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STATE GEOLOGICAL SURVEY
Allen F. Agnew, State Geologist

Report of Investigations 90

SHALLOW GROUND WATER RESOURCES IN THE WAGNER AREA, CHARLES MIX AND DOUGLAS COUNTIES, SOUTH DAKOTA

by
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UNION BUILDING
UNIVERSITY OF SOUTH DAKOTA
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CONTENTS

Page

ILLUSTRATIONS

Illustrations--Continued

Page

Table

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ABSTRACT

The Wagner area is in southeastern South Dakota in the extreme western part of the James Basin of the Central Lowlands Physiographic Province. The area occupies about 250 square miles and is drained southward by Choteau Creek.

Glacial deposits as much as 350 feet thick fill an ancient southwest-trending pre-Pleistocene stream valley, which drained the Wagner area. The valley was carved in Pierre shale, Niobrara chalk, and Carlile shale, all of Cretaceous age.

The Pleistocene deposits in the area include three glacial outwash bodies. A discontinuous surface outwash deposit along Choteau Creek is variable in composition and thickness, and yields small quantities of water to domestic and stock wells. A second sand and gravel outwash deposit, averaging 30 feet thick, is buried beneath about 65 feet of glacial drift. No wells are known to draw water from this deposit. The third and lowest glacial outwash deposit averages 50 feet thick through 90 percent of the area, and supplies water to nearly all the wells.

The lower outwash deposit contains about 2,100,000 acre-feet of water, and yields 200 to 900 gpm to 18-inch irrigation wells that are 150 to 200 feet deep. All wells tapping this lower outwash deposit are artesian wells, the head everywhere exceeding 120 feet above the sand. Wells along Choteau Creek, which were flowing about 5 gpm, stopped flowing in July, 1960 when a total of 98.8 acre-feet of water had been pumped for irrigation purposes during that summer.

This lower buried outwash deposit is recharged by Lake Andes. The water from the lower deposit should not be used for irrigation because of its poor chemical quality.

INTRODUCTION

Present Investigation

Nearly all the domestic and farm wells in the Choteau Creek valley at Wagner, South Dakota, draw water from deposits less than 300 feet below the ground. Water rises in the wells to within fifty feet of the surface over most of the area, and flowing wells are present in the low area along Choteau Creek at Wagner. In recent years fluctuations in the water level during the summer have caused wells to stop flowing, and have caused the water level in non-flowing wells to drop sufficiently to increase pumping costs and in some cases, to necessitate the installation of larger pumps. For this reason, the South Dakota State Water Resources Commission requested that the State Geological Survey make a study of the Wagner area (1) to determine the areal extent, thickness, and the geologic relations of the water producing deposits, (2) to determine the cause of fluctuations in water levels in these deposits, and (3) to map the surface sand and gravel deposits along Choteau Creek. The geologic study was accomplished by the State Geological Survey between June 15 and August 7, 1960. The State Geological Survey provided the writer as geologist, Robert Bliven as assistant, an earth-resistivity team of Richard Bruce and Charles Mickel, and a drill crew of Charles Mickel and Jerry Schweigert; the U. S. Geological Survey and the U. S. Bureau of Reclamation provided data from their Huron offices.

Location and Extent of Area

The city of Wagner has a population of 1, 586 (1960 census), and is located in Charles Mix County, in southeastern South Dakota. The area of study comprises about 250 square miles in the extreme western part of the James Basin of the Central Lowlands physiographic province (fig. 1).

Acknowledgments

The preparation of this report was greatly facilitated by the cooperation of the residents in the Wagner area. Special thanks are due to well drillers Emil Grosz of Delmont and Charles Oleson of Geddes, for making their drilling records available and for their readiness to offer assistance. The field work would have taken far longer without unpublished surveying records of the area provided by O. Barr Doolittle of the U. S. Bureau of Reclamation office in Huron. The study was performed under the supervision of M. J. Tipton, geologist in charge of ground water studies for the State Geological Survey.

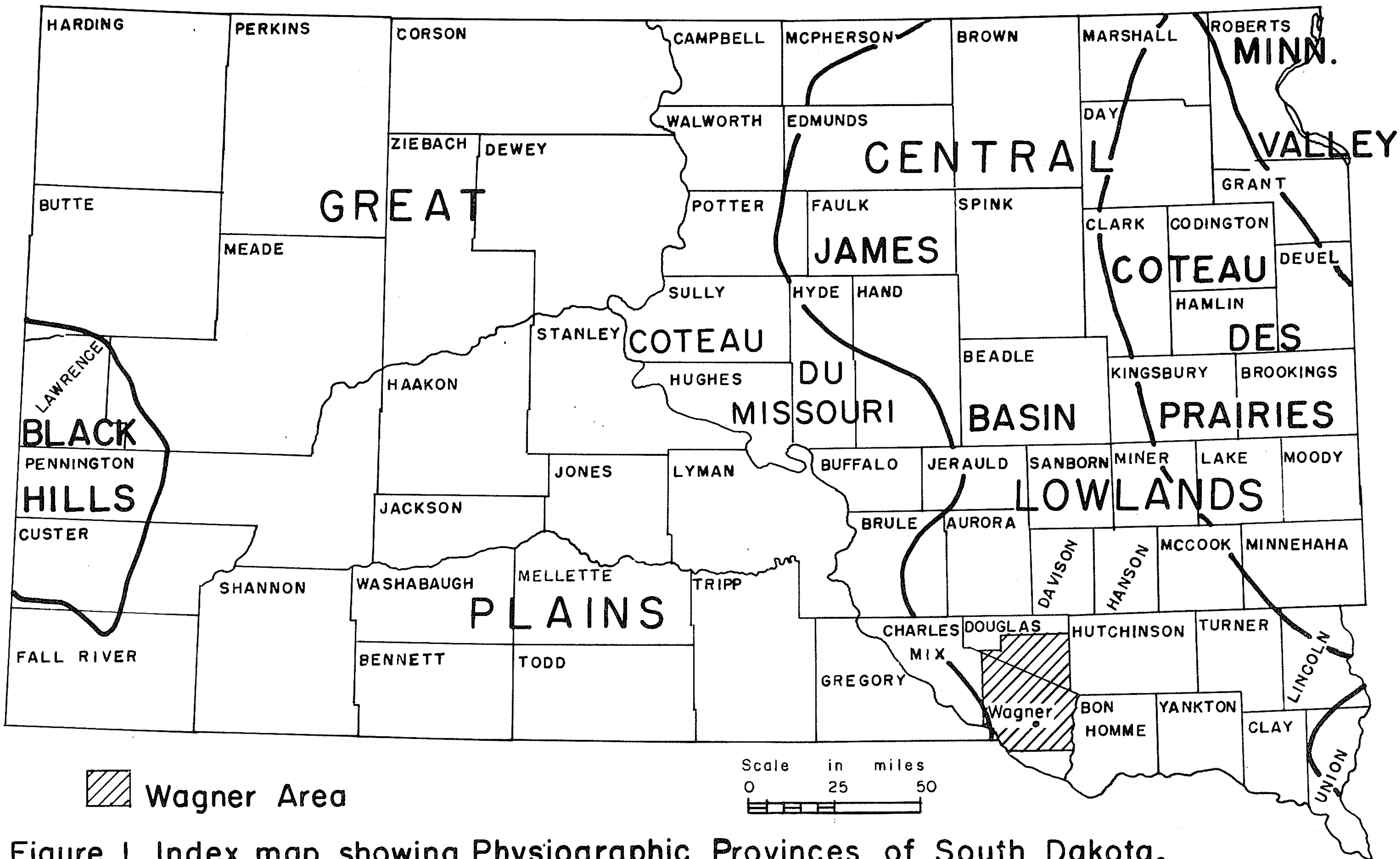


Figure I. Index map showing Physiographic Provinces of South Dakota, and Wagner area (Modified from Rothrock, 1943)

Previous Investigations

A reconnaissance study was made of the glacial deposits of Eastern South Dakota including the Wagner area by R. F. Flint (1955).

In 1956 the State Geological Survey published a report by Aaron Stoley summarizing the results of a detailed investigation of a surface glacial outwash deposit in Douglas County near the town of Delmont, South Dakota (fig. 2). A continuation of this deposit along Choteau Creek was mapped by the writer and is discussed in the present report.

Following the drilling of the first irrigation wells in the Wagner area in 1956, the State Water Resources Commission drilled observation wells in 1957 to determine the effect of irrigation pumping on water levels throughout the area. The water levels in these wells, along with flowing artesian domestic wells were measured by the Commission throughout the summer of 1959, and were compared with the amount of water pumped per month from irrigation wells.

Climate

The climate, characterized by a wide temperature range, has an average yearly temperature of 49 °, and an average yearly precipitation of 21 inches, according to records at the U. S. Weather Bureau Station in Wagner from 1916 to 1959.

Topography and Drainage

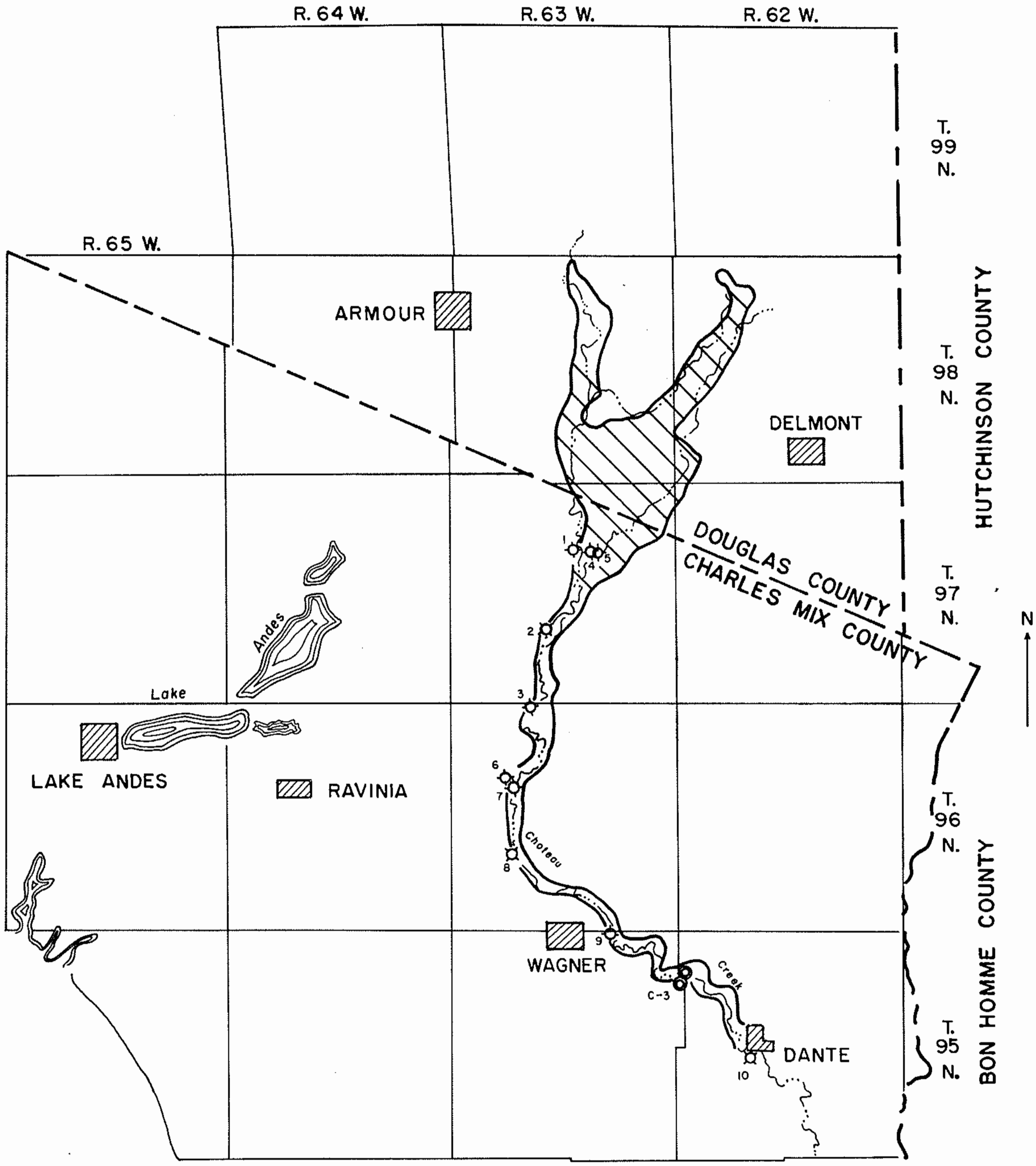
The topography and drainage of the area are typical of those left by the last ice sheets--that is, poorly drained and containing many closed depressions. Choteau Creek, the principal stream in the area, is small and intermittent, and there are a number of large swampy "pot-holes". The largest lake in the area, Lake Andes, fills 7 square miles of a closed depression just east-northeast of the town of Lake Andes.

Altitudes above sea level range from 1370 feet in the Choteau Creek valley at Dante to 1602 feet in the northeastern part of the mapped area. The maximum relief of the area is therefore 232 feet.

Well-numbering System

Wells in this report are numbered in accordance with the U. S. Bureau of Land Management's system of land subdivision. The first numeral of a well designation indicates the township, the second the range, and the third the section in which the well is situated. Lower-case letters after the section number indicate the well location within the section. The letters a, b, c, and d, are assigned in counterclockwise direction, beginning in the northeast corner of each tract. The first letter denotes the 160-acre tract, the second the 40-acre tract, the third the 10-acre tract, and the fourth the 2½-acre tract. To distinguish between two or more wells situated within the same tract, consecutive numbers beginning with 1 are added as a suffix to each well designation. Well 96-63-11adcd2 is the second well described in the SE¼SW¼SE¼NE¼ sec. 11, T. 96 N., R. 63 W; the method of designation is shown by Figure 3.

