North Dakota Geological Survey
HOWARD E. SIMPSON, Director
Bulletin No. 8

Artesian Water Conservation Fund
Artesian Water Paper No. 6

THE ARTESIAN WATERS OF NORTH DAKOTA

BY
HOWARD E. SIMPSON

INCLUDING ALSO:

The Fifth Biennial Report of the State Water Geologist
The Sixth Biennial Report of the State Water Geologist

GRAND FORKS, N. DAK., 1935.

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THE ARTESIAN WATERS OF NORTH DAKOTA[1]

HOWARD E. SIMPSON

DEFINITION

The term "artesian" is derived from Artesium, the Latin equivalent of Artois, the name of an ancient Province in northern France, where there are some of the most ancient of flowing wells. One of these wells in an old convent at Lillers, has flowed steadily since the year 1126.[2]

The term artesian at first included in its meaning little more than the superficial phenomena of flowing wells. With the investigation of the physical and geologic conditions of these wells the emphasis of the definition naturally shifted from the mere fact of the artificial fountain to the structural and dynamic relations that condition it. The mere fact of overflow is now considered unessential. An artesian well is, therefore, a well in which the water rises considerably above the ground-water table by natural hydrostatic pressure, which is a result of certain structural conditions. These wells are usually of small diameter, ranging from 1 to 16 inches, and of considerable depth. There are many 1-inch wells in southeastern North Dakota, and the Casselton city well is 16 inches in diameter throughout. The Harvey artesian well is 2,235 feet deep, whereas the 4-inch well of J. J. Scully, in the SW¼ sec. 15, T. 162 N., R. 75 W., Bottineau County, is only 14 feet deep and has a large flow of water with a temperature of 42°. Depth and diameter are not an essential part of the definition, for although many deep wells of the world are artesian in character, yet many shallow wells are as truly artesian as those whose waters rise from strata thousands of feet beneath the surface. The term "flowing well" is now generally used to designate that type of well whose waters overflow, and the others are generally termed "nonflowing wells." The distinction is of little scientific value but is very important to the owners of the wells.

REQUISITE CONDITIONS

The theory of artesian wells is well known and generally accepted. Little has been added since 1729, when Belidor in his "Science of engineering" stated the views then held as follows:

> It would be desirable to make such wells in all sorts of places, which appears impossible, since conditions of the terrane are requisite that are

1. Largely reproduced from: Simpson, Howard E., "The Geology and Ground Water Resources of North Dakota", United States Geological Survey, Water Supply Paper, No. 598, 312 p., Washington, 1929, by permission of the Director of the United States Geological Survey.

2. Norton, W. H., Artesian Wells of Iowa: Iowa Geol. Survey, vol. 6, p. 122, 1897.

not everywhere found, for as these wells are caused by waters which, proceeding from neighboring mountains, make a subterranean channel to a certain point where they are retained by beds of clay or rock which prevent escape, it is necessary that these beds be pierced by drills and that the water which is beneath should be capable of ascending in a vertical tube to the surface of the earth.[3]

The conditions have, however, been ably restated by a number of American writers, notably by Chamberlin[4] and Fuller[5].

The fundamental principle is very simple but the problem presented through the combination of varying conditions is commonly complex. Artesian water follows the common law of flow and appears to rise against gravity only because we see but a part of the stream. It rises because a great portion of the same stream is pressing down. The greater descending portion is concealed deep within the earth's crust and rises to higher altitudes perhaps hundreds of miles away.

To understand the simplest and most common types of artesian wells, one should imagine a pervious stratum, a bed that will absorb water freely, such as sand or sandstone, through which water can readily pass, that lies between two impervious beds, such as clay or shale, so that water may not escape either upward or downward, and the edges of these beds should rise to the surface in some high region and be covered only with soil or loose surficial material that will permit percolation. In the opposite direction they may dip down into the earth and either rise again to the surface, thus forming a basin, or the water-bearing stratum may wedge out or become so changed in character as to be impervious. Rain that falls on the surface and stream waters that pass over the upturned edge of the pervious bed will be absorbed into it and will fill it, if sufficient in quantity, to saturation. Ordinary wells that enter such a bed in the region of the outcrop find abundant water in it at slight depth. If a well enters this water-bearing bed at some place considerably below the level of the outcrop, the water rises in it and flows out at the surface because of the pressure of the mass of water in the higher portion of the bed. If surface water enters the outcropping edge of the bed as fast as the artesian water is drawn off below a constantly flowing well is obtained.

3. Norton, W. H., Artesian Wells of Iowa: Iowa Geol. Survey, vol. 6, p. 128, 1897.

4. Chamberlin, T. C., The Requisite and Qualifying Conditions of Artesian Wells: U. S. Geol. Survey Fifth Ann. Rept., pp. 125-173, 1884.

5. Fuller, M. L., Summary of the Controlling Factors of Artesian Flows: U. S. Geol. Survey Bull. 319, 1908.

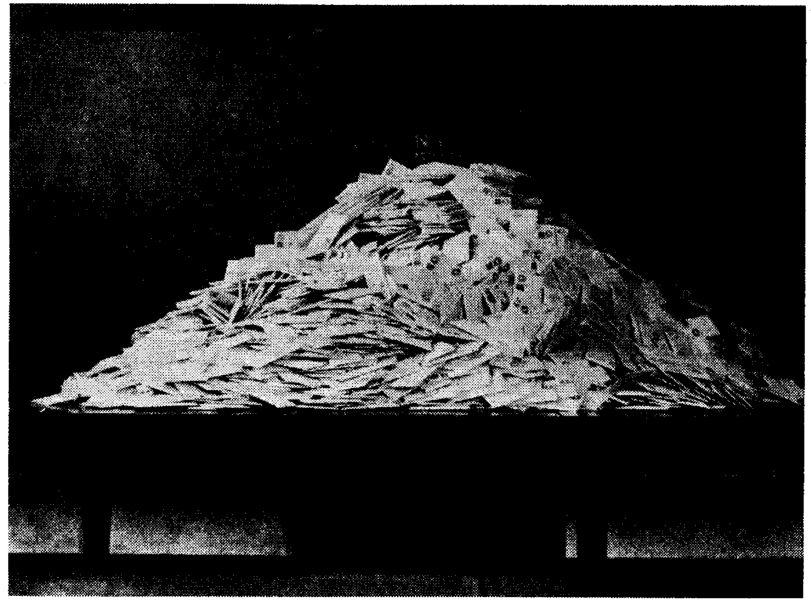

Fig. 1. A bit of advice to six thousand artesian well owners. An important factor in the conservation of artesian waters in North Dakota.

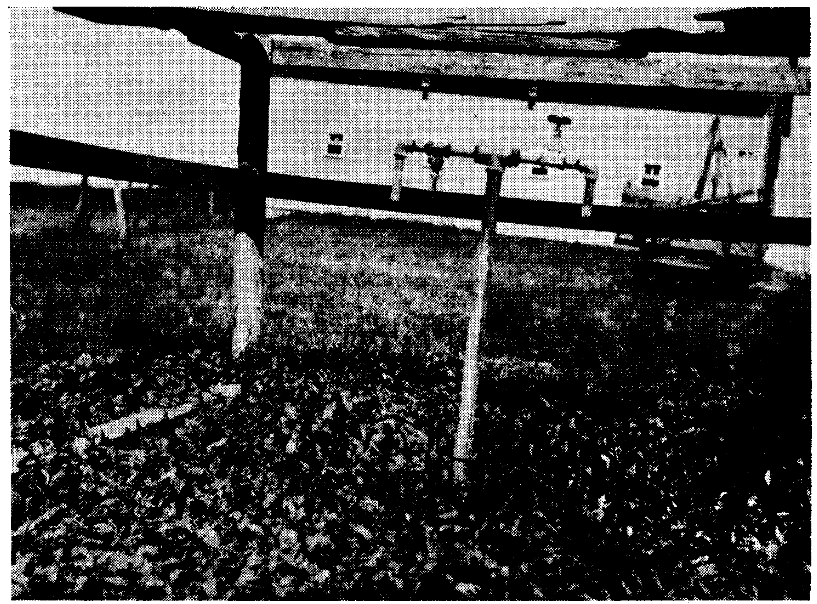

Fig. 2. A "dead" artesian well. Located within the marginal belt of lost pressure, a result of waste of others.

The requisite condition upon which artesian flows depend are stated by Chamberlin[6] as follows:

1. A pervious stratum to permit the entrance and the passage of the water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent escape upward, for the water, being under pressure from the fountainhead, would otherwise find relief in that direction.
4. An inclination of these beds, so that the edge at which the water enters will be higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface at the well.

These requisites have been generally accepted by all writers on this subject. Fuller objects to them, however, on the ground that they apply to a single class of flow—those from stratified rocks—and neglect all flows from other varieties of rock and even types of flow from the same rock. He also calls attention to many exceptions to the limitations mentioned and suggests new and more comprehensive essential conditions as follows:[7]

1. An adequate source of water supply.
2. A retaining agent offering more resistance to the passage of water than the well or other opening.
3. An adequate source of pressure.

He does not make the source specific because artesian waters may not be derived from a single source but from many different sources. The retaining agent may be a stratum, a vein, a joint, or even a water layer, and the pressure, although due to the variations in level, may be transmitted in many ways and modified by many factors.

A homely illustration of the more necessary conditions in the simple basin type of artesian system may be made by placing a small bucket within a large one and filling the space between them with coarse sand. If water is poured upon the sand until it is saturated and a small hole is punched through the bottom of the smaller bucket the water will rise into it in a small fountain, exactly as water rises in an artesian well. The sand represents the permeable water-bearing stratum, or aquifer, and the two buckets represent the two impermeable layers that prevent the escape of the water from the aquifer.

6. Chamberlin, T. C., The Requisite and Qualifying Conditions of Artesian Wells: U. S. Geol. Survey Fifth Ann. Rept., pp. 134-135, 1884.
7. Fuller, M. L., Summary of the Controlling Factors of Artesian Flows: U. S. Geol. Survey Bull. 319, p. 34, 1908.

The water gushes through the hole in the inner bucket owing to the pressure of the water held in the sand at a higher level.

In a larger way, we have an illustration in every system of waterworks that uses a gravity method of distribution. Water is supplied by the pumps to the elevated tank, from which it flows down and out through the mains to the delivery pipes, and through them it rises under a pressure proportional to the relative height of the water in the tank. The form and size of the receiving portion of the plant is immaterial, as shown by the fact that a reservoir or a standpipe produces the same results as an elevated tank or a simple pipe. In the artesian system the water-bearing stratum is both reservoir and conduit, and in North Dakota, it usually consists of a bed of sand or sandstone.

The region between Lansford and Westhope, in Bottineau County, contains a number of wells that yield gas in considerable quantities. Of these a few have an intermittent flow of water mingled with gas, and the flow of water is undoubtedly due to the pressure of the gas, which works on the principle of the air lift. Such wells are easily distinguished by the unsteady jetting character of their flow and are referred to in this report as gas lifts.

