used to operate a flour mill and an electric-light plant. Eventually the pressure decreased so greatly that the wells were abandoned as a source of power. The original yield of these wells, according to reports by Shepard[29] and Darton,[30] ranged between 1,450 and 5,000 gallons a minute. The combined flow from six of them, estimated from these same reports, must have been in the neighborhood of 20,000 gallons a minute. In 1915, according to Derr,[31] three of these wells, two 6-inch and one 8-inch, because of defective or corroded casing, had broken out underground and were running "wild." The combined flow of the three wells at that time was estimated as about 3,000 gallons a minute. A pool about 200 feet in diameter and of unknown depth had been formed and a large channel eroded to the Missouri River a short distance away. On account of erosion of the channel and slumping of ground around the pool, a highway bridge had been completely undermined, and the foundation of a flour mill had been so badly cracked that the building had to be moved. When the writer visited the wells, in July 1935, they were reported to be still flowing, but because of a high stage of the Missouri River, backwater had flooded the eroded channel and well.

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28. McCombs, John, and Fiedler, A. G., Methods of exploring and repairing leaky artesian wells: U. S. Geol. Survey Water-Supply Paper 596, pp. 4-32, 1927.
29. Shepard, J. H., The artesian waters of South Dakota: South Dakota Agr. Coll. Exper. Sta. Bull. 41, pp. 26, 27, 1895.
30. Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, pp. 74, 75, 1909.
31. Derr, H. M., Report on artesian wells: South Dakota State Engineer 6th Bienn. Rept., for 1915-16, p. 193, 1916.

Most of the wild wells are not equipped with shut-off valves, and on those that are so equipped the valves are so badly rusted that they cannot be closed. Some have been allowed to flow unrestricted since they were drilled 10, 20, or even 30 years ago. There are other wells that flow unrestricted but are not classified as wild wells because part of the water is put to some beneficial use, though this part is usually a small percentage of the total flow. The total waste from all these wells is great. Thus in a year the flow of water from the Standing Butte well is sufficient to cover an area of about 2¼ square miles 1 foot deep. The total amount of water wasted is without a doubt much more than the amount used. Curtailment of this waste would lessen the rate of the decline in head and would at least postpone the time when present flowing wells will cease to flow. It is essential to any effective plan of future water conservation. From time to time laws have been enacted to conserve the artesian water, but owing to lack of enforcement there has resulted little if any real conservation.

An act passed by the State legislature, during the session of 1919, known as Senate Bill 25, is quite definite in its requirements concerning the control of the flowing wells with large yield. It reads in part as follows:

> "Every owner of a well capable of delivering more than twenty-five (25) gallons a minute, shall provide and sustain a valve or valves, capable of controlling the discharge of the well, and only such escape of water shall be allowed as corresponds to the taxes assessed and paid for that year."

A penalty is provided for violation of this section of the act.

DETERMINATION OF HEAD AT PROPOSED WELL SITES

The altitude to which the water from the Dakota sandstone may be expected to rise is shown on the accompanying map by contours of the piezometric surface. Thus by means of these contours it is possible to estimate the altitude to which the water will rise at a proposed well site. In order to determine whether the well will be flowing or nonflowing it is also necessary to know the altitude of the land surface at the site. Wherever the piezometric surface is below the land surface nonflowing wells will be obtained, and wherever it is above the land surface flowing wells will be obtained. The depth at which the water will stand in a nonflowing well may be estimated by subtracting the altitude of the piezometric surface from the altitude of the land surface at the proposed site. The approximate height above the land surface to which the water will rise in a flowing well is found by subtracting the altitude of the land surface from the altitude of the piezometric surface. To obtain an estimate of the shutin pressure, in pounds to the square inch, at a prospective flowing well, the computed height in feet, to which the water will rise above the surface should be divided by 2.3. For instance, if at the proposed well site the altitude of the land surface is 1,900 feet and that of the piezometric surface as shown on the map is 2,000 feet, the well may be expected to flow, and the computed forecast of the shut-in pressure will be about 43 pounds to the square inch. It should, of course, be understood that the actual pressure may deviate considerably from the forecast, especially in localities far from wells on which measurements of head were obtained. Also, it should be remembered that the accompanying map represents the piezometric surface as it was in 1935 and that forecasts made after a lapse of a few years will be in error by an amount equal to the decline in head since 1935.

If, as is contemplated, artesian wells are to be drilled to relieve water shortage in certain localities, further and more intensive investigation of the localities is desirable. It is quite obvious that the scope and extent of an investigation such as the present do not permit an intensive study of every locality. In fact, such a study can best be made after the limits and areal extent of the locality have been determined. Strategic selection of the site for the first well drilled will give valuable information that can be used in selecting the sites of subsequent wells. As topographic maps are lacking for most of the area, the altitude of the land surface at the proposed well site will have to be determined, preferably by instrumental leveling from a bench mark of known altitude. A permanent bench mark should be established at each well site, in order that the altitude of the water level in the well can be determined at any time in the future, regardless of changes that may be made at the mouth of the well. If flowing wells are desired it may be necessary to prepare a topographic map of some localities in order to determine the low points of the land surface. After the well is completed provision should be made for measuring the water level. In nonflowing wells this may be done by leaving an opening through which a tape may be lowered to the water surface. In flowing wells valves should be provided so that the flow can be shut off and a pressure gage attached. Measurements of water level in the wells should be made periodically, as the resulting data will be valuable in future studies of artesian conditions.

The maximum size of the well will depend upon the quantity of water desired and the cost of drilling. In view of all the factors that might influence the life and usefulness of the well, it seems desirable that the top diameter should be not less than 4 inches and preferably larger.

In order that some idea may be formed as to the parts of the area where flowing wells may be obtained and the approximate lift that will be required in different parts of the area where the artesian water will not rise to the surface, the subject is discussed briefly below.

In the lack of topographic maps for most of the area it is not possible to make specific statements regarding the area of flow or the amount of lift in the areas that are too high for a flow. The area is traversed by four principal streams -- the Missouri River, the Cheyenne River, the Bad River, and the White River -- and is drained by numerous tributaries of these streams.

Some of these streams and some of their tributaries have broad, gently sloping valleys, but others are so deeply entrenched that the relief may be as much as 500 feet. Thus the area of flow or the amount of lift depends upon the configuration of the land surface. The subject can best be discussed geographically by counties or a grouping of counties.

Plains region bordering the Black Hills: This region comprises that part of Butte, Meade, Pennington, and Custer Counties which lies east of the outcrop of the Dakota sandstone. In Butte and Meade Counties flowing wells or nonflowing wells of moderate lift may be obtained in a district a few miles wide adjacent to the outcrop area. There are no known flowing wells from the Dakota sandstone in Pennington and Custer Counties, but flowing wells can probably be obtained in the lowlands for a few miles east of the outcrop. It is not probable that any flows will be obtained on the hogbacks or on the ridges between the stream valleys. Flowing wells may possibly be obtained in the southeastern part of Pennington County in the vicinity of Conata. The northern and eastern parts of Butte County and the central part of Meade County are believed too high to afford flows in the Belle Fourche Valley. In the eastern part of Meade County flowing wells can be obtained in the stream valleys of Cherry Creek and the Cheyenne River. In an oil test (Zeal well) at an altitude of 2,177.8 feet, drilled in 1927 in the NW$\frac{1}{4}$ sec. 16, T. 9 N., R. 17 E., a few hundred feet west of the highway bridge over Cherry Creek, an artesian was obtained from the Dakota sandstone at a depth of 2,600 feet. It is not likely that flowing wells will be obtained in central and northeastern Pennington County and eastern Custer County except in the Cheyenne River Valley and on some of its major tributaries.