Map of Surface Glacial Outwash Deposit in the Wagner Area. FIGURE 2



State Geological Survey Test Hole

State Water Resources Commission Observation Well

Area Underlain by Surface Glacial Outwash Deposit

Area Underlain by Surface Glacial Outwash Deposit Mapped by Stoley (1956)

Drafted by Lynn Hedges

Scale Miles
2 1 0 1 2 3 4

by
Ian R. Walker
March, 1961

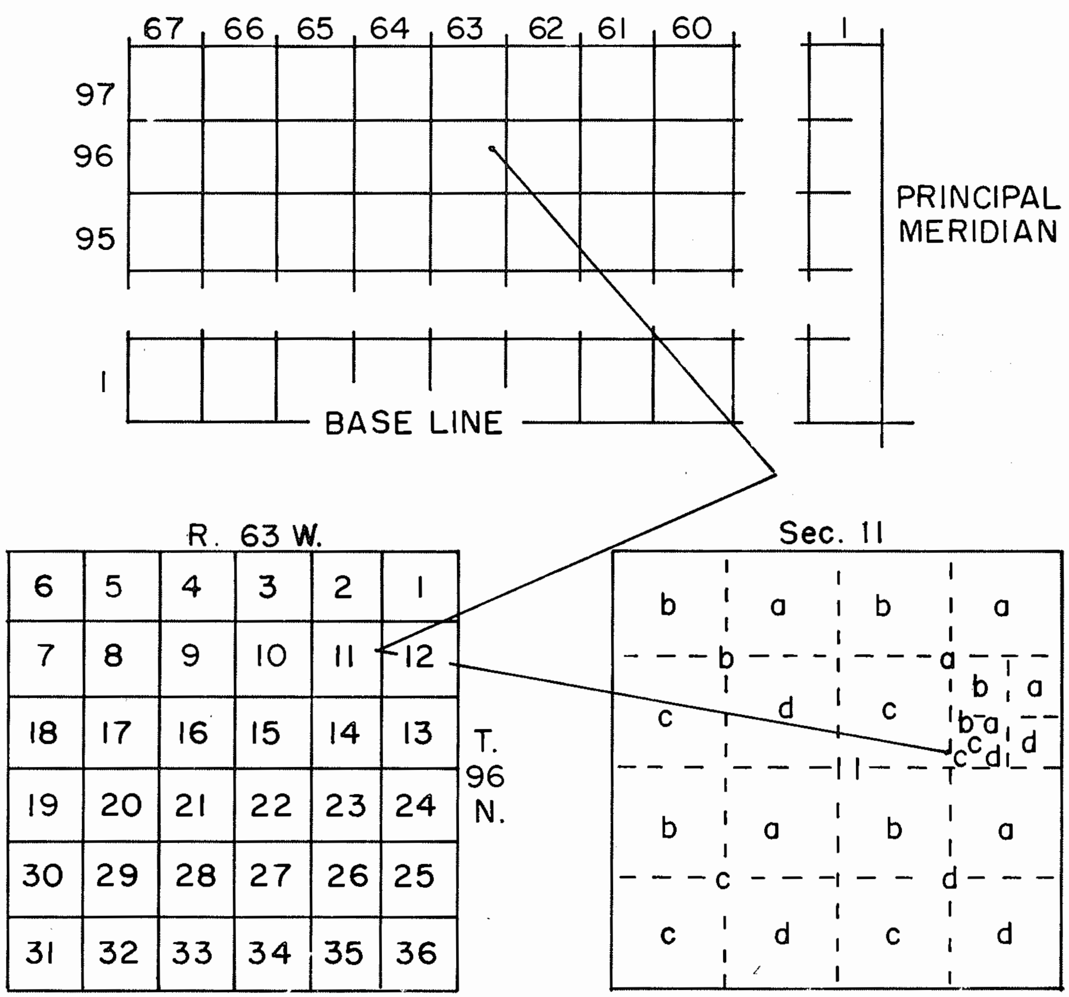


Figure 3. Well-numbering system

GENERAL GEOLOGY

Surficial Deposits

All of the surface deposits in the Wagner area, with the exception of the alluvium along Choteau Creek, were deposited by the last glacial ice sheet to cover Eastern South Dakota during the Pleistocene Epoch. This Cary glacier retreated from the area about 12,000 years ago, and had been preceded by four and possibly five other glaciers which had deposited material in this area before the Cary deposits were laid down.

These glacial deposits, called drift, are divided into till and outwash. Till is material that was deposited directly by the ice and consequently is a jumbled mass of unsorted clay, silt, sand, gravel, and boulders. Till generally does not yield much water to wells. Outwash deposits are material that was deposited by meltwaters of the retreating glacier, and consist principally of sand and gravel derived from the original unsorted till material. These outwash sands and gravels in places contain large amounts of water and usually transmit it readily.

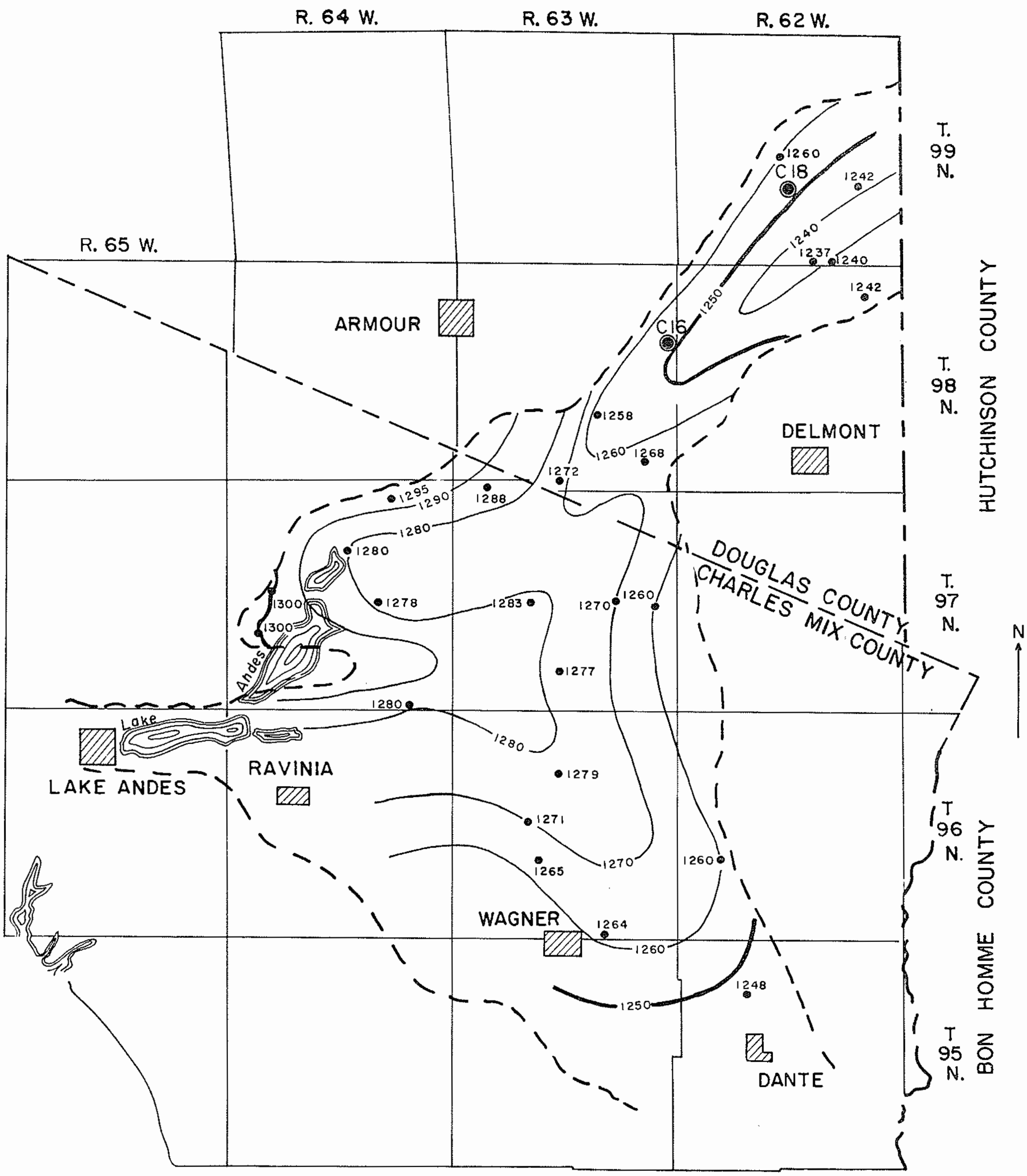
The deposits at the surface consist of Cary till except for the glacial outwash deposits along Choteau Creek (fig. 2). In the area studied, this Cary till is probably underlain by tills from previous ice advances, and the combined thickness of these tills ranges from 100 feet to more than 287 feet. These tills overlie at least two buried outwash deposits (pl. 1), the deeper and larger of which ranges in thickness from a feather-edge to as much as 140 feet and underlies an area of about 225 square miles. The upper surface of this lower buried glacial outwash deposit is at an average position of 1275 feet above sea level (fig. 4). The ground elevations in the area underlain by the lower buried outwash range from about 1370 feet in the Choteau Creek valley at Dante to more than 1600 feet north of Delmont in Douglas County. Thus, the differences in ground elevations generally reflect different thicknesses of till overlying the outwash deposit.

The areal extent and thickness of the upper buried outwash deposit is shown in Figure 5. This deposit generally occurs between 1340 feet and 1380 feet above sea level, being separated from the top of the lower outwash deposit by about 100 feet of till and small lenses of sand and gravel (pl. 1). This outwash averages 30 feet in thickness and is composed largely of coarse sand and gravel. To the writer's knowledge, no wells in the Wagner area draw water from this deposit.

These buried glacial outwash deposits are believed to be part of large pre-Cary outwashes which filled an ancient stream valley. This stream originated in northwestern Charles Mix County and drained southeastward through Lake Andes, and then northeastward through Delmont. Available records show that the upper of the two buried outwash deposits (fig. 5) is similar in outline to the buried outwash mapped in 1955 by Flint (fig. 6). Apparently Flint did not map the lower of the two buried outwash deposits. The present report is concerned mainly with the lower buried outwash deposit, as all the irrigation wells in this area produce from it.

The lower buried glacial outwash deposit was not penetrated north of Delmont in State Water Resources Commission observation wells

Map of Upper Surface of Lower Buried Outwash Deposit in the Wagner Area. **FIGURE 4**



Border of Area underlain by lower buried outwash deposit.

Contour on surface of lower buried outwash deposite, interval 10 feet.

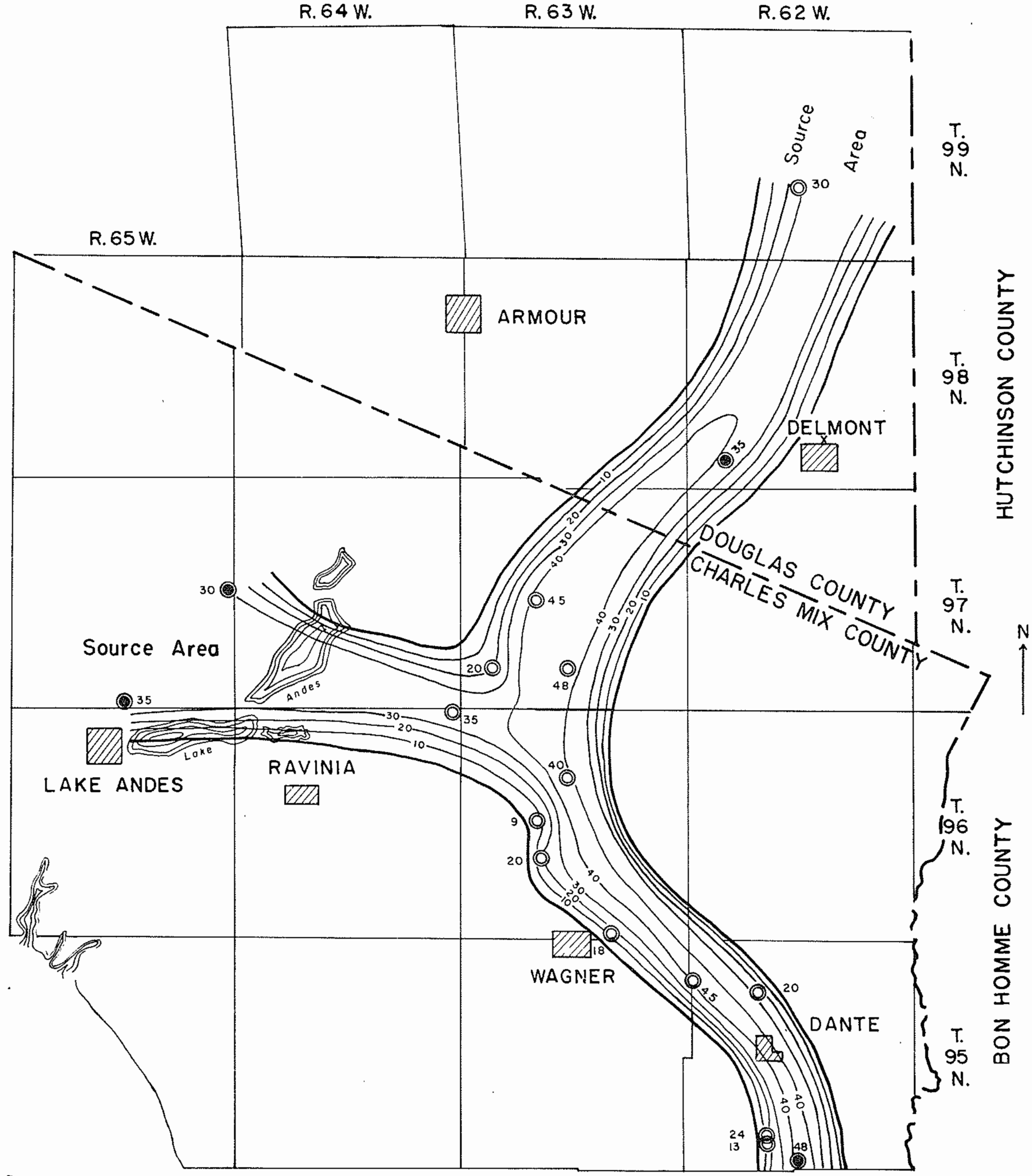
Well or test hole showing elevation of surface of lower buried outwash deposit.

Drafted by Lynn Hedges.

