UNITED STATES
DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

RECONNAISSANCE OF THE GEOLOGY AND GROUND-WATER HYDROLOGY OF THE BELLE FOURCHE IRRIGATION PROJECT, SOUTH DAKOTA

By Arthur J. Rosier

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of proposed report
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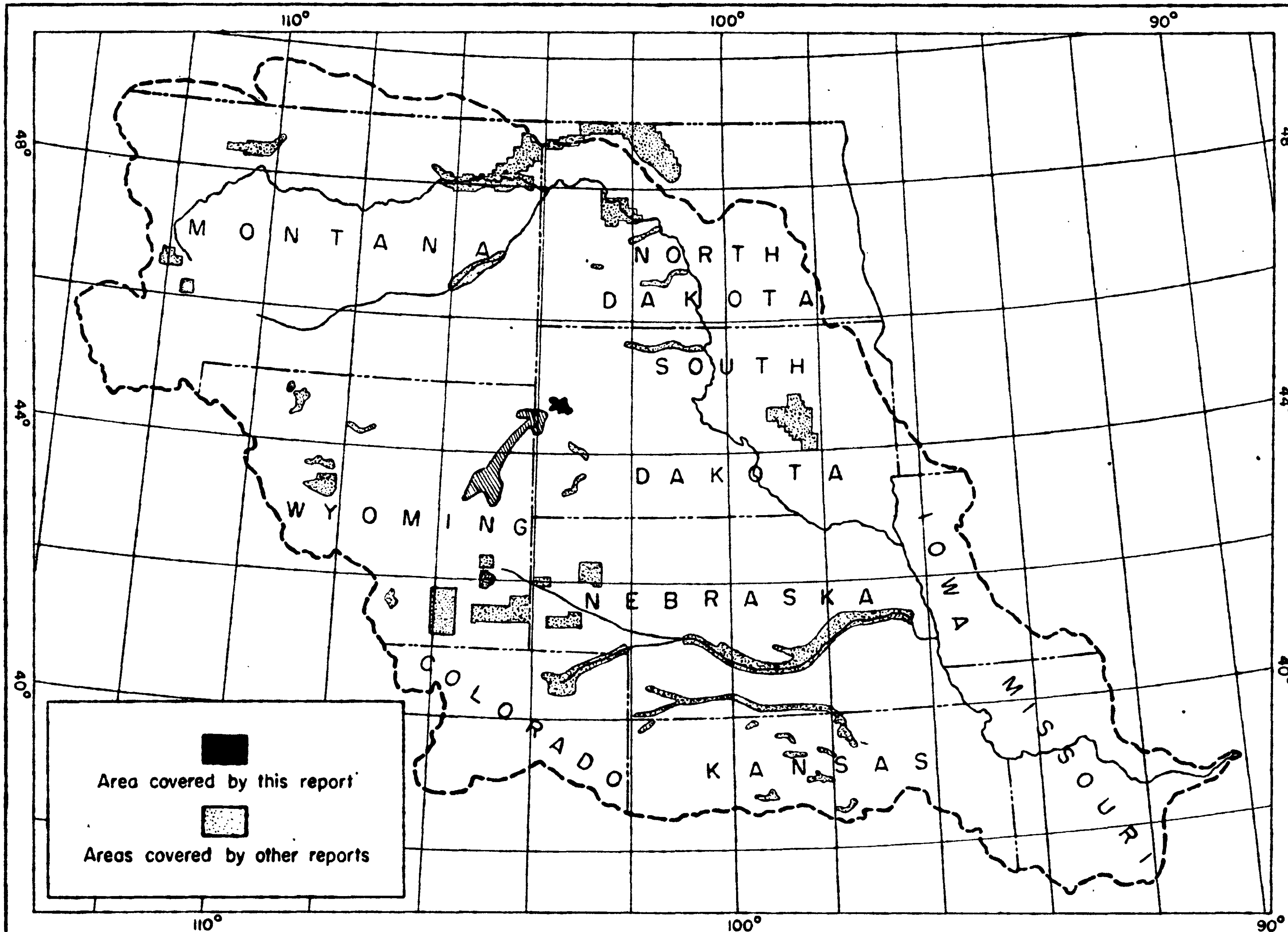

Frontispiece.—Map of the Missouri River Basin showing areas in which ground-water studies have been made under Missouri Basin program.

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ABSTRACT

The Belle Fourche irrigation project is in western South Dakota on the plains adjacent to the northeastern edge of the Black Hills. The project is drained by the Belle Fourche River and is characterized generally by broad shallow valleys that lie between hills with gentle slopes. The climate is semiarid.

Most of the area is mantled by residual clay, terrace deposits, and alluvium. The terrace deposits contain much water and are the most permeable deposits in the project area. The alluvial deposits of the Belle Fourche River and of the creeks south of the river contain much sand and gravel and are relatively permeable. The alluvium of the creeks north of the river is predominantly clay and is only slightly permeable; it greatly resembles the residual clay of the weathered bedrock formations, which are mostly shale in this area.

Although relatively abundant ground water is found in the unconsolidated materials above the bedrock formations, the ground water from the clayey deposits generally contains too great a concentration of objectionable salts to be fit for human or livestock consumption. The ground water in the more coarse materials is of better quality and in some small areas is satisfactory for domestic use. Most of the water for domestic use is hauled from deep artesian wells within the area.

The chief source of ground water is seepage from irrigation canals in the terrace and alluvial deposits. When this water moves to areas of lower permeability a correspondingly greater rise of the water table compensates for the lower permeability and results in the waterlogging of many areas. Open drainage ditches have been constructed in all large areas that are affected by high ground-water levels. Except in those areas that are underlain predominantly by clayey materials, these ditches usually have proven to be satisfactory for the control of ground-water levels. However, lining the canals seems to be a more satisfactory method of preventing the seepage that causes high ground-water levels.

A detailed investigation should be made of ground-water conditions in the Belle Fourche project area. Additional observation wells should be installed so that the effectiveness of the ground-water control measures can be determined.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The purpose of this investigation was to obtain detailed information on the occurrence of ground water in several small areas within the project and from this information to obtain a general picture of ground-water conditions in the entire project area. Ground-water conditions in four small areas are recorded in this report and the requirements for additional work are outlined. The field work for this report was done during the summer and fall of 1950.

This investigation is a part of the program of the Interior Department for the development of the Missouri River basin and was made under the general supervision of A. N. Sayre, Chief of the Ground Water Branch, United States Geological Survey, and G. H. Taylor, regional engineer in charge of ground-water studies under the Missouri River basin development program. G. A. LaRocque, Jr., district engineer, directly supervised the field studies and the preparation of this report.

LOCATION AND EXTENT OF AREA

The Belle Fourche irrigation project is near the western edge of South Dakota and is about 15 miles north of the Black Hills National Forest. (See frontispiece.) The project is almost wholly in southern Butte County but extends a short distance into the northern part of Meade County. The width of the project averages about 10 miles and the length is about 21 miles. The Belle Fourche River flows in an easterly direction through the southern part of project area. About three-fourths of the project is north and the remainder is south of the river.

METHODS OF STUDY

Only a few wells have been constructed in the Belle Fourche irrigation project because the shallow ground water contains such large mineral concentrations that it is not suitable for domestic or live-stock use. The few existing wells are so widely spaced that they are of little use in the determination of ground-water occurrence and movement. As almost no wells had been constructed in the two-thirds of the project area that is directly underlain by clay or bedrock, it was necessary to install observation wells in order to obtain even a minimum of ground-water information. Because the construction of an adequate network of observation wells in the entire project was not feasible in the allotted time, observation wells were constructed in four small areas in which the occurrence of the ground water was considered to be representative of the entire project. The relationship of the ground water to drainage ditches also was observed.

The kind of material to be penetrated determined the method that was used in the construction of observation wells. The jetting method was used in clay and shale materials. Driven wells, or wells constructed by a combination of jetting and driving, were installed in the areas that are underlain by very coarse materials.

The jetted wells are cased with 3/4-inch diameter or $1\frac{1}{4}$-inch diameter pipe. Sand and gravel are packed around the screen that is connected to the lower end of the pipe.

Three-quarter inch diameter pipe was used in the driven wells. The pipe was driven first to a desired depth, then the pipe was raised half a foot and the drive point was punched out to permit water to enter. A 5/8-inch diameter rivet was used as the drive point. Because the diameter of the head of the rivet was greater than the outside diameter of the pipe, friction along the sides of the pipe while it was being driven was reduced. A straight hole was maintained by turning the pipe as it was being driven.

A combination of jetting and driving was used to install some wells in the coarser materials. The bottom 2-foot section of a 3/4-inch diameter pipe was perforated with saw cuts and the lower end was either capped or fitted with a rivet drive-point. Water under pressure was forced through the pipe as it was being driven. The water enlarged the hole and thus reduced friction and moistened the material for ease of driving. Some of the penetrated material was washed to the surface by the water; a log of the hole was made from this washed material.

