# GEOHYDROLOGIC RECONNAISSANCE OF THE CROFTON UNIT, NORTHEASTERN NEBRASKA

U.S. GEOLOGICAL SURVEY

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16. Abstract (Limit: 200 words) This report describes sources, location, quantity, and quality of ground water in a 350-square-mile area whose potential for irrigation development is being evaluated by the U.S. Bureau of Reclamation.

The entire area is underlain by Precambrian Sioux Quartzite, which through most of the area is overlain by undifferentiated Paleozoic rocks. The Sioux and, where present, Paleozoic rocks are overlain unconformably by Cretaceous formations, including the Dakota and Niobrara Formations. Surface strata are Pleistocene and Holocene deposits of sand and gravel and Pleistocene glacial till.

The Dakota and Niobrara Formations are each capable of yielding water sufficient for irrigation wells in parts of the area. Pleistocene and Holocene deposits yield adequate water for irrigation in the southern part of the area and along the flood plain of the Missouri River.

Water from the Dakota Formation is so saline as to necessitate burdensome salinity-control measures for successful long-term irrigation use. Water from the Niobrara Formation is suitable for irrigation of most crops. Water from Pleistocene and Holocene deposits is highly variable, but is suitable for irrigation in the southern part of the area and along the Missouri River.

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By S. J. Kent, R. A. Engberg, and M. J. Ellis

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Lincoln, Nebraska

1981

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## FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) METRIC UNITS

The International System (SI) is a consistent system of metric units adopted by the Eleventh General Conference of Weights and Measures in 1960. Selected factors for converting inch-pound units used in this report to SI metric units are given below.

| Inch-pound units | Multiply by | To obtain SI units |
|---|---|---|
| inch (in) | 25.40 | millimeter |
| foot (ft) | 0.3048 | meter |
| foot per year (ft/yr) | 0.3048 | meter per year |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| acre | 0.4047 | hectare |
| gallon per minute (gal/min) | 0.06309 | liter per second |
| degree Fahrenheit (°F) | (°F -32)/1.8 | degree Celsius (°C) |

# GEOHYDROLOGIC RECONNAISSANCE OF THE CROFTON UNIT, NORTHEASTERN NEBRASKA

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## ABSTRACT

This report describes the results of a reconnaissance of the sources, location, quantity, and quality of ground water in the proposed irrigation project area called the "Crofton Unit," an area of approximately 350 square miles in northeastern Nebraska.

Precambrian Sioux Quartzite underlies the entire study area. Throughout most of the area, the Sioux is overlain by undifferentiated Paleozoic rocks. The Sioux and, where present, the Paleozoic rocks are overlain unconformably by Cretaceous formations, including both the Dakota and Niobrara Formations. Surface strata are Pleistocene and Holocene deposits of sand and gravel and Pleistocene deposits of glacial till.

The Dakota and Niobrara Formations are each capable of yielding sufficient water for irrigation in parts of the area. Pleistocene and Holocene deposits yield adequate water for irrigation in the southern part of the area where saturated thicknesses range from 25 to 176 feet and along the flood plain of the Missouri River where saturated thicknesses range from 40 to 101 feet. Reported yields of 13 Pleistocene irrigation wells sampled for water-quality analyses averaged 857 gallons per minute.

Water from wells developed in the Dakota Formation is a calcium sulfate type. Use of this water for successful long-term irrigation would necessitate burdensome salinity-control measures because of the salinity of the water. Water from wells developed in the Niobrara Formation is a calcium bicarbonate type and is suitable for irrigation of most crops. Water from wells developed in both Niobrara and Pleistocene deposits generally is a calcium sulfate type and may be used for irrigation of salt-tolerant crops with special measures for salinity control. The quality of water from Pleistocene and Holocene deposits is highly variable. In both the southern part of the area and along the Missouri River, water from these deposits is a calcium bicarbonate type and generally suitable for irrigation.