Scale Miles
2 1 0 1 2 3 4

by
Ian R. Walker
March, 1961

Isopach Map of Upper Buried Outwash Deposit in the Wagner Area FIGURE 5



Border of Area underlain by Upper buried outwash deposit.

Lines of equal thickness of upper buried outwash deposit, interval 10 feet.

State Water Resources Commission Observation Well.

State Water Resources Commission Test Hole.

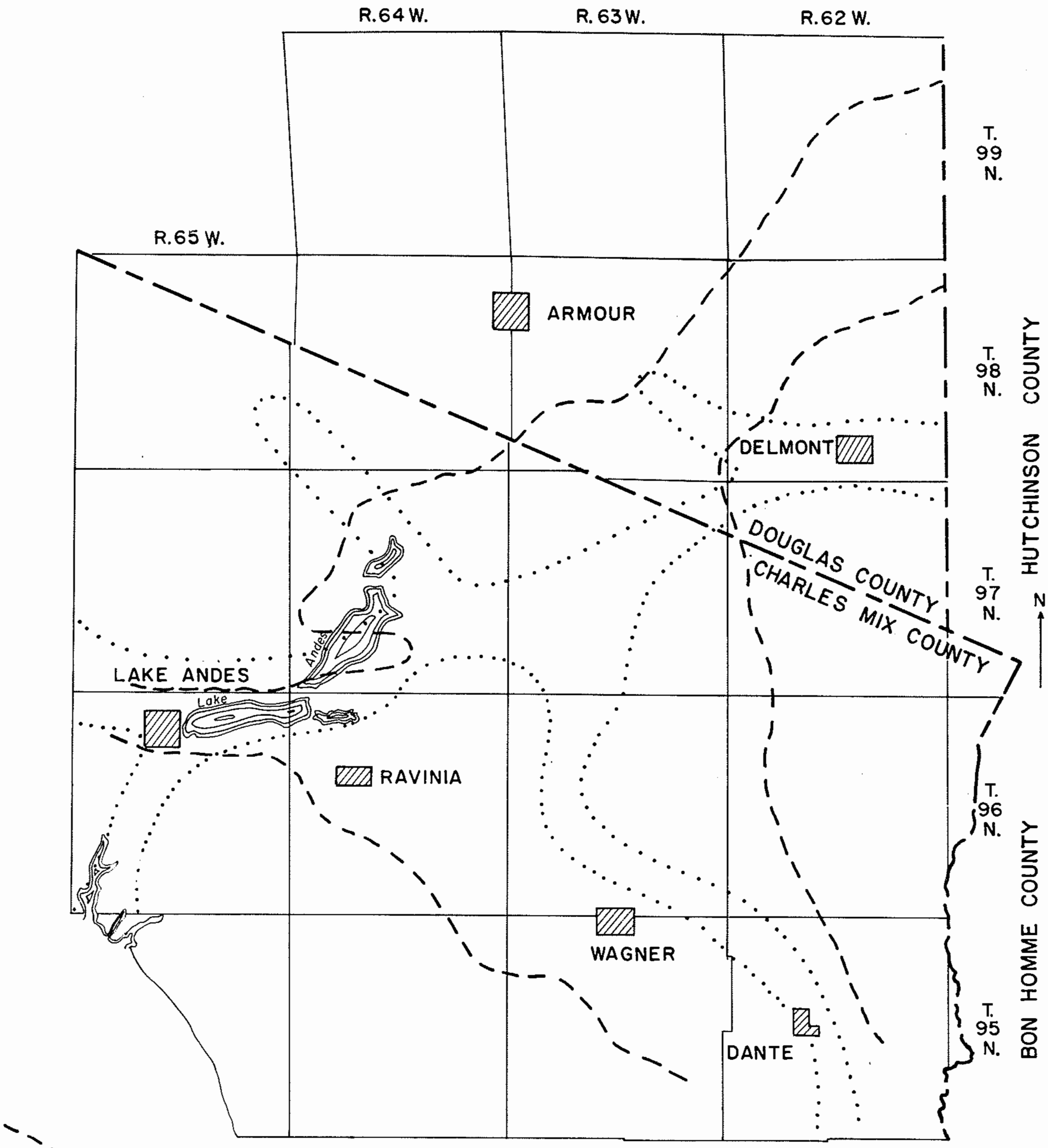
x City well

Drafted by Lynn Hedges

Scale 2 1 0 1 2 3 4 Miles

by
Ian R. Walker
March, 1961

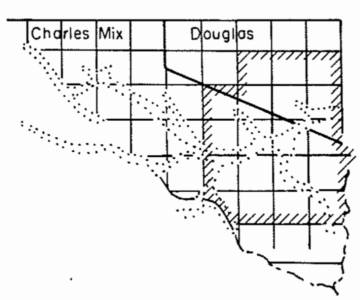
Map of Wagner Area Showing Lower Buried Outwash Deposit of this Report, and Outwash Deposit of Flint FIGURE 6



Border of Lower buried Outwash deposit.

Border of buried Outwash deposit of Flint (1955)

Drafted by Lynn Hedges.



Inferred pre-diversion drainage in Charles Mix and Douglas Counties (after Flint, 1955)

Scale — Miles: 2 1 0 1 2 3 4

by
Ian R. Walker
March, 1961

C-16 and C-18, even though domestic wells show it to be present there (fig. 4). An examination of the total depths of these wells and of the ground elevations reveals that both wells were bottomed above 1260 feet altitude (Appendix A). Figure 4 shows that the altitude of the upper surface of the lower outwash deposit is about 1250 feet above sea level where these wells were drilled. It is concluded therefore, that neither well was drilled deep enough to penetrate the lower buried glacial outwash deposit.

Meltwater flowing from the terminus of the Cary ice sheet deposited outwash gravel, sand, and silt in the narrow valley through which Choteau Creek now flows (fig. 2). The sands and gravels were deposited from meltwaters which fluctuated in volume, velocity, and direction, and therefore the sands vary considerably in degree of sorting and size of grain.

About thirteen square miles in Douglas County are underlain by this shallow glacial outwash deposit (Stoley, 1956, p. 39). These poorly sorted sands and gravels average 15.5 feet in thickness and are at or within ten feet of the surface.

Alluvium

Besides glacial drift, the only other surficial material in the area is alluvium, which consists of clays and silts deposited in Recent time by Choteau Creek. These alluvial deposits are confined to the present flood plain of Choteau Creek, which nowhere exceeds half a mile in width, and are generally about eight feet thick. These deposits are not considered a potential source of ground water because of their poor transmissibility.

Bedrock

Stratified sedimentary rocks are present beneath the unconsolidated surficial deposits of drift. The stratified rocks immediately beneath the drift in the Wagner area are in descending order the Niobrara Formation, the Carlile shale, and the Codell sandstone. All are of Cretaceous age.

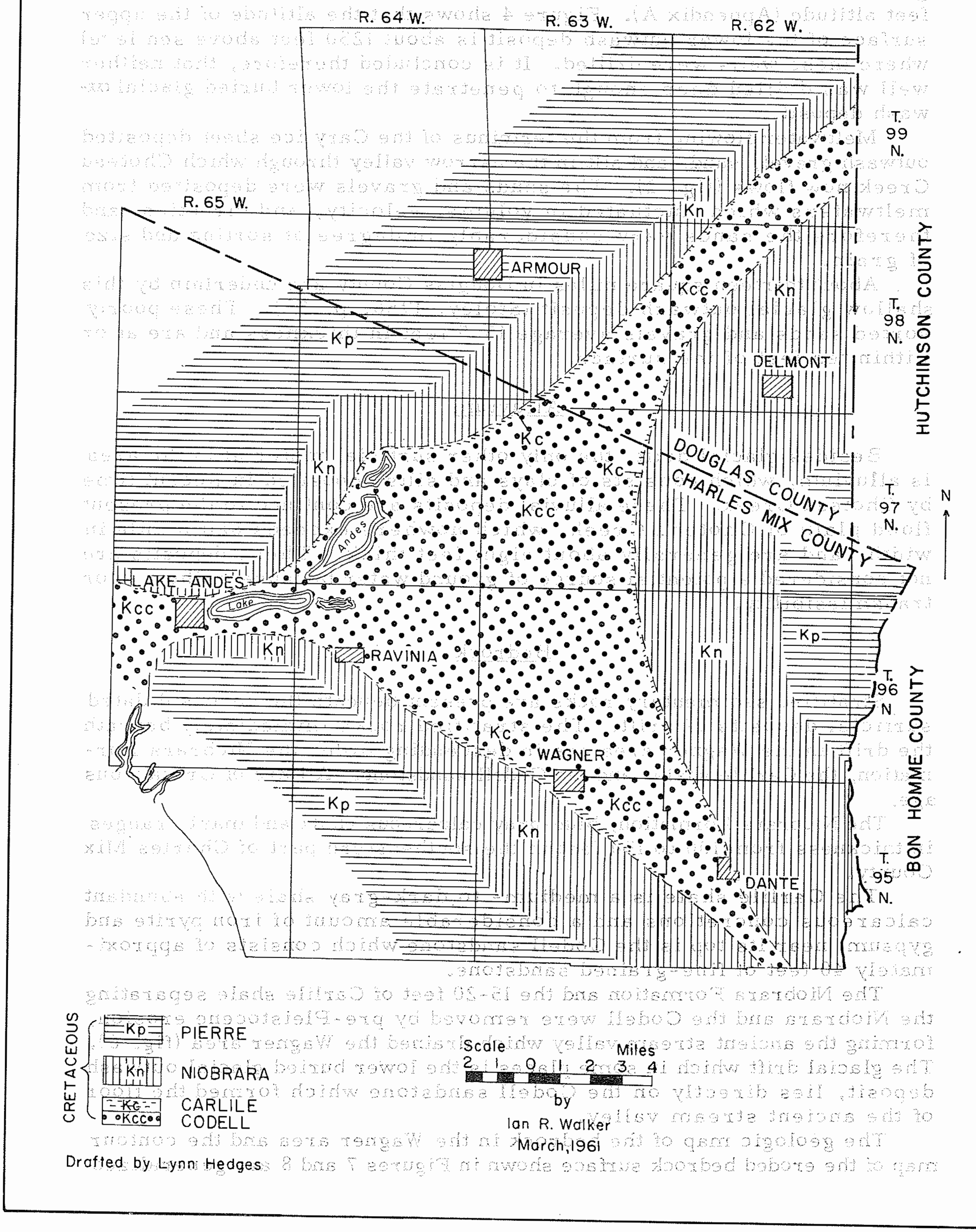
The Niobrara Formation, blue-gray calcareous chalk and marl, ranges in thickness from 100 to 150 feet in the southeastern part of Charles Mix County.

The Carlile shale is a medium- to dark-gray shale with abundant calcareous concretions and a considerable amount of iron pyrite and gypsum; near its top is the Codell sandstone which consists of approximately 40 feet of fine-grained sandstone.

The Niobrara Formation and the 15-20 feet of Carlile shale separating the Niobrara and the Codell were removed by pre-Pleistocene erosion, forming the ancient stream valley which drained the Wagner area (fig. 6). The glacial drift which in some places is the lower buried glacial outwash deposit, lies directly on the Codell sandstone which formed the floor of the ancient stream valley.

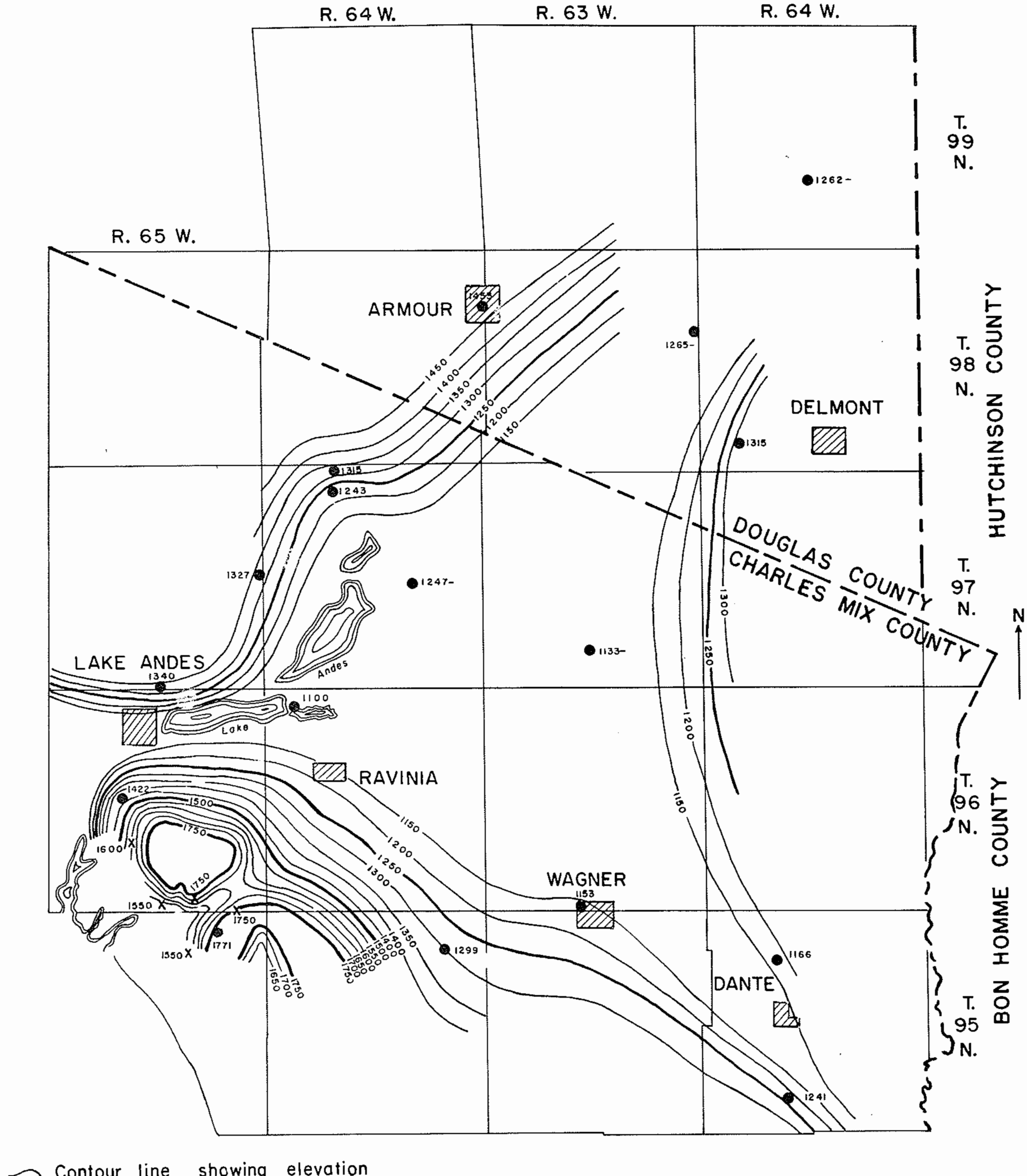
The geologic map of the bedrock in the Wagner area and the contour map of the eroded bedrock surface shown in Figures 7 and 8 are generalized

Map showing possible inferred distribution of Bedrock beneath the Glacial Deposits in the Wagner Area. FIGURE 7



Map showing Configuration of Buried Bedrock Surface in the Wagner Area.