Cheyenne River Indian Reservation: This area includes the counties of Armstrong, Dewey, and Ziebach. Flowing wells may be obtained in the valleys of the Moreau River, Missouri River, Cheyenne River, and Cherry Creek and far up their major tributaries. Here these streams are all deeply entrenched, and flows cannot be expected on the uplands. For instance, it is estimated that at an altitude of 2,360 feet, on the divide between the Moreau and Cheyenne Rivers, the water will rise only within 500 or 600 feet of the surface.

Haakon and Stanley Counties: These counties lie for the most part between the Cheyenne and Bad Rivers. Except possibly in southwestern Haakon County, flowing wells may be obtained in the valleys and for a considerable distance up the tributaries of these two rivers and in the valley of the Missouri River. Flowing wells were formerly obtained on the uplands in Stanley County, but the decline in head has been so great that this is no longer possible. It is estimated that in the vicinity of the Milesville post office (altitude 2,345 feet), in Haakon County, the water will rise within about 150 feet of the surface; in the vicinity of Moenville post office, between 150 to 200 feet of the surface; and in the vicinity of Sansarc post office, in Stanley County, between 150 feet and more than 200 feet of the surface, according to the topographic situation. At well 22, owned by Julius Roseth, about $1\frac{1}{2}$ miles west of Moenville, the water rose within 9 feet of the surface. However, this well is on the valley floor of a small creek that is entrenched about 150 feet below the surrounding plain. Thus the depth to water on the surrounding plain would be greater than 150 feet. The post offices just mentioned are in the drainage area of the Cheyenne River, the land surface rising to the south, and hence on the divide between the Cheyenne and Bad Rivers the depth to the water level would be greater.

At well 31, about 2 miles south of Hayes, in the flood plain of Frozenman Creek, the artesian water has a static level of about 49 feet above the land surface, but it is doubtful if a flowing well would be obtained at Hayes, which is about 60 feet higher. The depth to the water level in well 33, at the old Meers post office, was reported as about 80 feet, and in well 30, owned by Clyde Shaffner, about 8 miles northeast, it was reported as about 125 feet. In well 39, owned by Gradena Giddings, on a bluff overlooking the Missouri River, the depth to water is about 55 feet.

It is believed that for all of Stanley County and at least the eastern part of Haakon County the maximum pumping lift for wells on the uplands would not greatly exceed 250 feet.

Jackson and Jones Counties: These two counties lie between the Bad and White Rivers and occupy a position similar to that of Haakon and Stanley Counties. Flowing wells can be obtained in the valleys of the Bad River and some of the larger tributaries in Jones County and to some extent in Jackson County. Flowing wells can also be obtained in the valley and major tributaries of the White River in both counties. It seems probable, from a comparison of the contours of the piezometric surface and the altitude of the land surface, that flowing wells could be obtained in the southwest corner of Jackson County in the vicinity of Interior and possibly as far east as Weta, although this cannot be stated definitely. On the divide between the Bad and White Rivers from Kadoka east to Draper the water will rise within 200 to 400 feet of the surface. The following figures are only approximate but will give some idea of the lift that would be required: Kadoka 300 feet, Belvidere 200 feet, Stamford 350 feet, Okaton 375 feet, Murdo 375 feet, Draper 325 feet.

Washabaugh and Mellette Counties: Flowing wells may be obtained in the valley of the White River and up its tributaries in both these counties and far up the Little White River Valley in Mellette County. Very little is known about the altitude of the land surface in Washabaugh County, and therefore no predictions can be made as to the amount of lift on the uplands. This is also true of the western part of Mellette County. In the eastern part of Mellette County the wells at Wood and Mosher, owned by the Chicago & North Western Railway Co., afford data on the amount of lift. In 1930 the depth to water in well 46, at Wood, was about 160 feet, and in well 47, at Mosher, about 88 feet. Because of the general decline in head since that time the depth to the water level at present is somewhat greater.

Lyman County: Formerly flowing wells could be obtained in all parts of Lyman County except the high ridges and buttes. At present the area of flow is restricted to the valleys of the Missouri and White Rivers and, for some distances, their tributaries. In the broad valley of Medicine Creek, which is the largest tributary of the Missouri River draining Lyman County, flowing wells can be obtained from a point about midway between Vivian and Presho to its mouth.

It is estimated that at McClure (altitude 1,917 feet) the water level would rise within about 120 feet of the surface. At well 48, owned by the Rural Credits Board of South Dakota, near the north boundary line of the county, the depth to the water level is about 40 feet. In the eastern part of the county the water rises about 32 feet of the surface at well 62, owned by Andros Kenobbie; within about 55 feet of the surface at well 61, owned by the town of Reliance; and within about 115 feet at well 64, owned by Erwin Blum and near the bluffs overlooking the Missouri Valley. In well 69, owned by Ben Fulwider, about 1 mile north of Iona, in the southern part of the county, the depth to the water level is about 75 feet.

Tripp County: Flowing wells can be obtained in this county in the valley of the White River and far up its major tributaries, such as Cottonwood Creek, Dog-Ear Creek, Old Lodge Creek, No Moccasin Creek, and Black Dog Creek. The water will not rise to the surface on the divides between these tributaries, but the height that the water would have to be lifted can not be predicted because of the indefinite information as to the surface altitude. In well 73, about 5 miles northwest of Whitten, the water rises within about 17 feet of the surface; in well 74, about 4 miles northwest of Winner, it rises within about 68 feet of the surface; and in well 75, owned by Dr. S. E. Sibley and located in the valley of the West Branch of Bull Creek, it rises within 8 feet of the surface.

Gregory County: Flowing wells can be obtained in the valley of the Missouri River and up its tributaries in this county. The divides and uplands are too high to afford artesian flows, but nonflowing wells with only a moderate pumping lift may be obtained far up the slopes of the stream valleys.

SUMMARY

The Dakota sandstone underlies all of western South Dakota covered by this report from its outcrop along the Black Hills eastward to and beyond the limits of the area. It forms the principal source of artesian water supply in the area. It dips so steeply toward the east from its outcrop that in almost the entire western part of the area it lies so deep that the only wells which have penetrated it are oil prospects. The dip decreases farther east, however, and in the eastern part of the area the Dakota sandstone has been extensively developed for water supply. The hydraulic gradient and consequent movement of the artesian water is eastward from the outcrop area along the Black Hills toward the Missouri River.

Since development of the artesian-water supply began in western South Dakota there has been a pronounced decline in the static water level. The decline at first was probably local, but with extensive development it has become general and at the present time affects the entire area. The amount of decline varies from place to place over the area but is greatest in Lyman and Stanley Counties, especially near the mouths of the Bad and White Rivers. Thus the recorded total decline is about 300 feet over a 35-year period at Pierre and about 230 feet over a 24-year period at Chamberlain. The most rapid decline occurred in the early part of the period of artesian development, when the artesian pressure and flow were still great. Thus at Chamberlain the recorded decline in the 9-year period from 1891 to 1900 was 140 feet, or an average of about 15 feet a year, but in the 15 years from 1900 to 1913 it was only 90 feet, or, an average of about 6 feet a year. The decline in recent years has been slower, apparently averaging from less than 1 foot to a few feet a year, according to the local draft.