Thus we see that there is nothing mysterious about artesian water. The reason for its flow is as easily understood as that of the water from a tap or fire hydrant connected with the village waterworks, because the principle is the same. If all taps and hydrants in the village system were allowed to stand open, the supply in the reservoir would very soon be exhausted and then only a few of the lowest taps in the village would flow, since a few open taps can drain away the water as fast as it is pumped into the system. The same is true of an artesian system; if all wells are left wide open to flow to waste, the reservoir of sand or sandstone is soon drained and the wells, except perhaps those on very low ground, cease to flow. A few wells may waste all the water which enters the artesian reservoir from rainfall.[8]

TYPES OF ARTESIAN SYSTEMS IN NORTH DAKOTA

There are several types of artesian systems that differ from one another in geologic structure and origin. Of these types at least four are found in North Dakota.

The artesian basin (fig. 3) was the earliest known and is still the most commonly figured type, but the true basin is much less common than the artesian slope (fig. 5). The artesian basin is formed where alternating permeable and impermeable layers are laid down on a basin-shaped floor so that they slope from all sides toward the center. This type is

8. Simpson, H. E., Artesian Conditions: North Dakota Geol. Survey Bull. 2, p. 5, 1923. Revised 1935.

common in old lake beds, where the earlier deposits of sand on the concave floor are covered, except on the outer margins, with an impervious layer of fine silt. Wells driven into the sandy layer in the lower portions of the basin yield waters received on the margins. Perhaps the best-known American

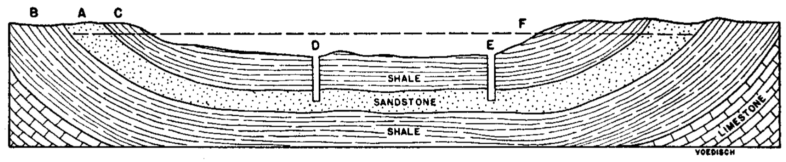

FIGURE 3.—Diagrammatic scetion of an artesian basin or syncline. A, Permeable stratum; B, C, impervious strata below and above A, acting as confining beds; D, E, flowing wells supplied by the permeable water-filled bed A. The broken line (F) shows the height to which the water will rise by artesian pressure. (After Chamberlin)

basin of this type is that of the San Luis Valley of Colorado, in which there are thousands of artesian wells.

Some artesian basins have a trough-shaped floor so that they slope from the sides toward the axis, and these are known as artesian synclines. Both basins and synclines may be produced by warping.

A modification of this type is found in the shallow drift artesian basin of the Red River Valley. (See fig. 4.) Here the central depression is an old river valley that opens toward the north, over which was spread a thick layer of glacial drift and later a thick bed of lake silt. In both these deposits occur beds and layers of sand that slope from the margin toward the axial line along which now flows Red River. This valley is spoken of as a modified form of the basin because it

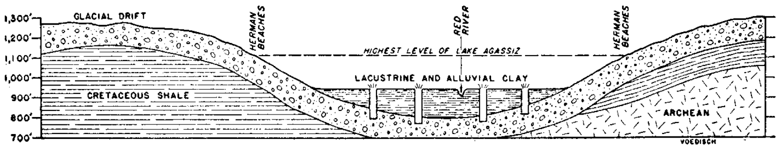

FIGURE 4.—Section of the Red River Valley artesian basin. (After Upham)

slopes toward the north, on which side the basin rim is wanting, and thus, as a pitching syncline, it also resembles a slope. The Red River Valley is therefore a combination of the synclinal basin and slope types.

More common and of vastly greater extent than the artesian basins are the artesian slopes. (See fig. 5.) Here the water-bearing formation dips gently from the higher outcropping area toward a lower land area, owing to the fact that

the formations were laid down on the margin of an old sea floor, now uplifted into sloping plains. Many of these slopes are therefore of vast extent, and their beds are of great thickness. Of this type are all three of the great artesian systems of the United States—the Atlantic coastal plain system, which extends from Long Island to Texas, and is about 100 miles in width; the upper Mississippi Valley system, which crops out in central Wisconsin and dips southward under Iowa, Illinois, Indiana, and Ohio; the Dakota system, which crops out in the Black Hills and eastern foothills of the Rocky Mountains and underlies North Dakota, South Dakota, Nebraska, and Kansas. The Dakota artesian area, which includes the southern portion of the Drift Prairie in North Dakota between the Pembina escarpment and Missouri escarp-

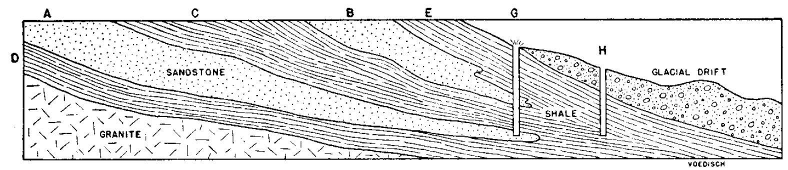

FIGURE 5.—Diagrammatic section of an artesian slope. A, B, Permeable water-bearing beds inclosed between impervious beds C, D, E. The permeable beds either thin out or pass into close-textured impervious beds, thus furnishing the conditions for a flowing well at G. H is either a dry hole or a nonflowing well. (After Chamberlin)

ment, is of this type, though it is modified by a slight rise on the eastern margin until it approaches the synclinal basin type.

A third type, which has been suggested by Fuller,[9] occurs in the plateau region, where deep valleys extend below the general ground water level and dissect nearly horizontal strata underlying the glacial drift. In these valleys the more permeable horizontal beds may yield springs and the water-bearing formations beneath the valley floor may yield weak artesian flows. The water rises in these wells more easily and with less friction than through the relatively impervious strata. The water-bearing formations are replenished by slow downward percolation through the overlying strata. This type may be referred to as the "narrow-valley type of artesian systems." (See fig. 6.) It is well illustrated in the many flowing wells of the valleys of Little Missouri River and its tributaries and also in the valley of Des Lacs River at Kenmare. Probably the slope conditions may also strongly influence the wells of the Little Missouri Valley.

9. Fuller, M. L., Summary of the Controlling Factors of Artesian Wells: U. S. Geol. Survey Bull. 319, p. 39, 1908.

The fourth type of artesian systems found in North Dakota has not heretofore been definitely described. It may be referred to as the "escarpment type." (See fig. 7.) This type occurs in a rather narrow belt that extends across the State in front of the Missouri escarpment and about the foothills of the Turtle Mountains. The formations beneath the

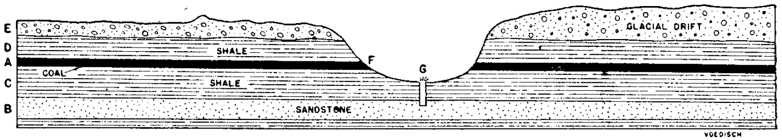

FIGURE 6.—Diagrammatic section showing an artesian system of the narrow-valley type. The permeable sandstone (B) beneath less permeable beds (C, D, E) yields weak artesian flows to wells in the valley (G). The coal bed (A) is water bearing and yields springs at its outcrop (F). (After Fuller)

escarpment are composed of soft shale, which in places contains sandy layers not clearly differentiated from it. Wells that penetrate these beds on the lowlands in front of the escarpment to depths as great as 500 feet find water in the sandy layers. The water, which rises in wells to the surface in small weak flows, seems to derive its hydrostatic pressure more from the higher ground-water level beneath the escarpment, which causes a slow general downward percolation of

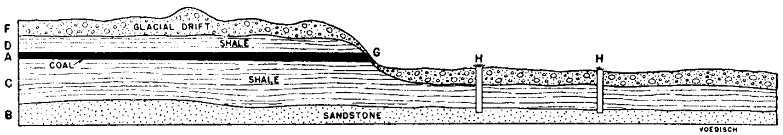

FIGURE 7.—Diagrammatic section showing an artesian system of the escarpment type. The permeable sandstone (B) beneath less permeable beds (C, D, F) may yield weak flows to wells on the lowland (H). The coal bed (A) is water bearing and yields springs at its outcrop (G). (Simpson)

the water, than from the elevation of water in the bed that is tapped. Of this type are the wells on the uplands in front of the escarpment southwest of Kenmare and Minot and south of the Turtle Mountains.

THE ARTESIAN AREAS IN NORTH DAKOTA

There are several separate areas of artesian flow in North Dakota each related to a distinct artesian system. These areas of artesian flow are commonly known as artesian basins.

A brief statement of artesian conditions in each of these areas follows:

Dakota Sandstone Artesian Area:* The southern two-thirds of the Drift Prairie lies within the original area of artesian flow of the Dakota Sandstone Artesian System. In this area Cretaceous sandstones yield flowing wells with light to heavy pressure. The area has been considerably constricted on all margins owing to loss of pressure and head. The depth ranges from 200 to 400 feet on the southeastern margin to 1,500 to 2,000 feet on the western margin. About 5,000 flowing wells have been drilled in this area.

Red River Valley Artesian Area: The eastern two-thirds of the Red River Valley lies within the area of artesian flow of another artesian basin closely connected with that of the Dakota. In this area either glacial drift or the Dakota sandstone or both will probably yield flowing wells with light to moderate pressure. The depth ranges from 150 to 500 feet. More than 2,000 flowing wells have been drilled in this area.

Maple River Valley Artesian Area: A very small drift artesian area is found in the Maple River Valley in western Cass county. In this area both glacial drift and Dakota sandstone will yield flowing wells, the glacial drift with very light pressure. The wells are few. The depth of the glacial drift is 25 to 50 feet and the Dakota sandstone 600 to 700 feet.

Missouri River System Artesian Area: The Little Missouri valley from near the South Dakota line to its confluence with the Missouri and the Missouri River valley from the Montana line to Fort Rice, about 25 miles south of Bismarck and Mandan, together with portions of their tributary valleys form an artesian area of the narrow valley type. Here sandstone and lignite of the Fort Union, Lance, and Fox Hills formations may yield flowing wells with light pressure. Included in this area are several segments of tributaries to the Missouri River, the most important being portions of the Spring Creek valley in Dunn County, the Knife River valley in Mercer County, and the Cannon Ball River valley in Hettinger County. The depth ranges from 50 to 1,000 feet, and the number of wells probably exceeds 500.

Crosby Artesian Area: Between the Missouri Escarpemnt and the International Boundary in the vicinity of Crosby, Divide County, is a small area in which glacial gravel and Fort Union sandstone and lignite may yield flowing wells

*Acknowledgement is made by the author of the assistance of Frederic W. Voedisch in re-locating the boundaries of this area within the lower half of the Souris River valley.—H. E. S.

with light pressure. The depth ranges from 150 to 500 feet. There are about 40 flowing wells in this small area.

Des Lacs Artesian Area: Between Berthold and Minot lies an elongated area in which flowing wells are obtained from Fort Union sandstone and lignite. This area lies in a narrow belt varying from one to three miles in width and passes near the village of Des Lacs, from which the area takes its name. The depth ranges from 100 to 300 feet and more than half of the drilled wells over-flow the surface with slight pressure. Many other wells do not flow but have water standing only a few feet below the surface.