FIGURE 8



Contour line showing elevation above sea level. (Interval 50 feet.)

● Well showing elevation of bedrock above sea level.

x Outcrop elevations of bedrock.

Drafted by Lynn Hedges.

Scale Miles
2 1 0 1 2 3 4

by
Ian R. Walker
March, 1961

and are subject to revision when the bedrock is more throughly examined by the writer, during the preparation of "The geology of the Wagner area, Charles Mix County, South Dakota", a Master's thesis at the University of South Dakota.

SHALLOW GROUND WATER

Hydrologic Properties of the Buried Glacial Outwash Deposits

Some geologic formations are known as aquifers--formations having properties that permit an appreciable amount of water to move through them under ordinary field conditions. The lower buried outwash deposit in the Wagner area is such an aquifer. Two properties, porosity and permeability, determine the amount of water which will move through an aquifer. Porosity is the percentage of voids in a given volume of material. The percentages of voids in a sample of well-sorted fine sand and a sample of well-sorted coarse gravel are about the same. If the material is poorly sorted--that is, consists of varying sizes of sands and gravels--the percentage of voids, and therefore the porosity, is low. Permeability, or the rate at which a fluid will flow through a material is greater for gravel than for sand, because the larger voids offer less resistance to flow than the smaller voids in finer sands. The lower buried outwash deposit in the Wagner area is composed largely of well-sorted coarse sand and fine gravel, and therefore has both high porosity and high permeability. The average porosity of three samples taken from the lower buried outwash deposit is 37.6 percent (Appendix A, Wells C-5, C-6, C-7). No data are available on the permeability of the deposit, because of the lack of equipment.

Two types of aquifers are present in the Wagner area. In one type, the water table stands within the body of sand and only that part of the sand below the water table is saturated. Wells in this type of aquifer are called non-artesian or water-table wells. In the second type of aquifer, the water-bearing sand is confined between layers of relatively impervious glacial till. The full thickness of the sand is saturated and the water is under enough pressure, or head, to cause the water level to rise above the top of the sand when a well is drilled into it. Such a well is said to be artesian. The surface to which the water from an artesian aquifer will rise is called the piezometric surface.

All the wells in the Wagner area which are drilled into the lower buried glacial outwash deposit are artesian wells. The head everywhere exceeds 120 feet above the level of the lower buried outwash deposit, and is as much as 140 feet in well C-12.

The lower buried glacial outwash deposit in the area studied underlies about 225 square miles, and contains an average thickness of about 50 feet of sand and gravel, all of which is water-saturated. Assuming an average porosity of 30 percent for the outwash sediments, it is estimated that the outwash deposit contains approximately 2,100,000 acre-feet or about 684,000,000,000 gallons of water. This is about four times as much water as can be stored in Lewis and Clark Lake at Gavins Point Dam at its full capacity. An acre-foot is the volume of water required to cover 1 acre to a depth of 1 foot.

Movement of the Ground Water

Figure 9 is a contour map of the piezometric surface constructed from measurements of static water levels in wells within the Wagner area. The static water level is the level at which the water rests when the well is not being pumped. Flowing wells result where the static water level lies above the ground surface (fig. 9, shaded area). Since ground water moves generally from areas of higher pressure to areas of lower pressure, the direction of water movement in the lower buried outwash is from west and east toward the center of the aquifer, and also to the north as shown by arrows drawn perpendicularly to contour lines (fig. 9).

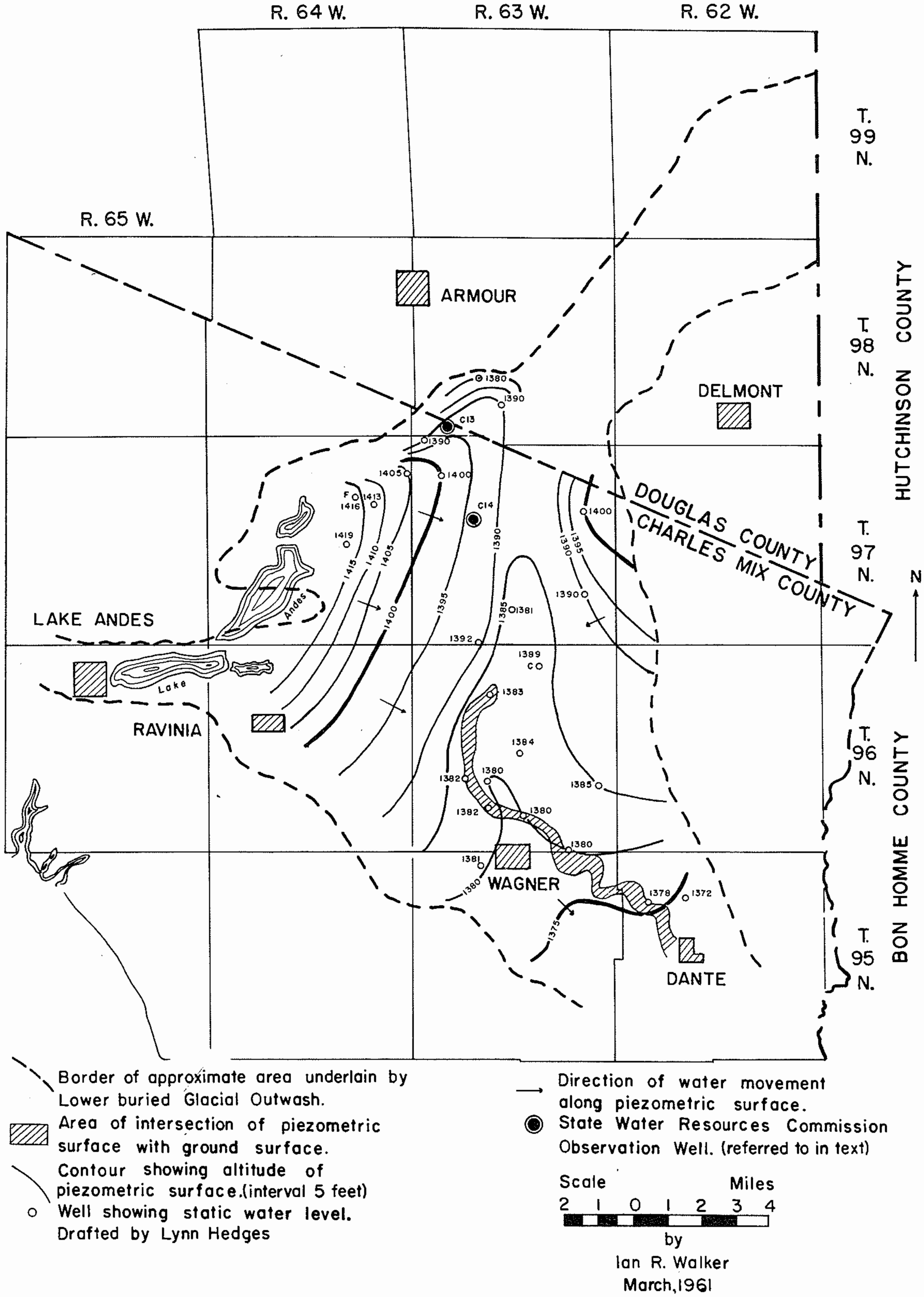
The contour map of the piezometric surface in the Wagner area should be useful for locating new wells. From such a map areas of favorable permeability can be ascertained, for the coefficient of permeability is inversely proportional to the hydraulic gradient. That is, in an area of uniform ground water flow, those parts having wide contour spacing (flat gradients) will have higher permeabilities than those with narrow spacing (steep gradients). Figure 9, therefore, shows that prospects for good-yielding wells are better in the center of the Choteau Creek valley north of Wagner, than to either the east or the west. A comparison of the yields and drawdowns of two of the irrigation wells in these areas shows this to be true. The yield per foot of drawdown (specific capacity) is often employed as a measure of well performance. The Kietzman well (F, fig. 9) yields 600 gpm (gallons per minute) with a total drawdown of 25 feet. The specific capacity is therefore 24 gpm. The Ahrens well (C, fig. 9) yields 960 gpm with a total drawdown of 15 feet. The specific capacity of the Ahrens well in the center of the aquifer is 64 gpm, or more than 2½ times that of the Kietzman well at the western edge of the aquifer.

Fluctuations of the Piezometric Surface

No records of water level fluctuations before irrigation are available in the Wagner area, so a comparison of fluctuations before and after irrigation pumping cannot be made. With the beginning of irrigation in the area in 1957, the State Water Resources Commission drilled three observation wells, two of which were drilled into the surface outwash deposit along Choteau Creek. The locations of these wells (C-1, C-2, and C-3) are shown on Plate 2, and the well logs are given in Appendix A. The irrigation wells do not tap the water supplies of this surface outwash deposit. Four additional observation wells (C-4, C-5, C-6, and C-7) were drilled by the State Water Resources Commission in 1958 (pl. 2). Well C-4 is not deep enough (Appendix A) to tap the lower buried glacial outwash deposit and therefore was not affected by irrigation pumping in 1959. Wells C-5, C-6, and C-7 (Appendix A) do tap the lower buried outwash deposit and were affected by irrigation pumping in 1959 (table 1). In the summer of 1960, 15 additional observation wells and test holes were drilled (pl. 2 and Appendix A). Not all of these new wells tap the lower buried glacial outwash deposit, and of those that do, only one water level reading has been made by the writer so that accurate conclusions cannot be drawn concerning the effects of irrigation pumping on these wells. In addition to the observation wells drilled by the State

Map showing Piezometric Surface of Water in Lower Buried Outwash Deposit in the Wagner Area.

FIGURE 9



Water Resources Commission, six artesian domestic wells (A-1 through A-6) were used as observation wells in 1959 (pl. 2). All tap the lower buried outwash deposit, all were flowing during the spring of 1959, and all stopped flowing about July 1, 1959. Table 1 shows the maximum decline from the top of the well and the drop as of January 15, 1960.

Table 1.--Water level declines in State and domestic observation wells during and after the 1959 irrigation season (for locations see pl. 2).

Well	C-5	C-6	C-7	A-1	A-4	A-5	A-6
Maximum decline of water from static level in 1959 (feet)	2.9	2.3	3.9	6.7	5.7	3.0	0.0
Decline in water level from static level as of January 15, 1960 (feet)	2.3	0.9	2.1	0.9	0.8	0.0	0.0

The irrigation wells (pl. 2) all tap the lower buried glacial outwash deposit and are capable of being pumped at comparatively high rates (table 2). The total amount pumped in 1959, 1246 acre-feet (table 3), would cover one square mile of land to a depth of about 2 feet. This same amount of water would saturate about 7 feet of the sand and gravel aquifer underlying the same area (State Water Resources Commission, unpublished information).

During July, 1960, the writer recorded weekly measurements of the three State Water Resources Commission observation wells which definitely tap the buried glacial outwash deposit (C-5, C-6, C-7), and of 12 domestic observation wells (pl. 2, A-1 through A-12). Fluctuations of the water level in some of these wells are shown in Table 4. The three Water Resources Commission observation wells do not reflect the fluctuations shown by the domestic observation wells.

The Water Resources Commission observation wells and the domestic observation wells have not been measured for a long enough time to determine the maximum level to which the water will rise. Without this information the maximum water level fluctuations cannot be given. The "static water levels" shown for the Water Resources Commission observation wells were determined when the wells were drilled; most of them were drilled in mid-summer at the height of the irrigation season, when water levels are fluctuating.

The extreme sensitivity of the artesian water level to irrigation pumping is shown in Figure 10. The total amount of water pumped from July 10-25, 98.8 acre-feet, would cover one square mile of land to a depth of 1.8 inches. This same amount of water would saturate about 4.8 inches of the lower buried glacial outwash deposit underlying the same area. The first domestic flowing well to stop flowing did so after eight days of light irrigation, when only 31.5 acre-feet of water had been pumped by the irrigation wells. All domestic flowing wells north of State observation well C-3 (pl. 2) had ceased flowing by August 1, 1960.

Table 2. Acre-feet of water pumped daily from irrigation wells July 10–25, 1960. (for locations see Pl. 2)

Well	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
A	0.72	2.6	2.6	2.6	2.6	2.6	0.72	—	0.72	2.6	2.6	2.6	2.6	1.9	0.72	0.72	28.9
B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C	—	—	—	—	—	—	1.2	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	36.3
D	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
E	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.4	—	2.4
F	—	—	—	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	31.2
G	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	0.72	2.6	2.6	5.0	5.0	5.0	4.3	6.3	7.0	8.9	8.9	8.9	8.9	8.2	9.4	7.0	98.8

Table 3. Acre-Feet of water pumped monthly from irrigation wells in 1959 (for locations see Pl. 2)

Well	April	May	June	July	August	Sept.	Oct.	Nov.	Total
A	—	—	—	80	52	—	31	—	201
B	—	—	—	64	75	—	—	—	139
C	66	80	12	98	12	—	—	—	268
D	42	—	—	73	65	—	—	—	180
E	—	—	—	70	70	—	—	—	140
F	—	—	—	112	120	—	—	—	232
G	—	—	—	52	34	—	—	—	86
Total	108	80	12	549	428	—	31	—	1246

Table 4.--Water level fluctuations in feet in State and domestic observation wells (July 5-August 1, 1960) (for locations see pl. 2)

Well	7-5-60	7-12-60	7-18-60	7-25-60	8-1-60	Total Fluctuation
C-5	0	0	0	0	---	0
C-6	0	0	0.1	0.3	---	Inconclusive*
C-7	0	0.2	0.3	0.2	---	Inconclusive*
A-1	flowing	flowing	0.1	.9	1.7	---**
A-2	flowing	flowing	flowing	flowing	stopped	---**
A-3	flowing	flowing	flowing	0.1	---	---
A-4	flowing	flowing	flowing	0.4	1.0	---**
A-5	flowing	flowing	flowing	0.3	0.7	---**
A-7	flowing	flowing	flowing	flowing	0.8	---**
A-9	---	---	0.5	1.3	2.0	2.0

* Figures represent a rise in water level caused by plugging of well.
** The maximum height to which water rises from these wells is unknown because it has never been measured, therefore, the total decline cannot be computed.