# INTRODUCTION

During the summer of 1978, the U.S. Geological Survey made a reconnaissance of the geology and ground-water resources of an area in northeastern Nebraska in the vicinity of Crofton. The purpose of the reconnaissance was to obtain information on the availability and quality of ground water that the U.S. Bureau of Reclamation could use in an appraisal of the potential for development of an irrigation project called the Crofton Unit. The reconnaissance included a literature search, a brief field examination of the area, and the collection of 41 water samples for chemical analyses. The reconnaissance was conducted as part of the program of the U.S. Department of the Interior for development of the Missouri River basin.

## Location and Extent of Area

The area comprising the Crofton Unit is in northeastern Nebraska and encompasses about one-half of Cedar County and a small part of northeastern Knox County (fig. 1). The area is about 350 $mi^2$, extending from about 8 mi south of Hartington north almost to the Missouri River, and from Crofton southeast nearly to the Cedar-Dixon County line. Included in the area is part of the Missouri River flood plain, most of the Bow Creek drainage basin, and the drainage basins of Antelope and Beaver Creeks.

## Previous Investigations

The earliest published information on ground-water resources for this area is in a report by Condra (1908) on the geology and water resources of a part of the Missouri River valley in northeastern Nebraska. Condra and Reed (1959) described the stratigraphy of the entire State, and Burchett (1978) prepared a bedrock map of Nebraska. Simpson (1960) studied the geology of the Yankton area of South Dakota and Nebraska, an area that includes the northern one-half of the Crofton Unit.

Water levels have been measured since 1934 in a few wells in the study area. Some wells were sampled for chemical analysis prior to 1978 by U.S. Geological Survey personnel.