The Lakota sandstone, which lies beneath the Dakota sandstone and separated from it by a layer of impermeable clay, is in the western part of the area and probably elsewhere at least equal to the Dakota sandstone as a source of artesian water. The areal extent of the Lakota sandstone is not definitely known, but probably it underlies all or most of the area covered by the investigation. Available data indicate that it yields larger flows of water under greater head than the Dakota sandstone, and that it forms a potential supply of artesian water that has been only slightly developed. Moreover, the water appears better suited for domestic use. Locally in the western part of the area where development has occurred there has been a decline in the static water level of the Lakota sandstone, and further decline is to be expected with increasing use.

The Minnelusa sandstone, about 1,000 feet beneath the Lakota sandstone, yields water copiously. So far as analyses have been made, the water is moderately hard but otherwise of good quality and low in fluoride. Except in a narrow strip close to its outcrop area this sandstone lies so deep that it could be developed as a source of water supply only at very heavy cost.

The Deadwood formation, which lies beneath the Minnelusa sandstone, does not appear to yield water as readily as the Minnelusa.

Eastward from the Black Hills the temperature of the water from the Dakota sandstone increases to a maximum and then decreases irregularly toward the Missouri River. The depth-temperature gradient appears to range from 23 feet of depth for each 1° F. increase of temperature in well 26, at Whitehorse, in the Cheyenne River Indian Reservation, to 9 feet in depth for each 1° F. in the vicinity of Chamberlain. In general the depth-temperature gradient appears to decrease from the Missouri River toward the west. The highest recorded temperature of water from the Dakota sandstone was 120° F. and the highest recorded temperature of any artesian water in the area was 130° F.

Along the edge of the Black Hills water from the Dakota sandstone was found to be of good quality and for the most part soft, except that some of the water was found to have an objectionally high content of fluoride. Both potable and nonpotable water were found in the eastern part of the area, the nonpotable water being to the north and the potable water to the south. The reported nonpotable water carried varying quantities of inflammable gas and has so high a salt content that it is unfit for culinary use. All the water can be used for livestock.

The corrosive action of most water from the Dakota sandstone on the well casing may cause underground leakage, but the extent and amount of leakage are not known. This corrosive action is greatest in the area of nonpotable water.

A great amount of artesian water has been wasted, and the annual waste is still great because of the unrestricted flow of "wild wells" and of some of the wells that are under control. Curtailment of this waste is essential to any effective plan of future water conservation.

WELL RECORDS

Records of artesian wells in western South Dakota are given in the two following tables, which include respectively artesian wells drawing from the Dakota sandstone and artesian wells drawing from the Lakota sandstone and deeper formations.

No.	Owner and Location	Date Completed	Depth Ft.	Diameter In	MEASURING POINT Description	Altitude (feet above sea level) a/	Above (+) or below (-) land surface Feet
	BUTTE COUNTY						
1	B.F. Fink, SE¼ Sec.23, T10N, R2E.	-	2019	6	Top of Inside casing.	3058	+ 2.7
5	E.D.Richards, Sec. 8, T8N, R1E.	1931	-	3	Top of casing	3196	+ 2.0
6	Mrs. Fred Ross, NW¼ Sec. 4, T9N, R4E.	-	1858	3½	-- --	2880	-
7	Gus Whitlock, SE¼ Sec.14 T8N, R4E.	1919	1132	3	Top of casing	2953	+ 1.0
9	Andy Rosander, SW¼, Sec. 28, T8N, R5E.	1909	2215	3	Discharge pipe	2776	+ 3.0
	MEADE COUNTY						
10	Mrs. Oliver Wells, NW¼ Sec. 29, T7N, R5E.	1925	-	2	Top of tee on casing	3140	+ 3.0
	CUSTER COUNTY						
16	City of Buffalo Gap, SW¼ Sec. 29, T6S, R7E.	1935	1538	6	Top of casing	c/ 3277.4	+ 1.0
	HAAKON COUNTY						
19	Chicago & North Western NW¼, Sec.13, T1N, R23E.	-	1842	3	-- --	1965	-
20	J. T. Singleton, SW¼ Sec.30, T6N, R23E.	1933	1948	6	-- --	-	-
21	Dan Bierwagon estate, NW¼ Sec.11, T6N, R21E	1925	2090	4	Discharge pipe	2079	+ 2.0
22	Julius Roseth, SW¼ Sec. 5, T6N, R23E.	1934	2130	4	Top of casing	c/ 2036.12	+ 1.0

From the Dakota Sandstone

Water Level: Feet above (+) or below (-) measuring point	Water Level: Date of measurement	Type of pump	Yield G.P.M.	Use of water	Quality	Temperature	Remarks
- 8.25 - 6.65 - 7.90 - 6.45	Aug2/35 Aug21/35 Sept2/35 Oct23/35	None	-	Unused	Soft	-	Ceased flowing in 1932.
-19.85	Aug20/35	None	-	Unused	Hard	-	-- --
+14 +		Flows	-	Domestic	Soft		Overflows tank 14 ft. above ground.
- 2.10 - .05 - 2.55 - .05	Aug6/35 Aug19/35 Sept3/35 Nov16/35	Lift	-	do	-	-	Ceased flowing in 1930.
+26.5	Aug 8/35	Flows	b/ 1/2	Domestic	-	58	Pressure head was 50 ft. sometime between 1909 and 1917 according to Darton.
+ 1.7	Aug19/35	Flows	4	Domestic and stock	Soft	-	Originally drilled to Lakota sandstone but caved in so water now comes from Dakota sandstone.
-34.75	Aug16/35	None	-	Unused	-	-	Drilling completed in Aug. 1935. Will be used as municipal water supply.
+40 +	June 28, 1935	Flows	b/50	Railroad	d/	112	Overflows tank about 40 feet above ground. Original pressure about 72 pounds.
e/+50		do	e/15	Stock	d/Soft	f/96	
+53	Aug 9/35	do	e/20	do	Saline	104	Pressure when drilled reported as 30 pounds Yield reported as 20 gal. a minute.
-10.00	June 22 1935	Lift	-	do	Saline	-	

No.	Owner and Location	Date Completed	Depth Ft.	Diameter In	MEASURING POINT Description	Altitude (feet above sea level) a/	Above (+) or below (-) land surface Feet
23	Wm.B.Alleman, SE¼, Sec.32, T9N, R24E.	1934	1662	4	Discharge Pipe	c/ 1563.61	+ 2.4
	ZIEBACH COUNTY						
24	Cheyenne River Indian Reservation, SE¼ Sec.31 T8N, R22E.	1934	1878	4	Discharge Pipe	c/ 1741	+ 2.0
25	do, SE¼ Sec.6, T9N, R19E	1934	2385	6¼	Top casing	c/ 1996.01	+ .5
	DEWEY COUNTY						
26	do, SE¼ Sec.12, T15N, R26E	1934	2021	4	Discharge pipe	c/ 1720.89	+ 1.5
	STANLEY COUNTY						
28	Sioux City Stock yards, SE¼ Sec.17, T7N, R27E.	1918	2000	4			0
29	E.J.Lacy, NW¼ Sec.35, T7N, R28E.	1918	1500	3	Land surface	1711	0
30	Clyde Shaffner, SW¼ Sec.29, T6N, R27E.	1911	1925	3	Land surface		0
31	Rural Credits Board, NE¼ Sec.5, T4N, R26E	1934	1699	4½	Discharge Pipe	1898	+ 1.1
32	Stanley County, SW¼ Sec.3, T4N, R28E		1480	3			
33	Meers Township, SE¼ Sec.8, T5N, R28E .	1911	1790	3	Land surface	1925	0
34	W.C.Lewis, SE¼ Sec.20, T6N, R29E	1910	1760	3	Land surface	1888	0
35	Mrs. George Huston, NW¼ Sec.8, T5N, R29E.	1909	1980	3	do		0
36	Rural Credits Board, NE¼ Sec. 10, T5N, R29E.	1908	1489	3			
37	do, SE¼ Sec.22, T5N, R29E.	1911	1768	3	Land surface	1974	0
38	do, NE¼ Sec.28, T5N, R30E			4			
39	Grandena Giddings, SE¼ Sec. 12, T5N, R30E.	1909	1600	3	Top of casing	1803.5	+ 1.0

