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WATER IN SOUTH DAKOTA

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Preface

The following report on "Water in South Dakota" is one chapter of a forthcoming monograph by C. L. McGuinness on the water supply of the United States, which will be published as a Water Supply Paper by the United States Geological Survey.

The report is an excellent summary and synthesis of available knowledge regarding the ground water resources of South Dakota, and the State Water Resources Commission and the State Geological Survey are therefore publishing it separately as Water Resources Report 2, in order to disseminate this information more widely in South Dakota.

Mr. McGuinness is well qualified to write such a volume, by virtue of his 24 years' experience in the study of ground water, for the United States Geological Survey. Mr. McGuinness holds a Master of Science degree from the University of New Mexico, and holds fellowship and membership in several geological societies. One of his major interests is ground water law.

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ABSTRACT

South Dakota has a moderate water supply and a large potential water demand; sources of ground water are widespread but the quality of much of the water is poor. Precipitation ranges from a little less than 14 to a little more than 28 inches and averages about 18 inches. Runoff ranges from less than 0.25 inch in the northeast center to about 2.5 inches in the Black Hills and averages about 0.7 inch for a total of 2.6 bgd (billion gallons per day). The only large stream in South Dakota is the Missouri River, which brings in about 14 billion gallons of water per day from North Dakota and discharges about 17½ bgd at the Nebraska line; flow increases to about 21½ bgd at the southeast corner of South Dakota. All other streams have had zero or near-zero flows, and the Missouri River has flowed as little as 1.6 bgd.

Ground water is available in small to moderate and locally large quantities from one or more aquifers in nearly all parts of the State. West of the Missouri River ground water is generally saline except in outcrop areas near the Black Hills, in Upper Cretaceous sediments in the northwest, and in Tertiary and Quaternary sediments in the south central. East of the Missouri River the Dakota Sandstone is the most extensively developed aquifer but glacial drift constitutes a potentially important aquifer, the principal one in the State capable of large future development.

Withdrawal use of fresh water in 1960 was about 280 mgd (million gallons per day), 46 mgd of ground water and 8.6 mgd of surface water for public supply; 33 and 26 mgd for rural supply; 6.7 and 6.8 mgd for industrial supply of which only 1 mgd of surface water was used for public-utility fuel-electric; and 34 and 120 mgd for irrigation, plus conveyance loss of 86 mgd. About 3.9 mgd of saline ground water was used by industry. Hydropower use amounted to about 11 bgd.

Major problems in the next 20 years relate to stabilizing agriculture, chiefly through more adequate water supplies; broadening industrial and recreational pursuits; and supporting urban services. The eastern area of South Dakota has good soil and has the most dependable water supply, but floods in some years and droughts in others are problems. Increased storage on local streams and development of ground water from glacial drift could solve part of the problem but additional water will be needed and the Missouri River is the obvious source. The east-central area offers the greatest

opportunities for additional agricultural development if water can be furnished. Precipitation is less than farther east and in many years is inadequate for crops and grass. Missouri River water is proposed for expanded irrigation but storage on local streams is also needed for flood and erosion control and to provide additional water for water supply and waste dilution. The west-central area is principally a stockraising area; hydrologic conditions are generally unfavorable for additional economical storage on local streams for irrigation and flood control. Principal needs are for stock water (recognized by construction of 70,000 small reservoirs, mostly in recent years) and for stabilization of the winter feed supply for stock. It is hoped that these problems may be solved through expansion of feed-crop growth in the east-central area. The Black Hills area has relatively abundant runoff but water supplies needed for municipal, recreational, and mining uses are commonly difficult and expensive to develop. Most of the surface flow has already been appropriated for downstream irrigation.

Economical techniques for saline-water conversion would be especially useful in South Dakota as there is considerable saline ground-water potential. Substantial hydrologic studies have been made to date but much additional information is needed, especially on location and yield of aquifers and on quality of both ground and surface water.

As in North Dakota, proposed development of Missouri River water and potential for substantial additional ground-water development, plus a growing awareness of the need for hydrologic information promise to lead to the desired stabilization of the State's economy.

INTRODUCTION

South Dakota is very similar to North Dakota in its physiography, geology, and hydrology. The differences so far as water is concerned tend to favor South Dakota: slightly greater precipitation resulting from greater influence of air masses from the Gulf of Mexico; the presence of the Black Hills which, along with the increased precipitation, are largely responsible for a somewhat greater total runoff; and glacial drift which, though it covers a smaller proportion of the State's area, may be somewhat more productive, at least in some areas, than that in North Dakota.

The western two-thirds of South Dakota is in the Great Plains physiographic province and the eastern third is in the Central Lowland province. The Black Hills make up a small, separate section of the Great Plains province in the southwestern part of the State. The rest of the Great Plains is mostly in the Missouri Plateau, divided into the larger unglaciated section west of the Missouri River and the smaller glaciated section east of the river. A small area along the south edge represents the north edge of the High Plains. The boundary between the Great Plains and the Central Lowland coincides very roughly with the western margin of the James River basin. The Lowland is made up mostly by the Western Lake section and includes the South Dakota part of the "prairie pothole" country; but the southeastern part of the Lowland--in general, the drainage area of the Big Sioux River--is in the Dissected Till Plains section. Except for the small area of the High Plains (Great Plains groundwater region), the State is divided between the Unglaciated and Glaciated Central ground-water regions, the boundary lying generally along the Missouri River.

The State is underlain by consolidated to semiconsolidated sedimentary rocks of Paleozoic, Mesozoic, and early Tertiary age. These are mantled in the High Plains by semiconsolidated to unconsolidated sediments of later Tertiary age; in virtually all the area east of the Missouri River by glacial drift of Quaternary age; and along the streams by alluvium of Quaternary age--including, especially along the Missouri River and in the glaciated area, some glacial outwash. The sedimentary rocks of Paleozoic and Mesozoic age form a shallow basin lying between structurally high areas represented by the Black Hills in the west and the nearly buried Sioux Quartzite ridge in the east. The strata dip gently except near the Black Hills, where they are upturned steeply.

The annual precipitation is least, about 14 inches, in the northwest corner of the State and increases gradually toward the east and southeast and rapidly toward the Black Hills to the south. In the Black Hills the precipitation averages a little more than 20 inches; just to the east it averages a little more than 15. In the middle of the State the precipitation ranges from about 16 to 17 inches on the north to 19 to 20 on the south. In the eastern third it ranges from about 20 inches on the north to 22 or 23 on the south. In the State as a whole it averages about 18 inches, about an inch more than in North Dakota.