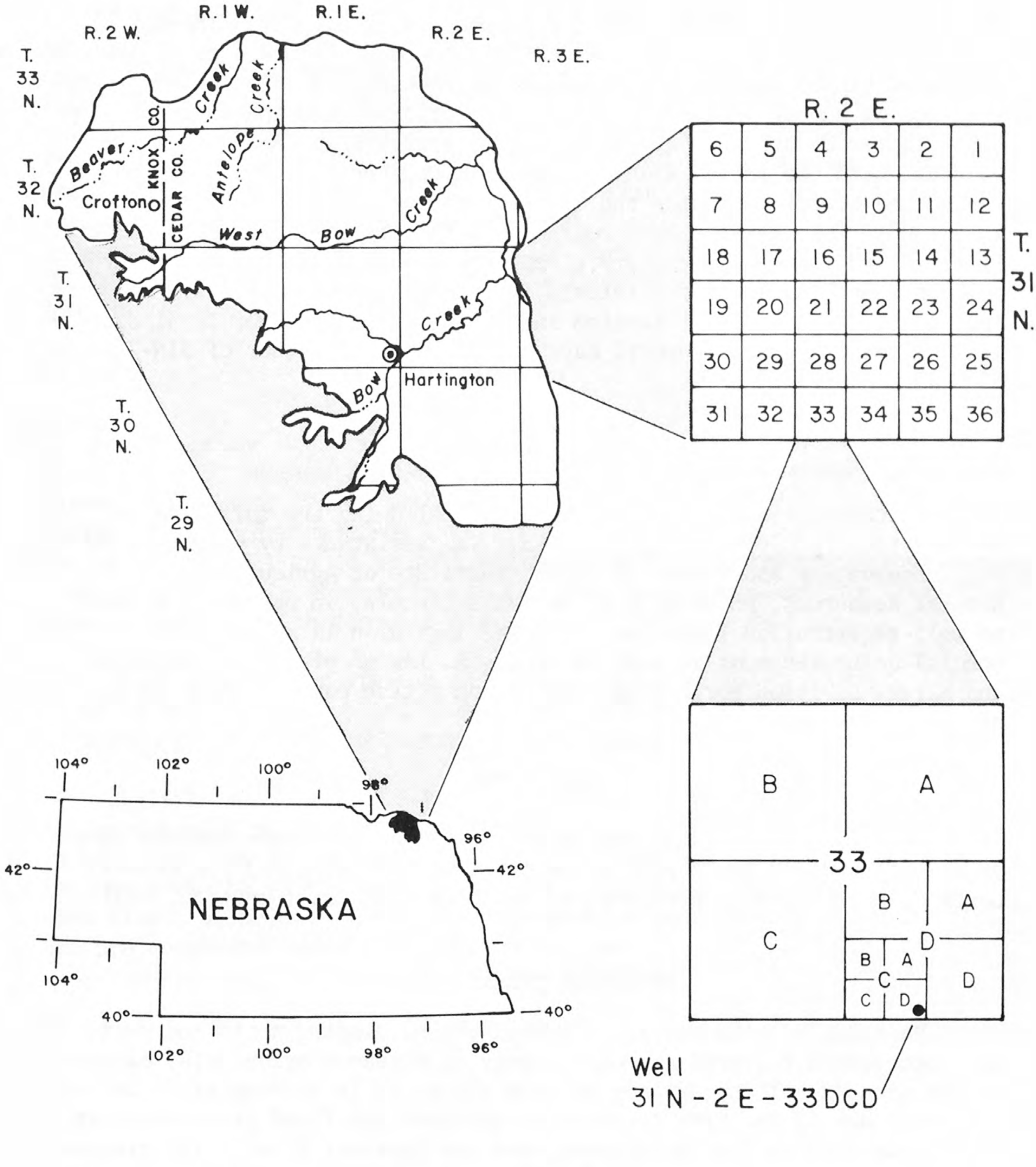



Figure 1.-- Location of Crofton Unit and example of the well-numbering system.

## Well-Numbering System

The well-numbering system, shown in figure 1, is based upon the well's location according to the land subdivisions surveyed by the U.S. Bureau of Land Management. The first numeral followed by N (north) indicates township, the second numeral followed by E (east) or W (west) indicates range, and the third numeral is the section. Letters following the section number indicate the well's location within the section. The first letter denotes the quarter section, starting in the northeast quadrant with the letter A and moving in a counter-clockwise direction. The second letter indicates the quarter-quarter section, also assigned in a counter-clockwise manner beginning with A in the northeast quarter. If third and fourth letters are given, the sequence is the same. Any numbers appearing after the letters indicate additional wells in the same tract. Thus, a well located in the SE¼SW¼SE¼ sec. 33, T. 31 N., R. 2 E., of Cedar County would have a well-location number of 31N-2E-33DCD.

## Acknowledgments

The cooperation of the well owners in allowing the collection of data on their property is appreciated. The assistance by personnel of the Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, in providing access to well-registration files and drillers' logs also is appreciated. Special acknowledgment is made to Dennis R. Lawton of the Conservation and Survey Division for his assistance and active participation in this study.

# GEOGRAPHY

The Crofton Unit is at the northern edge of the loess-covered part of Nebraska, along the border between the Great Plains and the Central Lowlands physiographic provinces of the United States (Fenneman, 1931).

## Topography and Drainage

The study area is mostly an eroded plain, sloping north and east; its topographic features are due largely to stream erosion. The majority of the area is rolling upland; in some places it is thoroughly dissected. The remainder of the area consists of terraces and flood plains of West Bow, Norwegian Bow, and Bow Creeks, and the Missouri River. The greatest relief can be found in an area 3 to 4 mi wide bordering the flood plain of the Missouri River.

## Climate

The subhumid climate of the study area is similar to that of other Plains regions, with a growing season lasting from May through September. The hottest month is usually July and the coldest month is January. Based on the normal monthly precipitation at Hartington, Nebr., June is the wettest month with 18 percent of the total annual precipitation (fig. 2). More than 65 percent of the total precipitation occurs during the growing season mainly as the result of local thunderstorms. Normal annual precipitation (1941-70) is 25.49 in (fig. 3) with an average for the past 86 years (1892-1977) of 26.20 in. During this period the largest amount of rainfall was 41.45 in. during 1915; the least was 14.31 in. during both 1955 and 1976 (National Oceanic and Atmospheric Administration, 1892-1977).