Water Level		Type of pump	Yield G.P.M.	Use of water	Quality	Temperature	Remarks
Feet above (+) or below (-) measuring point	Date of measurement						
+228 ±	July 29, 1935	Flows	e/ 40	do	d/ Saline	101	
+224 ±	July 30, 1935	Flows	e/ 40	Stock	d/ Soft, Saline	111	
e/ +276	Feb. 1935	do	e/ 500	do	d/ Saline	120	
+ 66 ±	July 26/35	Flows	e/ 50	Stock	d/ Saline	88	
f/ - 60	1930	Lift		Stock	d/ Saline		Reported to have flowed when first drilled.
	June 29/35	Flows	b/ 15	do	d/ Saline	88	Reported to have flowed 50 gallons a minute when drilled.
f/ -125	April/34	Lift		do	Saline		Flowed about 1 year after drilling.
+ 48	July 29/35	Flows	22	do	d/ Saline	110	
	June 29, 1935	do	b/ 30	Unused	d/	94	Flowed 160 gallons a minute when drilled. Recased in 1914.
f/ - 80	Spring/35	Lift		Stock	d/ Soft Saline	f/ 100	Originally flowed 26 gallons a minute; ceased about 1916.
f/ -75	June/34	do		do	d/		Flowed about 2 years after drilling.
f/ -25?	1934	do		do	d/ Saline		do
	July 1/35	Flows	12	do	d/ Saline	93	Flowed 45 gallons a minute when drilled.
f/ -90	Aug 1934	Lift		do	Saline		Water level 6 feet below ground when drilled.
	July 1935	Flows	b/ 25	do	d/ Soft	92	Recased about 1928.
-55.35	July 27/35	Lift		do	d/ Saline		Originally flowed 20 gallons a min.; ceased between 1923 and 1925

No.	Owner and Location	Date Completed	Depth Ft.	Diameter In	MEASURING POINT Description	Altitude (feet above sea level) a/	Above (+) or below (-) land surface Feet
40	Celia Samuelson, NW¼ sec.33, T5N, R31E.	1908	1315	4	Top of tee on discharge pipe	1494	+ 3.8
41	City of Fort Pierre, SW¼ Sec. 33, T5N, R31E	1905	1169	4	Land surface	1443	0
42	Frank Obele, NE¼ Sec.21 T109N, R79W	1917	1570±	3	Top of 4 by 6 inch timber	1834.5	+.2
43	Rural Credits Board, SW¼ Sec.22, T109N, R79W.	1910	1644	3	Land surface	-	0
	HUGHES COUNTY						
44	City of Pierre, SE¼, Sec.4, T110N, R79W.	1930	1226	10	Vent in discharge pipe.	1440	+ 3.5
	JONES COUNTY						
45	C.F. Williams, SE¼ Sec. 8, T1N, R29E.	1928	1730	3	Discharge pipe	1891	+ 2.0
	MELLETTE COUNTY						
46	Chicago & North Western SW¼ Sec.25, T41N, R27W	1930	1836	8	Land surface	2147	0
47	NW¼ Sec.12, T40N, R25W. do	1929	1681	8	Land surface	2040	0
	LYMAN COUNTY						
48	Rural Credits Board, NE¼ Sec.6, T108N, R77W	1918	1500±	4	Top of casing	1815	+ 1.0
49	Wm. Gorman, SW¼, Sec.32, T107N, R75W	1923	1430	3	Top of casing	1787	+ .5
50	R.C.Brodrecht, NE¼ Sec.21, T106N, R77W	1920	1520	3	Top of casing	1819	+ .8
51	O. J.Authier, NE¼ Sec.1, T105N, R79W.	1922	1640	4	Top of casing	1870	0

Water Level		Type of pump	Yield G.P.M.	Use of water	Quality	Temperature	Remarks
Above (+) or below (-) measuring point Feet	Date of measurement						
0.0	7/19/35	None	-	Unused	d/	-	Originally flowed 50 gallons a minute. May leak underground.
-	7/1/35	Flows	b/ 300	g/ Gas	d/	90	Recased in 1909 and again about 1920
-67.50 -66.20 -65.25	7/ 3/35 8/25/35 10/17/35	Lift	-	Stock	d/ Saline	-	
f/ 30 ?	-	Lift	-	Stock	Saline	-	Recased
+152 +	7/27/35	Flows	e/ 3000	g/ Gas	d/ -	90	City has 3 similar wells. Pressure at this well reported as 80 pounds when drilled.
+ 1.5	7/10/35	Flows	1¼	Stock	Soft Saline	96	
h/ -160.5	2/27/30	Lift	-	Railroad	-	-	
h/ 88.0	2/25/30	do	-	do	-	-	
- 40.9 - 41.6 - 43.9	7/25/35 8/25/35 10/17/35	Lift	-	Domestic Stock	Soft	-	Water level 8 or 10 feet below ground when drilled.
+ 1.7	7/12/35	Flows	½	Stock	Hard Saline	-	
- 6.85 - 7.50 - 7.55	7/18/35 8/25/35 10/21/35	Lift	-	Domestic Stock	Soft	-	Ceased to flow in 1931
- 31.75	7/25/35	Lift	-	Domestic Stock	Soft	-	Water level 18 feet below ground when drilled.

No.	Owner and Location	Date Completed	Depth	Diameter	MEASURING POINT Description	Altitude (feet above sea level)	Above (+) or below (-) land surface Feet
52	Chicago, Milwaukee, St. Paul & Pacific R.R., SW¼ Sec.10, T105N, R77W	1934	1480	6	-- --	-	-
53	City of Presho, SW¼, Sec.10, T105N, R77W	1929	1475	6	-- --	-	0
54	Burney, NW¼ Sec.15, T105N, R77W.	-	1530±	3	Top of suction pipe	1829	+ 3.5
55	City of Kennebec, NW¼ Sec.17, T105N, R75W	1917	1310	4	Discharge pipe	c/ 1690.56	+ 2.3
56	Spielmann Bros., SE¼ Sec.20, T105N, R75W	-	1249	3	Discharge pipe	1786	+ 2.1
57	Fred Menard, NW¼ Sec.32 T104N, R79W	1921	1630±	4	Top of casing	c/ 1904.20	+ .7
58	C.Blenke, SW¼ Sec.17, T104N, R77W	1914	1490	4	Top of inside casing	1891	+ 1.0
59	Wm. Stewart, NW¼ Sec.13 T104N, R76W.	1918	-	3	Top of 2 by 6 inch pump support.	1826	+ 1.5
60	G.C.McManus, NE¼, Sec. 32, T105N, R74W.	1918	1219	3	Top of casing	1799	+ .5
61	City of Reliance, SW¼ Sec.21, T105N, R73W.	1916	1130	4	Top of 4 by 4 inch timber	c/ 1796.67	+ .5
62	Anderos Kenobbie, SE¼ Sec.10, T106N, R73W.	1919	1280	4	Top of casing	1803	+1.5
63	W. M. Dinehart, SW¼, Sec.19, T105N, R71W.	1934	1140	3	-- --	-	-