It is safe to assume that the decrease in water levels in domestic wells tapping the lower buried glacial outwash deposit in the Wagner area is caused mainly by irrigation pumping. The evidence supporting such an assumption is as follows:

1. As Figure 10 shows, and as was reported by the State Water Resources Commission in 1959, there is a direct correlation between the lowering of water levels and irrigation pumping.
2. Effective August 27, 1959, the Commission directed that pumping be stopped from irrigation wells A, B, and C (pl. 2). The other irrigation wells likewise did no pumping after this date. A rise in the water level of the observation wells definitely reflected this irrigation pumping shutdown (State Water Resources Commission, unpublished information).
3. Fluctuations of water in wells penetrating artesian aquifers result primarily from changes in pressure rather than from changes in storage volume. The pumping of water for irrigation in the Wagner area has caused the piezometric surface to be lowered considerably as a result of a decrease in the artesian pressure in the buried outwash aquifer.

In addition, residents protesting the irrigation pumping say that their wells had never stopped flowing until irrigation pumping began in 1957.

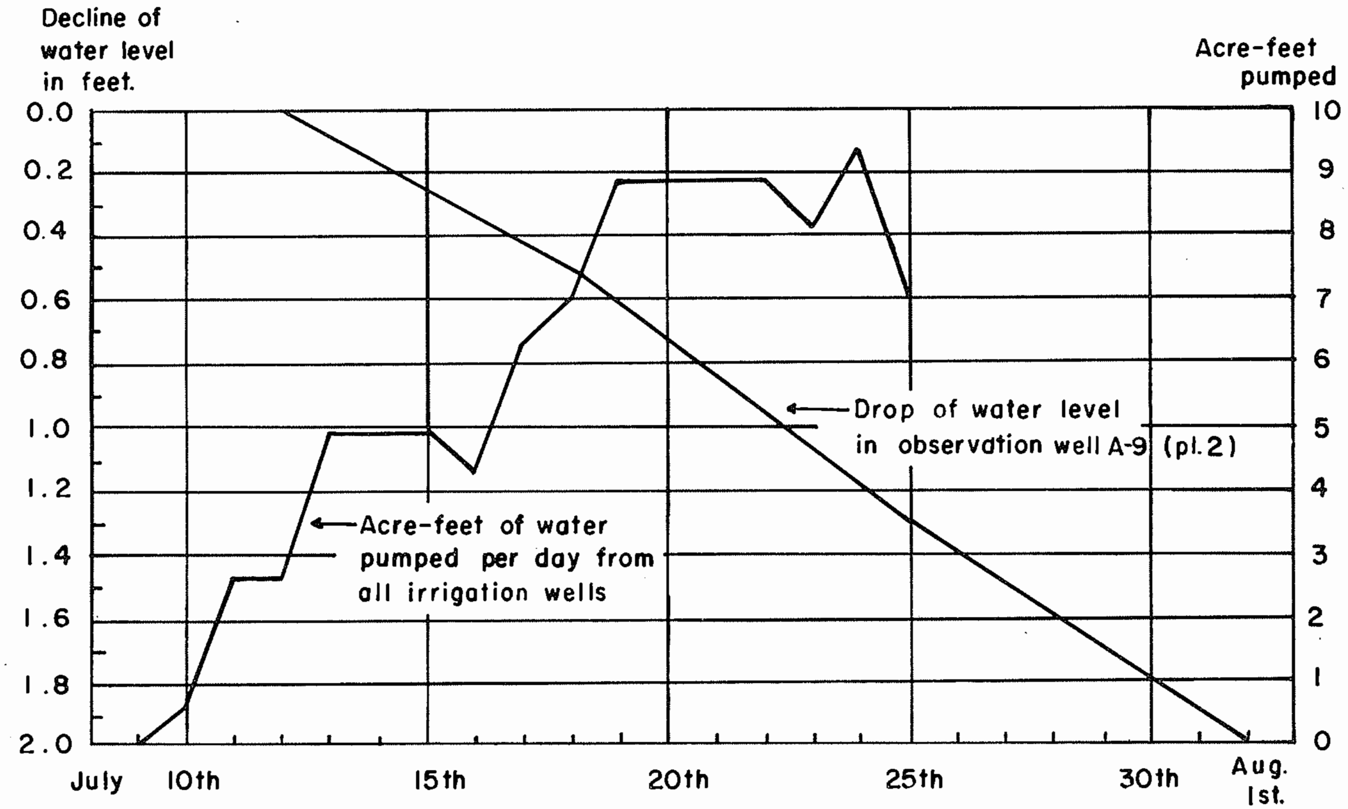


Figure 10. Graph showing relationship between irrigation well pumping and water fluctuation in domestic observation well A-9 between July 10 and August 1, 1960.

Discharge

Discharge from a buried outwash deposit is accomplished in several ways: (1) by down-gradient underflow through the outwash material, (2) by discharge from wells and, (3) by natural discharge at the surface through processes of surface runoff, evaporation, and transpiration.

Although it is difficult to determine how much discharge in the Wagner area is accounted for by underflow, it is probably a significant amount of the total discharge because of the relatively high permeability of the sand and gravel.

In recent years, most of the discharge by pumping has been from the irrigation wells north of Wagner, and a smaller amount has been accounted for by the farm wells in the area. The flowing wells discharge only a small amount. Domestic observation well A-3 (pl. 2) flowed at a rate of 6 gpm before irrigation pumping began in 1960. Assuming this to be average for flowing wells in the area, about 145 acre-feet of water was probably discharged by the domestic flowing wells each year before the introduction of irrigation into the area. This figure would be considerably less in a year when wells would not be flowing for three or more months, owing to irrigation pumping.

Evaporation and transpiration from the buried aquifer in the Wagner area are probably only small factors in the total discharge because of the covering of till on the outwash materials, which provides an effective seal against upward movement of water. There is no surface runoff from the buried aquifers in the Wagner area.

Recharge

Recharge to the buried outwash deposits comes either directly or indirectly from precipitation in the form of rain or snow. The buried glacial outwash deposit is probably not recharged directly by precipitation because the covering of till provides an effective seal against downward percolation. The buried outwash deposit is probably being recharged indirectly by precipitation which has collected in Lake Andes, located at the western edge of the deposit (fig. 9). The evidence for this assumption is as follows:

1. The piezometric surface pictured in Figure 9 shows the Lake Andes region to be a major recharge area, the highest known point on the piezometric surface being at about the same elevation as the lake bottom.
2. The well log of the State Game, Fish and Parks Commission well (Appendix C) at the hatchery on the eastern shore of Lake Andes shows sand and gravel layers from the surface to a depth of 270 feet. The sands and gravels would provide an ideal passageway for water seeping from the lake into the buried glacial outwash.

There is possibly a second but less important source of water on the eastern side of the buried outwash deposit. This "high" (fig. 9) in the piezometric surface may indicate seepage upward from the underlying bedrock formations. However, the "trough" in the piezometric surface along Choteau Creek may be caused by a constant loss of water from the buried glacial outwash deposit through the flowing wells in the area. In this case, the eastern part of the aquifer would become a source area for the central part and the flow lines in Figure 9 would be reflecting a loss of pressure in the center part of the aquifer rather than a recharge area in the eastern part of the aquifer.

Chemical Quality

All ground water contains minerals which are obtained (1) from the atmosphere as the water vapor condenses and falls, (2) from soil and underlying deposits as the water moves downward to the water table, and (3) from deposits below the water table, where the water is circulating. In general, the more minerals that a water contains, the poorer its quality.

The U.S. Department of Public Health has established standards for public drinking water (table 5) which show the maximum concentrations of chemical constituents that are recommended.

Table 5 shows the analyses of 27 water samples taken from the Wagner area. The locations of these samples are shown on Plate 2. Samples 1 and 2 are from Lake Andes, samples 3-15 are from the buried outwash deposit, samples 16-18 are from the Niobrara Formation, and samples 19-27 are from the Codell sandstone. The table shows that waters from the four sources are generally very hard and contain high amounts of calcium, sodium, sulfates, and total solids.

The difference in chemical quality between the water in the lower buried outwash (samples 3-15) and in its postulated source, Lake Andes (samples 1-2) is not abnormal, and is possibly due to the addition of certain ions to the water as it moves through the gravel. The similarity of the chemical quality of water in the lower buried outwash and of water in certain bedrock wells (samples 16, 18, 22, 26) is of interest, but sufficient data are not available to draw definite conclusions regarding its significance.

The standards for irrigation water classification are dependent upon the conditions under which the water is to be used. Consideration must be given to soil texture, infiltration rate, drainage, and salt tolerance of the crop. Large deviations from the optimum for one or more of these conditions make it unwise to use a water that would otherwise be safe.

The significance and interpretation of the quality ratings of the water for irrigation purposes used in this report are summarized by Wilcox (1955, p. 9) in Table 5.

Salinity Hazard

The abnormally high salt concentration of a soil solution reduces the rate at which plants absorb water; consequently growth is retarded. The retardation of growth is almost directly related to the total salt concentration, and therefore the electrical conductivity of the soil solution is largely independent of the kind of salts present.

Low-salinity water (C1) can be used for irrigation with most crops on most soils, with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.

Table 5 Chemical Analyses of ground water in the Wagner area.*

Source	Water Sample**	Parts Per Million: Calcium	Sodium	Magnesium	Nitrate	Iron	Chloride	Sulfate	Maganese	Fluoride	Hardness $CaCO_3$	Total Solids	Sodium percentage of Cations	Conductivity micromhos cm (25°C)	Classification of Irrigation water***
Lake Andes +	# 1	102	34	16	0	<0.1	15	255	0.2	1.1	320	832	17	950	C_3-S_1
	2	296	56	56	0	<0.1	30	820	0.2	1.3	975	1780	11	1890	C_3-S_1
Glacial Deposit Buried Outwash	3	58	386	11			220	506			189	1446	85		
	4	54	370	8			155	533			166	1366	86		
	5	64	382	13			106	711			212	1464	84		
	6	68	358	20			58	639			252	1434	80		
	7	88	320	24	1	0.5	140	610	1.1	0.9	320	1308	67	2150	C_3-S_2
	8	186	476	46	7	0.3	10	1375	3.9	1.3	655	2800	60	3010	C_4-S_2
	9	118	318	28	0	<0.1	278	410	1.2	0.7	410	1220	61	2000	C_3-S_2
	10	82	348	21	0	0.1	100	750	1.6	0.9	291	1104	71	2400	C_4-S_3
	11	92	346	26	0	0.1	213	520	0.2	1.1	335	1504	69	2200	C_3-S_2
	12	84	270	36	0	<0.1	100	520	0.2	1.2	360	1148	61	1950	C_3-S_2
	13	48	162	18	1	<0.1	30	285	0.2	1.0	195	612	62	1190	C_3-S_1
	14	158	290	34	0	0.1	80	885	1.7	1.0	535	1576	53	2190	C_3-S_2
	15	50	306	26	0	<0.2	25	615	0.2	1.0	231	1428	72	1900	C_3-S_2
Niobrara Chalk	16	19	248	10			144	542			89	1502	90		
	17	48	392	18			69	789			196	1428	86		
	18	74	248	22	0	<0.1	33	593	<0.2	1.2	276	1088	65	1770	C_3-S_2
Codell Sandstone	19	21	534	1			456	189			56	1632	96		
	20	19	485	2			251	292			54	414	96		
	21	252	144	52	0	0.4	125	900	<0.2	1.5	845	1796	26	2200	C_3-S_1
	22	24	516	10	2	<0.1	200	660	<0.2	0.6	87	1568	90	2700	C_4 S_3
	23	300	107	67	0	<0.1	108	970	<0.2	1.5	1020	3972	18	2200	C_3-S_1
	24	14	520	6	0	<0.1	215	505	<0.2	1.2	60	1576	94	2450	C_4-S_4
	25	368	352	96	4	<0.1	20	1825	<0.2	1.3	1710	3324	36	3600	C_4-S_2
	26	84	347	23		<0.2	100	770	<0.4	1.2	304	1696	70	2250	C_3 S_3
	27	244	344	36	4	12.5	13	1220	<0.2	1.1	755	2180	<10	2820	C_4-S_2
Public Health Drinking Water Standards****		—	—	150	10	0.3	250	250	0.1	1.0	—	500-1000	—	—	—

* Samples analyzed by State Chemical Laboratory, Vermillion, 1960, except for samples 3, 4, 5, 16, 17, 19, 20, which were analyzed by Dr. O.E. Olson, Station Biochemist, South Dakota State College, Brookings, 1960.

** For locations see Plate 2.

*** For an interpretation of the U.S. Department of Agriculture established standards for irrigation waters see p. 16

**** Drinking water standards from 1960 U.S. Public Health Service standards.

+ Sample No. 1 is from open water along the shore. Sample No. 2 is from beneath the ice near the center of the lake.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium (Alkali) Hazard

Excessive amounts of adsorbed sodium produce alkali soils. In such a soil the particles may disperse, and the soil may become unfavorable for the entry and movement of water and air and for tillage. Adsorbed sodium also may be toxic and cause various nutritional disturbances in plants.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of a sodium hazard.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils of high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils that have good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management--good drainage, high leaching, and additions of organic matter. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

According to the standards outlined above, the water from the buried glacial outwash in the Wagner area cannot be used on soils with restricted drainage, and even with adequate drainage, special management for salinity and alkalinity may be required.