## Soils

Soils in the study area are predominantly of the Moody and Crofton series (Elder, 1969) with the exception of those along the Missouri River flood plain. Moody soils are silty clay loam or silty loam in texture and are derived from loess. They occur predominantly on uplands having slopes of 1 to 10 percent and are moderately permeable. They are neutral to slightly acid soils and are considered excellent for irrigation where they occur with adequate drainage and gentle slope.

Crofton soils are similar in texture to Moody soils; however, they occur on much steeper upland slopes than do Moody soils. Crofton soils on slopes greater than 10 percent are considered unsuitable for irrigation.

Soils in the Missouri River flood plain are developed from alluvium. The predominant soils series near the river is the Haynie series. Haynie soils are neutral silt loams and are excellent for irrigation. Farther from the river are soils of the Luton series that are derived from clayey alluvium. These have a clayey texture, minimal permeability, and are considered unsuitable for irrigation.

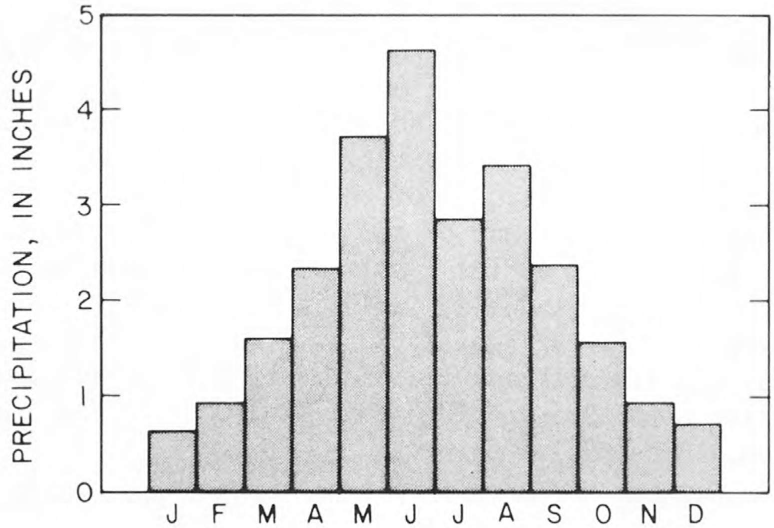



FIGURE 2.--NORMAL MONTHLY PRECIPITATION, HARTINGTON, NEBR., 1941-70.