Water Level		Type of pump	Yield G.P.M.	Use of water	Quality	Temperature	Remarks
Above (+) or below (-) measuring point Feet	Date of measurement						
-	7/ 2/35	Flows	180	Railroad	Hard	99	
e/ + 69	1929	do	e/ 125	Municipal	do	-	
- 5.15	7/24/35	Suction	-	Domestic	-	-	
+ 121	7/24/35	Flows	-	Municipal	Hard	96	Water ceased to overflow elevated tank 122 feet above ground in July 1935.
+ 28	7/24/35	do	9	Stock	Hard	72	
-15.65 -16.70 -16.35	7/24/35 8/29/35 10/21/35	Lift	-	do	-	102 f/	Flowed 18 gallons a minute when drilled Ceased to flow in fall of 1925.
-54.90 -56.10	7/15/35 8/26/35	Lift	-	Stock	Hard	-	Water level about 15 below ground when drilled.
- 2.85 - 3.15 - 3.40	7/12/35 8/28/35 10/21/35	Suction	-	Domestic Stock	Hard	-	Ceased flowing in March 1935
-21.35 -22.00 -22.00	7/11/35 8/28/35 10/21/35	Lift	-	Stock	Hard	-	Water level was 2½ feet below ground when drilled.
-52.80 -55.10 -57.55	7/11/35 8/28/35 10/21/35	Lift	-	Unused	d/ Hard	-	Water level was 2 or 3 feet below ground when drilled.
-33.45	7/11/35	Lift	-	Domestic Stock	d/ Hard	-	
-	7/12/35	do	-	do	-	-	

No.	Owner and Location	Date Completed	Depth	Diameter	MEASURING POINT Description	Altitude (feet above sea level)	Above (+) or below (-) land surface Feet
64	Erwin Blum, SW¼, Sec.30 T105N, R71W.	1918	1200±	3	Top of casing	1784	+ .8
65	City of Chamberlain, American Island, unsurveyed	-	644	4½	-- --	-	-
66	H.R.Wagner, NE¼, Sec.21, T104N, R73W.	1919	1132	3	Top of casing	1804	+ .4
67	E.S.Carpenter, Sec.5 & 7 T103N, R72W	1934	700±	4½	-- --	-	-
68	Stover Estate, SE¼, Sec.29, T103N, R72W	1926	750	3	-- --	-	-
69	Ben Fulwider, SE¼ Sec. 10, T101N, R72W.	1914	1280	6	Top of casing	1802	.0
	TRIPP COUNTY						
70	W.P.Kelley, SW¼ Sec.27 T102N, R77W.	1919	1475	3	Top of 2 by 12 inch plank	-	+1.0
71	Royal Union Life Ins.Co SE¼, Sec.33, T102N, R77W.	1918	1510	3	Top of casing	1910	+1.5
72	Lone Tree Township, NE¼ Sec.28, T101N, R77W	1917	1490	3	-- --	-	-
73	Rural Credit Board, SW¼ Sec.33, T101N, R78W	-	-	4	Top of casing		+1.3
74	Royal Union Life Ins.Co NE¼ Sec.11, T99N, R77W	1927	1480±	3	Top of casing	1991	+ .6
75	Dr.S.E.Sibley, SE¼ Sec.1, T99N, R74W.	1928	1500	3	Top of casing	1831	+1.0

Water Level: Above (+) or below (-) measuring point Feet	Water Level: Date of measurement	Type of pump	Yield G.P.M.	Use of water	Quality	Temperature	Remarks
-113.65 -115.60	7/13/35 10/20/35	Lift	-	Domestic Stock	-	-	Water level was about 40 ft. below ground when drilled.
-	7/13/35	Flows	b/ 120	Natatorium	Hard	70	
-84.00 -84.90	7/11/35 8/28/35	Lift	-	Stock	Hard Saline	-	Water level was about 50 feet below ground when drilled.
-	7/17/35	Flows	-	Irrigation	Hard	f/ 80	Group of 3 wells with a combined yield of 1100 gallons a minute
-	7/17/35	do	b/ 125	Stock	-	85	
-75.85 -76.05	7/13/35 8/27/35	Lift	-	do	Hard	-	Water level was about 30 feet below ground when drilled
-24.0	7/15/35	Lift	-	Domestic Stock	Hard	-	
- 2.80 - 3.00	7/15/35 8/26/35	Lift	-	do	do	-	Ceased flowing in 1932
-	7/15/35	Flows	b/ 30	Unused	-	114	
-18.75 -18.95	7/15/35 8/26/35	Lift	-	Unused	-	-	
-68.20	7/16/35	Lift	-	Unused	Hard	-	Water level about 60 feet below ground when drilled.
- 8.60	7/17/35	Lift	-	Stock	Hard	-	

Footnotes

(For records of artesian wells drawing from the Dakota sandstone)

a. The altitude of bench mark at most wells was determined by an altimeter or from topographic maps. Altitudes determined by instrumental leveling are specially indicated.

b. Estimated.

c. Bench-mark altitude determined by instrumental leveling.

d. Water carries gas.

e. Drillers' report.

f. Reported.

g. Only the gas carried in the water is utilized.

h. Measured by the Chicago & North Western Railway Company.

No.	Owner and Location	Date Completed	Depth	Diameter	MEASURING POINT: Description	Altitude (feet above sea level)	Above (+) or below (-) land surface Feet
	BUTTE COUNTY						
2	U.S.Bureau of Reclamation, SE¼ Sec36,T9N,R2E	1906	b/ 627	2	Top of T on casing	2999	+ 3.0
3	City of Belle Fourche, NW¼ Sec.11, T8N, R2E	-	b/ 881	4	Discharge pipe	3019	+ 2.6
4	do,NE¼ Sec.10,T8N,R2E	-	-	4	do	3016	+ 2.8
5	Belle Fourche Field Station, NE¼ Sec.24, T9N, R5E.U.S.Dept. of Agriculture	1935	2600	12½	Discharge pipe	2868	+ 2.5
	MEADE COUNTY						
11	Chas. Baker, NE¼ Sec.22 T6N, R5E.	1906	b/ 377	2	-- --	-	-
12	Bear Butte Well,SW¼ Sec.18, T6N, R6E	1919	c/ 690	10	-- --	-	-
13	St. Martin's Academy, SE¼, Sec.4, R5N, R5E.	1935	1225	6	Top of casing	3465	- 6.6
14	Frank Gruble, SW¼, Sec. 17, T5N, R6E.	1931	558	3	Discharge pipe	3270	+ 2.9
	PENNINGTON COUNTY						
15	City of Rapid City, NW¼ Sec.9, T1N, R7E	1935	1463	10	Land surface	3400±	0
	JACKSON COUNTY						
17	Weaver Oil Company, Sec.29,30, T3S, R22E	1935	3200±	8	Land surface	2137	0
	HAAKON COUNTY						
18	City of Philip, SW¼ Sec.13, T1N, R20E.	1934	2293	6	Top of casing	2158	+ 1.5
	STANLEY COUNTY						
27	Standing Butte, NW¼ Sec.10, T7N, R27E.	-	h/ 3508	-	Land surface	1958	0

Lakota Sandstone or Deeper Formations

Water Level		Type of pump	Yield G.P.M.	Use of water	Quality	Temperature	Remarks
Above (+) or below (-) measuring point Feet	Date of measurement						
+5.6	8/ 5/35	Flows	1	Domestic Stock	Soft	58	
+29	8/22/35	do	-	Unused	-	-	
+26	8/22/35	do	-	do	-	-	
c/ +23	3/27/35	do	30	Unused	-	c/ 81	Water level of Dakota sandstone during drilling reported as 250 feet below discharge pipe.
-	8/12/35	Flows	30	Domestic Stock	Soft	55	Darton reports pressure head was originally 50 pounds to the square inch.
-	7/31/35	do	d/ 3000	Unused	-	58	Aquifer reported as Minnelusa sandstone. Flow partly restricted.
-28160	7/31/35	Turbine	-	Domestic	-	-	Aquifer is Minnelusa sandstone.
+105	8/12/35	do	d/ 50	Domestic Stock	Soft	e/ 48	Static level of water from Dakota ss during drilling reported as about 10 ft. above land surface.
f/	1935	Flows	e/ 250	Municipal	-	f/	Water from Minnelusa ss.and Deadwood formation
e/ +2104	1935	do	g/ 450	Unused	-	130	Drilling in progress July/35.Aquifer unknown but probably Lakota ss.
d/ +57.5	1935	Flows	e/ 14	Municipal	Soft	110	Flow partly restricted Pressure of water from Dakota ss during drilling reported as about 6 lbs. to the square in.
-	6/22/35	Flows	g/ 1000	Unused	-	102	Aquifer unknown.