The soils in the Wagner area were formed from fine textured glacial till.

The resulting low infiltration rate of irrigation water into these soils and the poor drainage in the Wagner area will probably increase the accumulation of soluble salts and adsorbed sodium to the harmful stage.

According to the U. S. Department of Agriculture standards for irrigation water (Wilcox, 1955), the water from the buried outwash deposit should not be used to irrigate the poorly-drained fine-textured soils in the Wagner area.

State Water Resources Commission Observation Well Readings

A comparison of tables 1 and 4 shows that State Water Resources Commission observation wells C-5, C-6, and C-7 reflected the 1959 drop in artesian pressure in the Wagner area, but showed no such drop in 1960. In 1960 the domestic observation wells clearly showed the decrease in pressure caused by irrigation pumping. At the suggestion of Charles Dyer of the U. S. Geological Survey, the writer on November 5, 1960 poured water into six State observation wells in order to see if the wells were plugged. The results of the test are shown in Figure 11. Wells C-12 and C-13 were drilled in 1960, the others in 1958. The water fell rapidly in the newer wells, demonstrating that there is free movement of water to and from those wells. Well C-6 reacted much more slowly, and wells C-5 and C-7 showed no movement of water from the well into the aquifer. These three wells are plugged to some degree at least, and thus water is unable to flow freely into them from the buried outwash deposit. They are therefore of questionable value as observation wells, and the measurements taken in them in 1960 should not be considered in drawing conclusions concerning piezometric fluctuations in 1960 in the buried glacial outwash deposit in the Wagner area.

The writer feels there is a reasonable explanation for the plugging of these three observation wells. A well screen is placed in the bottom of the observation wells and it is designed so that the finer sand might be removed from around the screen, thus forming a natural filter of coarser sand and gravel. This process is called "development" of the well. It is important that the development process remove the finer material from the immediate vicinity of the well; otherwise, sand will later be drawn into the well and may eventually plug the screen and destroy the value of the well. Plugging in this way is possible only in wells which are being pumped or which are flowing under artesian conditions.

The observation wells in the Wagner area are neither pumped nor flowing, so the Water Resources Commission felt that the "development" referred to above was unnecessary. Figure 12 shows the relationship of observation well C-5 to the glacial drift. A four-inch hole was drilled to a depth of 140 feet, where the lower buried glacial outwash was reached. The outwash was penetrated to a depth of 165 feet and the hole was then filled with pea gravel to a depth of about 80 feet. A sand point with a 60-mesh screen was attached to the lower end of a galvanized steel casing having an inside diameter of 1¼ inches, and was placed in the drill hole to a depth of 85 feet. Gravel packing was placed between the casing and the drill hole, and was tamped from the 85-foot level to the surface. The well was tested by filling the casing with water; it was deemed satisfactory when the water lowered visibly.

In most cases the above procedure would be adequate for the construction of a satisfactory observation well. In the case of well C-5, it apparently was not. The well log shows a clean coarse sand and medium gravel (the upper buried outwash deposit) between 75 and 110 foot depths. The static water level in this well is at 35 feet, or 40 feet above the

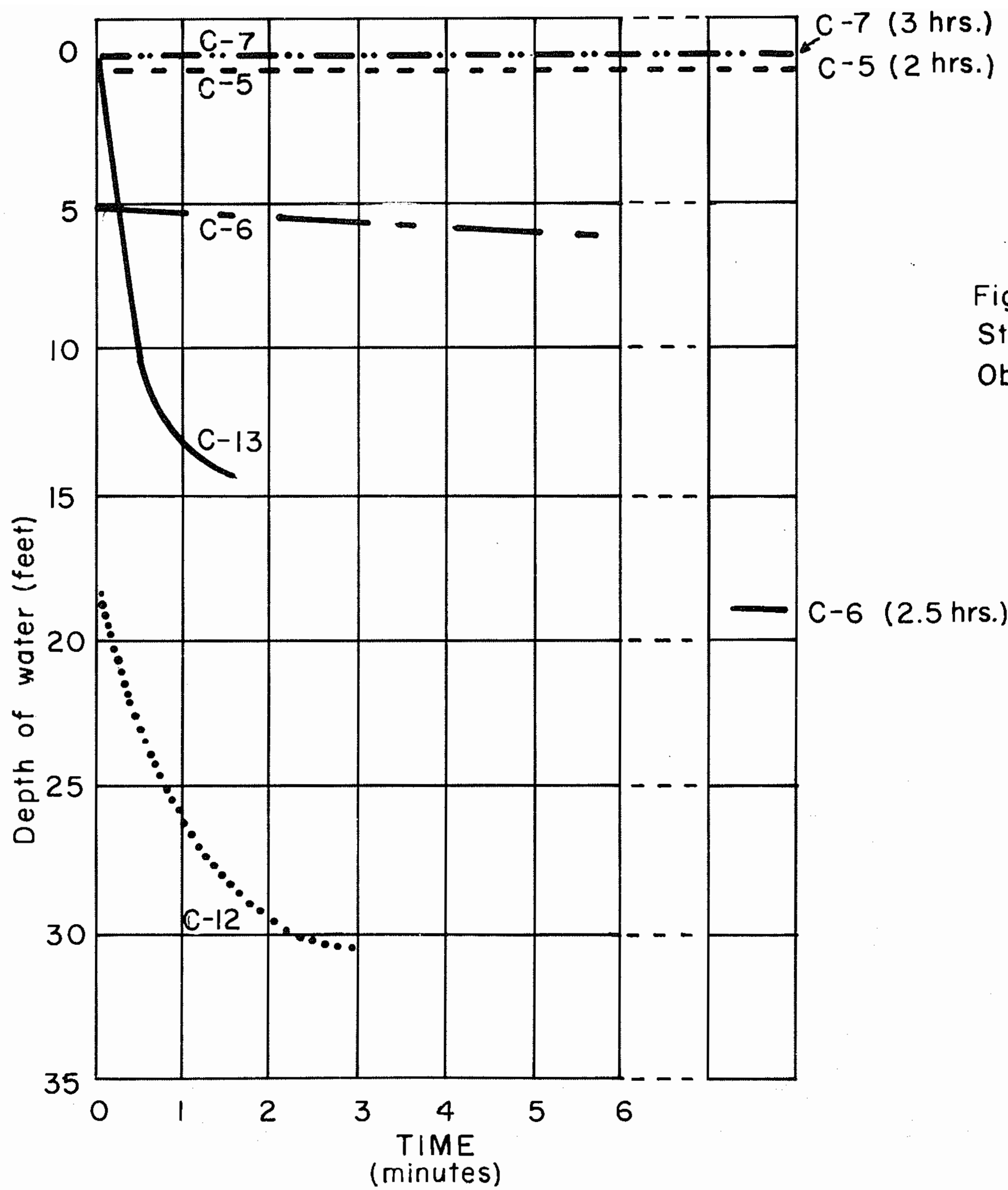


Figure 11. Results of pouring water into State Water Resources Commission Observation wells.

Well	Static Water Level
C-5	36.1
C-6	35.5
C-7	21.1
C-12	34.5
C-13	15.5

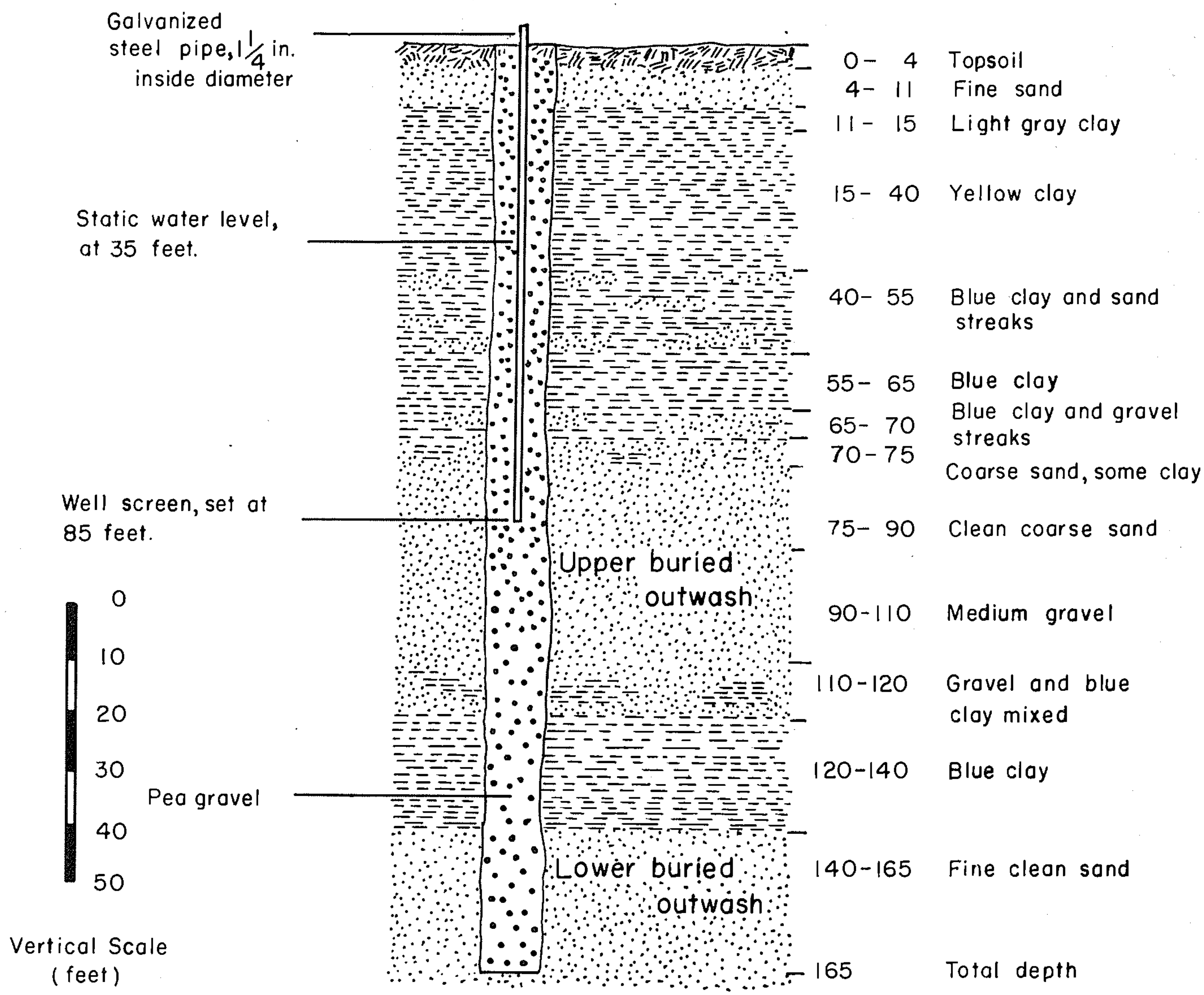


Figure 12. Lithologic log of State Water Resources Commission Observation Well C-5

top of this sand and gravel layer. It is probable therefore that water from the lower buried outwash deposit is continually flowing upward into the upper deposit. If, when the well was drilled, this flow was continuous, it can be assumed that fine sand from the lower buried outwash deposit was carried into the gravel-pack and upward toward the well screen until the voids in the gravel-pack became completely filled. Thus plugged, the well is no longer sensitive to fluctuations of water level in the Wagner area.

If, as is concluded here, the upper buried outwash deposit is indirectly responsible for the plugging of wells C-5, C-6, and C-7, it is reasonable to expect that the newer wells which tap both the outwash deposits (wells C-8, C-9b, C-14, C-15, C-19) will be similarly affected within a few years.

In this report, two static water levels are sometimes given for one well. For example, in Appendix A, the static water level for State observation well C-12 is given as 12 feet. In Figure 11 the static water level of the same well is given as 34.5 feet. The former level was measured in July when the well was drilled, the latter, on November 5. Thus, observation well C-12 showed a decline in "static water level" at the same time the domestic observation wells were reflecting the general rise of the piezometric surface due to decreased irrigation pumping in the fall. At least two other new (1960) State observation wells (C-13 and C-14) show a similar adjustment between the July drilling date and November 5.

Apparent discrepancies in static water levels are noticeable in a comparison of the static water levels given for wells C-13 and C-14 in Appendix A and on Figure 9. Well C-13 shows the static water level at an altitude of 1451 feet (Appendix A). The map of the piezometric surface shows the static water level at this same location to be at about 1395 feet, or 56 feet below the level given in Appendix A. Well C-14 (Appendix A and fig. 9) similarly shows a static water level at an altitude of 1422 feet and a piezometric surface elevation of about 1395 feet, a difference of 27 feet.

The static water level data from which the map of the piezometric surface in the Wagner area (fig. 9) was compiled, was collected from State and domestic observation wells, irrigation wells, and from farm wells. In those areas where the water levels in the State Water Resources Commission observation wells appeared not to reflect true static water levels due to plugging or to the newness of the well, the writer relied upon data from the irrigation and farm wells.

Surface Outwash Deposits Along Choteau Creek

The surface outwash deposits along Choteau Creek north of 97-63-22 (fig. 2) are useful as a water-producing zone, even though the sand rarely attains a thickness of more than 25 feet, and is generally saturated for only one third of its thickness, because the water is yielded rather freely to domestic and stock wells. It is doubtful whether the outwash would yield enough water for sustained irrigation, a conclusion which does not agree with Stoley (1956).

Available records indicate that the surface outwash south of 97-63-22 along Choteau Creek is discontinuous and is highly variable in composition and thickness (see Appendix B). In a few places it consists of gravel and sand, but in most places test holes penetrated only silt and fine sand. The test holes show a maximum thickness of about 26 feet.

The 10 feet of medium sand lying above the gravel in State observation well C-3 (fig. 2 and Appendix A) is thought by the writer to be part of the shallow outwash deposit. However, the 45 feet of gravel shown in the log of well C-3 is apparently part of the upper buried glacial outwash deposit and not part of the surface outwash deposit.