ACKNOWLEDGMENTS

The personnel of the Belle Fourche irrigation district were especially helpful and cooperative during the course of this study.

WELL-NUMBERING SYSTEM

Wells are numbered in this report according to their location within the land subdivisions of the Bureau of Land Management survey of the area. The first numeral of a well number indicates the township, the second the range, and the third the section in which the well is located. The lower-case letters following the section number indicate the location of the well within the section. The first letter denotes the quarter section and the second the quarter-quarter section. The letters (a, b, c, and d) are assigned in a counterclockwise direction beginning in the northeast quarter of the section or the quarter-quarter section. The numbers of two or more wells in a quarter-quarter section are distinguished by serial numbers that follow the lower-case letters. The numbers following the lower-case letters are also used to identify the wells in the several figures in this report.

The well-numbering system is illustrated in figure 1.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Belle Fourche irrigation project is on the plains adjacent to the northeastern edge of the Black Hills. The topography is characterized generally by broad shallow valleys that lie between hills with gentle slopes. Along the Belle Fourche River, however, escarpments as much as 200 feet high border the floor of the valley. A few isolated buttes are in the area and numerous so-called tepee buttes lie along the northeastern edge of the project. Most of the streams are bordered by remnants of terraces. The altitude of the area, which ranges from 3,200 feet to 2,700 feet above mean sea level, gradually decreases from west to east. The average altitude of the irrigated land is about 2,800 feet. The long ovate ridge between Owl and Indian Creeks, in the

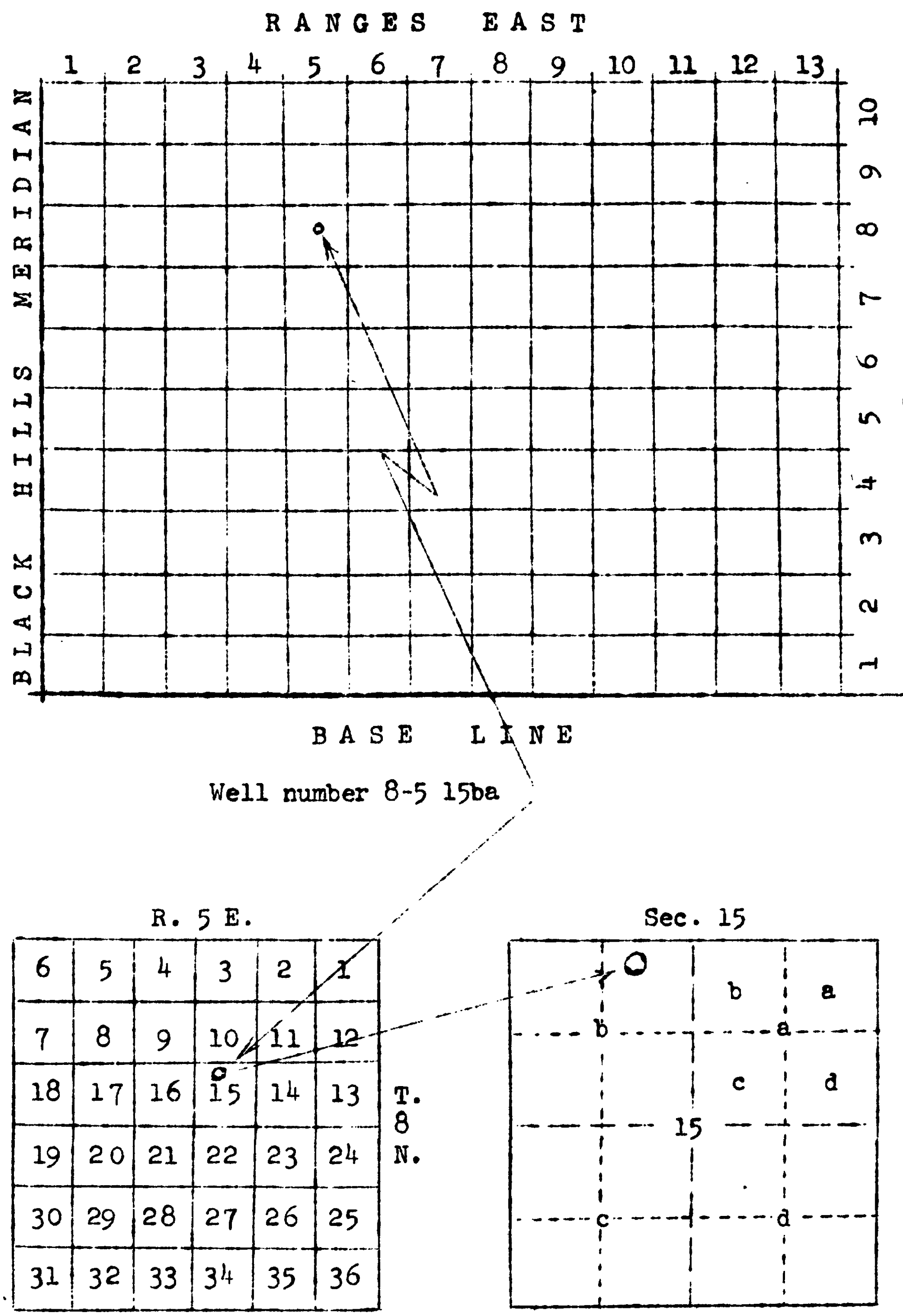

Figure 1.--Sketch showing well-numbering system.

western half of the project area, is too high to be irrigated under the present gravity-flow system.

The average annual runoff of the Belle Fourche River, which is the major stream that drains the area, is about 255,000 acre-feet. Several small streams discharge into the Belle Fourche River within the project area. (See fig. 2.) Willow, Dry, Horse, Owl, and Indian Creeks, the principal northern tributaries of the Belle Fourche River in the project area, flow southeast; Whitewood, Cottonwood, Stinkingwater, and Nine Mile Creeks, the principal southern tributaries, flow northeast. These streams carry off the excess surface irrigation water and, because ground water also discharges into them, their flows vary greatly. No measurements of the flow of the small streams of this area have been made. However, landowners report that the seasonal flow of the streams, when not influenced by return irrigation water, is as follows: Willow, Dry, Stinkingwater, and Nine Mile Creeks flow only when the rain is heavy; Horse, Owl, Indian, and Cottonwood Creeks flow perennially except in long periods of drought; Whitewood Creek flows perennially and carries considerable suspended matter, probably from the Lead and Deadwood mining areas.

CLIMATE

Climatic records have been kept at Orman since 1906, at Vale since 1908, and at Newell since 1921. Orman is in the western part of the area; Newell is in the approximate center of the project; and Vale is 6 miles south of Newell. (See fig. 2.) The normal or "adjusted mean"