Antler Artesian Area: Between Antler and Maxbass in Bottineau County is a very small area in which glacial drift and Fort Union sandstone yield a few flowing wells with very light pressure. The depth ranges from 100 to 250 feet. This small field lies within the Souris River Gas-Artesian area and is possibly influenced by it. The entire Antler Artesian area is undoubtedly underlain at considerable depth by the Dakota sandstone formation, from which flowing wells may be obtained in the eastern portion where the elevation of the terrain does not exceed 1550 feet above sea level. The depth of Dakota sandstone artesians in this area would probably approximate 2,500 or 3,000 feet.

Souris River Gas-Artesian Area: Within the so-called "Mouse River Loop" is an area in which Fort Union sand or sandstone will yield an intermittent flow of water in many wells due to gas pressure. A few wells in this field yield dry gas under pressure in excess of 100 pounds per square inch. Some flow intermittently and alternately gas and water and may yield gas with the water. The flow of the water wells is probably entirely due to gas pressure and they may therefore be classed as "gas lifts" rather than true artesians. The western wing of the area is developed upon a slight but well defined structure known as the Mohall anticline. The entire Souris River Artesian area is undoubtedly underlain at considerable depth by the Dakota sandstone formation from which flowing wells may be obtained in the eastern portion, where the elevation of the terrain does not exceed 1550 feet above sea level, at depths approximating 2,500 or 3,000 feet.

Pre-Glacial Valley Artesian Areas: These are small areas in which flowing wells of slight pressure may be obtained from assorted sands and gravels at the base of the drift especially in drift filled pre-glacial stream channels. Four of these are of sufficient importance to be mapped.

Grenora—Twp. 160, Range 103, Divide County, depth 35 to 114 feet.

Wild Rose—Twp. 159 and 160, Ranges 96 and 97, Divide and Williams Counties, depth 60 to 100 feet.

Long Lake (a and b)—Two areas both part of same pre-glacial channel (a) Twp. 137, R. 74; (b) Twp. 138, R. 72; Kidder County, depth 50 to 100 feet.

New Rockford—Twp. 148, R. 67, Eddy County, depth 60 to 80 feet.

ARTESIAN SYSTEM OF THE DAKOTA SANDSTONE IN NORTH DAKOTA

General Features

The artesian system formed by the Dakota sandstone is already well known through the work of Darton,[10] Nettleton,[11] Todd,[12] and others. It includes not only a large area in North Dakota but also large areas in South Dakota, Nebraska, Kansas, and adjacent States. It yields flowing wells throughout large areas in North Dakota and South Dakota and in smaller areas in several other states.

> The Dakota sandstone and the overlying dense plastic shales form the most remarkable artesian basin in the United States with respect to its great extent, the long distances through which its water has percolated from the outcrops of the sandstane in the western mountains to the areas of artesian flow, and especially the tremendous pressure under which the water in the sandstone was originally held by its thick and continuous cover of impermeable shale.[13]

The accompanying map (page 24) indicates the general limits of the original areas of artesian flow. There are probably 6,000 flowing wells that belong to this system in the State.

These waters have pressures at the surface that range from zero to the original pressure of 197 pounds to the square inch, in the well at Ellendale, which is used directly for fire protection and which obtains its water from the third horizon. Repeated tests on different gages showed an original pressure of 245 pounds to the square inch in a well 1,150 feet deep about 6 miles northwest of Page, Cass County, in the SW¼ Sec. 20, T. 143 N., R. 55 W., according to the North

10. Darton, N. H., Preliminary Report on Artesian Waters of a Portion of the Dakotas: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 609, 1896.

11. Nettleton, R. C., Artesian and Underflow Investigation: 52d Cong., 1st sess., S. Ex. Doc. 41, pt. 2, 1892.

12. Todd, J. E., Geology and Water Resources of a Portion of Southeastern South Dakota: U. S. Geol. Water-Supply Paper 34, 1900.

13. Meinzer, O. E., and Hard, H. A., The Artesian-Water Supply of the Dakota Sandstone in North Dakota, with Special Reference to the Edgeley Quadrangle: U. S. Geol. Survey Water-Supply Paper 520, p. 73, 1925.

Dakota Artesian Well Co., driller, and D. C. Moug, the owner. This well was abandoned because of the high mineral content of the water.

The flowing wells are used chiefly for livestock and domestic supplies on farms; a number are used for town and city water supply, and a few for irrigation.

GEOLOGIC RELATIONS

The geologic relations of the formations of North Dakota will be briefly reviewed because an understanding of them is necessary to a consideration of the artesian system. (See fig. 8.)

Between the Red River Valley and the Altamont moraine, near the Missouri, the surface formation consists of glacial drift, which in some places attains a thickness of more than 400 feet and is so continuous that exposures of underlying formations are few. Beneath the drift lies bedrock composed of Cretaceous shales, which have a thickness east

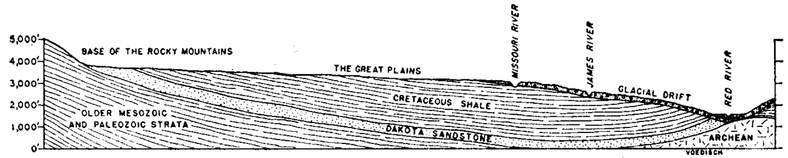

FIGURE 8.—Section of the Dakota artesian basin. (After Upham)

of the Missouri escarpment of 1,000 to 2,000 feet but which thin out eastward toward the Red River Valley. The lower shale beds are known as the Benton shale and are separated from the thick overlying beds of Pierre shale by a more or less calcareous formation known as the Niobrara shale. West of the Missouri escarpment these formations are overlain by a younger series of shale and sandstone of Tertiary age.

Beneath the Cretaceous shales lies a relatively thin but very wide-spread sheet of sand or soft sandstone that contains thin irregular bands of clay. This bed is the Dakota sandstone, the great waterbearing formation that underlies wide areas of the Great Plains. On the east this formation is buried under the thin margins of Cretaceous shales or in the extreme east perhaps by a thin cover of drift and lake sediments. It dips gently westward as the overlying younger sediments thicken, but still farther west it is brought to the surface by uplifts, such as the Black Hills in South Dakota and some of the mountain ranges in Wyoming and Montana, including the great anticlines of the Big Horn Mountains and the Front Range of the Rocky Mountains.

Beneath the Dakota sandstone in the western mountains lies a thick mass of sandstone, shale, and limestone, and these in turn rest upon granite and schist. Over wide areas in the eastern part of North Dakota the sandstone appears to rest directly on the granite, though in the La Moure well a core cut by the drill shows that a compact pinkish-buff limestone underlies the sandstone for at least 28 feet, and in the Grafton and Hamilton wells, where the Dakota is absent, a few hundred feet of these beds overlies the basement of igneous rock.

The westward dip of the sandstone and the rise of the surface in that direction carries the formation below the depth to which it is feasible to drill for water. The Dakota formation is not even reached by the 2,000-foot boring at Mandan or the 2,400-foot well at Max, and there are some doubts regarding the correctness of the identification of the white sand in the 1,800-foot hole drilled for gas near Westhope as belonging to the Dakota formation. The transition beds between the Benton shale and the Dakota sandstone appear to be reached near the bottom of the 3,965-foot oil test hole at Des Lacs. Throughout the western part of the State there appears to be no prospect for utilizing the water from the Dakota sandstone. The area is undoubtedly underlain by this formation, which contains large volumes of water, but it lies too deep to be recovered, and moreover the pressure is not sufficient to carry it to the surface in the plateau region west of the Missouri escarpment.

The Missouri escarpment forms the western boundary of the area of artesian flow. On the east the frayed edge of the sandstone passes underneath the silt of Lake Agassiz and the saline waters of the Dakota are mingled with the fresher waters of the drift in the Red River Valley artesian system. The northern boundary is an indefinite line where the altitude becomes so great that flows may not be obtained. Originally it approximated the line of the Great Northern Railway.

AREA OF INTAKE

Geologists agree that the chief artesian supply of the Dakota sandstone is derived from the outcrops of this formation in the high regions about the base of the Black Hills and upon the eastern foothills of the Rocky Mountains. In these regions the Dakota sandstone or equivalent beds are upturned and reach the surface over areas of greater or less width, together with the underlying sedimentary formations that lie on the surface of granite or other crystalline rocks.

The sedimentary rocks are more or less permeable to water, which is free to pass eastward under the plains region. Not only are there extensive areas in which more or less of the rainfall may sink directly, but the outcrops are crossed by streams of greater or less size, and some of the flow, it is thought, sinks into permeable sedimentary beds. This condition is reported to occur on Missouri River at Great Falls and on Big Horn River on the north flank of the Big Horn Mountains. The altitude of these tributary catchment areas ranges from 3,200 to 7,000 feet above sea level, whereas that of the areas where flows are obtained in North Dakota is 1,100 to 1,300 feet.

PERMEABLE BED

The chief water-bearing bed of the basin is the Dakota sandstone. This formation consists of fine light-gray to white sand and sandstone, with interstratified beds of clay, shale, and limestone. Pyrite and ironstone concretions are common and make drilling with light hydraulic rigs difficult in places. Although the texture and therefore the capacity to hold and transmit water differs greatly, water is almost invariably found in the white sandstone, and in many places two or even three beds yielding flows are found, separated by shaly layers of more compact sandstone or rarely by limestone.

The gathering ground of artesian waters consists of the area of outcrop of the permeable water-bearing formation. The formation itself, above the highest level of flow from the artesian wells, constitutes the artesian reservoir. In regard to this reservoir there are many and strong popular misconceptions. Frequently the reservoir of an artesian well or basin is supposed to be in some lake. Because of the salty water in many wells in the southeastern part of North Dakota the water is thought to have its source in Devils Lake, but the water from some of these wells rises above the level of the lake, and the history of the lake and the conditions of its existence show that it can not be a reservoir of artesian water. The lake is underlain by hundreds of feet of relatively impervious clay shale. The sandy beaches afford no subterranean outlet, and the surface of the lake, which represents the exposed ground-water level, is being constantly replenished from the outseeping ground waters as the water from the surface evaporates. The lake is receiving rather than delivering supplies of ground water. Rivers contribute to the artesian supply only in the areas of outcrop of the permeable beds. Many believe the artesian reservoir to be a subterranean lake or pool. That of the Dakotas has been spoken of as "an underlying sea of water reaching from the British possessions to Texas" or "from the Atlantic to the Pacific." Nothing could be more erroneous. Small subterranean pools and streams undoubtedly exist in limestone regions, but in the Dakota sandstone the water is stored in the interstices, cracks, and crevices of the water-bearing rock.