To the writer's knowledge, no domestic or stock wells draw water from the surface outwash south of 97-63-22.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study by the State Geological Survey show that the lower buried glacial outwash deposit underlies about 225 square miles in the Wagner area. This buried outwash averages 50 feet in thickness, ranging from a feather-edge to at least 140 feet. It is composed largely of well-sorted coarse sand and fine gravel and therefore has both high porosity and high permeability. Irrigation wells north of Wagner yield as much as 64 gpm per foot of drawdown.

Artesian heads of more than 100 feet cause wells to flow along Choteau Creek, and water rises within 50 feet of the surface throughout most of the area. The piezometric surface is in hydrologic continuity with Lake Andes, and it is concluded that the lake is recharging the lower buried outwash deposit.

The lower buried glacial outwash deposit has a water storage volume of about 2,100,000 acre-feet. However, the piezometric surface is sensitive to irrigation pumping, and in the summer of 1960, all but the southernmost flowing wells stopped flowing when 98 acre-feet of water was pumped by the irrigation wells.

The surface glacial outwash deposit along the Choteau Creek valley consists of poorly sorted silt, sand, and gravel deposits which are discontinuous and highly variable in thickness. These deposits might yield small quantities of water to dug and driven wells.

The writer makes the following recommendations for further development of water resources in the Wagner area:

1. According to the U. S. Department of Agriculture standards for irrigation waters, the water from the lower buried outwash should not be used for irrigation, because of its poor chemical quality.
2. If the present irrigation wells in the area continue to be used, controlled pumping tests of several wells should be run before plans are made for long-term use of water from the lower buried outwash deposit.
3. Reliable observation wells should be measured frequently enough to determine the maximum yearly water-level fluctuations in the area.
4. Losses in artesian pressure are most noticeable in flowing wells. Domestic observation wells throughout the area (not just along Choteau Creek) will probably show water level fluctuations due to irrigation to be more widespread than previously suspected.
5. If additional observation wells are drilled in the Wagner area, logs of the wells should be checked to determine whether some development, or even casing of the well, is necessary to prevent plugging of the well screen. The dan-

ger of plugging may be reduced if the well screen is placed down in the lower buried outwash deposit. State Water Resources Commission observation wells should be tested frequently to see if they are plugged or otherwise functioning improperly.

6. In 1959, Lake Andes nearly dried up. If, as is concluded here, the lake is the major source of recharge for the buried outwash deposit, present yields will be sustained only as long as Lake Andes is kept filled with water. Frequent water level measurements of the lake should be taken in the future.

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APPENDIX A

Logs of Water Resources Commission Observation Wells and Test Holes in the Wagner Area

(logged by Water Resources Commission; for locations see plage 2)

Well C-1
Location: 98-63-36a
Surface Elevation: 1450 feet
Date Drilled: summer, 1957
Static Water Level: 16.1 feet

Pleistocene and Recent deposits, undifferentiated:

0- 2	topsoil
2- 4	sand, coarse
4-10	clay, brown
10-13	gravel, fine
13-16	sand, coarse
16-25	gravel
25-29	sand
29-35	gravel
35-57	sand, medium
57-60	clay, blue
60	total depth

* * * * * * * *

Well C-2
Location: 97-63-30d
Surface Elevation: 1420 feet
Date Drilled: summer, 1957
Static Water Level: 5.5 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 8	clay, brown
8-35	sand, medium
35-55	gravel
55-60	clay, gray
60	total depth

* * * * * * * *

Well C-3
Location: 95-62-7b
Surface Elevation: 1375 feet
Date Drilled: summer, 1957
Static Water Level: 6.2 feet

Pleistocene and Recent deposits, undifferentiated:

0-3	topsoil

(continued on next page)

Well C-3--continued

3- 7	clay, brown
7-17	sand, medium
17-62	gravel
62-65	clay, blue
65	total depth

* * * * * * * *

Test Hole C-4a
Location: 97-64-3b
Surface Elevation: 1475 feet
Date Drilled: summer, 1958

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 22	clay, brown
22- 65	clay, blue, shallow streaks of fine sand
65- 90	shale
90-120	clay, blue and fine sand streaks
120-150	clay, blue
150	total depth

* * * * * * * *

Well C-4
Location: 96-64-1a
Surface Elevation: 1445 feet
Date Drilled: summer, 1958
Static Water Level: 18.1 feet

Pleistocene and Recent deposits, undifferentiated:

0- 2	topsoil
2- 20	clay, yellow
20- 30	gravel and yellow clay mixed
30- 50	clay, blue
50- 85	gravel, coarse; some clay
85- 95	sand, medium with streaks of clay
95-120	sand, medium
120-152	clay, blue
152	total depth

* * * * * * * *

Well C-5
Location: 96-63-9d
Surface Elevation: 1419 feet
Date Drilled: summer, 1958
Static Water Level: 35.0 feet

Pleistocene and Recent deposits, undifferentiated:

0- 4	topsoil

(continued on next page)

Well C-5--continued

4- 11	sand, fine
11- 15	clay, light gray
15- 40	clay, yellow
40- 55	clay, blue and sand streaks
55- 65	clay, blue
65- 70	clay, blue and gravel streaks
70- 75	sand, coarse, some clay
75- 90	sand, coarse, clean
90-110	gravel, medium
110-120	gravel and blue clay mixed
120-140	clay, blue
140-165	sand, fine, clean
165	total depth

Percent voids 39.2

* * * * * * * *

Well C-6
Location: 96-63-21c
Surface Elevation: 1415 feet
Date Drilled: summer, 1958
Static Water Level: 34.6 feet

Pleistocene and Recent deposits, undifferentiated:

0- 4	topsoil
4- 6	clay, yellow
6 - 10	sand, fine and yellow clay
10- 40	clay, yellow
40- 50	clay, blue
50- 70	gravel, very coarse, dirty
70-150	clay, blue with some grit
150-178	sand, fine
178	total depth

Percent voids 34.6

* * * * * * * *

Well C-7
Location: 96-63-35c
Surface Elevation: 1397 feet
Date Drilled: summer, 1958
Static Water Level: 18.0 feet

Pleistocene and Recent deposits, undifferentiated:

0- 6	topsoil
6- 15	gravel, coarse
15- 20	clay, yellow

(continued on next page)

Well C-7--continued

20- 38	gravel, coarse
38- 70	clay, blue
70- 74	gravel, coarse
74-133	clay, blue with grit
133-155	sand, medium white getting coarser to 155 feet
155-178	pea gravel
178	total depth

Percent voids 39.0

* * * * * * * *

Well C-8
Location: 95-62-8ad
Surface Elevation: 1450 feet
Date Drilled: summer, 1960
Static Water Level: 80 feet

Pleistocene and Recent deposits, undifferentiated:

0- 25	clay, brown
25- 39	sand, dirty, brown
39-115	clay, blue, some sand and gravel
115-135	sand, fine, gray
135-160	clayey sand
160-202	clay, blue
202-284	sand, medium to coarse

Niobrara (?) Chalk

284	chalk, total depth

* * * * * * * *

Test Hole C-9
Location: 95-62-34c
Surface Elevation: 1410 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 25	clay, brown
25- 37	clay, blue
37- 85	sand, brown, some medium coarse gravel
85- 88	clay, blue
88- 93	sand, fine, gray
93-182	clay, sandy, blue

Codell (??) sandstone

182-185	sandstone
185	total depth

* * * * * * * *

Test Hole C-9a
Location: 95-62-33b1
Surface Elevation: 1450 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 28	clay, brown
28- 73	clay, blue
73- 83	sand, coarse and gravel
83- 96	clay, sandy, some gravel
96-120	sand, coarse, some gravel
120	total depth

* * * * * * * *

Well C-9b
Location: 95-62-33b2
Surface Elevation: 1450 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 28	clay, brown
28-100	clay, blue
100-113	gravel, coarse, some sand
113-138	clay, sandy
138-148	sand, fine
148-150	clay, gray
150-209	sand, some coarse gravel

Niobrara (?) chalk

209-210	chalk
210	total depth

* * * * * * * *

Well C-10
Location: 97-65-34c
Surface Elevation: 1475 feet
Date Drilled: summer, 1960
Static Water Level: 33.3 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 17	clay, brown
17- 53	clay, blue
53- 59	sand and coarse gravel
59-100	sandy clay-sand streaks 90-100 feet
100-104	sand, coarse, some clay
104-135	clayey sand

Niobrara (?) chalk

135-160	chalk
160	total depth

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Test Hole C-11
Location: 97-64-4b
Surface Elevation: 1485 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 20	clay, brown
20- 31	clayey gray sand, some coarse gravel
31-170	till, blue, some sand and gravel

Niobrara (?) chalk

170-188	chalk
188	total depth

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Test Hole C-11a
Location: 97-64-5da
Surface Elevation: 1440 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 14	clay, brown
14- 19	sand and gravel
19-179	clay, blue, some sand and gravel
179-197	extremely hard layer of hardpan or boulders

Niobrara (?) chalk

197-210	chalk

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Well C-11b
Location: 97-65-13dd
Surface Elevation: 1520 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 27	clay, brown
27- 85	clay, blue
85-100	sand, coarse gravel
100-145	sandy gray clay with sand streaks
145-175	gravel, coarse, sand, some clay
175-193	clay, sandy, gray

Niobrara (?) chalk

193-200	chalk
200	total depth

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Well C-12
Location: 97-64-23bb
Surface Elevation: 1453 feet
Date Drilled: summer, 1960
Static Water Level: 12 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 27	clay, brown
27- 34	sand, gray
34-147	clay, blue
145-150	sand
150-175	clay, blue
175-206	sand, medium to coarse, gray, some gravel
206	total depth

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Well C-13
Location: 97-63-6a
Surface Elevation: 1463 feet
Date Drilled: summer, 1960
Static Water Level: 12 feet

Pleistocene and Recent deposits, undifferentiated:

5- 25	clay, brown
25-175	clay, blue
175-229	sand, coarse, some gravel

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Well C-14
Location: 97-63-21b
Surface Elevation: 1448 feet
Date Drilled: summer, 1960
Static Water Level: 26 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 35	clay, brown
35- 95	clay, blue
95-140	sand, fine to medium, gray, some gravel
140-165	clay, sandy, blue-gray
165-234	sand, medium, gray, some shale and gravel
234	total depth

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Well C-15
Location: 97-63-28d
Surface Elevation: 1393 feet
Date Drilled: summer, 1960
Static Water Level: 10 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 10	clay, brown
10- 15	gravel, dry
15- 57	sand, very fine, gray
57- 65	clay, blue
65- 90	sand, medium to coarse
90-116	sandy clay
116-255	sand, well sorted
255-260	sandy clay, some lignite
260	total depth

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Test Hole C-16
Location: 98-63-13aaa
Surface Elevation: 1505 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 26	clay, brown
26- 58	clay, blue
58- 72	clayey sand
72-210	sandy clay
210-240	sandy chalk
240	total depth

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Test Hole C-17
Location: 98-62-32bbbc
Surface Elevation: 1500 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 22	clayey sand
22- 35	clay, brown
35- 80	clay, blue
80-115	sand, coarse, brown
115-185	sandy clay
Niobrara (?) chalk	
185-190	chalk
190	total depth

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Well C-18
Location: 99-62-27bbbb
Surface Elevation: 1602 feet
Date Drilled: summer, 1960

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 35	clay, brown
35-155	clay, blue
155-185	sand, coarse gravel
185-190	sandy gray clay
190-210	gravel, coarse
210-340	sandy gray clay
340	total depth

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Well C-19
Location: 96-63-16c
Surface Elevation: 1403 feet
Date Drilled: summer, 1960
Static Water Level: 18.3 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 16	clay, brown
16- 25	sand, medium, clean, brown
25-105	sandy gray clay
105-132	clay, blue
132-160	sand, coarse gravel
160-200	sand, muddy
200	total depth

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APPENDIX B

Logs of South Dakota State Geological Survey Test Holes Along Choteau Creek, Wagner, South Dakota

(logged by State Geological Survey; for locations see plate 2)

Test Hole 1
Location: 97-63-10cc
Surface Elevation: 1383 feet

Pleistocene and Recent deposits, undifferentiated:

0- 4	clay, sandy, tan
4- 9	clay, pebbly, tan
9-14	clay, pebbly, sandy, tan
14-18	clay, sandy, gray
18-24	clay, blue

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Test Hole 2
Location: 97-63-28ba
Static Water Level: 4.0 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 7	clay, black
7-13	sand, coarse and pebbles, some brown clay
13-27	sand, coarse and fine gravel
27-31	gravel, medium
31-34	gravel, medium, some gray clay
34-37	clay, blue

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Test Hole 3
Location: 96-63-4bb
Static Water Level: 8.0 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 7	clay, black
7-12	clay, black, some sand
12-17	sand, fine with some coarse sand, clay stringers
17-24	sand, coarse and medium gravel
24-25	clay, blue

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Test Hole 4
Location: 97-63-10ddl
Surface Elevation: 1385 feet

Pleistocene and Recent deposits, undifferentiated:

0-3	topsoil
3-8	clay, brown with some sand and pebbles
8	struck rock; abandoned hole

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Test Hole 5
Location: 97-63-10dd2
Surface Elevation: 1385 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 8	clay and fine sand stringers
8-13	sand, fine to coarse
13-14	clay, black
14-23	sand, coarse and fine gravel
23-28	clay, blue

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Test Hole 6
Location: 96-63-17ba
Surface Elevation: 1381 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 8	clay, tan
8-12	clay, blue

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Test Hole 7
Location: 96-63-17ac
Surface Elevation: 1382 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3-12	clay, brownish gray
12-18	sand, coarse and gravel
18-23	clay, blue

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Test Hole 8
Location: 96-63-29ab
Surface Elevation: 1377 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3-13	clay, dark gray
13-17	clay, dark gray, some sand

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Test Hole 9
Location: 95-63-2ba
Surface Elevation: 1378 feet
Static Water Level: 6.5 feet

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 8	clay, light to dark gray
8-18	clay, light gray, some sand
18-23	clay, blue

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Test Hole 10
Location: 95-62-21bc

Pleistocene and Recent deposits, undifferentiated:

0- 3	topsoil
3- 8	clay, dark brown
8-13	clay, grayish brown
13-21	clay, dark gray

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APPENDIX C

Log of State Game, Fish and Parks Commission Well #1

Location: 96-64-7a (plate 2)
Surface Elevation: 1440 feet
Logged by: Charles L. Baker (?)