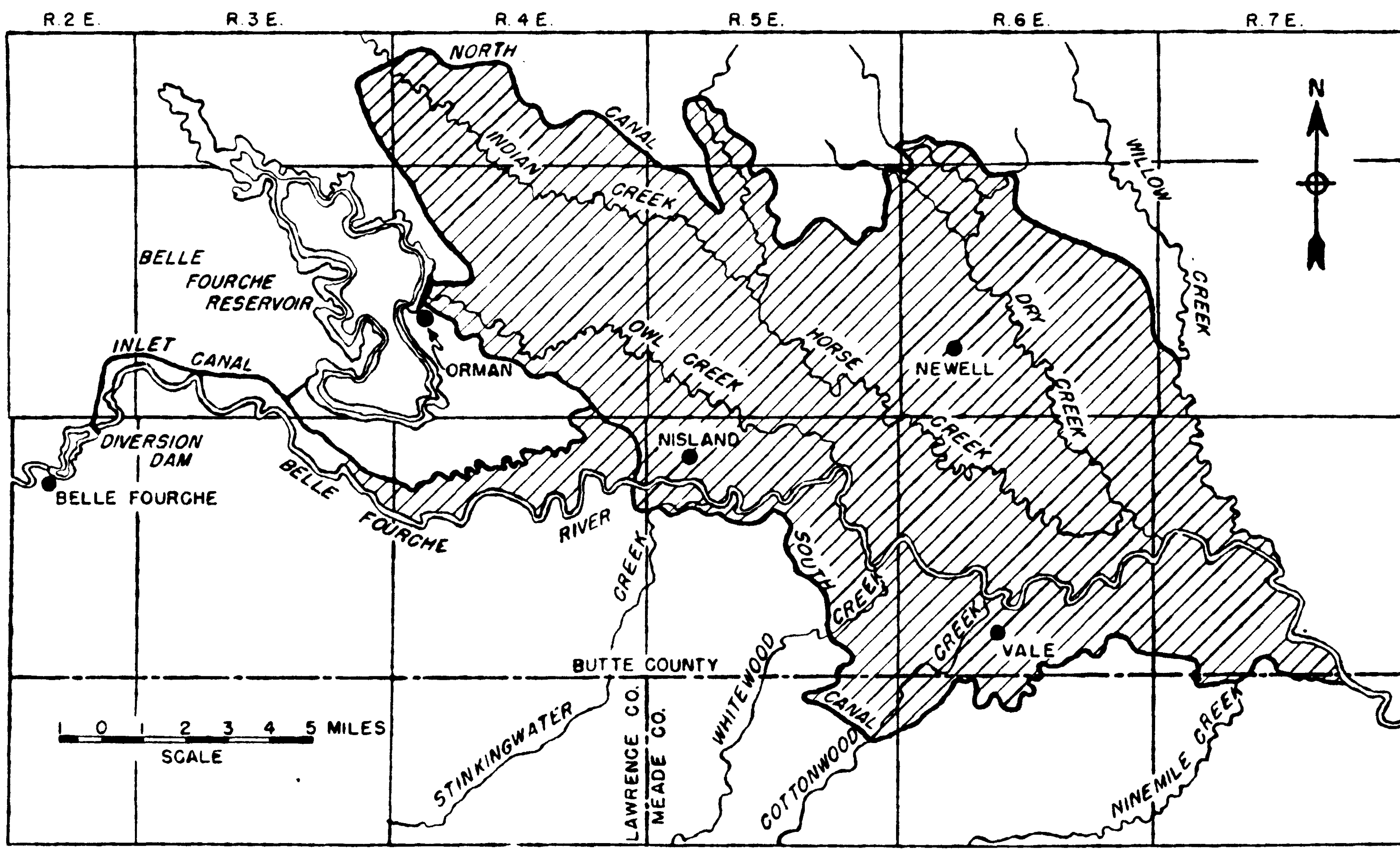

Figure 2.—Map of the major irrigation features and natural drainage of the Belle Fourche irrigation project.

annual precipitation, as computed by the United States Weather Bureau, is 15.06 inches at Orman, 16.45 inches at Vale, and 16.08 inches at Newell. More than three-fourths of the precipitation is received during the growing season--that is, from April 1 to September 30. December, January, and February are the driest months of the year. March is usually the month of greatest snowfall. Graphs of the annual precipitation at Fort Meade, which is 22 miles south of Newell, from 1881-1918 and at Newell from 1921-49 are shown in figure 3. The cumulative departure from the actual average for the period 1881-1910 at Fort Meade and for the period 1921-49 at Newell are also shown in the same figure. An upward trend of a graph showing cumulative departure from average indicates periods of above-normal precipitation; a downward trend indicates periods of below-normal precipitation. The cumulative departure from actual average for these stations is correct for their short periods of record, but if the amount of precipitation had been recorded for a much longer period these curves probably would have a different shape. Comparison of the precipitation records for Fort Meade and Newell with the record for Rapid City, S. Dak. (50 miles south of Newell) shows that the record for Fort Meade is probably for a period of above-average precipitation and the record for Newell is probably for a period of below-average precipitation.

The mean annual temperature at the three stations in the project area is 46°F. The last killing frost in the spring generally occurs during the first or second week of May and the first killing frost in autumn generally occurs in the later part of September. The highest recorded temperature in the project area is 110°F; the lowest recorded temperature is -39°F.

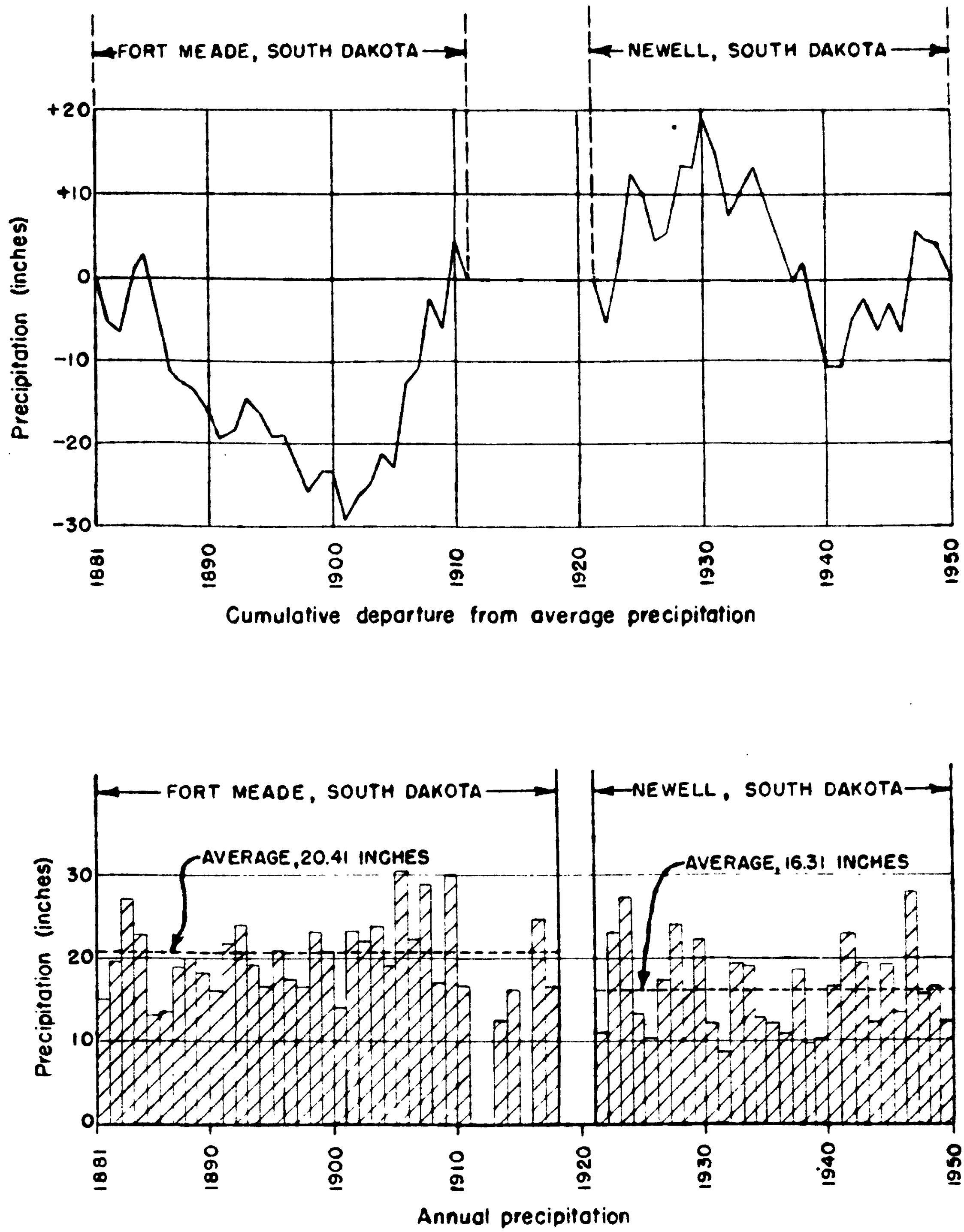

Figure 3.— Graphs showing annual precipitation at Fort Meade, S. Dak. (1881–1918) and Newell, S. Dak. (1921–1950) and cumulative departure from average precipitation at Fort Meade, S. Dak. (1881–1910) and Newell, S. Dak. (1921–1950).

HISTORY OF THE BELLE FOURCHE IRRIGATION PROJECT

The Belle Fourche irrigation project is one of the oldest projects of the United States Bureau of Reclamation. The first survey was begun in July 1903 by R. F. Walter, engineer for the Reclamation Service, who found irrigable lands on both sides of the Belle Fourche River. The irrigable lands on the north side of the river were open for settlement, but those on the south side were nearly all privately owned. He concluded that, although little stream flow data were available, irrigation was feasible if a reservoir for storage and a distribution system were constructed.

After the Secretary of the Interior authorized the project on the basis of preliminary surveys, construction plans and specifications were prepared. Meanwhile further studies of stream flow were made and other sources of water were explored. Construction of the project was begun in 1905, and water was delivered in 1908 for a first time to 12,000 acres.