Footnotes

(For records of artesian wells drawing from the Lakota sandstone or deeper formations.)

a. Altitude of bench mark determined by an altimeter or by a hand level.

b. By N. H. Darton, U. S. Geol. Survey Water-Supply Paper 227, 1909.

c. By Beyer Aune, superintendent, Belle Fourche field station, U. S. Department of Agriculture.

d. Reported when drilled.

e. Reported.

f. See p. 54.

g. Estimated.

h. Depth when drilling ceased. Reported to have caved below 2,500 feet.

WATER SUPPLY FOR WEST-CENTRAL SOUTH DAKOTA

General conditions and recommendations

The scarcity of water in the plains region of west-central South Dakota has greatly retarded its growth and development. Surface water over most of the area are meager in volume and in places highly mineralized. Springs are rare, and the flow of the streams that cross the area are variable in both quantity and quality. During years of subnormal precipitation the water-supply problem over most of the area becomes acute. The conditions were especially critical during the drought of 1933-34, when many farmers and ranchers were forced to haul water long distances for domestic use and to sell livestock while there was still fair pasture left. Critical water shortages for human and livestock use may be expected again in the future unless plans can be made and carried out to provide an adequate supply of water during the periods of drought.

The problem is by no means hopeless, but in order to be successful in solving it a careful study of the geology and hydrology of each locality is required. The method that will solve the problem in one locality is not necessarily one that will solve it in another locality. It is not possible in this report to recommend a definite solution for each locality, but some practical advice is given as to the proper solution of the whole water-supply problem of the area and in some detail for different parts of the area.

West-central South Dakota has three sources of water supply--namely, deep artesian water, shallow ground water, and surface water. The surface water includes not only the water that may flow in the stream channels but also the water from rainfall and snowfall that is stored in house cisterns and the storm water that is stored in small reservoirs. The water from all these sources, with the possible exception of some from the shallow ground water, is suitable for livestock, but not all is suitable for human consumption. In some localities the supply from a single source is not always adequate, and hence it is necessary to utilize different sources.

The artesian water is at many places in the area unsuitable for domestic use, because of its salinity and fluoride content. The shallow bodies of ground water, though not extensive, in some localities furnish valuable supplies, some of which is of fairly good quality. However, during a prolonged period of drought, when there is little or no replenishment, this source of supply may fail. With proper precautions the water that is stored in cisterns is suitable and generally adequate for domestic use but totally inadequate for livestock. In addition to stream flow, the surface-water supply is augmented by impounding storm water in reservoirs formed by building dams across the small drains and valleys. This water is everywhere subject to contamination and not generally suitable for domestic use without treatment.

In the localities where there is no shallow ground water and where the artesian water occurs at great depth, the cost of wells is too great to make it economically feasible to have wells close enough together to form the sole supply of water for livestock. In these localities small reservoirs have furnished and must continue to furnish a large part of the water supply for livestock. In the last year or two considerable progress has been made in the construction of dams to provide reservoirs throughout the State. According to a report by the South Dakota State Planning Board,[32] there were in the fall of 1934 a total of 368 dams in the State that had been built with funds provided by the Federal Emergency Relief Administration. Of this number 247 were west of the Missouri River, and it is estimated that 200 are in the area covered by this report. In addition, many private dams have been built by farmers and ranchers, and doubtless more dams have been constructed by emergency relief work during 1935. In areas which depend largely upon surface water in which the artesian water lies at considerable depth, the function of the artesian wells should be to furnish a reliable reserve for use in extreme drought, when the reservoirs and shallow wells fail. According to the State Planning Board[33] "it is the opinion of many ranchers that range cattle should have adequate water supplies within at least 3 miles of their pasture." Thus, to provide artesian water within reach of all livestock in times of extreme drought, artesian wells would have to be spaced about 6 miles apart and would serve as community wells. However, the spacing and location of the artesian wells must be determined largely by the available pasture and other sources of water supply, as well as the topography and the depth to the artesian formations. In areas where the drilling of artesian wells is not feasible because of the great depth to the water-bearing strata, and where the pumping lift is excessive, the impounding of storm water and the development of any existing bodies of shallow ground water is of paramount importance.

It is essential that sources of water for human consumption in all parts of the area should be of satisfactory quality. Possible sources of water supply satisfactory for domestic use on the farms and ranches are (1) artesian wells where the artesian water does not contain undesirable amounts of salt or fluoride; (2) shallow wells that are protected from surface pollution and yield water that does not contain undesirable amounts of mineral matter; (3) properly constructed cisterns in which are stored supplies of clean rain and snow water or good clean water hauled from some satisfactory source. A thorough survey would probably show that much of the water that has been considered fairly acceptable for human use is unsatisfactory in respect to fluoride.

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32. Water resources of South Dakota, p. 6, South Dakota State Planning Board, 1935.
33. Idem, p. 25.

The rural residents of the area who have no other source of supply largely use the storm water for domestic use, frequently taking it from the reservoirs that also supply the livestock. Such a supply is uncleanly and repulsive and constitutes a menace to health, as the water may become dangerously contaminated. The following suggestions, if observed, will reduce but not eliminate the hazard of contamination of the water:

The drainage area of the reservoir should be free from dwellings, garbage or sewage disposal dumps, barnyards, stock corrals, or any concentration of human beings or livestock. The reservoir should be enclosed by a strong tight fence, preferably woven wire, built several feet above the high-water mark. This would prevent access by livestock to the water in the reservoir, and the usual trampling and wallowing that result when animals have free access to a body of water. Care should be exercised to prevent the reservoir from being used as a place for swimming, bathing, or boating. If it is desired to supply water for livestock use from the reservoir, a short pipe line should be constructed from the reservoir to a watering trough or a series of troughs. By installing an automatic float control at the discharge end of the pipe the troughs could always be kept full, and no water would be wasted. A valve in the pipe line could be provided for withdrawing water for domestic use.

The State Planning Board[34] has made the following recommendations, which are heartily indorsed:

> "The development of pure and adequate urban water supplies is a thing of major consideration. The execution of a survey to test the quality of water in the State from the standpoint of bacterological and chemical content, and especially to determine the amount of fluorine, is highly desirable, and should be one of the most important enterprises contemplated.
>
> "Enlarging of the staff of the State Board of Health and requiring them to make periodical examinations and reports on all urban water supplies in the State seems highly desirable in the interest of public health."