In the average year, three-fourths to four-fifths of the precipitation falls during the growing season, April-September. There are great variations from year to year, however. In the 30 years preceding 1959 the average precipitation over the State ranged from as much as 30 inches to as little as 12 (State Officials, 1960, p. 315). In the eastern section of generally greatest precipitation there have been variations from 50 to 10 inches (idem, p. 305). Periods of several successive years of drier or wetter than normal weather are common. There are variations in the usual pattern within years as well as from year to year, and sometimes the seasonal distribution is such that crops are poorer in a particular year than they are in another year of less total, but better distributed precipitation. For example, in 1960 the spring was wet in much of eastern South Dakota, but there was little rain in late July and August and as a result the yields of some crops were poor. It is variations in precipitation, and thus in the soil moisture, that are principally responsible for the instability of agriculture which in recent years has been marked by an annual decline of 1 to 2 percent in farm population (idem, p. 315).

The State is almost entirely within the Missouri River basin. The northeast corner drains into the Red River of the North through tributaries emptying into Lake Traverse and the Bois de Sioux River.

The Missouri River flows generally southeastward through the State from the north-central edge to the Nebraska line between Gregory and Charles Mix Counties. Thence it forms the South Dakota-Nebraska border to the southeast corner of South Dakota just north of Sioux City, Iowa.

The principal tributaries that enter the Missouri River from the west are, from north to south, the Grand, Moreau, Cheyenne, Bad, and White Rivers. The Keyapaha drains a small area in the south central and enters the Niobrara River, a tributary of the Missouri, in Nebraska. The Little Missouri drains the northwest corner and enters the Missouri in North Dakota. The Cheyenne is the largest of the western tributaries and drains the entire Black Hills area.

On the east the major tributaries of the Missouri flow southward and enter the Missouri at or near the southeast corner of the State. They are the James on the west, the Big Sioux on the east, and the Vermillion between them. The Big Sioux forms the eastern border of South Dakota where it adjoins Iowa.

Of all the streams in South Dakota only the Missouri has a large and well-sustained flow. Nearly all the other streams have had zero flow at one or more times during periods of record extending back into the 1940's, 1930's, or 1920's. The only exceptions are the White River at Oacoma, whose minimum flow in 1928-57 was 0.5 cfs (cubic feet per second); and the Big Sioux, whose minimum flow at Dell Rapids in 1948-57 was 1 cfs and at Akron, Iowa, in 1928-57 was 7 cfs (U.S. Geological Survey, 1958, p. 347, 394, 399).

The Missouri brought in an average of about 14 bgd from North Dakota during 1929-57. At Mobridge, S. Dak., below the mouth of the Grand, the average flow during that period was about 14.4 bgd. At

Fort Randall Dam, just above the Nebraska line, the flow in 1947-57 was about 17.6 bgd. At Sioux City, Iowa, the flow in 1897-1957 averaged about 21.5 bgd.

The annual runoff is 0.25 inch or less in an area generally between the James and Missouri Rivers north of the latitude of Huron. It is 0.25 to 0.5 inch in an adjacent belt and in a prong that extends southwestward up the Cheyenne River to the foothills of the Black Hills. It is 0.5 to 1.0 inch in the rest of the State except in the Black Hills, where it rises to about 2.5 inches, and in a strip along the south-central and east-central edges of the State and in the southeast corner, where it rises above an inch and is about 2 inches at the southeast corner near Sioux City, Iowa. It averages about 0.7 inch for a total of 2.6 bgd from South Dakota's 77,047 square miles, or roughly two-fifths more than North Dakota's 1.7 bgd, from an area a tenth larger than that of North Dakota. South Dakota's average rate of runoff is lower than that of any other conterminous States except Arizona (which has the same rate), Nevada, New Mexico, and North Dakota; and the total runoff within the State is less than that in any except Delaware, Rhode Island, and of course North Dakota. This fact emphasizes the importance of ground water, which in 1960 accounted for more than two-fifths of the total withdrawal use; and of the Missouri River, which represents the largest single source for potential future development.

Water use currently is modest. Withdrawal use in 1960 totaled a little more than 280 mgd, only about 400 gpd (gallons per day) per capita, which is low for a State in which irrigation is important. The use of fresh water was distributed as follows: 46 mgd of ground water and 8.6 mgd of surface water for public supply, 33 and 26 mgd for rural supply, 6.7 and 6.8 mgd for industry (including 1 mgd of surface water used in generation of public-utility fuel-electric power), and 34 and 120 mgd for irrigation. In addition to the water applied for irrigation, about 86 mgd, largely surface water, was accounted for by "conveyance losses." About 3.9 mgd of saline ground water was used by industry. Hydropower use was substantial, about 11 bgd, representing mostly Missouri River water.

GROUND WATER STUDIES

Completed Studies

A substantial amount of information on ground water is available in publications of the Federal and State Geological Surveys. Several of the old reports of the Federal Survey relate to or contain information on ground water in South Dakota. The oldest is a report by Darton (1896) on artesian water in a part of the Dakotas, that in South Dakota covers the area east of the 101st meridian--that is, east of a line a few tens of miles west of the westernmost longitude reached by the Missouri River. Another report by Darton (1897) describes developments in artesian-well drilling and irrigation in eastern South Dakota.

A report by Todd and Hall (1904) describes the water resources of a part of the lower James River valley, from a little north of Huron to a little south of Mitchell and Alexandria.

A report by Darton (1905) presents general information on the central Great Plains, including most of South Dakota. A later report by Darton (1909) is the first devoted entirely to the subject of ground water in South Dakota. A still later one by Darton (1918) presents more details about artesian water in the vicinity of the Black Hills.

Meinzer (1929) discussed problems of quality of water in the Dakota Sandstone, the principal artesian aquifer in eastern South Dakota, with particular reference to the Canton area southeast of Sioux Falls. In an earlier report, Meinzer and Hard (1925) discussed the artesian water of the Dakota Sandstone in North Dakota, with emphasis on the Edgeley quadrangle in the southeastern part of that State. Much of what is said in general about the Dakota Sandstone in North Dakota applies to South Dakota also.

Leverett (1932) described the Quaternary geology of Minnesota and parts of adjacent States, including the glaciated area of South Dakota. Much of the information on glacial deposits is of interest in relation to ground water. A recent report by Flint (1955) is devoted entirely to eastern South Dakota.

Folios of the Geologic Atlas of the United States covering quadrangles in South Dakota contain some information on ground water. These and other completed studies are listed in the bibliography.

A. N. Sayre (1936) of the U.S. Geological Survey, in a report to the U.S. Corps of Engineers, described ground-water supplies and dam sites in the James and Sheyenne River basins in eastern North and South Dakota. M. E. Kirby (1935) of the Corps of Engineers, in a report prepared under the direction of Sayre, described ground water in the vicinity of Huron, on the James River in east-central South Dakota.