Water from the Belle Fourche River is diverted by the Belle Fourche diversion dam into the inlet canal of the Belle Fourche Reservoir. This diversion dam, which is 1½ miles downstream from the city of Belle Fourche and about 7 miles west of Fruitdale, is a concrete gravity weir with flanking earth dikes. The water flows through the inlet canal, which has a capacity of 1,635 second-feet, for 6½ miles to the Belle Fourche reservoir on Owl Creek. The storage dam is an earth-filled structure with precast concrete protection on the upstream face. The reservoir capacity is 177,500 acre-feet of live irrigation storage. The North and South canals, which have a combined length of 90 miles, distribute water from the reservoir to the project lands. The capacity of the North canal is 650 second-feet and the capacity of the South canal is 350 second-feet. This system supplies water to 531 farm units, where alfalfa, hay, sugar beets, corn, oats, and barley are the chief crops.

Water for domestic use is usually obtained from deep artesian wells because the high concentration of salts in most of the shallow ground water is objectionable. The cost of drilling a well to an artesian aquifer generally is prohibitive for most of the landowners. A well at Nisland supplies the largest amount of artesian water, and many farmers haul water from this well to their homes. Most farmers store excess irrigation water for livestock use in reservoirs and ponds.

GEOLOGY

GENERAL

The Belle Fourche irrigation project lies partly in the Belle Fourche quadrangle, which was mapped by N. H. Darton and C. C. O'Harra (1909), and partly in the Newell quadrangle, which was mapped by N. H. Darton (1919). The geologic map (pl. 1) that accompanies this report was traced from the geologic maps of these two quadrangles. The following brief description of the geology of the Belle Fourche irrigation project is based wholly on the descriptive material in the Belle Fourche (No. 164) and Newell (No. 209) folios of the Geologic Atlas of the United States.

The dip of the bedrock formations in the Belle Fourche irrigation project is less than 1° to the northeast. Because of this low dip and the relatively flat topography, the outcrop areas of the formations are wide in comparison to the thickness of the formations. The Graneros shale of early reports, the Greenhorn formation, the Carlile shale, and the Niobrara formation, all of Late Cretaceous age, are exposed in parallel bands that cross the southwest corner of the area; the bedrock in the remainder of the area is the Pierre shale, also of Late Cretaceous age. The soils derived from these formations are composed mostly of clay. The bedrock formations are mantled by unconsolidated terrace deposits in parts of the upland area and by alluvium in the valley areas.

STRATIGRAPHY

Cretaceous System

Upper Cretaceous Series

Graneros shale.--The Graneros shale of early reports consists of dark-gray shale that contains ferruginous limestone concretions in many places. The shale is mostly soft and is thinly laminated except where reduced to clay by long weathering. The upper part of the formation is exposed in a belt that trends southeastward from the Belle Fourche reservoir. In part of the area of outcrop it is mantled by a thin veneer of terrace deposits or alluvium. The thickness of the formation is about 1,000 feet, but only the upper part of the formation is exposed in the area described in this report.

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Greenhorn formation.--The Greenhorn formation consists of impure limestone that includes sand and clay in varying quantities. The limestone beds are separated by shale layers half an inch to 3 inches or more thick. The unweathered formation is gray and moderately compact. On weathering, the limestone beds become harder and appear as thin pale-buff slabs on the outcrop. Many weathered fragments are covered with a white incrustation of calcium carbonate that makes the outcrop conspicuous. The base of the formation is clearly distinct from the underlying Graneros shale of early reports, and the upper part grades into the overlying Carlile shale. The Greenhorn formation is exposed in a narrow belt that extends southeastward from the Belle Fourche reservoir. It is 25 to 35 feet thick in this area.

Carlile shale.--The Carlile shale is a dark-gray or black fissile shale that contains numerous ferruginous limestone concretions and in some places thin beds of sandstone. The limestone concretions are mostly 3 to 5 feet in diameter and are traversed by calcite-filled cracks. The surface of the concretions is generally yellowish to yellowish red. In the upper part of the formation the concretions are less numerous and are mostly grayish. The Carlile shale is exposed in a 2-mile-wide belt that extends southeastward from the north end of the Belle Fourche reservoir. The formation is 600 to 800 feet thick in this area.

Niobrara formation.--The Niobrara formation consists of soft light-gray to buff mixtures of clay and calcium carbonate in various proportions, in greater part consisting of impure chalk that grades into and is interbedded with calcareous shale. On weathering it becomes

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chrome-yellow, a characteristic feature of this formation. It underlies part of the valleys of Indian and Owl Creeks and is exposed in a butte about half a mile north of Nisland and in the cliffs on the south side of the Belle Fourche River southeast of Nisland. It is mantled in much of this area by terrace deposits and by the alluvium of Cottonwood Creek. It is 150 to 200 feet thick in this area.

Pierre shale.--The Pierre shale consists mostly of soft dark-gray fissile shale with many iron-stained concretions. Most of the concretions are oval and smooth-surfaced and measure from a few inches to 2 feet or more. Some of the concretions are gray limestone that weathers to a bright brown-red. The concretions break up on exposure and accumulate on the surface as small irregular fragments. Concretions of limestone and aggregates of shells in masses that range from a few cubic inches to several thousand cubic feet appear as rocky masses that cap conical hills of soft shale, which are known as "tepee buttes." The lowest member of the Pierre shale is lighter colored and contains thin brown lenses and flat concretions of iron. Weathered surfaces of the Pierre shale are generally yellowish. The Pierre shale is widely exposed in the central, northern, and eastern parts of the area. It underlies the valleys of Indian Creek and the Belle Fourche River in these parts of the area and is mantled in many places by terrace deposits. It is about 1,400 feet thick.

Quaternary System

Pleistocene Series

Terrace deposits.--The terrace deposits consist of loam, sand, gravel, and boulders. The coarse materials are largely quartz or quartzite and were derived mostly from the Black Hills. In some places the terrace deposits contain a large proportion of locally-derived materials; this is especially true of some of the terrace deposits along Indian Creek where they are yellowish to gray owing to the presence of lime carbonate that was derived from the chalky shales of the Niobrara formation. The most extensive deposits in the project are on the south side of the Belle Fourche River east of Vale. Other terrace deposits are present at various levels on either side of the Belle Fourche River and at a few places along tributary streams. The thickness of the terrace deposits generally ranges from 12 to 15 feet; in a few places it may be as great as 30 feet.

Recent Series

Alluvium.--The alluvium of the Belle Fourche River valley and its tributaries from the southwest is composed of loam, clay, sand and gravel that was derived largely from the Black Hills area. As the tributaries from the northwest drain areas that are underlain largely by shale, the alluvium in the valleys of these streams is composed mostly of loam and clay except where coarser material that was eroded from higher-lying terraces is incorporated in the alluvium. The boundary of the alluvium is hard to define in many places because the alluvium merges into the hillside wash on the slopes adjoining the valley. The width of the areas that are underlain by alluvium ranges from a half mile to about 4 miles. Along the Belle Fourche River the alluvium ranges in elevation from water level to 30 feet above the stream and occupies the flood plain and the first and second benches--features that are separated locally but that merge irregularly in most parts of the valley. The alluvium near the Belle Fourche River averages 25 feet thick, but it is much thinner in the smaller valleys and varies irregularly from place to place.

GROUND WATER

Some irrigated areas on the project have become partially or entirely unproductive because of waterlogging or because the soil has become impregnated with mineral salts. The cause of the waterlogging is seepage from the reservoir, from the canals and laterals, and from irrigation. When the water table is close to the land surface the air that is necessary for optimum plant growth is excluded from the soil zone. Also, evaporation of water from the capillary zone above the water table causes the deposition on the land surface of the minerals that were dissolved in the water. If these conditions become generally prevalent the soil may eventually become wholly unproductive.

The major areas in the project that have become partially or entirely waterlogged are those areas where drains have been constructed. (See pl. 1.) Most of the drains are open ditches that are 6 to 8 feet deep and that were constructed between 1928 and 1932.

During this period, observation wells were installed in some of the waterlogged areas as an aid in the design of the drainage system. These wells were cased with wood and were not kept in good repair. They have since deteriorated to such an extent that probably none of them are now usable. If the effectiveness of the drainage systems was to be determined, periodic water-level measurements should have been made after the drains were constructed; however, this apparently was not done.

Seepage of water from irrigation canals is probably the chief source of ground-water recharge. The areas of greatest seepage loss are where the irrigation canals are cut into the sands and gravels of the terrace and alluvial deposits. Because the bedrock underlying these deposits is nearly impervious the ground water moves laterally to lower-lying areas. Where these areas are underlain by materials that are relatively less permeable, the ground-water level rises to compensate for the lesser permeability. In the areas of low permeability, the removal and disposal of the excess ground water are problems that cannot be resolved easily.

The occurrence of waterlogging can be prevented by controlling the conditions under which surface water becomes ground water or by constructing facilities for the drainage of the excess water. The lowering of a high water table probably can be solved best by a combination of both methods.

The occurrence of excess ground water can be prevented by lining the canals and reservoirs and by rigidly controlling the amount of irrigation water that is applied to the land. An example of the satisfactory results that are achieved by the lining of a canal is described in the following paragraph.