It would seem that the best solution of the problem of domestic water supply would be to provide safe, reliable, and otherwise satisfactory supplies at the urban centers and other convenient places. These supplies would be derived from wells where practicable and from reservoirs of adequate size in other places and should be provided with proper sanitary protection and treatment of the water. All these supplies would be regularly inspected by the State Board of Health and would be under its control. Water from these supplies could then be hauled as needed in clean tank cars to fill the cisterns on the farms and ranches, thus making it practicable to discontinue entirely the use of water

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34. Idem, p. 67.

from the farm and ranch reservoirs for domestic purposes. The State and local health authorities could be of further service in educating the people in respect to cleanly and sanitary methods of constructing and operating cisterns and of handling water supplies.

Conditions and recommendations by counties

In the following discussion the writer has endeavored to point out the type of solution of the water-supply problem best adapted to the different parts of each county.

Armstrong County.--Armstrong County, in the Cheyenne River Indian Reservation, is bounded on the east by the Missouri River and on the south by the Cheyenne River and is drained by numerous tributaries of these streams. There are no towns in the county, which is sparsely settled and devoted principally to grazing. Neither are there any artesian wells, although flowing wells could be obtained in the stream valleys. The artesian water from the Dakota sandstone would be so saline as to be unpalatable for human use, but it would be satisfactory for livestock. Water for livestock can be obtained from the two rivers bounding the county, and at distances from the rivers by impounding storm water in reservoirs constructed on some of the numerous drains. Whenever the economic situation warrants, artesian wells could be drilled, to serve as a standby reserve in periods of drought. Water for human consumption can be obtained by the development of shallow wells in the stream valleys and gravel terraces bordering the streams, by the storage of rain and snow water in cisterns, and by using the water from such reservoirs as are free from contamination. Some of the bodies of shallow ground water could also be developed to yield adequate supplies for livestock.

Butte County.--In the southwest corner of Butte County an adequate supply of water for human and livestock use is obtained from artesian wells of moderate depth, although in some localities the supply for livestock is supplemented by water stored in reservoirs. The south-central part of the county, in the irrigated area served by the Orman Dam, is amply provided with water during the irrigation season. At the end of the season it is customary to fill the reservoirs and water holes with surplus irrigation water, thus providing a supply for livestock through the fall and winter. This irrigation water with proper treatment is also suitable for domestic use. Along the southern edge of the county the Belle Fourche River, below the mouth of Redwater Creek, provides water for livestock, though generally the water is not acceptable for human use. Above the mouth of Redwater Creek the river often goes dry during the summer and fall. Water may also be obtained from shallow wells dug in the alluvium of the Belle Fourche Valley, but as a rule it is too highly mineralized for domestic use.

In the northern and eastern parts of the county the artesian water lies so deep that no artesian wells have ever been drilled. The water supply of this section of the county consists largely of water stored in reservoirs and such bodies of shallow ground water as occur in the stream valleys. The shallow ground water is likely to fail during periods of extreme drought. The solution of the water-supply problem in this section of the county seems to lie in the construction of large reservoirs, capable of impounding water in sufficient quantity to carry through periods of drought. Before the water from such reservoirs is used for human consumption it should be approved by the State Board of Health. If the water is not acceptable and the stored cistern water is not adequate, it may be necessary to haul water from acceptable sources, such as Belle Fourche or other nearby towns.

Custer County.--The western and central parts of Custer County, which lie mostly in the Black Hills uplift and have numerous springs and streams, do not present any water-supply problem. In the eastern and southeastern parts of the county the depth to the artesian water is so great that it is not economically feasible to drill artesian wells except in a narrow strip close to the outcrop area of the Dakota sandstone.

Several large creeks flow eastward from the slopes of the Black Hills uplift to the Cheyenne River. In the alluvium of these stream valleys there are bodies of shallow ground water, which yield water to shallow wells. In general this water is adequate and satisfactory for domestic and livestock use, although in some localities it is hard and contains considerable mineral matter. The construction of reservoirs to impound storm water for livestock, although not so necessary as in other counties, is desirable, especially on the divides and uplands.

Dewey County.--In the western part of Dewey County there are deposits of sand which in many places will yield water to shallow wells. In addition there are bodies of shallow ground water in the fill of the Moreau and Missouri Rivers and in the gravel terraces along these streams. One spring is reported about a mile northwest of the Indian school at Whitehorse, and there may be others in the county. Flowing artesian wells from the Dakota sandstone can be obtained in the valleys and tributaries of the Moreau and Missouri Rivers, but the water is too saline to be used for domestic supply, though satisfactory for livestock use. On the divides and uplands water for livestock use can be supplied by constructing large reservoirs for impounding storm water. This supply may be supplemented during periods of drought by artesian water from wells drilled in the stream valleys. Water for domestic use can be obtained from the bodies of shallow ground water wherever the quality is good, from reservoirs when acceptable, and from stored cistern water. It is possible to obtain large supplies from the alluvium of the Missouri Valley.

<u>Gregory County</u>.--In the southwestern part of Gregory County water can be obtained at shallow depths from deposits of sand, and in the eastern part from the valley fill in the Missouri Valley. In the northern and northeastern parts of the county flowing artesian wells can be obtained from the Dakota sandstone in the Missouri River Valley and its tributaries. On higher lands, where the lift is not excessive, water may be pumped from the artesian wells. So far as is known the artesian water does not contain large amounts of mineral matter and is satisfactory and adequate for domestic and livestock needs.

Although the artesian water over most of the county is probably ample to supply livestock needs, it is desirable that reservoirs to impound storm water should be constructed. The use of reservoir water in place of artesian water for livestock would permit many of the flowing artesian wells to be shut off for at least a part of the year and thus reduce the draft and conserve the supply of artesian water.

<u>Haakon County</u>.--There are in Haakon County areas of considerable extent in which shallow ground water, adequate for domestic and livestock use may be obtained. The principal areas where shallow ground water occurs are in the valleys and tributaries of the Bad and Cheyenne Rivers and in the gravel terraces bordering them. Most of this water is of good quality and acceptable for domestic use. Because of the cumulative effect of the recent drought, the shallow wells at Philip failed in the fall of 1934, and it was necessary to drill an artesian well to supplement the city water supply. There are no large known bodies of shallow ground water in the central part of the county, on the broad drainage divide between the Cheyenne River and the Bad River, although locally, in the larger drains, there probably are small bodies that could be developed.

In the northern part of the county artesian water from the Dakota sandstone is too saline to be satisfactory for domestic use, but in the southern part, although also saline, it can be used. The municipal well at Philip, drawing from the Lakota sandstone, yields artesian water satisfactory for domestic use. Except in the southwestern part of the county, flowing wells from the Dakota sandstone may be obtained in the valleys and for a considerable distance up the tributaries of the Cheyenne and Bad Rivers. On the higher parts of the drainage divide between these two streams the pumping lift may exceed 250 feet.

In the central part of the county and elsewhere where shallow ground water is not available and the pumping lift for the artesian water is excessive, livestock will have to depend chiefly upon storm water impounded in reservoirs, to be supplemented during periods of drought by water from artesian wells located on low lands. The best domestic supplies can be obtained by utilizing the available shallow ground water of good quality, such artesian water as is not objectionable, stored cistern water, and reservoir water that is free from contamination.

Jackson County.--Bodies of shallow ground water occur in the valleys and tributaries of the Bad and White Rivers, in gravel terraces along these streams, and in sand deposits in the southwestern part of Jackson County. Flowing wells also can probably be obtained over most of these same areas from the Dakota and Lakota sandstones. On the drainage divide between the Bad River and the White River, however, the artesian water occurs at great depth and requires so high a lift that it cannot be considered a source of water. Thus over a large part of the county, where ground water cannot be obtained, surface water must form the chief source of supply. The construction of reservoirs to impound storm water and the storage of water in cisterns on the divides and uplands, and the development of both shallow and artesian ground water wherever feasible, as in the stream valleys, appear to afford the logical solution of the water-supply problem in the county.