In a special project in cooperation between the Federal and State Surveys, Robinson (1935) prepared a map of the piezometric surface of the Dakota Sandstone in an area covering roughly half the area of South Dakota, extending from the west edge of the State between southern Harding and northern Fall River Counties eastward to a line extending southward from southwestern Edmunds to northwestern Gregory County. (It is now recognized that the "Dakota" in western South Dakota, including most of the area covered by Robinson's map, is actually a group of older sandstones of the Inyan Kara Group plus, where present, the stratigraphically higher Newcastle Sandstone. The area of 33,000 square miles shown for the Dakota in the table on page 11 is for the formation as now defined.) In another such project E. P. Rothrock, State Geologist, and E. G. Otton of the U.S. Geological Survey prepared a report (1947) on the ground-water resources of the Sioux Falls area.

Projects of the South Dakota State Geological Survey, largely independent but for later years including some in cooperation with the U. S. Geological Survey, have covered substantial areas and resulted in several reports, published in the Reports of Investigations series. Relatively brief reports have been published as Report of Investigations No. 17, by E. P. Rothrock, on the Lake Kampeska area northwest of Watertown in Codington County; No. 24, by E. P. Rothrock and B. C. Petsch, on a shallow-water supply for Huron; No. 30, by E. P. Rothrock and Dorothy Ullery, on water-level fluctuations in wells in eastern South Dakota; and No. 40, by E. P. Rothrock, on the Miller area in Hand County. Additional reports are listed in the bibliography.

Geologic quadrangle maps and reports of the South Dakota State Geological Survey contain information on ground water. These cover all the quadrangles lying in the Big Sioux and James River basins and in the Tertiary area, plus the Glencross, Little Eagle, Miscol, and Timber Lake quadrangles covered in the series of coal maps.

Other State reports of interest are a preliminary planning report by the South Dakota Planning Board (1935), a report by the same agency (1936) on artesian flow in South Dakota, and a four-volume report by Searight and Meleen (1940) describing rural water supplies by counties. The latter report is a valuable compilation of information available as of 1940 on the occurrence and availability of ground water throughout the State. It was a cooperative product of the Works Projects Administration, the Agricultural Extension Service and South Dakota State College, and the South Dakota State Geological Survey.

The program of the Department of the Interior for development of the Missouri River basin involved preparation of a considerable number of reports on areas in South Dakota. Among those completed to date are reports on the Angostura irrigation project on the Cheyenne River in Fall River and Custer Counties in southwestern South Dakota (Littleton, 1949); reports on the Oahe unit of the James River division in eastern South Dakota including an open-file progress report (Waring and Bush, 1950) on the southeastern part of the unit and basic-data appendixes (Jones and others, 1957) to the final interpretive report on the whole unit, now in preparation; a reconnaissance of the Belle Fourche project on the Belle Fourche River in Butte and Meade Counties in west-central South Dakota (Rosier, 1951); open-file reports on the Cheyenne River and Standing Rock Indian Reservations in northern South Dakota and southern North Dakota (Maclay, 1952) and on nine towns in the Cheyenne Reservation in South Dakota (Wilkens, 1960); a report on the Rapid Valley unit of the Cheyenne division on Rapid Creek in Pennington County (Rosier, 1953); a reconnaissance of the lower Grand River valley in Perkins and Corson Counties (Tychsen and Vorhis, 1955); a report on the Crow Creek-Sand Lake area east of the James River in Brown and Marshall Counties in northeastern South Dakota (Koopman, 1957); a report on the lower Niobrara River and Ponca Creek basins in southern South Dakota and northern Nebraska (Newport, 1959); and a report on the Lake Dakota Plain area, covering the southern two-thirds of an ancient lake in the James River basin which extended from Redfield, S. Dak., to Oakes, N. Dak. (Hopkins and Petri, in press). A report by Petri (1958) summarizes the quality of surface water in South Dakota, with emphasis on the content of selenium, boron, and fluoride. One by Colby and others (1953) describes the quality of water and problems of erosion and sedimentation in the Moreau River basin in northwestern South Dakota. Geology and ground water at the Jewel Cave National Monument, in western Custer County in the Black Hills, are described by Dyer (1961).

The current program in cooperation with the South Dakota Water Resources Commission began in 1955. Cooperation with the State Geological Survey was resumed in 1959. Products completed to date in cooperation with the two agencies include a map of east-central South Dakota (in general, the area between Aberdeen and Huron and west of the James River) showing areas underlain by more than 25 feet of permeable sand and gravel, largely of glacial origin (Jones, 1956), a progress report on the cooperative investigation (Jones, 1956), a progress report on artesian wells in the whole State (Davis and others, 1961), and a report on glacial deposits in the Flandreau area in Moody County and adjacent parts of Brookings and Lake Counties in east-central South Dakota (Lee and Powell, 1961).

An open-file report prepared as a part of the cooperative program of the Federal and Nebraska Geological Surveys estimates the amount of underflow across the South Dakota-Nebraska line in the Niobrara River and Ponca Creek basins, of interest in relation to compact negotiations (Reed and Keech, 1957).

Current Studies

Current studies include 2 projects in cooperation with the State Water Resources Commission, 3 in cooperation with the State Geological Survey, 1 in cooperation with both agencies, and 1 which forms a part of the Federal program for development of the Missouri River basin.

The projects in cooperation with the Water Resources Commission are statewide. One combines a continuing inventory of artesian wells and local studies of shallow aquifers, the latter mainly to determine the effect on the quality of shallow water of leakage or waste of water from artesian wells. About 1,500 wells flowing more than 20 gpm had been inventoried by December 1959. Data collected through June 1958, on 1,045 wells, were published in Water-Supply Paper 1534 (Davis and others, 1961).

The other is a project of test drilling and establishment of observation wells in shallow aquifers, as a means of determining the location of the aquifers and keeping track of the effects of development.

Projects in cooperation with the State Geological Survey include the study of the Flandreau area, mentioned previously, completed in 1961 (Lee and Powell); studies in Sanborn and Beadle Counties, the first and second of a series of proposed county studies; and a State-wide study of the geology and occurrence of ground water, to refine the existing information, show where additional water is available, collect information on quality of water, and keep track of the effects of development.

The study in cooperation with both State agencies is designed to outline the geology and hydrology of the glacial deposits in selected drainage basins in eastern South Dakota. Currently under study is the Lake Madison-Skunk Creek basin, an area of about 675 square miles west of the Flandreau area, in Lake, Moody, and Minnehaha Counties.

The Federal project is a study of the geology and ground-water resources of the Pine Ridge Indian Reservation in southwestern South Dakota. The purpose of the project is to determine the quantity and quality of ground water available for domestic, agricultural, and industrial use.