Seepage from the South canal was the cause of a high water table in an area in NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 15, T. 8 N., R. 5 E. (See fig. 4.) The South canal in this area was constructed on a terrace deposit that is composed of a very permeable deposit of sand, gravel, and boulders, and that is underlain by shale. The terrace deposits are about 18 feet thick at wells 5 and 2 on the west side of the canal and less than 3 feet thick at well 14 on the east side of the canal. Seepage of water from the canal caused swampy conditions around well 14. In the late summer of 1949, while water was still flowing through the canal, 21 observation wells were installed in this area by the Belle Fourche irrigation district and the U. S. Geological Survey. The depth to water in these wells was measured the first time on Sept. 30, 1949. (See table 1.) The flow of water from the reservoir into this canal was shut off on the same day, but the water level in this part of the canal did not recede for about 3 days. During October the water level in the observation wells declined an average of 1.8 feet. Because the water in the wells froze during the winter months, accurate measurements of the water level could not be made. Before water was again turned into the canal, the stretch of the canal in this area (see fig. 4) was lined with asphalt. During the summer of 1950, essentially no deposition of alkaline salts occurred and the corn showed a healthy growth where in recent years the plants were stunted or failed to grow. The water level in the observation wells fluctuated in response to the application of irrigation water, but in none of the wells did it rise to the level that prevailed in previous years. This is an example of lowering an undesirably high ground-water level by reducing the amount of recharge.

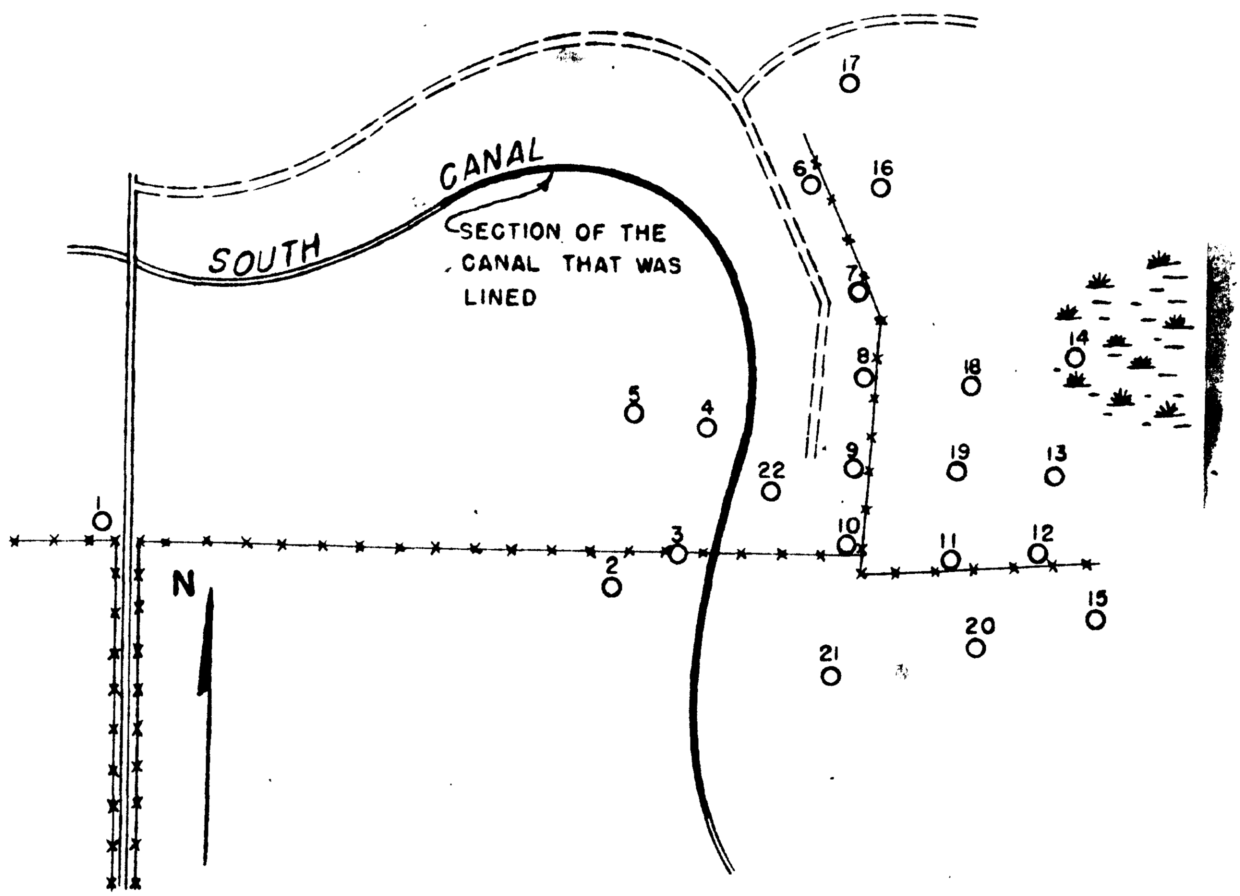

Figure 4.—Map of an area in sec. 15, T. 8 N., R. 5 E., where seepage from South canal has caused a high ground-water level.

An area adjacent to the Shaw lateral in secs. 25, 26, 35 and 36, T. 8 N., R. 5 E., is affected by seepage from the Shaw lateral and possibly also from the South canal. (See fig. 5.) This area is becoming too moist for proper cultivation and alkali is being deposited on the surface. Excessive infiltration of water to the land southeast of the

Table 1.--Water-level measurements in observation wells in secs. 15 and 16, T. 8 N., R. 5 E.

[feet below land-surface datum]

Well number	Depth of well, feet	1949				1950					
		9-30	10-5	10-14	10-29	5-22	6-13	7-17	8-18	9-14	10-23
8-5-16aa1	5.5	....	.....	.....	.....	.....	.....	.....	Dry	Dry	Dry
-15bc2	12.5	4.95	7.01	10.14	9.95	Dry	Dry	Dry	Dry	Dry	Dry
-15ba3	12.5	6.08	8.57	9.19	Dry	Dry	Dry	Dry	Dry	Dry	Dry
-15ba4	12.0	Plugged....		.....	.....	.....	.....	.....	.....	.....	.....
-15ba5	18.4	Plugged....		.....	.....	.....	.....	.....	.....	.....	.....
-15ba6	9.3	....	.....	.....	.....	.....	.....	.....	7.96	7.61	7.70
-15ba7	8.2	8.00	8.07	7.73	6.26	3.86	4.51	5.31	3.96	4.31	4.22
-15ba8	8.1	3.01	3.23	3.38	Dry	6.24	6.32	Dry	Dry	Dry	Dry
-15ba9	7.0	3.02	3.30	4.18	5.10	Dry	Dry	Dry	Dry	Dry	Dry
-15ba10	17.1	4.50	6.12	6.61	9.26	10.82	10.87	11.11	10.61	11.51	12.25
-15ba11	8.5	....	2.71	2.97	3.88	6.58	7.27	Dry	Dry	Dry	Dry
-15ba12	11.2	....	10.81	9.68	8.93	7.27	6.88	7.81	9.06	9.51	6.89
-15ba13	8.9	5.39	5.52	5.98	6.90	7.84	8.24	8.81	Dry	Dry	Dry
-15ba14	7.0	.00	.00	.00	.00	.00	.12	.38	2.61	4.53	.77
-15bd15	12.4	8.20	8.35	7.93	6.46	Dry	Dry	Dry	Dry	Dry	Dry
-15ba16	12.5	8.32	6.16	7.92	8.00	8.17	Destroyed......................				
-15ba17	12.5	8.35	8.31	8.35	8.20	7.79	....do..........................				
-15ba18	7.9	1.05	1.14	1.06	1.36	1.78	....do..........................				
-15ba19	7.4	....	2.35	1.67	3.57	6.24	....do..........................				
-15bd20	7.5	2.43	3.04	4.36	5.64	Dry	....do..........................				
-15bd21	7.2	2.98	3.91	Dry	Dry	Dry	....do..........................				
-15ba22	15.7	1.59	3.74	.....	.....	.....	....do..........................				