Jones County.--Jones County, which lies largely between the Bad River and the White River, is similar in many respects to Jackson County, on the west. The water-supply problems are similar and the solution essentially the same for both counties. Briefly this solution is to conserve the surface water on the uplands by the construction of impounding reservoirs and to develop the shallow and artesian ground water in the stream valleys.

Lyman County.--Lyman County does not have as serious a water-supply problem as some of the other counties west of the river. Flowing artesian wells or nonflowing wells with only moderate lifts can be obtained from the Dakota sandstone over a large part of the county. The artesian water is adequate and is used for both domestic purposes and livestock, although in some localities its hardness and mineral content are objectionable. However, in order to conserve the artesian water supply, a surface water should be utilized to the greatest extent possible. This may be done by impounding the storm water in reservoirs and using it for livestock in place of artesian water. By so doing the flowing artesian wells can be shut off whenever the water is not needed, thus reducing the draft and conserving the artesian water.

It should be possible to obtain adequate supplies of water for domestic and livestock use from the alluvium in the valleys of the White and Missouri Rivers, but so far the development of shallow ground water in the alluvium has not received much attention.

Meade County.--In the western part of Meade County adequate water of satisfactory character can be obtained from streams and springs and from artesian wells drilled to the Dakota, Lakota, or Minnelusa sandstone. In the northeastern part of the county there are rather extensive deposits of sand, which yield water to shallow wells. Such wells if properly developed should yield an adequate supply of water for domestic and livestock use. In the central and eastern parts of the county, however, there is need for additional water supplies. Locally in this area there occur bodies of shallow ground water which may be developed. These are principally in the alluvium of the valleys of the Belle Fourche and Cheyenne Rivers and their tributaries. In some localities during periods of drought this supply of ground water may fail.

The artesian water over nearly all of the central and eastern parts of the county lies so deep that it cannot be developed except at great cost. Thus for areas in which a permanent supply of ground water cannot be obtained reservoirs must form the principal source of supply, especially for livestock. The flow of the Belle Fourche and Cheyenne Rivers is also available for livestock.

The water supply for human needs will depend upon the locality. It may be obtained from the shallow ground water, from reservoirs free from contamination, or from water stored in cisterns, or it may have to be hauled from acceptable sources.

Mellette County.--In the southern and central parts of Mellette County there are more or less extensive deposits of sand in which occur bodies of shallow ground water. There are also bodies of shallow ground water in the alluvial deposits of the White River and Little White River valleys and their major tributaries. This water may be recovered by wells of shallow to moderate depth. So far as is known, the water is satisfactory and adequate for domestic and livestock needs, although in some places it may have a rather high mineral content.

Flowing artesian wells can be obtained in the White River Valley, for a short distance up its major tributaries, and for a considerable distance up the Little White River Valley. Nonflowing wells with only a moderate lift can be obtained in the eastern part of the county. Elsewhere in the county the artesian water lies at considerable depth, and the lift would be so great that the cost of developing it is prohibitive. Thus on the divides and uplands in the northern part of the county impounding reservoirs must form the principal source of water supply.

Pennington County.--The western part of Pennington County, from Rapid City west to the State line, is well supplied with water from the numerous streams and springs in the Black Hills uplift. Throughout the central and eastern parts of the county there are rather extensive bodies of shallow ground water. These occur for the most part in the alluvium of the stream valleys, in the gravel terraces bordering the valleys, and in sand deposits of Tertiary and Cretaceous age. The sand deposits occur largely in the eastern and southern parts of the county, although locally there are also some in the central part. So far as is known, an adequate and satisfactory supply of water has been obtained from these bodies of shallow ground water.

The artesian water, except in a very narrow strip close to the outcrop of the Dakota sandstone, lies so deep over the central and eastern parts of the county, that its development as a source of water supply is not feasible. The lift would be excessive over most of this area, except in the southeast corner of the county, in the vicinity of Conata, where there is a possibility of obtaining flowing wells. In the parts of the county where ground water cannot be obtained, storm water impounded in reservoirs must form the chief source of supply.

Stanley County.--The artesian water in Stanley County lies closer to the surface in the eastern part than in the western part, but artesian wells can be obtained over practically all of the county without undue cost. Flowing wells from the Dakota sandstone can be obtained only in the valleys. The lift in nonflowing wells on the uplands depends upon the topographic situation. Over practically all of the county the artesian water is too saline to be suitable for domestic purposes, although it is satisfactory for livestock.

Bodies of shallow ground water occur in the alluvium of the valleys of the Missouri, Cheyenne, and Bad Rivers and their tributaries and also in the gravel terraces bordering these streams. This supply of ground water is believed to be adequate in most places for domestic use and livestock, though not everywhere satisfactory in quality. On the higher lands and divides, where shallow ground water cannot be obtained and where the pumping lift of the artesian water is considerable, the construction of reservoirs to impound storm water would add materially to the water supply of the county. Nonflowing artesian wells having a moderate or small lift and flowing wells in the stream valleys can be used to supplement this supply when needed. By closing the flowing artesian wells when the water is not needed, the draft from the artesian basin would be reduced and an effective start made on the conservation of the artesian water.

Water for domestic use can be obtained from the bodies of shallow ground water or from reservoirs where the quality is satisfactory, and from cisterns. If these supplies fail or are inadequate water must be hauled from acceptable sources.

Tripp County.--In the south half of Tripp County there are deposits of sand which, according to reports, yield an adequate supply of water to shallow wells. In the north half of the county, from Winner to the White River, there are numerous artesian wells drawing from the Dakota sandstone. Flowing wells are obtained only in the valleys, so that it is necessary to pump wells on the divides and uplands. So far as is known, the artesian water is satisfactory for both domestic and livestock use. Shallow ground water can also be obtained in the alluvium in the valleys of the White River and its tributaries in the northern part of the county.

The water supply of the county can be greatly augmented by the construction of impounding reservoirs to provide water for livestock. Such a program would also tend to conserve the artesian water, as flowing wells could be shut off when the artesian water was not needed. Where reservoirs are located on the higher lands, water from them could be used in place of water from the pumped artesian wells and thus effect a considerable saving in the pumping cost.

Washabaugh and Washington Counties.--These two adjacent counties are similar in many respects, and as not a great deal is known concerning their water supply they are here treated together. Both counties are rather sparsely populated. In both there are deposits of sand in which occur bodies of shallow ground water. Except possibly in the White River Valley, the artesian water in both counties lies at too great a depth to be developed as a source of supply except at heavy cost. The construction of reservoirs to impound storm water would add greatly to the readily accessible water supply.

Ziebach County.--In the northern part of Ziebach County there are extensive deposits of sand in which occur bodies of shallow ground water. So far as is known, this water is satisfactory as to both quantity and quality. In the southern part of the county the only bodies of shallow ground water of consequence are confined to the alluvium in the valleys of the major streams, such as the Cheyenne River and Cherry Creek, and to the gravel terraces bordering them. In most localities these bodies of ground water should yield adequate supplies, although the quality is uncertain. Flowing artesian wells from the Dakota sandstone can be obtained only in the major stream valleys. Nonflowing wells can be obtained elsewhere in the county but only at great cost. The artesian water, moreover, is too saline for domestic use, although satisfactory for livestock.

On the divides and uplands reservoirs must form the principal source of water for livestock. In the areas where shallow ground water cannot be obtained, water for domestic use must come largely from cisterns or from reservoirs that are free from contamination.