Proposed Studies

Three general types of studies are proposed to meet future needs. The first would include studies of specific areas, generally counties, to obtain and present up-to-date information on the availability of water for domestic, municipal, industrial, and irrigation use, for the information of both water users and State and county officials responsible for planning future developments.

The second would be long-range studies of the occurrence of artesian water in the central and western parts of the State and the availability of water to meet large-scale demands. The studies would indicate where and how much water is available, and also its quality in relation to anticipated future desalination projects similar to that at Webster in northeastern South Dakota, where the second of the pilot plants of the Interior Department's Office of Saline Water went into operation in 1961.

The third would be an extension of the studies of glacial deposits in eastern South Dakota, now begun in the Lake Madison-Skunk Creek basin, to provide at least general quantitative information on the availability of water for large-scale uses, especially irrigation.

GROUND-WATER RESOURCES

Ground water is an important resource in South Dakota, as it meets the bulk of the demand for municipal and rural water, about half the demand for industrial water, and a substantial fraction of the demand for irrigation water.

South Dakota, like its sister State to the north, is an area in which artesian water has been of the utmost importance in the settlement of the State and the development of agriculture, the chief industry. Artesian aquifers, from which water flows or once flowed or is available from moderate depths, underlie nearly all the State. Shallow ground water is absent or scarce in much of the State, especially in the unglaciated western two-thirds. Hence, the availability of artesian water and the development of low-cost methods of drilling deep wells were of special importance in enabling settlement, which otherwise might have been confined to river valleys where water is available from alluvium. Much of the artesian water is of rather poor quality, but it has been used nevertheless.

In recent years, the potential importance of water, of generally better quality, in glacial drift in the eastern third of the State and in unconsolidated deposits in the western two-thirds (including the deposits of the High Plains along the south edge of the State) is becoming more generally realized, and most current effort in ground-water studies is devoted to these unconsolidated-rock aquifers.

Even in the glaciated eastern part of the State, the artesian aquifers have been better known and more generally developed than those in glacial deposits. In 1960 about 40 mgd was withdrawn from the Dakota Sandstone in the eastern part of the State.

Table 1 lists the principal aquifers of Paleozoic or later age in the State, the geologic system or series to which each belongs (in descending order, as the strata are penetrated by the drill), the approximate area of extent and maximum thickness, the "aquifer potential," the "state of development," and the salinity of the water. The latter three items are shown in terms of numbers up to 5. As to the aquifer potential, 0 indicates a nearly impervious rock and 5 an aquifer of high potential. As to development, 0 indicates a virtually undeveloped aquifer, 1 to 3 indicate increasingly greater withdrawal, 4 indicates a withdrawal about equal to the estimated sustained yield, and 5 indicates withdrawal in excess of estimated current replenishment. As to salinity, the numbers 1 to 5 have the following meaning, in parts per million:

1	0- 500
2	500-1,000
3	1,000-2,000
4	2,000-3,000
5	3,000+

In the following descriptions of aquifers, "water of good quality" means water that contains less than 1,000 ppm of dissolved solids and is acceptable for domestic use and irrigation. "Saline water" means water containing more than 1,000 ppm of dissolved solids; in South Dakota, much of it contains more than 2,000 ppm. Hardness is described in terms that indicate the relatively great hardness of water in South Dakota. For example, one commonly used classification shows soft water as having a hardness of 0-60 ppm as $CaCO_3$; moderately hard water, 61-120 ppm; hard water, 121-180 ppm; and very hard water, more than 180 ppm. In this report as it applies to South Dakota, "soft" water has a hardness of 0-120 ppm; "hard" water, 121-600 ppm; "very hard" water, 601-1,000 ppm; and "extremely hard" water, more than 1,000 ppm.

Table 1.--Principal aquifers in South Dakota

[System or series: Ca, Cambrian; Ord, Ordovician; Miss, Mississippian; Penn, Pennsylvanian; Perm, Permian; Tr, Triassic; Ju, Jurassic; K, Cretaceous; Pal, Paleocene; Ol, Oligocene; Mio, Miocene; Plio, Pliocene; Q, Quaternary; L, Lower; M, Middle; U, Upper]

Aquifer	System or series	Estimated extent (sq. mi.)	Maximum thickness (feet)	Estimated potential as aquifer	State of development	Salinity of water
Glacial outwash	Q	Unknown	Unknown	5	1	1-5
Ogallala Formation	Plio	3,000	200	2	1	1-2
Arikaree Sandstone	Mio	5,000	500	3	1	1-2
White River Group	Ol	Unknown	300	0-1	0	1-3
Fort Union Formation	Pal	2,700	1,000	1	2	3-4
Hell Creek Formation	UK	8,700	425	1	1	3
Fox Hills Sandstone	UK	11,600	250	1	3	1-3
Niobrara Formation and Codell Sandstone Member of Carlile Shale	UK	70,000+	400	3	3	3-4
Greenhorn Limestone	UK	70,000+	350	1	3-4	4-5
Dakota Sandstone	UK	33,000	460	5	4	3-5
Newcastle Sandstone	LK	Unknown	100	1	0	3-5
Inyan Kara Group	LUK	46,000	600	3	1-2	3-5
Unkpapa Sandstone	UJu	Unknown	225	0-1	0-1	2-5
Sundance Formation	UJu	40,000	450	0-1	1	5
Spearfish Formation	Tr and Perm	32,000	700	0-1	1	5
Minnekahta Limestone	Perm	39,000	50	2	1	2-5
Minnelusa Formation	Penn	37,000	1,200	5	1	1-5
Pahasapa Limestone and subsurface equivalents	LMiss	39,000	900	3-4	0-1	1-5
Bighorn Group	UOrd	32,000	760	5	0	3-5
Winnipeg Formation	MOrd	30,000	425+	3	0	3-5
Deadwood Formation	LOrd and UCa	Unknown	450	2	1	2-5

Precambrian Rocks

Precambrian "basement rocks," not listed in table 1, underlie the whole State but crop out at the surface or beneath glacial drift in relatively small areas. Schist, quartzite, slate, pegmatite, granite, and amphibolite crop out in perhaps 1,000 square miles in the core of the Black Hills uplift in Lawrence, Meade, Pennington, and Custer Counties. These rocks discharge some tens of thousands of acre-feet per year of water of good quality into streams through springs and seeps emerging from fractures in the rocks. The water as it appears in the streams is fully appropriated for use in downstream areas, and consumptive use of any substantial fraction of the water in the Black Hills would affect downstream water rights. Similar rocks crop out beneath glacial drift in southeasternmost Roberts and northeastern Grant Counties in northeastern South Dakota but are hydrologically unimportant.

The Sioux Quartzite of Precambrian age underlies most of southeastern South Dakota and crops out beneath the drift in a sizable area and at the land surface in small areas in Davison, Hanson, McCook, Minnehaha, Turner, and Lincoln Counties. It consists of massive quartzite interbedded with thin shale and a few porous zones of poorly cemented quartz sand. Locally it yields small quantities of water from fractures or from the porous zones.