Pleistocene and Recent deposits, undifferentiated:

0- 20	sand and gravel, clayey
20- 30	sand and chalk fragments
30- 70	sand
70- 90	sand, coarse, gray, with gravel
90-170	sand, fine, gray, with gravel
170-270	gravel, fine to 200 ft. depth, coarse below, with fine sand 240-270
270-340	grit conglomerate with sand
340-360	sand, cemented

Codell (?) sandstone

360-380	sandstone

Pre-Codell deposits

380-960	shales, sandstone, limestone, and chalk
960	Sioux Quartzite (total depth)

APPENDIX D

Log of Corps of Engineers Codell Observation Wells and Test Hole

(logged by Corps of Engineers)

Well No. 917
Location: 96-65-16c (plate 2)
Surface Elevation: 1422 feet

0- 58	clay, brown
58-105	Pierre shale, undifferentiated
105-123	Gregory Member Pierre shale, marl
123-157	Sharon Springs Member Pierre shale, dark shale
157-224	Niobrara chalk (Smoky Hill Member)
224-297	Niobrara chalk (Fort Hays Member)
297-317	Carlile shale
317-375	Codell sandstone
375-386	Carlile shale
386	total depth

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Well No. 918
Location: 95-64-11a (plate 2)
Surface Elevation: 1504 feet

0- 56	clay, gray
56- 70	sand, clayey
70- 81	clay
81- 85	sand, clayey
85-205	clay, gray
205-267	Niobrara chalk (Smoky Hill Member)
267-317	Niobrara chalk (Fort Hays Member)
317-333	Carlile shale
333-366	Codell sandstone
366-372	Carlile shale
372	total depth

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Test Hole G 8
Location: 95-65-11bd
Surface Elevation: 1805 feet

0-34	sand
34	Pierre shale
34	total depth

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APPENDIX E

Irrigation and Domestic Well Records

S - Stock
D - Domestic

I - Irrigation
C - Cooling of generators

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Luebke, R. J.	99-62-10a		460		Codell		D, S		
Luebke, R. J.	99-62-10a		250		Niobrara	Chalk	D, S		
Puepke, H.	99-62-17ba		285		Niobrara	Chalk	D, S	1959	
Grosz, T.	99-62-18d		525		Codell		D, S		
Hartman, P.	99-62-19c		396		Codell		D, S		
Terringer,	99-62-23bd		380		Outwash	Sand	D, S		
Pape,	99-62-26dd		290		Outwash	Sand	D, S	1944	
Baier, W.	99-62-29d		350		Outwash	Sand	D, S		
Brasz, M. A.	99-62-35c		310		Outwash	Sand	D, S	1925	
Boettcher, J.	98-62-1c		310		Outwash	Sand	D, S	1960	
	98-62-9d		330		Codell		D, S	1930	
Bietz, T.	98-62-11a		313		Outwash	Sand	D, S		
Delmont City Well	98-62-27		921	2"	Dakota	Sandstone	D		
Ruff, A.	98-62-28b		190		Niobrara	Chalk	D, S	before 1930	

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Reinfelt, T.	98-62-30a		313		Codell		D, S		60
Fink, A.	98-62-33b				Niobrara				
Florey, R.	98-63-14a		330		Codell		D, S		
Florey, R.	98-63-14a		190		Outwash	Gravel			
Hinckley, D.	98-63-19dd		380		Codell		D, S		
Evans, R.	98-63-22dd	1429	172		Outwash	Sand	D, S	1954	
	98-63-26a		314		Codell		D, S		
	98-63-26a		210		Outwash	Sand	D, S		
Doeering, J.	98-63-31a		315		Codell		D, S		
Batteman, L.	98-63-28d		180	2"	Outwash	Gravel	D, S	1939	50
Schroeder, D.	98-63-29a		260	2"			D, S	1927	120
Wonder, J.	98-63-33dd		125	1"	Outwash		D, S	1949	
Wonder, J.	98-63-33da		195	10"	Outwash	Sand	I	1958	
Meyers, E. H.	98-64-10c		373		Codell		D, S		
Armour Town Well	98-64-12	1514	757	6"	Dakota	Sandstone	D		
Kietzman, H.	98-64-20a		390		Codell		D, S	1940	
Harrington, F.	98-64-25b		280		Codell		D, S	1955	

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Shortreed,	98-64-32d				Niobrara	Chalk	D, S		
McGraff, J.	98-64-35d		290		Codell (?)		D, S	1936	
Howley, C. R.	98-64-36c		300	3"	Codell		D, S	1958	
Schmidt, O.	97-62-5a		280		Codell		D, S		
Will, O.	97-62-7aa		320		Codell		D, S		
Holton, J.	97-62-18cd		179		Niobrara	Chalk	D, S	1951	80
Hrdlicka, C.	97-63-4da	1410	160	3"	Outwash		D, S	1951	65
Black,	97-63-6a		364	1¼"	Codell		D, S	1946	
Power Plant	97-63-6b		420	6"			C	1953	75
Power Plant	97-63-6b		180	6"			C	1936	
Glantz, P.	97-63-6c		180	2"	Outwash		D, S	1904	60
Glantz, P.	97-63-6c		300	3"			D, S	1953	60
Hollman, P.	97-63-7a	1450	120	2"			D, S		55
Hollman, P.	97-63-7a	1450	180	2"	Outwash		D, S	1920	55
Kolecka, A.	97-63-9b	1420	165	1"	Outwash		D, S	1943	40
Williams, H.	97-63-10 c	1405	174	3"	Outwash	Sand	S	1949	
Kolecka, E.	97-63-17a		197	2"	Outwash	Sand	D, S		60

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Meyer, E.	97-63-18b	1425	180	2½"			D, S	1925	45?
McCarthy, J.	97-63-21b		144	2½"	Outwash	Sand	D, S	1957	
Brox, W.	97-63-23b		185	2"	Outwash	Sand	D, S	1942	
Ewing, E.	97-63-24b		190		Outwash	Sand	D, S		
Martin, V.	97-63-25cb	1436	196	2"	Outwash	Sand	D, S	1904	60
Verzani, R.	97-63-24d		208		Outwash	Sand	D, S	1947	
Broz, W.	97-63-27aa		175	2"			D, S	1910	80?
Petrak, M	97-63-30c		135	2"	Outwash	Sand	D, S	1959	
Kucera, A.	97-63-31dd	1403	160	2"	Outwash	Sand	D, S	1910	12?
Weichman, F.	97-63-32dd	1393	183	2"	Outwash	Sand	D, S	1957	12
Weichman, N.	97-63-34cc	1394	150	2"	Outwash	Sand	D, S		20
Weichman, P.	97-63-34cd		155	18"	Outwash	Sand	I	1957	22
Stone, C.	97-63-35b		180	2"	Outwash	Sand	D, S		40?
Horner, G.	97-63-35dd		190	2"	Outwash	Sand	D, S		40?
Farke, C.	97-64-1d		193	3½"			D, S	1957	85?
Schroeder, A.	97-64-3d		240	2"		Sand	D, S	1943	
Fryda,	97-64-5a		330	2"	Codell		D, S	1941?	
Uhlbrich, J.	97-64-6ad		400		Codell			1958	

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Youngstrum, D.	97-64-9bb		338	2''	Codell		D, S		60
Youngstrum,	97-64-9d		400	4''	Codell		D, S	1916	15?
McFarland, D.	97-64-10c	1465	185	2''	Outwash	Sand	D, S	1940?	
McFarland, D.	97-64-10c		206	18''	Outwash	Sand	I	1957	90
Kietzman, R.	97-64-10d		190	2''	Outwash	Sand	D, S		
Soulek, R.	97-64-11d	1463	180	2''	Outwash	Sand	D, S		60
Fryda, C.	97-64-12a	1454	180	2''	Outwash	Sand-gravel	D, S	1943	32?
Meyer, E.	97-64-13d		180	2½''			D, S	1925	45?
Banks, W.	97-64-15c	1468	185				D	1952	
Linnell, D.	97-64-17c		180		Outwash	Sand-gravel	D, S		
Linnell, D.	97-64-17c		325		Codell			1952	
VonCollen, G.	97-64-21d	1446	320	2''	Codell		D, S		
Johnson, H.	97-64-24a	1433	165	2''	Outwash		D, S		60?
Kreeger, P.	97-64-24a	1440	180	2''	Outwash	Sand	D, S		
VonCollen, G.	97-64-25d	1446	160		Outwash		D, S		
Johnson, A.	97-64-26d	1466	180				D, S		
Howley, D.	97-64-27a	1448	180	2''	Outwash	Sand	D, S		

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Schmidt, J.	97-64-27c	1472	425	2''	Codell		D, S	1948	
Jones, W.	97-65-26c		394		Codell			1958	
Carda, E.	97-65-34b		410		Codell				
Hahn, E.	96-62-4c				Niobrara				
Ehrasmann, H.	96-62-8c		200	3''			D, S		
Andersh, E.	96-62-9d		200	4''					40
Link, R.	96-62-17a		200					1950	
Peters, H.	96-62-19b		242	3''	Outwash	Sand	D, S	1956	
Soukup, J.	96-62-20cc		265	2''				1926	100?
Uherka, J.	96-62-21c		92						Flowing
Uherka, W.	96-62-21a		115						Flowing
Holec, S.	96-62-23c		590		Codell				
Homolka, E.	96-62-33c		225		Outwash	Sand			120?
Dostol, J.	96-62-34b		449		Codell			1942	
Weichman, A.	96-63-2a		180	2''	Outwash	Sand	D, S	1930?	
Barkley,	96-63-2c		190	2''	Outwash	Sand	D, S	1919	
Kaberna, W.	96-63-2d		196	4''	Outwash	Sand	D, S	1958	60?
Stone, A.	96-63-3b		200	2''	Outwash	Sand	D, S	1946	

Appendix E- Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Ahrens, C.	96-63-3da		156	18"	Outwash	Sand	I	1957	24
Ahrens, C.	96-63-3dd		174		Outwash	Sand	D, S	1958	40
Petric, D.	96-63-7b	1455	144(?)	2"	Outwash		D, S		
Jasperson, E.	96-63-9b	1383	101		Outwash		S	1941	Flowing
Slaba, J.	96-63-9c	1395	145		Outwash			1959	
Jasperson, E.	96-63-9dd	1416	165	2"	Outwash	Sand	D, S	1948	16?
	96-63-10c	1440	155	2"	Outwash		D, S		40?
Horner, C.	96-63-14a		191	2"	Outwash		D, S	1957	
McKee, E.	96-63-15bc	1422	154					1958	
Holsbauer,	96-63-15bd		170	18"	Outwash		I	1957	
Rubesruk,	96-63-16cd	1398	145					1955	
Uecher, B.	96-63-17c	1420	165	2"	Outwash			1959	
Cihak, F.	96-63-20c	1445	200	2"	Outwash		D, S		
Slaba, J.	96-63-20dc	1380	148					1956	
Uecher, R.	96-63-20dd	1401	147		Outwash		D, S		Flowing
Stillion, C.	96-63-21c	1395	173		Outwash		D, S	1956	
Holsbauer,	96-63-22bb	1406	158	7"	Outwash		D, S	1958	21

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Uherka, C.	96-63-25a		220		Outwash		D, S		
Bradley, J.	96-63-28b	1383	118		Outwash		D, S		Flowing
Kaberna,	96-63-28c	1384	90	2"	Outwash	Sand	S		Flowing
Hollenbeck, C.	96-63-31b	1478	165	3"	Outwash		D, S		65?
Kaberna,	96-63-29dd	1426	150		Outwash	Sand	D, S		
Buus, P.	96-63-30b	1474	240		Outwash	Sand	D, S		
Nesgaard, M.	96-64-1c	1475	189	2"	Outwash		D, S		
Cuka, E.	96-64-2ab	1480	215	3"	Outwash	Sand	D, S	1947	
Scott, R.	96-64-3dc	1488	183		Outwash	Sand	C, S		
Novok,	96-64-5ab		310	2½"	Codell		D, S		
Weaver, B.	96-64-7aa		370		Codell		D, S	1957	
Barkley, E.	96-64-10c	1482	200	2"	Outwash	Sand	D, S		
Havranek, E.	96-64-12ba	1473	189	2"	Outwash	Sand	D, S		
Andersh, L.	96-64-12dd	1460	208	2"	Outwash	Sand	D, S		
Buus,	96-64-13bb	1567	250	2"	Codell?		D, S		
Kokesh,	96-64-15cd		205	2"	Outwash		D, S	1954	14
Barkley, E.	96-64-15ba	1468	215		Outwash		S	1954	
Lebeda	96-64-24cb		242	2"	Outwash			1944	

Appendix E - Irrigation and Domestic Well Records--Continued

Name	Location	Ground Elev.	Depth of Well (feet)	Dia.	Geologic Source	Character of Material	Use of Water	Date Drilled	Depth to Water
Davis, G.	96-64-35bb	1497	240		Outwash		D, S		
Hansen, L.	96-65-1bb	340	2''		Codell				
Stastany, J.	96-65-5c	1470	189		Outwash	Sand	S		
Svatos, E.	96-65-7dc		920		Dakota				30
Burger, J.	96-65-13a		500		Codell				
Cihak, A.	95-62-2dd		400?		Codell				
Kaberna,	95-62-5bb		82		Outwash	Sand	S		Flowing
Kaberna, F.	95-62-5bb		90		Outwash	Sand	D, S		Flowing
Kaberna, F.	95-62-6bb		225		Outwash	Sand	D, S	1946	
Kaberna, F.	95-62-7ab	1375			Outwash	Sand	S		Flowing
	95-62-17c		188		Outwash	Sand	S		Flowing
Cuka, M.	95-62-30c		298		Codell		D, S		
Hall, W.	95-63-6dd	1475	252		Outwash	Sand	D, S		90
Houska	95-63-22d		370		Codell		D, S		
Hron, J.	95-64-1d	1496	290	3''					
Mundt, E.	95-64-12a	1499	260		Outwash	Sand	D, S		
Schroeder, A.	95-64-12c	1472	365		Codell		D, S		
Hall, E.	95-64-14b		84		Outwash	Gravel	D, S	1930	12