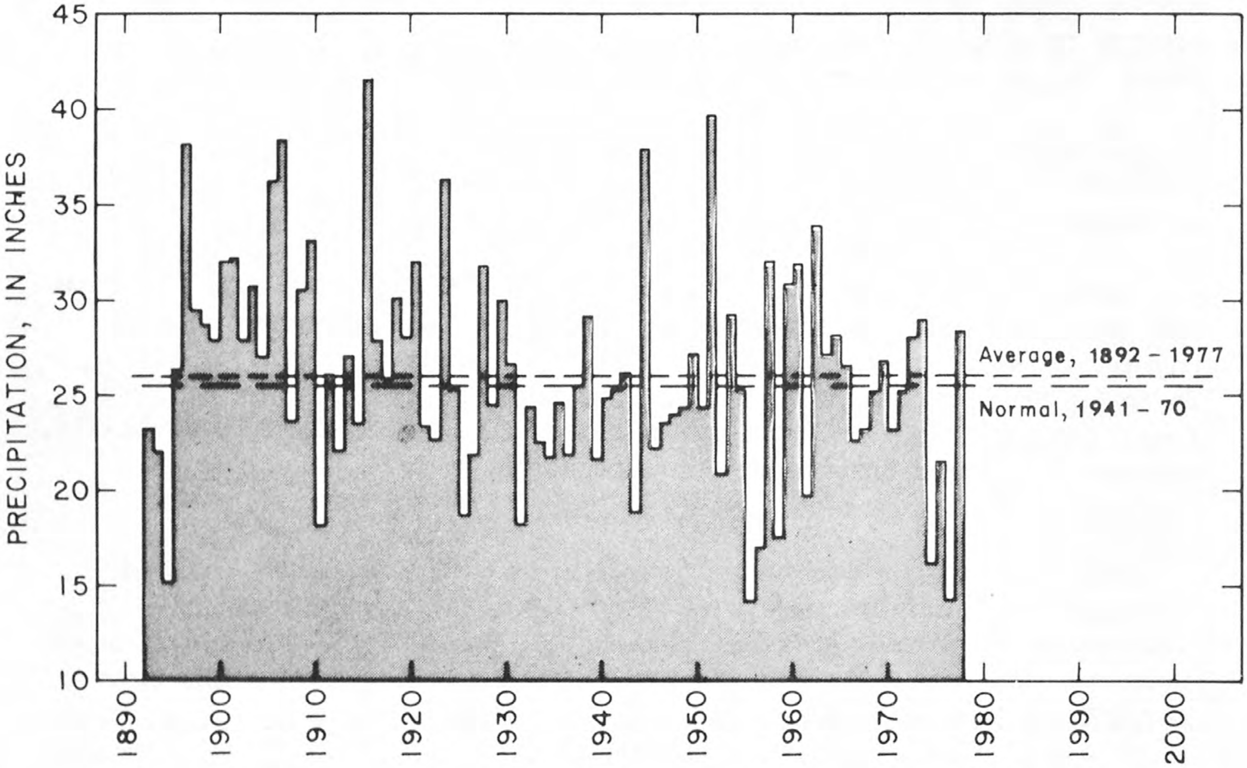



FIGURE 3.--AVERAGE ANNUAL PRECIPITATION, HARTINGTON, NEBR., 1892-1977.

## GEOLOGY AND OCCURRENCE OF GROUND WATER

### Stratigraphy

The entire study area is underlain at depths of from 800 to 1,000 ft by the Sioux Quartzite of Precambrian age. The Sioux Quartzite is a very hard, grayish-orange-pink orthoquartzite consisting of fine to coarse quartz sand with some unidentified silt- and clay-sized particles cemented by silica. The cement is faintly stained surficially by red ferruginous oxides (Simpson, 1960).

Throughout most of the study area, the Sioux Quartzite is overlain by Paleozoic rocks. Because of the lack of data, no attempt is made in this report, stratigraphically, to differentiate these rocks. Information in a report by Carlson (1970) indicates that these rocks are of Cambrian, Ordovician, and Devonian age. Most are limestones and dolomites, but thin sandstone and shale beds occur.

The Lower Cretaceous Dakota Formation, which is the oldest formation in the study area penetrated by water wells, unconformably overlies the Paleozoic rocks or the Sioux Quartzite where the Paleozoic rocks are absent. Upper Cretaceous formations in ascending order above the Dakota Formation are the Graneros Shale, Greenhorn Limestone, Carlile Shale, and the Niobrara Formation (see table 1). Two other formations, the Pierre Shale (Upper Cretaceous) and the Ogallala Formation (upper Tertiary) have thinned out or have been eroded away in part of the study area, being present in only about 50 percent of it. The Niobrara and Carlile crop out in the northern part of the study area.

The areal distribution of the bedrock formations directly beneath the Pleistocene or Holocene deposits is indicated in figure 4. Where Pleistocene or Holocene deposits are absent, the formations shown crop out.