Deadwood Formation

The Deadwood Formation of Late Cambrian and Early Ordovician Age crops out around the Black Hills and underlies an unknown area down the dip. It consists of quartz sandstone, commonly conglomeratic, gray and green shale, limestone, and, where thickest, thin-bedded soft sandstone interbedded with clay. It has a maximum known thickness of 450 feet. The sandstone yields small to moderate amounts of good to saline artesian water used for stock and domestic supplies. In some localities the aquifer could support a modest increase in withdrawal.

Winnipeg Formation

Sandstone and shale of the Winnipeg Formation of Middle Ordovician Age lie above the Deadwood Formation in the northern Black Hills. In the subsurface north and northeast of the Black Hills the formation thickens to at least 425 feet. The sandstone unit is reported to yield saline water under pressure where penetrated by oil-test holes in northwestern South Dakota. The water is not used, and the potential of the supply for development is unknown but on the basis of reported yields is estimated at 3 in table 1.

Bighorn Group

The Bighorn Group of Late Ordovician Age crops out in a narrow band around the north side of the Black Hills and underlies some 32,000 square miles in the western, northwestern, and north-central parts of the State, extending southward to Pennington County, eastward to western Brown County, and southeastward to 20 or 30 miles northwest of Pierre. It consists of massive tough mottled buff limestone and dolomite and is as much as 760 feet thick. It contains a large volume of saline water under high artesian pressure at temperatures as high as 225°F. It is undeveloped as a source of water.

Silurian and Devonian Rocks

Rocks of Silurian and Devonian age do not crop out but are present in the subsurface in northwestern and north-central South Dakota. Their potential as aquifers is unknown.

Pahasapa Limestone and Subsurface Equivalents

The Pahasapa Limestone and subsurface equivalents of Early Mississippian Age underlie an area similar to but extending a little farther southeastward and southward than that of the Bighorn Group, extending to a line running approximately from northwestern Brown County past Pierre to the Nebraska line in southeastern Fall River County--an area of about 39,000 square miles. The unit consists of massive light-gray to buff limestone or dolomite and is as much as 900 feet thick.

Parts of the Pahasapa and equivalents are cavernous and highly permeable. Surface streams that cross the outcrop, which surrounds the Black Hills, lose all or part of their water into the limestone. In the surrounding area wells yield large quantities of good to saline water under high artesian pressure. The water that moves downdip helps to recharge overlying formations. In the central part of the State several wells more than 4,000 feet deep flow 100 gpm or more each from the subsurface equivalents of the Pahasapa. These wells supply water for one large stock ranch and for the towns of Midland and Eagle Butte. Considerably more water could be withdrawn from the unit than now is.

Minnelusa Formation

The Minnelusa Formation, the only formation of Pennsylvanian age reported in South Dakota, underlies some 37,000 square miles northwest of a line running approximately from the North Dakota line in northeastern McPherson County through Pierre to the Nebraska line in southwestern Bennett County. It crops out in a belt surrounding that of the Pahasapa Limestone and has a maximum known thickness of about 1,200 feet. At the base it consists of red shale interbedded with limestone and sandstone; in the middle, of interbedded sandstone, limestone, dolomite, shale, and anhydrite; and at the top, of yellow to red sandstone and limestone. The sandstone beds are commonly fine grained and limy, but locally they yield abundant supplies of good to saline water under high pressure. Several irrigation wells in the northern Black Hills obtain good water from the Minnelusa. A well drilled near Sturgis initially yielded 4,000 gpm. The flow has been reduced to about 750 gpm, at a temperature of 68°F; the closed-in pressure is 160 pounds per square inch.

The water supply of the Minnelusa is developed on only a modest scale but would support a large sustained yield.

Minnekahta Limestone

The Minnekahta Limestone of Permian age underlies about 39,000 square miles northwest of a line running approximately from the North Dakota line in McPherson County a little west of Pierre to the Nebraska line in Todd County. It reaches a maximum known thickness of 50 feet and crops out in a narrow band around the Black Hills. It is not generally considered an aquifer, but on the northeast flank of the Black Hills it yields moderate quantities of good quality water to both flowing and nonflowing wells. Because the limestone is hard and dense, is not notably cavernous, and crops out in only a narrow band, it is not freely recharged in the outcrop. Apparently the water in it is derived largely from underlying rocks, moving upward along joints and faults. The water supply is only slightly developed but has a moderate potential.

Spearfish Formation

The Spearfish Formation of Permian and Triassic age underlies about 32,000 square miles northwest of a line running approximately from the North Dakota line in McPherson County to the Nebraska line in Bennett County, passing some 20 or 30 miles west of Pierre. It consists of as much as 700 feet of sandy red shale and soft red sandstone and siltstone and contains masses and stringers of gypsum and limestone. It crops out in a belt a few miles wide running around the Black Hills. It is of generally low permeability but yields small quantities of saline water at widely scattered localities, generally from cavernous zones formed by solution of gypsum. It has only a small potential for further development.

Undifferentiated Rocks of Jurassic Age

Oil drillers in the Williston Basin in northwestern South Dakota and adjacent North Dakota and Montana report as much as 60 feet of massive crossbedded salmon-colored sandstone. The water-bearing character of the sandstone is unknown.

As much as 45 feet of red siltstone containing lenses and stringers of gypsum and limestone, believed to represent the Gypsum Spring Formation of Late Jurassic Age, is found in northwestern South Dakota. It is low in permeability but is reported to yield small quantities of saline water to a few wells.

Sundance Formation

The Sundance Formation of Late Jurassic Age underlies about 40,000 square miles west of a line that runs approximately from the North Dakota line in northwestern McPherson County southwestward to eastern Dewey County, southeastward some 20 or 30 miles east of Pierre to central Lyman County, and then southwestward to the Nebraska line in south-central Todd County. It consists of as much as 450 feet of gray-green shale containing some limestone, sandstone, and red shale. It is of low to moderate permeability. Locally it is reported to yield flows of saline, corrosive water.

Unkpapa Sandstone

The Unkpapa Sandstone of Late Jurassic Age crops out in the eastern Black Hills and underlies a small area extending perhaps as much as 10 to 15 miles east from the outcrop. It consists of as much as 225 feet of fine-grained massive sandstone ranging from white to purple or buff. It is not considered an important aquifer but yields small quantities of at least slightly saline water to some wells. A modest increase in the current withdrawal would be possible.