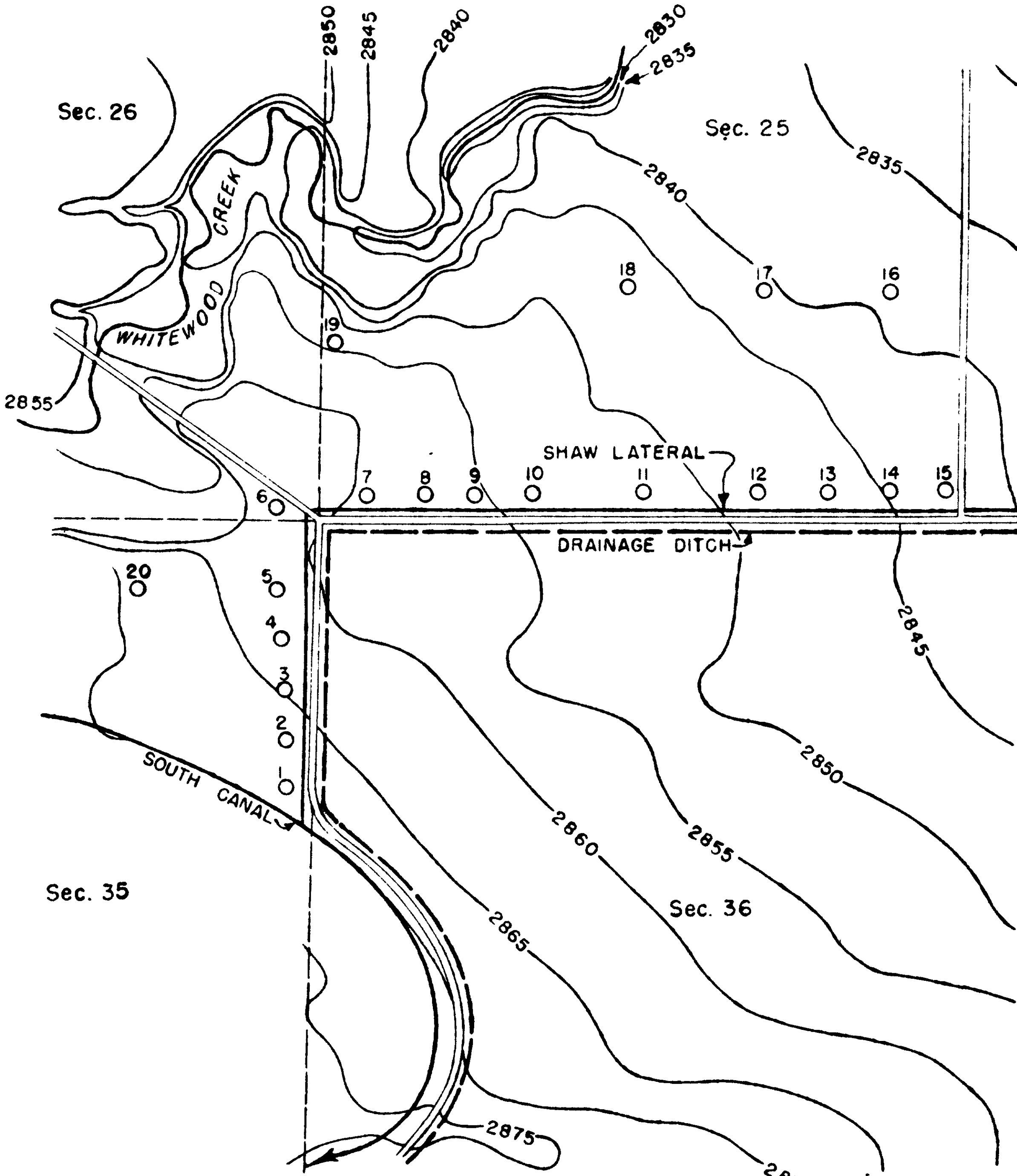

Figure 5.— Map of an area in secs. 25, 26, 35, and 36 where seepage from South canal and Shaw lateral is causing high ground-water level.

Shaw lateral is apparently prevented by the compacted material underlying the road that parallels the lateral and by the drainage ditch that parallels the road. The engineers of the Belle Fourche irrigation district believe that lining the Shaw lateral through this area will alleviate this ground-water problem. Observation wells have been installed along this part of the canal in order that the fluctuations of the water table before and after lining the canal can be determined. Wells 1-6 were jetted and wells 7-15 were driven. The wells penetrate the alluvial material to the shale bedrock and are cased by 3/4-inch diameter or $1\frac{1}{4}$-inch diameter pipe. The alluvium, which is 8 to 9 feet thick, grades downward from a clay loam at the surface to sand, gravel, and boulders at the base, and it is underlain by the impervious Pierre shale. As the wells were installed after the water in the irrigation canals was shut off, the water-level measurements made in the fall of 1950 show the water table to be declining. (See table 2.) Reading should be continued for a complete annual cycle before the canal is lined in order that a record of water-level fluctuations before the canal is lined will be available for comparison with measurements that are made after the canal has been lined--the effectiveness of the canal lining can be determined in this way. A continued program of water-level measurements will provide a basis for the determination of the need for repair of the canal lining and for the comparison of this type of lining with different types of lining that may be installed in other canals.

In many areas, the installation of adequate drainage facilities is the most feasible method of controlling high water levels. Generally, open ditches that are 5 to 8 feet deep have been used for drainage in the Belle Fourche irrigation district. These ditches, which are for the drainage of both surface and subsurface water are satisfactory in some areas but are not satisfactory in others. The material in which a drain is constructed in part determines the effectiveness of the drain. Clay and other materials of low permeability are drained less

Table 2.--Water-level measurements in observation wells in secs. 25, 26, and 35, T. 8 N., R. 5 E.

[feet below land-surface datum]

Well number	Depth of well, feet	10-25-50	11-21-50	12-12-50
8-5-25cc7	8.4	....	7.60	7.67
-25cc8	8.4	....	7.50	7.51
-25cc9	8.4	....	7.60	7.56
-25cc10	8.4	....	6.99	7.08
-25cc19	13.2	....	10.77	10.82
-25cd11	8.4	....	7.80	7.71
-25cd18	8.4	....	7.93	8.03
-25dc12	8.4	....	3.12	3.36
-25dc13	8.4	....	7.11	7.24
-25dc14	8.4	....	7.62	7.63
-25dc15	8.4	....	7.68	7.72
-25dc16	8.4	....	3.99	4.25
-25dc17	8.4	....	4.67	4.84
-26dd6	8.1	2.38	2.64	2.87
-35aa2	4.8	3.86	4.04	4.23
-35aa3	5.3	3.77	4.12	4.41
-35aa4	7.2	3.53	3.85	4.33
-35aa5	5.2	4.31	4.72	5.02
-35aa20	8.4	....	7.91	7.93
-35ad1	8.6	2.16	2.40	3.21

easily than materials of a high permeability. Also, the sides of a drain that has been excavated in fine material tend to puddle, thereby reducing the free flow of ground water into the drain. Because most of the soil on the project north of the river is composed of clay, open drainage ditches in these areas generally are not effective and act only as surface drains. If a drain is excavated in a material that is fairly permeable, the drain generally is satisfactory.

An example of the ineffectiveness of drain ditches in material of low permeability is described in the following paragraph.

A field in SW$\frac{1}{4}$ sec. 5, T. 8 N., R. 5 E. is bordered on three sides by open drainage ditches (see fig. 6), but the water table continues to be sufficiently high that the deposition of alkali occurs on the land surface. The land along the southern edge of this area is reported to become swampy when the irrigation canal through the area is carrying water. Seepage from the irrigation canal where it crosses higher-lying terrace deposits west of the field is probably the source of most of the ground water that causes the high water level. The water moves from the terrace deposits into the alluvium, which consists in this area of a topsoil that is about 3 feet thick and is underlain by sand, gravel, and boulders, the total thickness of which is not known. The landowner reports that the flow of water in the drainage ditches of the terrace deposits increases soon after water is turned into the canals and the southern border of the field becomes swampy a few weeks later. The water that moves into the area from the terrace deposits is supplemented possibly by seepage from the laterals where they cross the alluvium and from the ditch that drains water directly from the terrace deposits. The other drainage ditches are neither sufficiently deep nor closely enough spaced to intercept the amount of water that is required to prevent waterlogging of the lower part of the field. A network of observation wells was installed in this area in November 1950. Each well was constructed by driving an 11-foot length of 3/4-inch diameter pipe