The value of any rock as a water-bearing layer depends on its permeability rather than on its porosity. Permeability is that property by which it permits water to pass through it and depends not only on the amount of pore space but also on the size of the pores. Clay absorbs water in large quantities but transmits none. Many sandstones absorb and transmit water in large quantities. A loose quartz sand or sandstone, if sufficiently coarse, like the Dakota sandstone, makes a good water-bearing formation. A slight admixture of clay or lime, although it may but slightly lessen the amount of water which a rock will hold, will decidedly impair the power to transmit water. This fact is well illustrated in the Dakota sandstone, in the shaly and limy layers which commonly divide the formation into several portions known to the drillers as first water, second water, and third water. The fact that these water-bearing layers are clearly separated is shown by the very different quality of the waters at different depths.[14]

The capacity of porous rocks as reservoirs is further increased by the numerous planes of stratification and the joints which divide the beds into rhombic blocks. These blocks are in many places broken by many small cracks and fissures, especially near the surface. Water readily percolates through all these openings below the water level and collects in them in large quantities. The capacity of these natural underground waterways is very great. The reservoir sandstone of the Dakota formation probably absorb a quantity of water that amounts on an average to at least 10 per cent of their volume. Many layers can undoubtedly absorb 20 per cent of their volume.

CONFINING BEDS

In order that water transmitted from the reservoir may rise in the well above the water table it must be confined within the water-bearing bed. This confinement is effected

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14. Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and Underground Waters of Southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, pp. 68-74, 1911. Shepard, J. H., The Artesian Waters of South Dakota: South Dakota Agr. Coll. and Exper. Sta. Bull. 41, 1895.

by layers of impervious rock or their equivalent, both above and below the water-bearing bed. The best confining strata consist of heavy clay, for it is practically impermeable, but shale, shaly limestone, and most crystalline rocks are also effective. The Dakota sandstone lies below many hundred feet of dense plastic shale, which is effective in preventing upward leakage. Within these formations the pervious layers are saturated with water but the impervious layers yield no water to the drill.

MEASUREMENT OF PRESSURE

The pressure may be measured at the well mouth in pounds to the square inch by means of an ordinary gage. From this gage the head, which is of more significance, may be calculated by multiplying the pressure in pounds to the square inch by 2.3 feet, the number of feet to which a pressure of 1 pound will lift a column of water 1 inch square. By adding the altitude above sea level of the well curb a convenient plane of comparison may be had.

The head may also be measured by coupling on water-tight tubing and carrying this up until water stands at the top but does not overflow. The size of the tube is immaterial, and the test is easily made with a rubber hose on the well-rig ladder or in a near-by building or tree.

FACTORS THAT AFFECT PRESSURE

Altitude of Intake Area

The question whether a given well will flow or not depends on several conditions, chiefly the altitude of the intake area. The greater the altitude of the intake of the reservoir above the region of the wells the stronger is the hydrostatic pressure and the heavier the flow.

In the southwestern part of the Red River Valley the Dakota sandstone is so thinly covered and so much of the cover is composed of the unconsolidated lake silt and glacial drift that the heavy artesian pressure causes the water to burst out around the casings of wells in such a way that it occasionally gets beyond control and does serious damage to farm land.

Altitude of Well Mouth

The highest head, relative to the top of the well, is found where the altitude of the well mouth above sea level is least. Wells in the deeper valleys show stronger pressure than wells on the adjacent uplands. The oldest well in Valley City had an initial pressure of 56 pounds at the curb, but the pressure

had decreased to 40 pounds in 1921. On the upland just east of the city flows are very weak, and it is doubtful whether they can be obtained on the highest points. Thus one of two wells may overflow and the other may not, although they may be exactly alike in all respects except that one is drilled on higher ground than the other, and both may tap the same water-bearing rock.

Other factors may produce changes in the head of a well or group of wells, such as leaks in the casings and the drilling of other wells to the same horizon. Wells drilled on low ground commonly cause those on higher ground to cease to flow. All these factors should be considered in plans to utilize the pressure for protection against fire, for power, or for manufacturing.

YIELD OF ARTESIAN WELLS

Accurate measurement of the yield of artesian wells is seldom made. The reported flow is generally but a loose estimate. For pumped wells the amount delivered by the pumps can be calculated with considerable accuracy.

The yield of a flowing well is generally determined in one of three ways—by noting the time necessary to fill a receptacle of known capacity, the larger the receptacle the better; by measuring the flow over a weir; or by recording the flow by means of a current meter set in the pipes.

The maximum yields reported in North Dakota are 1,000 gallons a minute from the Minneapolis, St. Paul & Sault Ste. Marie Railway well at Enderlin and 800 gallons a minute from the city well at Ellendale. In 1923 the flow of about 400 artesian wells, 1 to 2 inches in diameter, averaged about 3 gallons a minute.

USES OF ARTESIAN WATER

Domestic supply.—Artesian waters are commonly used in North Dakota as a general supply for home and farm. In the southeastern part of the State many hundreds of farms utilize these waters for all purposes, or for all purposes except drinking and cooking, for which shallow waters from the drift are largely used. As the waters grow more saline toward the north their use for domestic purposes decreases, though they are generally used for stock.

Fire protection.—Wherever pressure and flow are sufficient the artesian wells are connected directly with the mains, and the natural pressure of the water is used for protection against fire. This practice has now been largely discontinued because of loss of pressure.

Irrigation.—The use of artesian wells for irrigation has not been general in North Dakota, owing to the large mineral content of the water. In South Dakota the waters are less strongly mineralized and have been more extensively used for this purpose, especially for gardens.

Power.—Many of the artesian wells formerly yielded water under sufficient pressure to furnish power for minor mechanical operations. Among the uses to which the water has been put in North Dakota are the running of dynamos for small electric lighting plants, the operation of grist and feed mills, the operation of lathes and blowers in blacksmith shops, and many minor uses about the farms. The use of the flowing water for power has largely been discontinued owing to decrease of pressure and resulting loss of power.

CONSERVATION OF ARTESIAN WATER

The popular theory of unlimited natural resources in ground water and particularly in artesian waters[15] which pre-

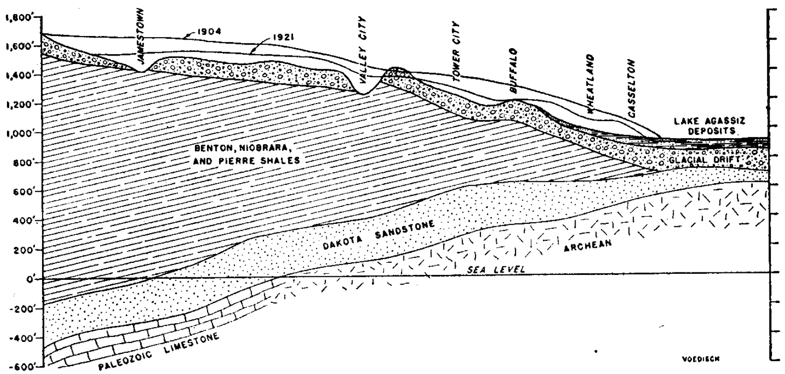


FIGURE 9.—Section across the Dakota area of artesian flow along the Northern Pacific Railway, showing hydraulic profiles, or height to which the artesian water would rise, about 1904 and 1921. (Simpson)

vailed when the early wells in this basin revealed such astonishing pressures and flows has in less than 40 years proved false. (See fig. 9.) Owing to careless drilling and finishing of wells, unlimited waste of water, and failure to control old and "wild" wells, the pressure and supply of this artesian water is being rapidly exhausted. The State engineer, who was directed by the legislature on February 26, 1916, "to investigate all matters and conditions connected with the construction, use, and maintenance of our artesian wells in the State of North Dakota," called attention in his manuscript report to the governor, dated November 1, 1919, to the fact that throughout a

15. McClure, P. F. (compiler), Resources of Dakota, Pierre, 1887.

considerable portion of the Dakota artesian basin the head had been so reduced that "a large proportion of the wells where the original pressure is known has ceased to flow, and in all cases the flow has been greatly reduced." A report by the State engineer of South Dakota to the governor of that State, which was submitted in the same year, reveals a similar situation throughout that part of the Dakota artesian basin, in which he estimates that 10,000 artesian wells have been drilled. In his general considerations of the conditions in South Dakota[16] the State engineer says:

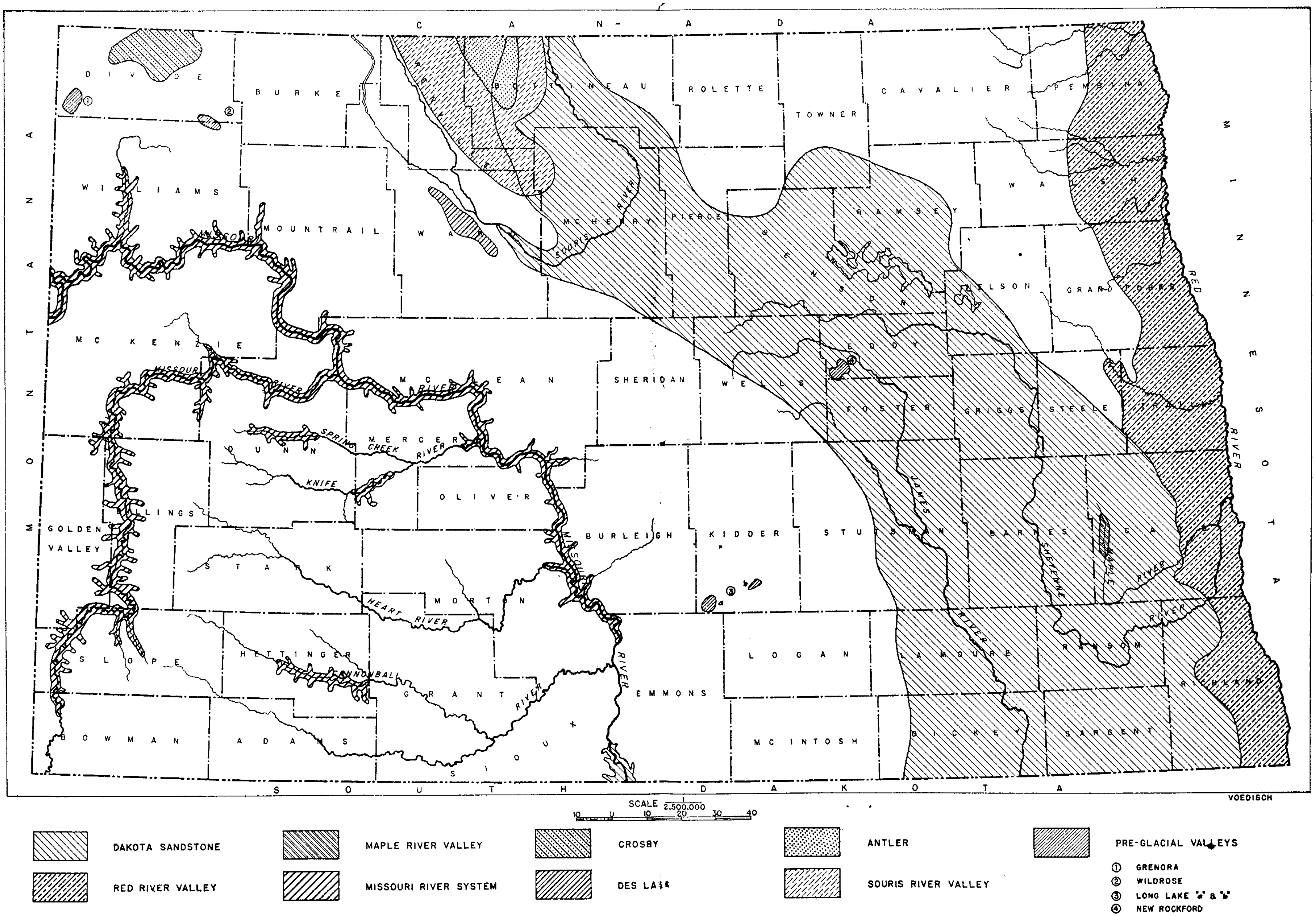
"There was a time when we did not know but that the artesian water supply was inexhaustible; later we began to surmise that it was failing; and to-day we know that it is failing at such a rapid rate that if the present waste continues to be tolerated in connection with the sinking of new wells it will only be a few years until there will not be remaining a single flowing artesian well in the State of South Dakota. True, the water supply in the Dakota sandstone can never be exhausted, but when the last well in the valleys of the James and Missouri Rivers quits flowing, it will be a sad day for the farmers in counties like Sully, where there are no running streams or surface wells to be had, and very deep pumping will have to be resorted to.