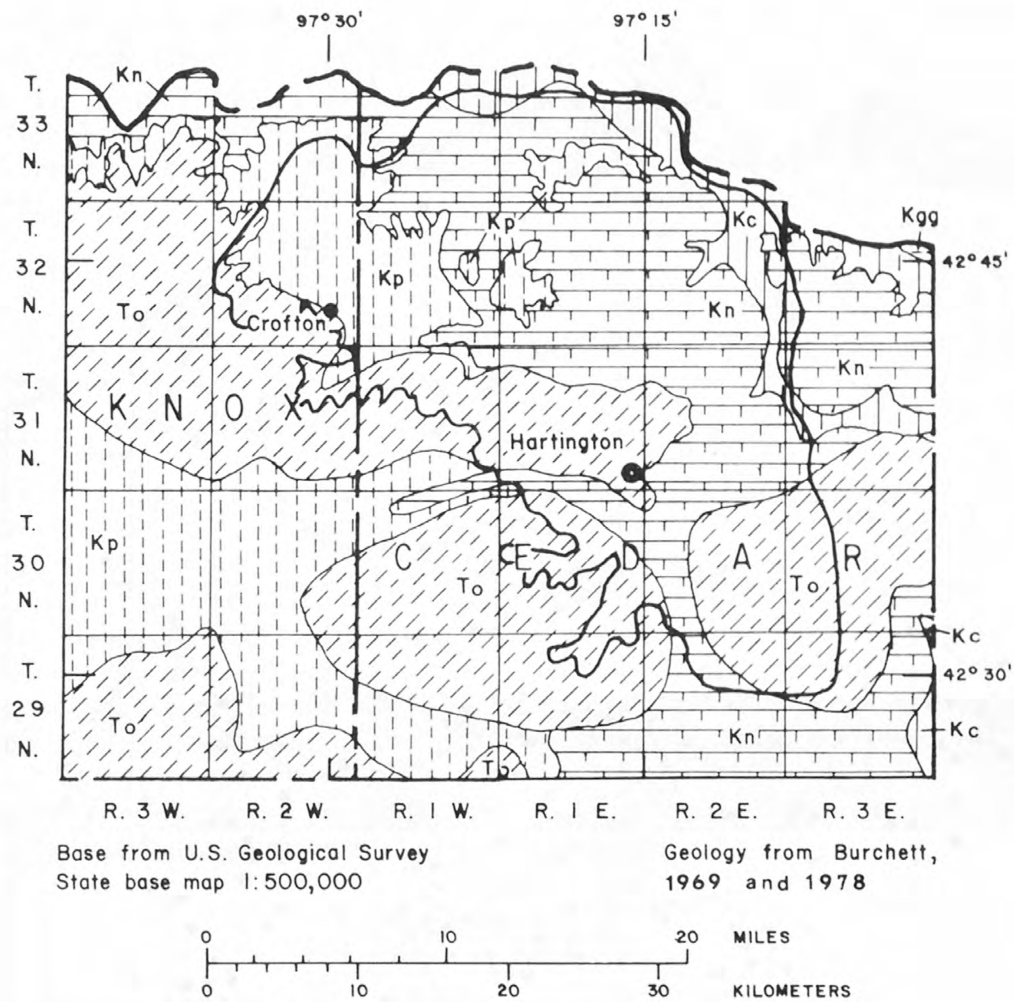
### Description of the Aquifers

The major aquifers supplying water in the area are the Dakota and Niobrara Formations of Cretaceous age, and sand and gravel deposits of Pleistocene age. Each of these aquifers is capable of yielding sufficient volumes of water for irrigation in places in the study area. Generally, yields of 500 gal/min or more are considered adequate even for flood irrigation. Some irrigation wells in the area are screened both in Niobrara Formation and Pleistocene deposits. These particular wells will be discussed separately in the water-quality section.

Approximately 150 irrigation wells were registered through December 31, 1978, for the Crofton Unit. Their location and the location of irrigation wells in the surrounding area are shown in figure 5.

Table 1.--Generalized section of geologic formations and their water-bearing properties
(Modified from Simpson, 1960)