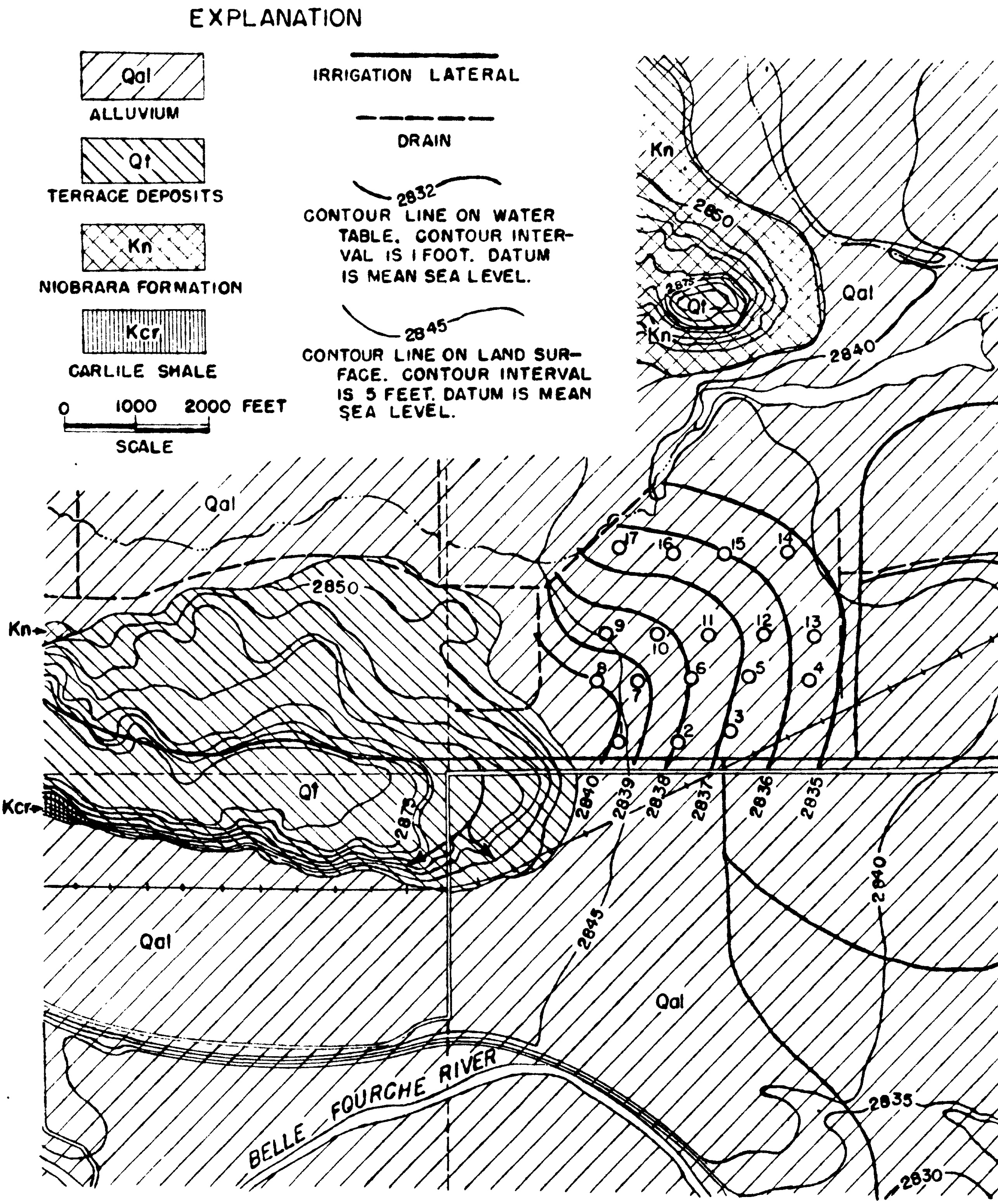

Figure 6.– Map of an area in secs. 5, 6, 7, and 8, T. 8 N., R. 5 E., where seepage from higher-lying terrace deposits is causing a high ground-water level.

to a depth of 9 feet below the land surface. Measurements of the water level in these wells are shown in the following table:

Table 3.--Water-level measurements in observation wells in SW$\frac{1}{4}$ sec. 5, T. 8 N., R. 5 E.

[feet below land-surface datum]

Well number	11-21-50	12-12-50	Well number	11-21-50	12-12-50
8-5-5ca14	4.65	4.90	8-5-5cd3	6.50	6.54
-5ca15	4.32	4.62	-5cd4	5.29	5.44
-5ca16	5.22	5.42	-5cd5	Dry	Dry
-5cb17	6.35	6.35	-5cd6	4.41	4.65
-5cc1	6.28	6.90	-5cd10	4.48	4.79
-5cc7	4.06	4.42	-5cd11	4.28	4.54
-5cc8	5.22	5.54	-5cd12	4.40	Dry
-5cc9	5.11	5.36	-5cd13	4.74	4.89
-5cd2	5.41	5.65			

Except in a few isolated areas, the seepage of water from stock ponds does not cause waterlogging of agricultural land. The reservoirs generally are constructed by building a small dam across a draw; a few, however, were excavated. Because most of the draws have been eroded into the shale bedrock, seepage visibly affects only the bottom of the draws below the dam.

Seepage of irrigation water is not known to be the primary cause of waterlogging in any area in the Belle Fourche project, although probably some of the small waterlogged areas are caused by recharge of this kind. Because the soils in the area generally are clayey, most of the excess irrigation water is discharged into the surface drains and only a small amount of water percolates to the zone of saturation.

The soil along Indian Creek in the northwestern part of the project is composed of alluvial and residual clays of relatively low permeability and are especially susceptible to waterlogging and to the deposition of alkali salts. Apparently no continuous body of more permeable material underlies the soil zone; however some sand was encountered when an observation well (10-4-32da) was installed near Indian Creek. The water table is close to the surface in much of this part of the project. The numerous open drainage ditches that have been constructed in this area effectively lower the water table beneath only narrow strips of land that border the drains. The puddling of the sides of the drains by summer showers tends to reduce the possibility of free flow of ground water into the drains. The water flowing in many of the drains is largely surface-water runoff.

Observation wells were installed in the late summer of 1950 along a north-south line across Indian Creek valley. (See fig. 7.) Water-level measurements made in these wells in the fall of 1950 are in table 4.

Table 4.--Water-level measurements in observation wells along a line across Indian Creek valley

[feet below land-surface datum]

Well number	Depth of well, feet	9-7-50	10-25-50	11-21-50	12-12-50
9-4-4bb	9.2	4.42	4.32	4.49	4.61
-5da	11.9	1.25	1.11	1.31	1.48
-5dd	5.5	Dry	Dry	Dry	Dry
-8da	24.5	3.90	3.72	3.73	3.89
-8dd	10.0	4.68	4.48	4.58	4.63
-17da	7.8	3.94	3.92	4.11	4.22
10-4-20dd1	10.1	2.42	2.41	2.46	2.53
-20dd2	6.3	2.95	2.94	3.07	3.19
-29da1	6.5	.61	.53	.86	1.21
-29da2	10.2	1.41	1.19	1.42	1.61
-32aa	12.6	3.41	3.36	3.57	3.61
-32ad	5.7	Dry	Dry	Dry	Dry
-32da	25.0	6.44	6.53	6.62	6.67