That this condition is due to the general falling off of the artesian head may be seen from the fact that new wells do not obtain the same flow and pressure that the original wells obtained.

From the facts shown in these reports of official investigations of the State engineers of both North Dakota and South Dakota, it will be seen that unless this waste of artesian water is checked the greater part of the Dakota artesian area in North Dakota will cease to yield flowing water, and another valuable natural resource will have been dissipated. This situation is alarming to those who depend upon this source of supply for home and stock as well as to those interested in the preservation of our natural resources for the use of future generations on these prairies.

Next to soil, ground water is the most valuable natural resource of North Dakota. Next to natural springs, artesian wells are the most economic means of recovery of ground water for man's use. They are of especial value to stock interests in both grazing and diversified farming, on account of the unpumped flow of an unpolluted stream, cool in summer and warm in winter. The saving in pumps and windmills, or engines and gasoline, and in tank heaters and fuel amounts to thousands of dollars on every stock farm in the course of a few years, to say nothing of the still greater value in better form and flesh on the horses, increase in beef, pork, and mutton on the meat animals and best of all in amount of milk, cream, and butter produced from the dairy cows.[17]

16. Derr, H. M., Sixth Biennial Report of the State Engineer to the Governor of South Dakota, p. 150, Pierre, 1916.
17. Simpson, H. E., Artesian Water Conditions: North Dakota Geol. Survey Bull. 2, p. 5, 1923, Revised Edition, 1935.



MAP OF NORTH DAKOTA SHOWING ORIGINAL AREAS OF ARTESIAN FLOW
BY HOWARD E. SIMPSON

Conservation should be enforced by eliminating the waste of water though permitting its unlimited use.

METHODS OF REDUCING THE FLOW OF ARTESIAN WELLS[18]

Many methods of limiting the flow of artesian wells have been tried because of the need arising from the superabundance of water, lack of good drainage, and damage to land and highways. Now that a still greater need is recognized in the conservation of the water, the saving of it for future use, more effective methods are being used than formerly. The methods now in use in the Dakota Artesian Area in North Dakota are here reviewed.

VALVES

The ideal method of control of a flowing well is by means of a valve set below frost and operated by means of a handle reaching to the surface. Drainage of the pipe above the valve into a frost pit or otherwise is necessary to prevent freezing when the valve is entirely closed. By this method the flow of water may be controlled by the owner and may be cut off entirely when not in use as in a city water system.

The valve may also be placed on the pipe above the surface of the ground making it easier of access, but in this case a certain amount of water must be permitted to flow in winter in order to prevent freezing.

Two types of valves are in common use—the globe valve and the gate valve. In the globe valve a globular surface fits into a hemispherical cup, which when open presents a large surface to the flowing water and the wear is correspondingly slight. In the gate valve two surfaces resembling the edges of a pair of semi-circular shears close upon one another in such a way as to permit more rapid wear upon the valve.

In general globe valves are used to restrict the flow of water while gate valves are used primarily as shut-off valves, where normally only two positions are used, i. e., tight shut and wide open. The globe valve is capable of much more accurate regulation than any gate valve, and due to its construction may be repaired more easily. A gate valve, on the other hand, is difficult to repair and if it is used for any great length of time with the disc in any intermediate position, rapid wear is apt to take place. It is safe to assume, therefore, that where valves are required for throttling, as in artesian

18. Simpson, H. E., Methods of Reducing the Flow of Artesian Wells: North Dakota Geol. Survey Bull. 3, 1924, Revised Edition, 1932.

wells where a constant flow is permitted, globe valves should be preferred but where valves for shut-off services are required, as in artesian wells valved below the frost level, a gate valve should be used.

Valves, besides easily getting out of order through wear and rust, are so easily turned and put out of adjustment by children and irresponsible persons as to render them unsatisfactory unless they are permanently chained and padlocked, and a padlock exposed to the action of spattering water is frequently so rusted that it cannot be unlocked. In the valve also lies a certain amount of danger from wells drawing their supply from a bed of soft or "muddy" sand. There is under ordinary conditions no danger from reducing the flow of an artesian well, especially if it is done slowly. But caving is liable to occur in the water bearing formations due to sudden shock or jar when the valve is opened suddenly and the back pressure is released. In this case the water becomes roily or sandy and the well may even become plugged with sand or mud and the flow stopped. This necessitates cleaning out the well at considerable expense.

Reducers

For the reasons above mentioned, a reducer is recommended. This permits the uniform and constant flow of a limited amount of water and avoids all danger of roiling or sanding due to the sudden turning on of the well by inexperienced hands. A reducer can, however, be removed in a few moments in case of emergency by the aid of a pipe wrench.

For wells in which the pressure and flow are strong enough to give adequate fire protection where fire protection is needed, it may be well to place an outlet and gate valve between the well and the reducer so that in emergency the valve may be opened and the free flow of the well secured at once. Such an arrangement should not be made in connection with any well the history of which indicates its liability to yield mud or sand with the water. The sudden opening, and not the reduction, of such wells may prove injurious.

The standard form of reducer which screws into the end of the pipe cannot be secured in size sufficiently small to greatly reduce the flow of the water and it presents such a small surface to the action of the water that the orifice rapidly wears larger.

The same objection holds to the use of a standard plug, through the center of which a hole has been drilled, except that this hole may be made small enough; but the pressure remains high and the orifice is liable to be closed with small pieces of sediment carried up by the water.

Better than either of these is a nipple filled with babbit metal through which a small hole is bored; a hole one-eighth of an inch in diameter is usually sufficient to yield one gallon of water per minute under a normal pressure of several pounds. For light pressures a larger hole may be used. Owing to the softness of babbit, it will occasionally have to be refilled and rebored.

In emergency and as a temporary expedient even a hardwood plug notched in the sides or with a hole bored through the center may be fitted into the end of the pipe. In the latter case the plug after being bored should be sharpened like a lead pencil and the pointed end inserted in the pipe. This tends to avoid the clogging of the hole. The swelling of the wood as it becomes water soaked should, however, be anticipated.

The most satisfactory reducer in use in the Dakota Artesian Area, one introduced and long recommended and used by the North Dakota Artesian Well Company, Oakes, North Dakota, is known in the field simply as the "inside reducer." This reducer is not patented and may be secured from the company above mentioned in 1¼, 1½ and 2 inch sizes or made by a blacksmith in size to fit any well pipe at a cost of from $1.50 to $4.00 apiece, depending upon the number made and the size of each. The following description, and the accompanying drawings illustrating this reducer, furnish sufficient information to guide any blacksmith in the making of the reducer. It can then be readily and inexpensively installed. (See fig. 10.)

A cylindrical piece of steel shafting two or more inches in length and of the same diameter as the well pipe to be fitted, is threaded with standard threads on each end, leaving about one-half inch in the middle not threaded. A one-eighth inch hole is drilled through the center of the shafting and one end is drilled and tapped to insert a three-eighths inch pipe.

A piece of standard three-eighths inch pipe one foot to four feet in length is welded and tapered at one end. On the other end is cut a standard three-eighths inch pipe thread and a dozen or more one-eighth inch holes are drilled through the side of the pipe at well spaced intervals or an equal number of slots may be cut with a hack saw. The three-eighths inch pipe is then screwed into the shafting and the reducer is complete.

This reducer may be fitted into the pipe leading from the well either vertically or horizontally, the tapered end of the pipe being inserted first and the inner end of the reducer used as a plug, added lengths of well pipe being screwed to the outer end of the reducer. The reducer thus becomes an inside union in the well pipe. By this method the flow is greatly reduced; the pressure is also reduced through friction on the walls of the small holes and any particle of sand or gravel which enters the reducer may pass entirely through it and out without danger of clogging.

Results of Reduction

The flow from a well thus reduced is constant and without great force. In an emergency the reducer may be removed by a small pipe wrench and again replaced when the emergency is passed, but it cannot be tampered with by children

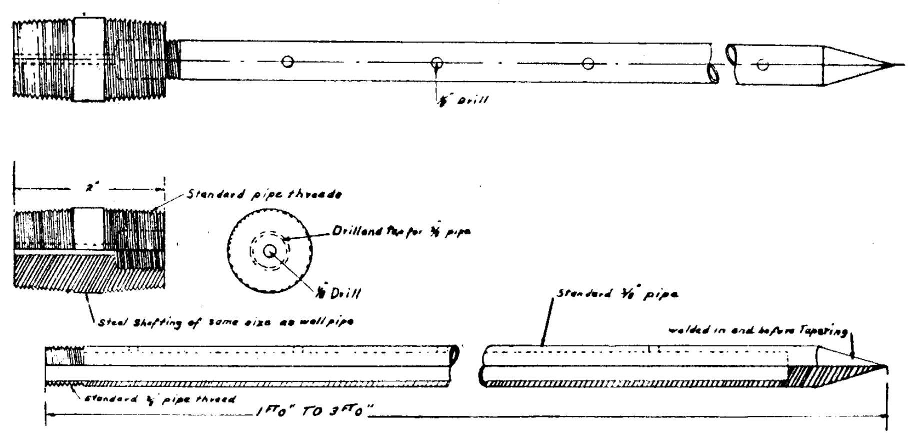


FIGURE 10.—Inside reducer recommended for use in flowing wells in North Dakota

and irresponsible strangers. The flow is kept open to prevent freezing and gives an amount of water sufficient for the stock of an ordinary farm if used with an ample storage tank, and if the reducer is placed at the tank outlet of a looped line of pipe passing through the house, as is a common custom, it will maintain sufficient back pressure to give a good strong flow at the house tap. If all lead pipes are properly buried 1 foot underground and the exposed loops covered in winter, there will be ample flow to prevent freezing through a considerable line of pipe, and abundant water may be furnished to both house and stock, cool in summer and moderately warm in winter.