| Erathem | System | Series | Formation | Lithology | Water Supply |
|---|---|---|---|---|---|
| Cenozoic | Quaternary | Holocene | | Alluvial deposits | Principal source of water supply to wells, reported yields range from 550 to 1,500 gal/min; also transmits water to recharge other aquifers. |
| | | Pleistocene | | Sand and gravel deposits interbedded with clayey till. | |
| | Tertiary | Miocene | Ogallala Formation | Sand, silty clay, interbedded with a little volcanic ash and orthoquartzite. | Not a known source of water supply; may yield water to some domestic wells. |
| Mesozoic | Cretaceous | Upper Cretaceous | Pierre Shale | Shale and claystone, interbedded with thin bentonite layers, marl and sand; fissile to thin bedded, soft, weak. | Not a source of water supply to wells. |
| | | | Niobrara Formation | Argillaceous limestone, chalky, medium bluish-gray weathering to dark yellowish-orange; soft, sub-firm, highly fractured in places. | Significant source of water supply to wells through secondary porosity. Reported yields range from 360 to 900 gal/min. |
| | | | Carlile Shale | Moderate gray calcareous shale, fissile, soft, weak; interbedded with clayey siltstone. | Not a source of water supply to wells. |
| | | | Greenhorn Limestone | Light to medium dark gray limestone, interbedded with argillaceous limestone, marl, calcareous shale, and two very thin layers of bentonite. | Do. |
| | | | Graneros Shale | Medium to dark gray shale, fissile, soft, weak; interbedded with thin layers of silt and sand in lower part. Few scattered thin layers of bento-nite material. | Do. |
| | | Lower Cretaceous | Dakota Formation | Sandstone, yellowish white in color, cemented in part by calcium carbonate interbedded with medium to dark gray claystone and shale; numerous thin layers of black carbonaceous material. | Significant source of water supply to domestic and stock wells. Irrigation wells possible. Potential yields may be as much as 600 gal/min. |
| Paleozoic, undiffer-entiated | | | | Predominantly limestones and dolomites, but some thin sandstone and shale beds. | Not used as a source of water in study area. |
| Precambrian | | | Sioux Quartzite | Orthoquartzite, grayish-orange pink, fine to coarse-grained. | Not a source of water supply to wells. |




## EXPLANATION

TERTIARY — Ogallala Formation — To

CRETACEOUS
- Pierre Shale — Kp
- Niobrara Formation — Kn
- Carlile Shale — Kc
- Greenhorn Limestone and Graneros Shale, undivided — Kgg

CONTACT

BOUNDARY OF CROFTON UNIT

FIGURE 4.--BEDROCK GEOLOGY OF CROFTON UNIT AND SURROUNDING AREA.