Cretaceous Rocks

Inyan Kara Group

The Lakota and Fall River Formations represent the Inyan Kara Group of Early Cretaceous Age in South Dakota. The lower sandstone member of the Lakota Formation, formerly considered a separate formation and called the Lakota Sandstone but now called the Chilson Member, underlies about 46,000 square miles west of a line running approximately from the North Dakota line in northwestern Brown County to the Nebraska line in south-central Todd County. It is a hard coarse, locally conglomeratic, buff to gray sandstone containing thin partings of shale and reaching a maximum known thickness of 485 feet. It is a permeable and productive aquifer, but except in and near its outcrop it yields saline water. The water is usually under enough pressure to flow from wells. The supply is developed only moderately and could support a considerably greater withdrawal, even though the recharge is small and most of the water withdrawn would come from storage.

Above the Chilson Member of the Lakota Formation in the southeastern Black Hills are the relatively thin and impermeable Minnewaste Limestone Member and Fuson Member, a shale. These were formerly recognized as separate formations. They are not considered aquifers.

Above the Lakota Formation but covering a smaller area of about 30,000 square miles, mainly in the western part of the State, is the Fall River Formation, up to 200 feet of fine- to medium-grained massive white to buff sandstone containing thin layers of silt and clay. The Fall River is seldom differentiated in drill holes from the sandstone of the Lakota Formation below, and little is known of its water-bearing capacity as a separate aquifer; hence, it is not listed in the preceding table. The sandstone of the Fall River Formation and the Newcastle Sandstone are the "Dakota" Sandstone of the older reports on western South Dakota and adjacent area.

Newcastle Sandstone

Above the Inyan Kara Group and separated from it by the Skull Creek Shale is the Newcastle Sandstone of Early Cretaceous Age. The sandstone is as much as 100 feet thick and covers an unknown area in western South Dakota and adjacent areas. It is an important producer of saline water in Wyoming but its potential in South Dakota appears to be low.

Graneros Shale and Dakota Sandstone

Above the Newcastle Sandstone is the Graneros Shale of Early and Late Cretaceous Age, of which the Newcastle was formerly considered a member. The Graneros is mostly shale but contains a few thin beds of sandstone which may yield small quantities of highly mineralized water.

The Graneros, which crops out in a belt several miles wide around the Black Hills, appears to grade eastward into the Dakota Sandstone of Late Cretaceous Age. Together the Graneros and Dakota underlie the whole State except for the area of older rocks in the Black Hills and wedge-shaped areas in northeastern and southeastern South Dakota. The wedge in the northeast takes in all but westernmost Grant County and parts of adjacent counties. That in the southeast extends westward as far as central Davison County, northward to the general vicinity of Brookings, and southward to about the latitude of Canton in central Lincoln County.

The Dakota Sandstone underlies about 33,000 square miles in eastern South Dakota. East of the eastern limit of the Lakota

Formation it lies on the Precambrian bedrock. It is a soft moderately fine-grained porous light-gray sandstone as much as 460 feet thick. It is a major source of ground water in eastern South Dakota.

The Dakota is not uniformly permeable but yields water from zones of relatively great permeability separated by zones of lower permeability. As many as seven separate zones are recognized in some places. The water ranges from soft to extremely hard and generally is saline.

The Dakota is tapped by thousands of flowing and pumped wells in eastern South Dakota but is developed most heavily in the James River basin, where the total discharge is probably declining slowly toward the rate of maximum sustained yield. A total of about 40 mgd was withdrawn from the Dakota in 1960, about 36 mgd from flowing wells and 4 mgd from pumped wells.

Greenhorn Limestone

Above the Graneros Shale and Dakota Sandstone is the Greenhorn Limestone of Late Cretaceous Age, which covers virtually the whole State except for the area of older rocks in the Black Hills and the areas where the Sioux Quartzite forms the bedrock in southeastern South Dakota. The Greenhorn is mainly a dark-gray calcareous shale. In the western part of the State, where the thin Orman Lake Limestone Member lies at the base and there is as much as 30 feet of slabby impure limestone at the top, the maximum thickness of the Greenhorn is about 350 feet. In southeastern South Dakota, near the Sioux Quartzite ridge, the Greenhorn is about 30 feet thick and yields soft saline water to some farms and homes. Flowing wells generally yield less than 5 gpm, and many wells are pumped. The Greenhorn is not widely tapped as an aquifer, and its additional potential is small.

Carlile Shale and Niobrara Formation

Above the Greenhorn Limestone are the Carlile Shale and Niobrara Formation of Late Cretaceous Age, which crop out around the Black Hills and underlie an area similar to that underlain by the Greenhorn. Both the Carlile and the Niobrara crop out locally in southeastern South Dakota, and the Niobrara crops out along the Missouri River at and south of Fort Thompson.

The Carlile consists of as much as 750 feet of gray shale grading from dark at the bottom to light at the top. It contains many large concretions and sandy layers. At or near the top is the Codell Sandstone Member, a fine-grained quartz sandstone as much as 80 feet thick. The Niobrara Formation is a chalky marl containing shale and clay, ranging in thickness from 120 feet in eastern to 400 feet in western South Dakota.

The Codell and the Niobrara appear to form a single aquifer, as much as 400 feet thick, in eastern South Dakota. The water is generally soft and saline. The aquifer is heavily developed for farm and domestic use in the central and southern James River basin but appears to be capable of substantial additional development.

Pierre Shale and Fox Hills Sandstone

The Pierre Shale of Late Cretaceous Age overlies the Niobrara Formation and underlies all South Dakota except for the area of older rocks around the Black Hills, a small area south of Big Stone Lake in northeastern South Dakota, the James River valley in the 20 miles or so south of Mitchell, the lower Vermillion and Big Sioux River valleys, and the area along the Missouri River where the river forms the South Dakota-Nebraska border. It is the first of the Mesozoic rocks to have large areas of outcrop, cropping out not only in a broad belt around the Black Hills uplift but also west of the Missouri River in a large triangle that extends westward to join the outcrop east of the Black Hills at the junction of the Belle Fourche and Cheyenne Rivers. The Pierre is as much as 2,500 feet thick. It is mainly shale that is highly impermeable, but locally fractured or sandy zones at the top of the Pierre yield small supplies of highly mineralized water.

The Fox Hills Sandstone, also of Late Cretaceous Age, overlies the Pierre shale in about 11,600 square miles in northwestern South Dakota, north of the Belle Fourche River. It crops out in a belt as much as 30 to 40 miles wide adjacent to the outcrop of the Pierre, and then passes beneath the younger Hell Creek Formation to the northwest.

The Fox Hills is a grayish-white to yellow sandstone as much as 250 feet thick. It commonly yields moderate quantities of water of good quality to properly constructed wells. The supply is rather heavily developed but could support a modest increase in withdrawal.