Above all, the waste of water will be largely stopped, artesian flow and pressure will be conserved, and flooding of many acres of valuable land and much damage to highways will be avoided.

ARTESIAN WATER LEGISLATION[19]

Ground water legislation passed by the State legislature of 1921 and amended in 1925 has for its chief object, the conservation of the artesian waters of the state.

The great and progressive decline in artesian head throughout the Dakota Artesian area through the first thirty-five years of its use was well established, and the desirability of preventing further decline and of saving the wells that are still flowing after nearly a half century use in the area is now almost universally recognized.[20] To this end conservation of artesian waters is being enforced by eliminating the waste of water though permitting unlimited use.

The results obtained through the service of education, inspection and advice carried out under this legislation give a considerable degree of satisfaction and lead to an increasing hope that this most valuable natural resource may be saved not only for our own use but for many generations to follow on the rich prairie plains of North Dakota.

19. For a more complete presentation of this subject the reader is referred to: Artesian Water Papers, North Dakota Geological Survey, by Howard E. Simpson, listed on the last page of this paper. These contain the complete biennial reports of the State Water Geologist for 1921 to 1933 as follows:

A. W. P., No. 1, First Biennial Report, 1923.
No. 3, Second Biennial Report, 1925.
No. 4, Third Biennial Report, 1927.
No. 5, Fourth Biennial Report, 1929.
No. 6, Fifth Biennial Report, 1931.
Sixth Biennial Report, 1933.

20. Meinzer, Oscar E. and Herbert A. Hard, "The Artesian Water Supply of the Dakota Sandstone in North Dakota", U. S. Geological Survey, Water Supply Paper No. 520, E. 1925, also "Geology and Water Resources of the Edgeley and LaMoure Quadrangles, North Dakota", U. S. Geological Survey Bulletin 801, 1929.

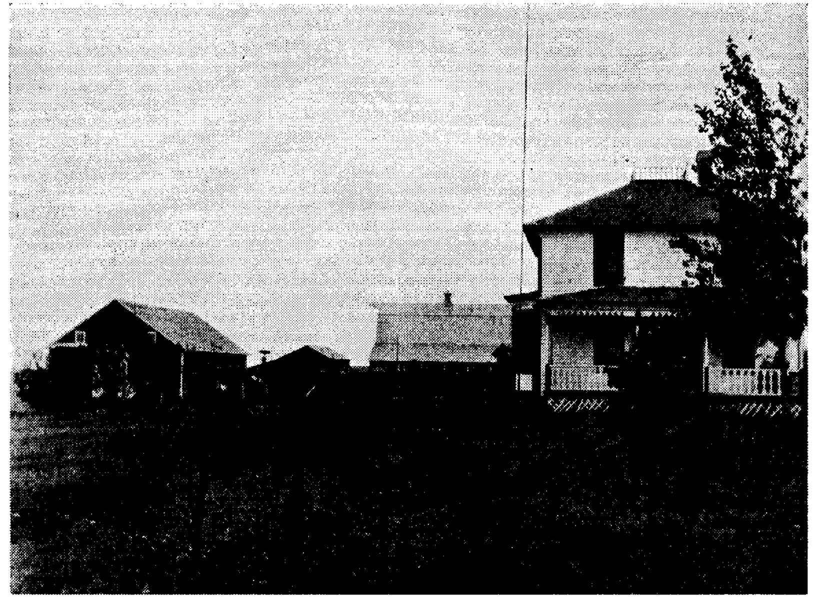


Fig. 11. A "good" artesian well. Note control valves and sanitary surroundings.

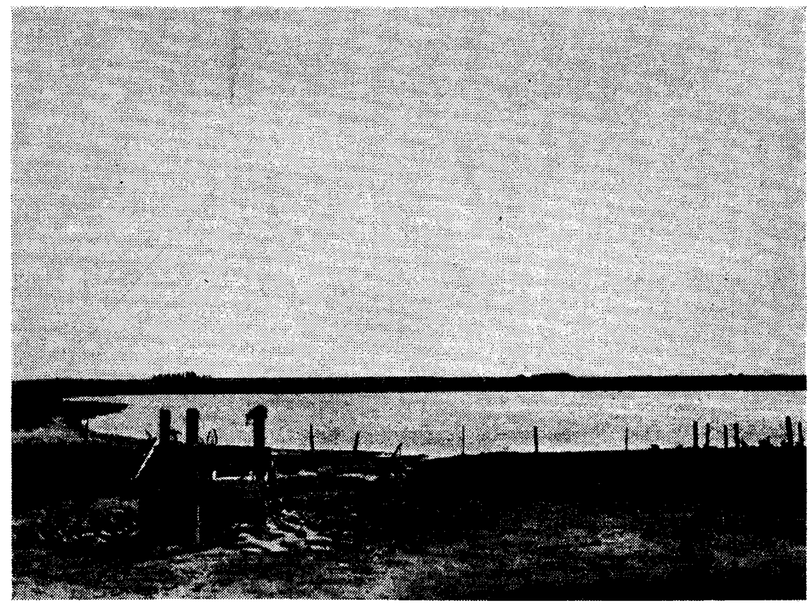


Fig. 12. A "bad" artesian well and its characteristic saline pond.

THE FIFTH BIENNIAL REPORT

of the

STATE WATER GEOLOGIST

In charge of the Artesian Water Conservation Fund

North Dakota Geological Survey*

Introduction

This report marks the completion of the first decade of service in the program of artesian water conservation and ground water development in North Dakota. The results of this specialized scientific service have never been more appreciated or more needed than in the years of the biennium just completed. The exceptional conditions of drought which have prevailed so widely over the United States have demonstrated how essential an adequate supply of good water is to modern life, both rural and urban. Fortunately, North Dakota has not suffered as have many other portions of the country, yet the appreciation of the need of better water supplies has never been more marked than at present. Cities and villages especially are seeking improvement both in increased quantity and quality and we are but at the threshold of the industrial life of the state.

The work of the State Water Geologist during the past biennium has followed the general lines originally laid down by the Artesian Water Conservation Law and developed through the eight preceding years. First, the conservation of the artesian waters has been promoted by the field inspection of every individual artesian well, whether flowing or non-flowing, in all townships not previously inspected in both the Dakota and the Red River Valley artesian areas. The owner of every well which was flowing in any way in violation of the artesian water law was advised, if possible orally, and in every case in writing, as to the action which he should take to bring his well into compliance with the law.

Second, the citizens of the state have been advised and assisted through consultation and written counsel in working out the most desirable control and use of their wells. This has included the making of investigations, surveys, and reports for cities and villages to determine the best available source of water supply and the most feasible means of obtaining it.

*Submitted in mimeographed form to the Governor and the Twenty-Second Legislative Assembly of the State of North Dakota, January 12, 1931.

The citizens, and particularly the farmers and ranchmen, have been assisted in a large way through cooperation with the well drillers in the improvements in their methods of making and finishing wells.

Further, both the conservation of the artesian waters and the development of better water supplies have been forwarded in an educational way by the publications which have been completed and issued, and are now available for use by the people of the state.

Field Work

The **first field season** of the biennium, that of 1929, was largely given over to the preliminary inspection of artesian wells in the Dakota artesian area and the Red River Valley artesian area in the southeastern portion of the state. Mr. Robert B. Simpson and Mr. Herbert H. Sand again rendered excellent service as Field Assistants in the work of inspection during this season as they had during the two preceding seasons. The inspection of all artesian wells, both flowing and non-flowing, numbering approximately 1800, in 60 townships was made during the field season. This work was done chiefly in Richland, Cass, Traill, Sargent, Ransom, and Barnes counties and marked the completion of the inspection of all artesian wells, numbering about 6000, in the major fields of the state.

The large amount of work done during this season, with two assistants in the field, largely exhausted the appropriation. A relatively small amount of work could, therefore, be carried out in the second half of the biennium.

During the **second field season,** that of 1930, an artesian water survey was made by the State Water Geologist and an assistant in the upper Missouri River Valley and in the lower Little Missouri Valley in North Dakota.

The Missouri-Little Missouri Artesian Area: In this survey both sides of the Missouri River Valley were visited from the Montana line to Elbowoods, opposite the confluence of the Little Missouri, and up the Little Missouri River Valley to the Roosevelt Bridge.

Practically all of the lower valley floors on either side of each river to a certain, yet variable, height above the river are found to lie within an artesian area. This area is of the narrow valley type and has about two score of wells now flowing. They are valuable on all farms, but are of especial value to the ranch owners because of the continuous flow of relatively warm water in the sheltered winter pastures among the woods of the "second bottoms" and on the lower "flats" of valleys during the severe winter season. Each flowing well within the areas mentioned in these two valleys was visited and studied, and altimeter readings were taken by which it was possible to map very accurately the limits of the artesian area.

This survey connected with that of the upper Little Missouri area, made by the State Water Geologist in 1922, which began a little below Challoner's Ferry, the present site of the Roosevelt Bridge, and extended up river to a point some miles above Marmarth.

We now know that the Missouri-Little Missouri Artesian area is continuous from the Montana line west of Williston along the courses of these two rivers to within a few miles of the South Dakota line south of Marmarth. There are already several hundred excellent flowing wells in this belt, which is about 350 miles long and from one to three miles wide. This is, therefore, one of the most unique of narrow valley artesian basins known.

Office Work

As in previous years, a very considerable amount of office work was done in connection with the field work in preparing the work for the field assistants, in handling their reports, in sending out advice to well owners as needed, and in filing all records. Besides this work directly related to the work of field inspection, there has grown up a very large body of official correspondence with well owners, well drillers, and city and village officials in connection with that portion of the state law which provides that the State Water Geologist "shall have the power of oversight and supervision of the waters of the State, and shall advise the citizens of the state as to the practicability of measures affecting the underground waters of the state." This has been interpreted to refer to all ground water supplies, both individual and public.

Complying with these instructions of the law, the State Water Geologist has answered all requests for information and given advice to all who have asked as fully and completely as possible, even though many of these requests came from without the state and some from foreign countries. This has required scores of personal interviews in the office, hundreds of individual letters, each bearing suggestions and advice upon particular problems, and the mailing of many circular letters, papers, and reports.

City and Village Surveys

During the biennium ground water surveys, special investigations, and reports have been made by the State Water Geologist for the Standing Rock Indian Agency and School at Ft. Yates, the Fort Totten Indian Agency and School at Ft. Totten, the State Hospital for the Insane at Jamestown, Devils Lake, Wahpeton, Lakota, McVille, Valley City, Westhope, Minot, Walhalla, and Lehr.

In most of these cases the public water supply has been improved in quantity or quality or both through the drilling of new wells or the deepening or enlargement of the old ones.

The State Public Health Laboratory has cooperated in making analyses of water samples, both bacteriological and chemical, and the Department of Chemistry of the University has assisted with chemical analyses of special samples of both water and rock material.