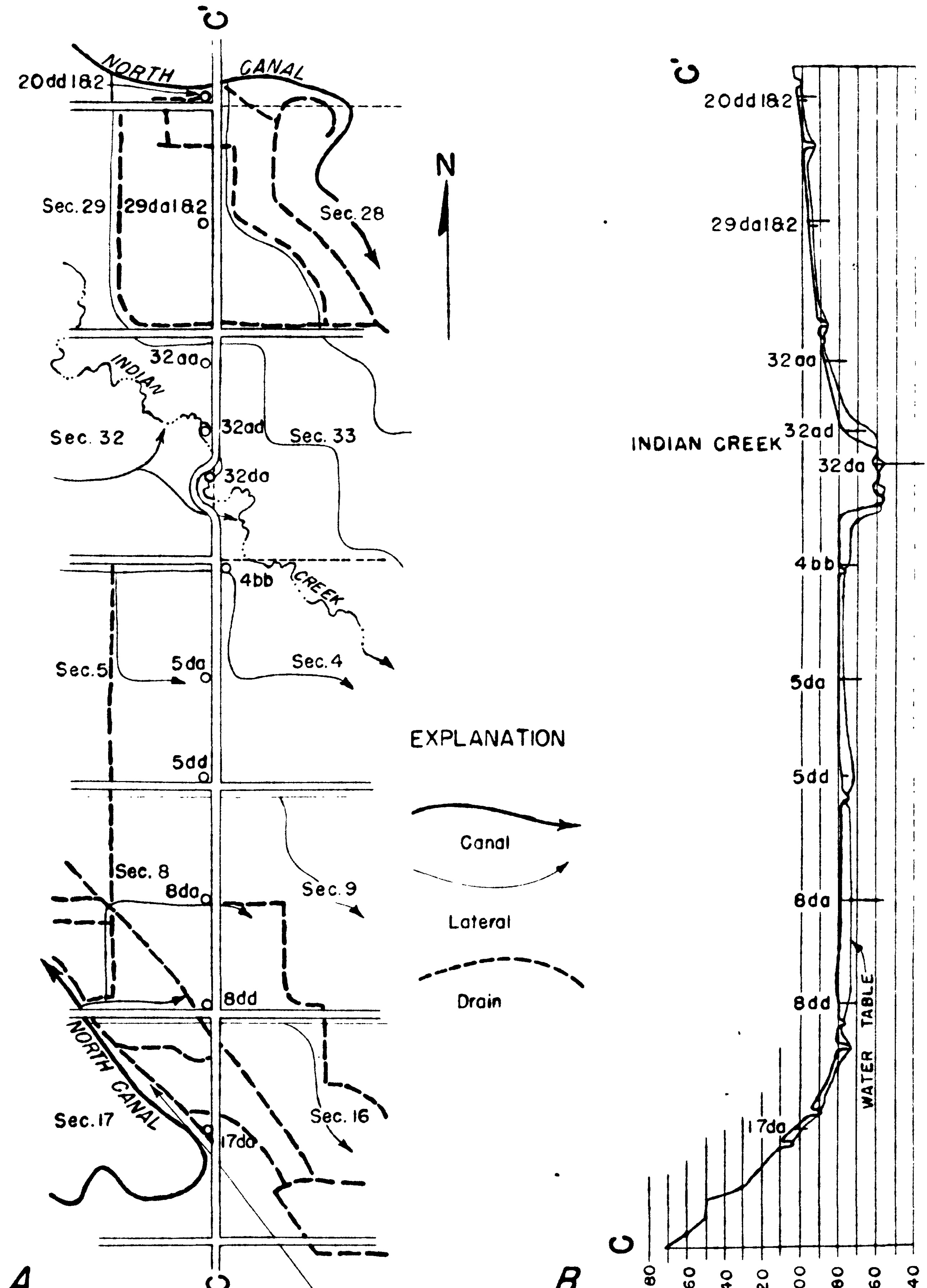

Figure 7.—A, Map of an area in the valley of Indian Creek where observation wells were installed; B, profile of Indian Creek valley.

CONCLUSIONS

The alluvium, terrace deposits, and residual clay that mantle most of the Belle Fourche irrigation project are underlain by bedrock formations that are relatively impermeable. Nearly the full thickness of the mantlerock materials is saturated in many parts of the area. The source of much of the ground water in these materials is seepage from irrigation canals and from water that is spread on the land; in low-lying areas, part of the ground water generally is derived by underflow from higher lands.

Many areas in the project are waterlogged during at least part of the year. Evaporation of the ground water in some of these areas has resulted in the concentration in the soil of salts that are injurious to plant growth. Open drainage ditches have been excavated and sections of some canals have been lined in efforts to lower the water table in local areas. Where the drains are in coarse-grained, permeable material, satisfactory results have been achieved. Drains in the less permeable fine-grained materials remove only small amounts of ground water; however, by discharging excess surface water they remove from the area a potential source of additional ground-water recharge. The lining of the canals generally has reduced effectively the seepage that was causing a high water table in adjacent areas.

An extensive study of ground-water conditions in the Belle Fourche irrigation project is a prerequisite to the planning of measures that will remedy the existing serious conditions. The study should include the determination of the extent, the thickness, and the permeability of the water-bearing materials, the depth to water, the sources and amount of recharge, and the means and amount of discharge. Measurements of the water level in observation wells throughout the project should be made periodically in order that significant rising trends in the fluctuations of water levels could be detected and corrective measures taken before the land becomes waterlogged or the concentration of salts becomes harmful. The several problem areas should be studied individually; the conditions at the time of the study should be recorded to provide a basis for comparison with the changed conditions that are effected by remedial facilities.

Table 5.--Records of observation wells in Butte County

Well number: See description of well-numbering system in body of report.
Type of well: B, bored; Dn, driven; J, jetted.
Character of water-bearing material: Cl, clay and sandy clay; G, gravel; S, sand.

Well number	Owner	Type of well	Depth of well below land surface (feet)	Diameter of iron or steel pipe casing (inches)	Character of water-bearing material	Height of measuring point (top of casing) above land surface (feet)	Altitude of measuring point above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
8-5-5ca14	U. S. Geol. Survey	Dn	7.8	3/4	S,G	3.2	2,843.1	7.85	11-21-50
-5ca15	.....do............	Dn	8.4	3/4	S,G	2.6	2,842.9	6.92	11-21-50
-5ca16	.....do............	Dn	8.4	3/4	S,G	2.6	2,844.1	7.82	11-21-50
-5cb17	.....do............	Dn	8.4	3/4	S,G	2.6	2,845.3	8.95	11-21-50
-5cc1	.....do............	Dn	8.3	3/4	S,G	2.7	2,848.7	8.98	11-21-50
-5cc7	.....do............	Dn	8.2	3/4	S,G	2.8	2,846.2	6.86	11-21-50
-5cc8	.....do............	Dn	8.2	3/4	S,G	2.8	2,848.0	8.02	11-21-50
-5cc9	.....do............	Dn	8.2	3/4	S,G	2.8	2,846.8	7.91	11-21-50
-5cd2	.....do............	Dn	7.4	3/4	S,G	3.6	2,846.9	9.01	11-21-50
-5cd3	.....do............	Dn	8.1	3/4	S,G	2.9	2,845.2	9.40	11-21-50
-5cd4	.....do............	Dn	8.2	3/4	S,G	2.8	2,843.5	8.09	11-21-50
-5cd5	.....do............	Dn	7.6	3/4	S,G	3.4	2,844.7	Dry	11-21-50
-5cd6	.....do............	Dn	8.2	3/4	S,G	2.8	2,845.2	7.21	11-21-50
-5cd10	.....do............	Dn	8.4	3/4	S,G	2.6	2,845.4	7.08	11-21-50
-5cd11	.....do............	Dn	8.3	3/4	S,G	2.7	2,844.4	6.98	11-21-50

Table 5.--Records of observation wells in Butte County--Continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
8-5-5cd12	U. S. Geol. Survey	Dn	8.7	3/4	S,G	2.3	2,843.3	6.70	11-21-50
-5cd13	.....do............	Dn	8.2	3/4	S,G	2.8	2,842.9	7.54	11-21-50
-15ba3	.....do............	J	12.5	3/4	S,G	1.1	....	7.18	9-30-49
-15ba4	.....do............	J	12.0	3/4	S,G	3.9	....	.....	....
-15ba5	.....do............	J	18.4	3/4	S,G	2.0	....	.....	....
-15ba6	.....do............	J	9.3	3/4	Cl	1.8	....	9.76	8-18-50
-15ba7	Irrigation district	Dn	8.2	1¼	S,G	1.8	....	9.80	9-30-49
-15ba8	.....do............	Dn	8.1	1¼	S,G	1.9	....	4.91	9-30-49
-15ba9	.....do............	Dn	7.0	1¼	S,G	2.0	....	5.02	9-30-49
-15ba10	U. S. Geol. Survey	J	17.1	3/4	S,G	3.5	....	8.00	9-30-49
-15ba11	.....do............	Dn	8.5	3/4	S,G	.5	....	3.21	10- 5-49
-15ba12	.....do............	Dn	11.2	3/4	S,G	2.3	....	13.11	10- 5-49
-15ba13	.....do............	J	8.9	3/4	S,G	.2	....	5.59	9-30-49
-15ba14	.....do............	J	7.0	3/4	S,G	2.0	....	2.00	9-30-49
-15ba16	Irrigation district	Dn	12.5	1¼	S,G	1.5	....	9.82	9-30-49
-15ba17	.....do............	Dn	12.5	1¼	S,G	1.5	....	9.85	9-30-49
-15ba18	U. S. Geol. Survey	J,Dn	7.9	3/4	S,G	1.1	....	2.15	9-30-49
-15ba19	.....do............	J,Dn	7.4	3/4	S,G	1.6	....	3.95	10- 5-49
-15ba22	.....do............	J	15.7	3/4	S,G	2.4	....	3.99	9-30-49
-15bc2	.....do............	J	12.5	3/4	S,G	1.5	....	6.45	9-30-49
-15bd15	.....do............	Dn	12.4	3/4	S,G	1.6	....	9.80	9-30-49
-15bd20	.....do............	Dn	7.5	3/4	S,G	1.5	....	3.93	9-30-49
-15bd21	Irrigation district	Dn	7.2	1¼	S,G	2.8	....	5.78	9-30-49
-16aa1	U. S. Geol. Survey	J	5.5	3/4	Cl	1.5	....	Dry	8-18-50
-25cc7	.....do............	Dn	8.4	3/4	S,G	2.6	....	10.20	11-21-50
-25cc8	.....do............	Dn	8.4	3/4	S,G	2.6	....	10.10	11-21-50
-25cc9	.....do............	Dn	8.4	3/4	S,G	2.6	....	10.20	11-21-50
-25cc10	.....do............	Dn	8.4	3/4	S,G	2.6	....	9.59	11-21-50