Hell Creek Formation

The Hell Creek Formation of Late Cretaceous Age overlies the Fox Hills in about 8,700 square miles in northwestern South Dakota. It crops out except where it is overlain by the Fort Union Formation. It consists of as much as 425 feet of brown shale and gray sandstone; it is sandiest in its lower part, which contains lenses of lignite also. Concretions and lenses of iron compounds are common. The formation yields small supplies of water to farm wells, and it has only a modest potential for further development.

Tertiary Rocks

Fort Union Formation

The Fort Union Formation is the oldest rock of Tertiary age in South Dakota. It overlies the Hell Creek and is the surficial rock in about 2,000 square miles. The outcrops lie within a crude triangle whose base is the North Dakota line between longitudes of about 101°00' and 103°30' and whose apex is 10 or 15 miles south of the Moreau River. The formation is divided into three outcrops by a belt of outcrop of the Hell Creek Formation a few miles wide along the South Fork of the Grand River and a belt about 20 miles wide along the Moreau River. Thus the outcrop of the Fort Union south of the Moreau is small and isolated, covering only 100 square miles or so.

The Fort Union consists of three members. The basal member is as much as 350 feet of gray clay and sandstone containing thin beds of lignite, the middle member as much as 225 feet of green marine shale and yellow sandstone, and the upper member as much as 425 feet of light-colored clay and sand containing coal beds.

The formation yields small to moderate quantities of saline water. The city of Lemmon in Perkins County obtains a part of its water from two wells in the Fort Union. The water has a high content of sodium and sulfate and is barely potable. The formation is developed on a moderate scale as an aquifer and has only a modest additional potential because precipitation is scanty in the outcrop areas, and the outcrops are above the level of the larger streams so that the formation cannot receive recharge from them.

White River Group

The Chadron and Brule Formations make up the White River Group of Oligocene age. The group consists of as much as 300 feet of light-colored clay, sandy channel fillings, and lenses of limestone and underlies an area of several thousand square miles in southwestern South Dakota, around the north edge of the High Plains. The Chadron, as much as 190 feet thick, yields small to moderate quantities of good to slightly saline water to shallow wells, but its potential, like that of the Fort Union Formation, is low because of scanty precipitation. The Brule is not known to be water bearing.

Arikaree Sandstone and Ogallala Formation

The Arikaree Sandstone of Miocene age and the Ogallala Formation of Pliocene age underlie about 5,000 and 3,000 square miles, respectively, in the High Plains south of the outcrop of the White River Group, mainly in Shannon, Bennett, and Todd Counties. The Arikaree, as much as 500 feet thick, consists mainly of light-colored clay and silt; the Ogallala, as much as 200 feet thick, consists of light-colored sand and silt. The formations have been developed on a small to moderate scale and yield water of good quality. They have not been studied sufficiently to establish their value as aquifers, but their potential is estimated at 3 and 2, respectively, in the table on page 11.

Glacial Deposits

Glacial drift underlies virtually all the area east of the Missouri River. The limit of the thick drift lies along the river south of about 44° north latitude and touches the river or is no more than a few miles east of it in the area to the north. Thin deposits of drift or scattered boulders of a substage preceding the last one extend as much as 40 miles west of the river in the area north of a point 25 miles south of Chamberlain. The drift east of the river is as much as 700 feet thick, though the average thickness is much less, perhaps no more than 40 feet (Flint, 1955, p. 27). It consists mainly of clay but includes lenses or surficial sheets of outwash sand and gravel which collectively form the most promising source of ground water of good quality for future development in the State. The water supply is already developed on a substantial scale for domestic, municipal, and irrigation use, but in relation to the potentially available supply the development to date can be considered small. The water generally is of good quality but locally is saline.

The principal published source of information on the character and distribution of the glacial deposits is the report of Flint (1955). Plate 1 in his report is a map of the glacial deposits and shows the distribution of outwash deposits at the surface. Information on the subsurface distribution of permeable deposits is relatively scanty. The report of Searight and Meleen (1940) does not consistently identify as glacial drift the aquifers penetrated by shallow wells east of the Missouri, but much can be inferred from the information given in the report as to the water-bearing character of the drift. Maps and reports of the State series mentioned on page 7 contain information on ground water in the glacial deposits.

The few detailed studies made to date present specific information on the subsurface deposits. These include the studies in the Sioux Falls area (Rothrock and Otton, 1947), the Oahe unit (Waring and Bush, 1950; Jones and others, 1957), the Crow Creek-Sand Lake area (Koopman, 1957), the Lake Dakota Plain area (Hopkins and Petri, in press), the Flandreau area (Lee and Powell, 1961), Day County (Rothrock, 1935), the Parker-Centerville area (Tipton, 1957), the Brookings area (Lee, 1958), the Watertown-Estelline area (Steece, 1958), the North Sioux City-Yankton area (Jorgensen, 1960), the Wagner area (Walker, 1961), and the Huron-Wolsey area (Walker, 1961). An open-file map prepared by Jones (1956) covers an area of a couple of thousand square miles generally west of the

James River between Aberdeen and Huron and shows by means of contour lines the total thickness of sand and gravel where it exceeds 25 feet. The areas where the permeable deposits are thickest (more than 100 feet in three areas totaling some 75 or 80 square miles) bear little relation to the distribution of surficial outwash; similar conditions have been shown in other areas studied to date and doubtless will be shown by future studies in other areas.

Nevertheless, the surficial deposits, especially those along existing perennial streams, are the most freely recharged and the most obvious and readily accessible sources for immediate development. There are actually or potentially productive deposits, mostly narrow, along nearly all the larger streams, including most of the course of the Missouri River across the State; many of the creeks that enter the Missouri directly; and the James, Vermillion, and Big Sioux Rivers and their principal tributaries. Sizable areas of outwash include widened portions of some of the river valleys, such as that of the Missouri downstream from Yankton, the James River valley in northern Beadle and southern Spink Counties, and the Big Sioux and Deer Creek valleys in the vicinity of Brookings. Sizable areas bearing little or no relation to present streams include, among others, one in Campbell and northern Walworth Counties, crossing the Spring Creek valley and taking in Mound City; one east of Swan Lake in southeastern Walworth and northeastern Potter Counties; one south of Redfield; one east of Woonsocket; a long, narrow one extending from north of Clark in Clark County to beyond Lake Thompson south of DeSmet in Kingsbury County and then passing down the East Fork of the Vermillion River; and an area of outwash plains and lakes northeast of Webster. Allen F. Agnew, State Geologist, in a report included in the State's presentation to the Senate Select Committee on National Water Resources (State Officials, 1960, p. 320-332), mentions some of the principal outwash deposits considered capable of substantial development, of which only the Parker-Centerville plain along the Vermillion River has been pumped on a substantial scale to date--70 irrigation wells in 1959, and more since.