As heretofore, the aim in all of this work has been to assist the citizens by determining through a field survey and report the best water supply available for public use. In these surveys, since the service is of especial value to but a limited number, the bill of expense, calculated exactly as in the state service, has been presented to the city auditor rather than to the state auditor in order to conserve the very limited appropriation for the larger good.

The number of city, village and state institutions in North Dakota for which these surveys and reports have now been made is about forty. About thirty of these have already developed or improved their water supplies on the basis of recommendations in these reports.

Work With Well Drillers

The work begun by the State Water Geologist in 1915 in assisting the well drillers of the state through organization and short school methods in annual conventions to render the best and most efficient service to the citizens of their respective communities has now become not only state-wide but national in scope. The representatives of six state associations in the Middle West, including North Dakota, Minnesota, Iowa, Wisconsin, Illinois, and Indiana, met in Minneapolis last February with the Minnesota Well Drillers Association and perfected the organization of the American Association of Water Well Drillers under the direct patronage of the United States Geological Survey and the Geological Surveys of the several states. Since that meeting Michigan, Nebraska, and South

Dakota have completed their organizations, and the well drillers of several other states are considering organizing.

The primary aim of these associations is to elevate the standards in the water well drilling business and to improve the quality of water supplies.

The Missouri River Diversion Project

The Missouri River Diversion Project comes partially within the field of service of the State Water Geologist since it is of vital interest to a very large portion of the citizens of the state through its possible relation to the water supply, sewage disposal, health, and recreation facilities of the Devils-Stump Lake Region, and the Sheyenne, James, and Red River Valleys, and to the economic condition of the state as a whole. In the interest of this project he appeared at the hearing before the United States Army Engineers at Jamestown on May 9, 1930, accompanied Secretary of War Hurley on his inspection of the Devils Lake basin, July 28, 1930, and addressed the North Dakota Water and Sewage Works Conference at Grand Forks on December 9, 1930.

Outside Work

During the summer of 1929 the State Water Geologist was employed by the Canadian Geological Survey on the recommendation of the United States Geological Survey for a study of the ground water resources of the city of Regina, Saskatchewan. The conclusions presented in his report were accepted by the city and the work of developing an additional ground water supply estimated at between two million and four million gallons daily, in accordance with the recommendations, has been started.

Other investigations of ground water supplies or projects have been made during the biennium outside the state of North Dakota in Great Falls, Montana; Methuen, Massachusetts; Oakdale, Pennsylvania; Clarksburg, West Virginia; Canton, Dover, Salem, and Dayton, Ohio; Madison, South Dakota; and the State Soldiers Home, Hot Springs, South Dakota.

Publications

The publication of "The Geology and Ground Water Resources of North Dakota" as Water Supply Paper, No. 598, of the United States Geological Survey, Washington, D. C., is the culmination of a cooperative work between the North Dakota and United States Geological Surveys, extending over a period of years.

The following statement regarding this work was issued by the Department of the Interior as a "Memorandum for the Press," dated March 26, 1930.

"Water Resources of North Dakota: Better and more abundant water for the farms, ranches, villages, and cities of North Dakota is a possibility presented in a report just issued by the United States Department of the Interior under the title, 'The Geology and Ground Water Resources of North Dakota'. Howard E. Simpson is the author. The study was made by the United States Geological Survey in cooperation with the North Dakota Geological Survey.

"This report also contains a discussion of the chemical character of the water, by Harry B. Riffenburg. It is published as Geological Survey Water Supply Paper 598 and may be obtained from the Superintendent of Documents, Government Printing Office, Washington, for 50 cents. It sets forth in detail the results of an investigation covering a period of several years. The topography, climate, geology, and water supply of the State in general and of each of the counties are considered. The object of the investigation was to furnish to each community information showing the best ground water supply available, whether artesian water can be found in that locality, at what depths water may be reached, through what formations the drill must pass, and what mineral compounds the water is likely to contain. The general availability and usefulness of the supplies are compared as to cost, purity, and permanence wherever the available data permit.

"The book contains a map showing the several artesian areas in which flowing wells may be obtained, analyses of 196 typical waters representing the best supplies in every county of the State, and a table of the public water systems of cities and villages that have waterworks. The general descriptions of the rock formations and detailed discussions of the conditions governing the occurrence of ground water in each of the 53 counties should be of great value to well drillers and will enable many cities and villages and many farmers and stockmen to improve their water supply. Because of the importance of the 7000 flowing wells to the farming interests in this agricultural State, especial attention is given to the program for the conservation of artesian waters now being carried out under State legislation, a form of conservation in which North Dakota is doing pioneer work."

Other publications relating to ground water by the State Water Geologist during the biennium are as follows:

"The Ground Water Resources of North Dakota," a chapter in "Geology and Natural Resources of North Dakota," the University of North Dakota Departmental Bulletin, Vol. XIV. No. 1, January, 1930, issued by the Division of Mines and Mining Experiments in the College of Engineering in co-operation with the North Dakota State Geological Survey as Bulletin No. 11.

"A Report on the Ground Water Resources of Regina, Saskatchewan," one of a series of three "Reports on Regina Water Supply" by Nicholas S. Hill, Jr., New York; R. O. Wynne-Roberts, Toronto; and Howard E. Simpson, University of North Dakota; printed by order of the City Council, Regina, 1930. (Note: This report is also being published by the Geological Survey, Division of Mines, Ottawa, Canada.)

"Essential Points in Prospecting for City Ground Water Supplies," a brief two-page article reviewing current practice in ground water prospecting, is published in Water Works Engineering, the Journal of the Waterworks Profession, New York, November 5, 1930.

"Prospecting for Water," a two-page article in The Improvement Bulletin, Vol. 70, No. 14, August 23, 1930, St. Paul.

Plans for 1931-32

1. **Conservation:** The conservation of the artesian waters of North Dakota will be the primary aim of this work in the future as it has been in the past. The essential principle of the program for conservation remains unchanged: "Conservation means efficient use. Stop the waste of artesian water while permitting unlimited use."

2. **Inspection:** The inspection of 6000 flowing wells of the Dakota Artesian Area in North Dakota having been completed and the owners of all wells which were flowing to waste in violation of the artesian water conservation law having been notified in writing how to bring their wells into compliance with the law, it is planned to begin and carry as far as possible during the biennium a reinspection of those flowing wells which have been found on the first inspection to be flowing in violation of the law.

(a) In the cases of owners whose wells are still found to be flowing contrary to the law, a second notice should be given to comply with the law within three months.

(b) The names of the owners of flowing wells who fail to meet the legal requirements within the season specified may be filed with the States Attorney of the County with a request for action.

(c) Attention will be given especially to the serious problems involved in "wild wells," "old wells" and "leakers" and the situations in which large wastes of water and damage to public highways are involved.

3. **Study of Progress:** A study of a series of selected type wells within the Dakota Artesian Basin in order to determine as fully as possible the results of the 10 years' work under the Artesian Water Conservation Law. It is suggested that a cooperative arrangement be made with the U. S. Geological Survey to undertake this in order that the results may be wholly unbiased and impartial.

4. **County Water Survey:** It is planned to make a detailed survey of the ground water resources of one type county to be selected outside of the main artesian area. This survey should include a farm, village, and city study and a report so complete that on the basis of this it would be possible to advise the owner of each farm the depth at which he may probably find the best water supply and the kind of well by which it may be secured. It should also indicate in so far as possible the best available ground water supply for each city and village within the bounds of the county; quality, quantity, and approximate cost being considered. It would be the plan if this detailed farm survey of a county proves feasible to extend it to other counties of the state as time and funds permit. The desirability of having the county bear one-half of the expenses of such county ground water survey is under consideration.

5. **City, Village and Industrial Surveys:** A detailed survey of the ground water resources and a report with recommendations as to the method of securing the best available water supply for each and every city, village, and industrial plant, for which such a survey and report is requested. The expense in each of these cases should be borne by the municipality or industrial plant benefited, the work being done at the legal per diem.

6. **Improvement of Farm Supplies:** Equal in importance with the administration of the program of conservation of flowing wells should be a program of improvement through experimental studies of ground water supplies on the farms. This is essential to diversified farming and the development of the livestock and dairying interests.

7. **Standardization of Wells:** The State Water Geologist should assist the State Sanitary Engineer and the well drillers in the standardization of drilled farm wells. Good wells can only be obtained through proper methods of drilling and finishing. This means the recognition of certain standards so that every farm owner may know when he has a good well and whether he has paid a fair price for it.

8. **Cooperation:** The heartiest cooperation should be extended to the United States Geological Survey in its investigation of the methods of drilling and finishing of water wells in order to better the water supplies, and to the state and national well drillers associations, whose chief object is to elevate the standard of well drilling.

9. **Omission of Artesian Census:** The annual census provided by law, taken first in 1921 and in two additional years since, is believed to be an unnecessary expense during the coming biennium in view of the complete checking of the most important areas during the inspection by the State Water Geologist and his field assistants and deputy. This will be omitted, therefore, during this biennium except in counties containing portions of the minor fields not yet inspected.

This program will guide the State Water Geologist in his work during the next biennium. For these ends we respectfully request that the present biennial appropriation be continued as the least amount with which the program outlined may be carried forward.

Respectfully submitted,

Howard E. Simpson,
State Water Geologist.

Grand Forks, N. Dak.
January 10, 1931.

THE SIXTH BIENNIAL REPORT
of the
STATE WATER GEOLOGIST
In Charge of the Artesian Water Conservation Fund
North Dakota Geological Survey*

Introduction

Twelve years have passed since the program of artesian water conservation and betterment of ground water supplies was adopted in North Dakota. The law of 1921 was pioneer legislation in artesian water conservation. In the words of the Chief of the Ground Water Division of the United States Geological Survey it was, "The first adequate attempt to conserve artesian waters on a large scale." That the work has been successful in a large degree is attested by the same high authority in writing of our conservation program in an official report following a personal field investigation. He says, "The law passed by the State Legislature in 1921 has already greatly reduced the waste, checked the decline in pressure, and kept wells flowing that would otherwise have failed by this time or would fail in the near future."

That the work has been done economically is evidenced by the statement of an Engineer of the same Federal Survey after field observation: "I have been amazed at the amount of work accomplished in North Dakota on the very small appropriation available."

It is fortunate indeed that this program had been well developed and sound progress made before the three years of severe drought in 1929 to 1931, the effects of which are not yet over. Specialized scientific service in connection with water supplies was never more needed nor more appreciated in the Northwest than in those years. The increased rainfall of the past season has improved shallow ground water conditions somewhat but the apparent permanent lowering of ground water level with accompanying drying up of lakes, ponds, marshes, small springs and shallow wells calls for the utmost caution in the efficient use of the supplies that remain and the most courageous facing of the necessity for the increased development of the best of all available water supplies both underground and surface.

The work provided for by the Artesian Water Conservation Fund during the past biennium has followed the two lines

*Submitted in mimeographed form to the Governor and the Twenty-Third Legislative Assembly of the State of North Dakota, January 5, 1933.

specified by law, viz., artesian water conservation and ground water development. The program followed the definite system worked out through the past decade for the best utilization of the water resources by the people of the state. This included the re-inspection of wells flowing in violation of law, the making of surveys and reports for new or improved institution, city and village supplies, cooperation and advice to well drillers and individual citizens and the survey of the newly organized artesian field in the Missouri River Valley.

While as much of the work on the farms and in the cities and villages has been made as direct and personal as possible yet much greater results have, perhaps, been accomplished through educational work, chiefly through the use of the Artesian Water Papers. Two new papers have been issued during the past year, one describing briefly the general ground water resources of the entire state, the other the artesian waters of the state with especial emphasis on the Dakota Artesian Basin. A most important early paper, relating to the methods of reducing the flow of artesian wells, has been revised and enlarged. The cost of all of these papers has been borne by the Artesian Water Fund and they have been distributed free to citizens of the state.

Field Work

The completion of the first inspection of all flowing wells in the major artesian areas of the state, numbering approximately 6,000, during the previous biennium, permitted the placing of the emphasis of the field work during this biennium upon the **re-inspection** of those wells which were found on the first inspection to be flowing in violation of the law. The smaller number now requiring attention permitted such rapid work that more than one-half of the area of the major artesian basins was covered in the biennium and the remainder can be re-inspected during the coming biennium. Where necessary, advice was given the second time, with the request for compliance within three months.

Especial attention was given to the more serious problems involved in "old wells," "wild wells," and "leakers" and the situation in which large waste of water and damage to public highways is involved, with a considerable degree of success in getting some of the most serious of these fully cared for.

Mr. Robert B. Simpson and Mr. Herbert H. Sand again served as field assistants and did most of the work of re-inspection. Their work was of especial value because of the experience gained during four preceding seasons in making the initial inspection of the wells in the same territory.

The survey of the artesian conditions in the **Missouri Valley** was continued from the confluence of the Little Missouri at Elbowoods down to the South Dakota line, thus completing the study of the Little Missouri-Missouri Valley artesian area in North Dakota. Mr. Carl G. Peterson served as field assistant in this work.

It is now known that practically all of the lower terrace and bottom lands on either side of the Missouri River from the Montana line nearly to Fort Rice, 25 miles below Bismarck and Mandan, lie within this artesian area. A few wells of the narrow valley type of artesian are now flowing. They are valuable assets to the lowland farms and are of especial value to the ranch owners who winter large herds of cattle in the woods on these bottoms. In many pastures they have an equal summer value because of the difficulty cattle have in getting to the river for water over the mud flats and the danger of becoming mired down.

The Little Missouri-Missouri Valley Artesian area is unique because of its remarkable length in proportion to its width. As surveyed in North Dakota it is more than 600 miles long and from one to four miles in width.

Owing to the general financial situation only imperative work has been done during this biennium in developing new **city and village supplies** or in making improvements on the old ones. Special investigations and reports have been made for Bottineau, Valley City, Minot, Watford City, Mohall, Velva, Hatton, Bowbells, the State School for the Blind at Bathgate, Sullys Hill Big Game Preserve at Devils Lake for the U. S. Biological Survey, and Standing Rock Agency and School at Fort Yates for the U. S. Indian Service.

Office Work

A very considerable amount of office work was required in preparing and directing the work of the field assistants, in working over their reports, sending out the advice to well owners, filing records and caring for the large body of correspondence which has grown up with well owners, well drillers and city and village officials. Much of this work relates to ground water supplies outside of the artesian fields. This duty is imposed upon the State Water Geologist by that portion of the state law which provides that he "shall advise the citizens of the state as to the practicability of measures affecting the underground waters of the state."

Missouri River Diversion

Interest in the Missouri River Diversion Project developed in the preceding biennium has continued throughout this biennium. Because of its relation to water supply, sewage disposal, health and recreation in the Devils-Stump Lake Region and in the valleys of the Sheyenne, James and Red rivers and to the economic condition of the state as a whole, it was considered to lie in part within the field of service of the State Water Geologist. He therefore, at the request of the Governor, appeared at the hearings conducted by the United States Army Board of Engineers at Bismarck and at Williston and presented evidence regarding the possible benefits of this diversion to the State.

Outside Work

During the summer of 1930 the State Water Geologist was employed by the Board of Charities and Corrections of the State of South Dakota to make a survey of the ground water resources of the State Tuberculosis Sanatorium at Sanator, near Custer, in the heart of the Black Hills.

Publications

Official publications of the State Water Geologist during the biennium include the following:

"The Ground Waters of North Dakota" with the Fourth Biennial Report of the State Water Geologist, Artesian Water Paper, No. 5, 26 p., 4 fig. 1932. (Bulletin No. 7, North Dakota Geological Survey.)

"Methods of Reducing the Flow of Artesian Wells," Artesian Water Paper No. 2, 6 p., 1932. (Revised Edition.) (Bulletin No. 3, North Dakota Geological Survey.)

"The Artesian Waters of North Dakota" with the Fifth Biennial Report of the State Water Geologist, Artesian Water Paper No. 6, 1932 (Bulletin No. 8, North Dakota Geological Survey.) (Prepared but not printed.)

Other publications relating to ground water by the State Water Geologist during the biennium are as follows:

"Methods of Prospect Drilling for City Ground Water Supplies," Water Works Engineering, July 29, 1931, 2 p., 1 fig. New York.

"Ground Water Supply Provides Present and Future needs of Minot, North Dakota," Water Works Engineering, June 1, 1932, 4 p., 4 fig. New York.

Recommendations

1. **Conservation of Artesian Waters:** The conservation of the artesian waters of the state must continue to be the primary aim of this work throughout the biennium of 1933-1934. The essential principle of the program still must be, "Unlimited use of artesian water without waste."

2. **Re-inspection:** The most important work to be done is the completion of re-inspection of all wells unlawfully flowing to waste at the time of the first inspection. The owners of all of these were advised in writing of the action necessary to bring their wells into compliance with the law. The owner of every well still flowing in violation of the law should be again advised, orally if possible, and in every case in writing, requesting compliance within three months. The names of the owners who fail to comply with this advice and request should be filed with the States Attorney of the County with a request for action.

3. **"Wild Wells":** Definite progress has been made in bringing old "wild wells" under control. There still remain a few conspicuous exceptions. The cost of control in some cases is beyond the ability of the owner to pay and even greater than the value of the property on which the well is located. In such cases enforced action would be confiscatory. In such cases adjustments should be made if possible whereby the township and county would bear a portion of the expense. This should apply especially where roads and highways are being seriously damaged by artesian water and should be brought about in each instance through mutual agreement.

4. **Research and Revision:** A careful restudy of the entire artesian water situation in the Dakota Artesian Basin should be made to determine as fully as possible what progress has been made in conservation, what the future needs in development are, and to provide the basis for a re-writing of the artesian water law in the light of past experience for presentation to the State Legislature in January, 1935. It is suggested that the United States Geological Survey be requested to cooperate in this work in order that the finding may be impartial and authoritative.

5. **City and Industrial Survey:** When requested, surveys for state institutions, cities, villages, and industrial plants should be made to determine the best available source of water supply for each and the most feasible means of obtaining it. This is a field in which the State Water Geologist may render valuable service not only in securing better local

water supplies but in promoting great economies. The actual expense in each of these surveys should be borne by the beneficiary, the work being done at the legal per diem.

In order to anticipate possible growth and industrial development, every city should have a definite program of water supply development and a sufficient supply of water "in sight" to meet the demands which may be reasonably expected within the next ten years, at least. This plan, subject of course to amendment and revision, should be followed through the changes of city government with geologic advice and engineering supervision from a relatively permanent personnel.

6. **Farms Wells:** Continued attention should be given to individual owners of wells in this period of increasing need of water supply, and every possible assistance rendered, especially upon the farms, to improve the water supplies both in quantity and quality. This service has been extended in the past without expense to individual citizens.

One of the most effective and far reaching ways in which this service has been rendered has been by assisting the well drillers, individually and through their state wide organization in improving the methods of drilling and finishing wells and in developing a standard type of farm well. When certain standards come to be recognized, each farm owner may know when he has a good well and whether he has paid a fair price for it. This is the interpretation of the State Water Geologist of that statement of the law which says: "It shall be his duty to advise the citizens of the State as to the practicability of measures affecting the underground waters of the state" and "to counsel and consult with the owner and assist him to work out the most desirable control and use of his well."

7. **Cooperation:** Cooperation should be continued with the United States Geological Survey, the State Public Health Laboratory and the State Sanitary Engineer in all matters relating to improvements in ground waters supplies. The cooperation with these and with the State Engineer and the State Fish and Game Board in connection with the location and occurrence of surface water supplies should be continued and extended in order to develop a unified program for larger and better water supplies to replace the rapidly disappearing surface waters of North Dakota.

8. **The Artesian Census:** The annual listing of the flowing wells by the assessors as required by law is now an unnecessary expense in view of the completion of the first inspection and the relatively small number of new wells that are now being drilled. It is recommended that this be omitted in 1933 and 1934.

These recommendations, if accepted by the Governor and Legislature, will guide the State Water Geologist in his work for the biennium. To carry out this service we respectfully request that the biennial appropriation requested through the Budget Board be allowed as the least possible amount with which the program outlined may be adequately carried forward.

Respectfully submitted,

Howard E. Simpson,
State Water Geologist.

Grand Forks, North Dakota
January 5, 1933.

ARTESIAN WATER PAPERS

North Dakota Geological Survey

No. 1. Artesian Water Conditions and the First Biennial Report of the State Water Geologist, by Howard E. Simpson. 1923. 8 p. (Bulletin No. 2, N. D. G. S.) Revised Edition, 1935.

No. 2. Methods of Reducing the Flow of Artesian Wells, by Howard E. Simpson. 1924. 4 p., 1 fig. (Bulletin No. 3, N. D. G. S.) Revised Edition, 1932.

No. 3. The Conservation of Artesian Water and the Second Biennial Report of the State Water Geologist, by Howard E. Simpson. 1926. 24 p., 1 fig. (Bulletin No. 5, N. D. G. S.)

No. 4. A Method of Water Prospecting and the Third Biennial Report of the State Water Geologist, by Howard E. Simpson. 1927. 20 p., 1 fig. (Bulletin No. 6, N. D. G. S.)

No. 5. The Ground Waters of North Dakota and the Fourth Biennial Report of the State Water Geologist, by Howard E. Simpson. 1932. 26 p., 4 fig. (Bulletin No. 7, N. D. G. S.)

No. 6. The Artesian Waters of North Dakota and the Fifth and Sixth Biennial Reports of the State Water Geologist, by Howard E. Simpson, 1935, 48 p., 12 fig., 1 map. (Bulletin No. 8, N. D. G. S.)

Artesian Water Papers will be sent free upon receipt of request addressed to the State Geologist, University Station, Grand Forks, North Dakota, accompanied by three cents in postage for each paper requested.