There is some indication that, on the average, the glacial drift in South Dakota may have a somewhat greater average permeability than that in North Dakota. The course of the glaciers apparently was a little west of south (Flint, 1955, p. 137-138), so that the glaciated area in South Dakota was nearer the terminus and should be characterized by a higher proportion of melt-water deposits than that in North Dakota. Also, on the average, the rocks over which the glaciers traveled may have yielded a higher proportion of durable fragments in South than in North Dakota. Flint (idem, p. 137) calls attention to the high proportion of fragments of the Sioux Quartzite in the drift in southeasternmost South Dakota, south of the main outcrop of the Sioux beneath the drift. Large areas of the Sioux Quartzite are present in southeastern

South Dakota and adjacent southwestern Minnesota and doubtless contributed substantially to the debris later deposited in South Dakota. In the corresponding area in northwestern Minnesota and adjacent North Dakota the rocks beneath the drift are mostly relatively soft, fine-grained sedimentary rocks that might be expected to be ground up thoroughly by the glaciers.

PROBLEMS, PROSPECTS, AND NEEDS

South Dakota's basic water problems are those related to a surface-water supply that commonly is inadequate and variable, and a ground-water supply that is abundant in few areas and is generally of poor chemical quality. The chief hopes for the future lie in expanded use of Missouri River water in the part of the State east of the river; additional storage on other streams; development of ground water of fairly good quality from glacial deposits, as well as from other aquifers where they contain such water; and conversion of saline ground water. The problems and proposed solutions are set forth in some detail in the State's report to the Senate Select Committee (State Officials, 1960, p. 305-332).

The economy is chiefly agricultural at present and probably will be so for at least some decades to come. Because of variations in precipitation and of a small and uncertain supply of water for irrigation, agriculture has never been stable, alternating between prosperity in periods of several wetter than normal years and extreme difficulty in years of inadequate or poorly distributed precipitation. Only about 140,000 acres was irrigated in 1960, a total smaller than that in any other of the 17 western States except North Dakota and considerably smaller than that in Arkansas, Florida, Louisiana, and Mississippi. The chief needs of the State are for stabilization of agriculture, broadening of industry and recreational pursuits, and support of the related urban activities.

The principal water source proposed for increased irrigation supply is the Missouri River. The Oahe Reservoir, now under construction, is planned to furnish water to a large area east of the river, principally in the James River basin. The State hopes that, largely through use of Missouri River water and increased irrigation with ground water, it will be possible to stabilize and increase agricultural activities east of the Missouri, including the growth of sufficient stock feed to support an increased stock-raising industry west of the river.

Other principal reservoirs in existence, under construction, authorized, or proposed are those shown in the following table, in which the Oahe Reservoir is included for completeness.

Table 2.--Principal reservoirs

Sponsor: BR, Bureau of Reclamation; CE, Corps of Engineers.
Purpose: F, flood control; I, irrigation; M, municipal supply; N, navigation; P, power generation.

Reservoir	River or basin	Sponsor	Purpose
Shadehill	Grand River	BR	F, I
Belle Fourche	Cheyenne River basin	BR	I
Pactola	Do.	BR	F, I, M
Deerfield	Do.	BR	I, M
Rapid Valley	Do.	BR	I
Coldbrook	Do.	CE	F
Cottonwood Springs	Do.	CE	F
Angostura	Do.	BR	F, I, P
Oahe	Missouri River	CE	F, I, N, P
Big Bend	Do.	CE	F, P
Fort Randall	Do.	CE	F, N, P
Gavins Point	Do.	CE	F, N, P
Blunt	Medicine Creek	BR	I
Byron	James River basin	BR	I
Cresbard	Do.	BR	I
Scatterwood	Do.	BR	I
Traverse	Red River	CE	F

In the area west of the Missouri, the reservoirs included in the above list apparently just about cover the range of economically feasible projects (idem, p. 308). Thousands of stock reservoirs have been built and have helped to stabilize the stockraising industry, and though these involve a substantial loss of water by evapotranspiration they have proved essential to the regional economy. The effect of stock-pond construction on downstream water supplies appropriated for irrigation or other uses has not been evaluated fully, but a study in the Cheyenne River basin above Angostura Dam suggested that reservoir losses (evaporation and seepage) may account for as much as half the runoff in a dry year (Culler and Peterson, 1953, p. 1; Culler, 1961).

East of the Missouri, no major irrigation projects except those based on Missouri River water have been justified to date; there is one major flood-control reservoir, Lake Traverse in the Red River basin. Surface storage on local streams would be desirable for flood control, irrigation and other water-supply needs, waste dilution, and recreation and conservation of fish and wildlife, but apparently economic justification has been lacking so far as major projects are concerned. Ground water is looked to as a promising source for irrigation, and there has been a great increase in the drilling of irrigation wells in the last several years.

The ground-water supply of the Dakota Sandstone, the principal consolidated-rock aquifer in eastern South Dakota, is approaching full development. The glacial drift, which is already developed on a substantial scale, is the principal source for future development for municipal, rural, and industrial water supplies as well as for additional irrigation. West of the Missouri, the prospects lie mainly in construction of wells for stock, domestic, and municipal water (as well as of ponds for stock water). More intensive studies doubtless will extend the areas in which artesian water of acceptable quality can be obtained. And, in the High Plains and vicinity and at least in some areas in northwestern South Dakota, studies probably will lead to increased development of shallow water of fairly good quality.

More economical methods of converting saline ground water would be a great boon to the whole State, enabling the improvement of the quality of water used for public supply and perhaps for stock. Many communities at present are using water containing 4,000 to 6,500 ppm of dissolved solids. Such cities as Philip and Eagle Butte in western South Dakota and Redfield in eastern South Dakota are among those where better water is badly needed. The city of Webster, formerly in this class, is now benefiting from the operation of the pilot desalination plant of the Office of Saline Water, where about 250,000 gpd of good water is being produced from a brackish ground-water source by the electric membrane process. If the operation proves to be successful and economical, many additional similar plants may be built in the future.

Disposal of sewage and industrial wastes is a problem owing to the lack during dry periods of sufficient streamflow for adequate dilution. Thus it is necessary to place emphasis on removal of wastes by treatment rather than dilution by streamflow.

A great deal of effort will be required to overcome the deficiencies of a small and variable natural water supply and so to achieve the desired stabilization and diversification of South Dakota's economy. The State has given evidence of its determination to do its part by taking such steps as establishing the State Water Resources Commission for hydrologic investigations and planning, providing more adequate support for investigations of the State Geological Survey, and, in 1955, modifying its water laws to promote the highest possible degree of beneficial use of the limited water resources. As in North Dakota, there is good reason for hope that, through these intensified efforts, the battle ultimately will be won in spite of the obstacles thrown up by nature.

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