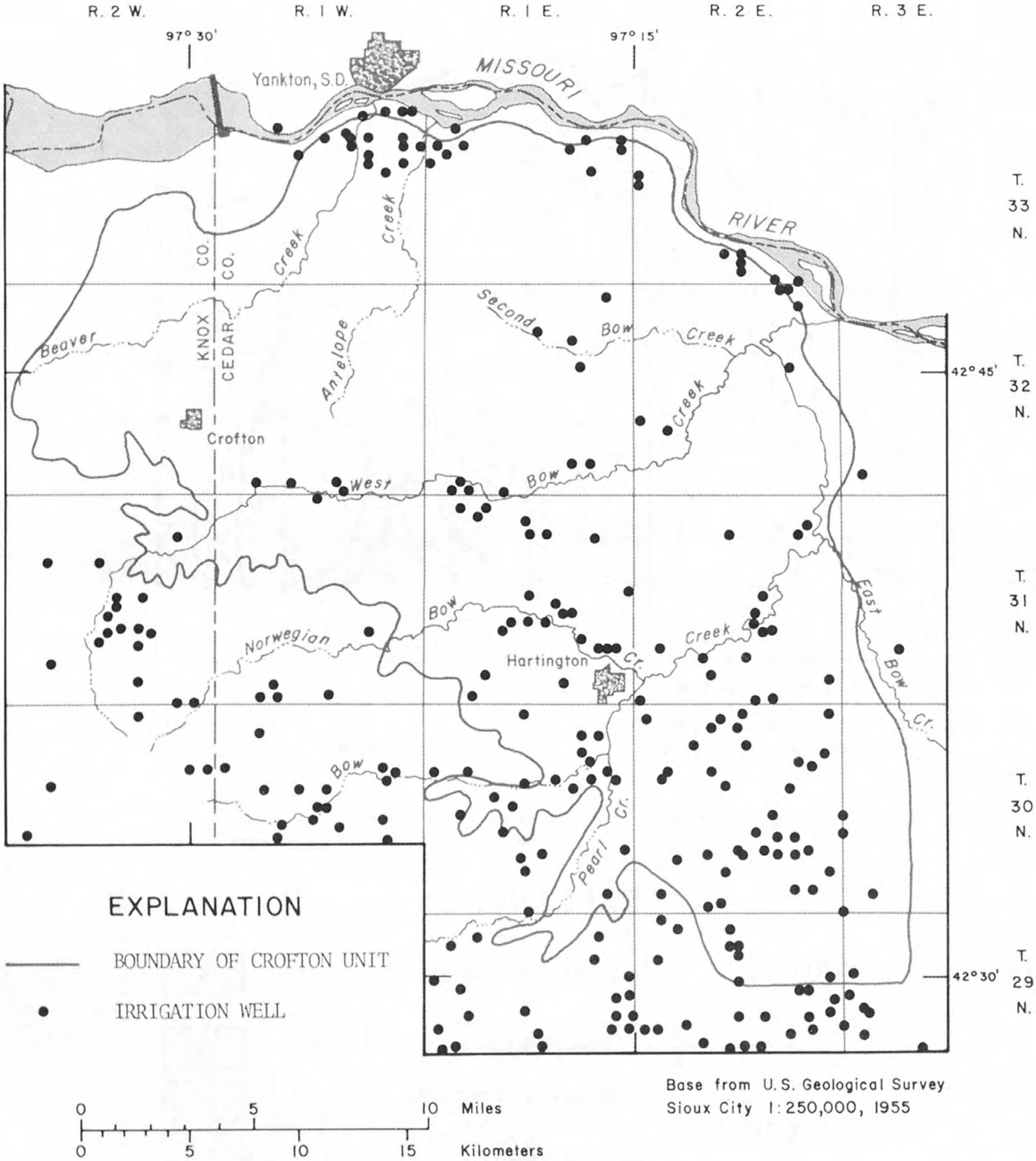



FIGURE 5.--LOCATION OF REGISTERED IRRIGATION WELLS IN THE CROFTON UNIT AND SURROUNDING AREA THROUGH DECEMBER 31, 1978.

## Dakota Formation

The Dakota Formation underlies the entire study area and ranges in thickness from 400 to 560 ft, according to unpublished test-hole data. The Dakota is comprised of a lower unit of fine- to coarse-grained, yellowish-white sandstone, a middle unit of gray claystone and shale, and an upper unit of yellowish-white sandstone interbedded with some gray shale.

The Dakota Formation has been developed only locally in the northern one-half of the study area, principally for domestic and stock use. Water is available from shallow overlying aquifers in the southern one-half of the study area, so wells there are commonly not drilled into the Dakota. The depth at which water from the Dakota Formation occurs in the study area generally makes this formation economically infeasible as a source of water for irrigation. Only one irrigation well in the study area is supplied by the Dakota Formation. This well, 31N-1E-13DDB, is 820 ft deep and yields 600 gal/min. The location of wells in the area developed in the Dakota Formation along with available data for 1978 regarding depth to water and water-level altitude are shown in figure 6. Depth to water, as used here, is the depth to water from the land surface. Water-level altitude is the altitude of the water table above the National Geodetic Vertical Datum of 1929, which is approximately sea level.

Water in the Dakota Formation is confined by the Graneros Shale. There are some flowing Dakota wells in the study area.

## Niobrara Formation

The Niobrara Formation underlies all the study area and crops out in the northern part of the area. According to unpublished test-hole data, the thickness of the formation ranges from 200 to 340 ft. The formation is a medium bluish-gray argillaceous limestone that weathers to a dark yellowish-orange.

The location of wells in the Crofton Unit believed to be producing mainly from the Niobrara Formation, depth to water in the wells, and water-level altitudes are shown in figure 7. Water levels have been recorded semiannually for 12 years in one observation well in this area (fig. 8). The water level in this well has been slowly declining since 1967 at a rate of approximately 0.25 ft/yr. Four more observation wells were established during 1975 and 1976; water levels for these wells are shown in table 2.

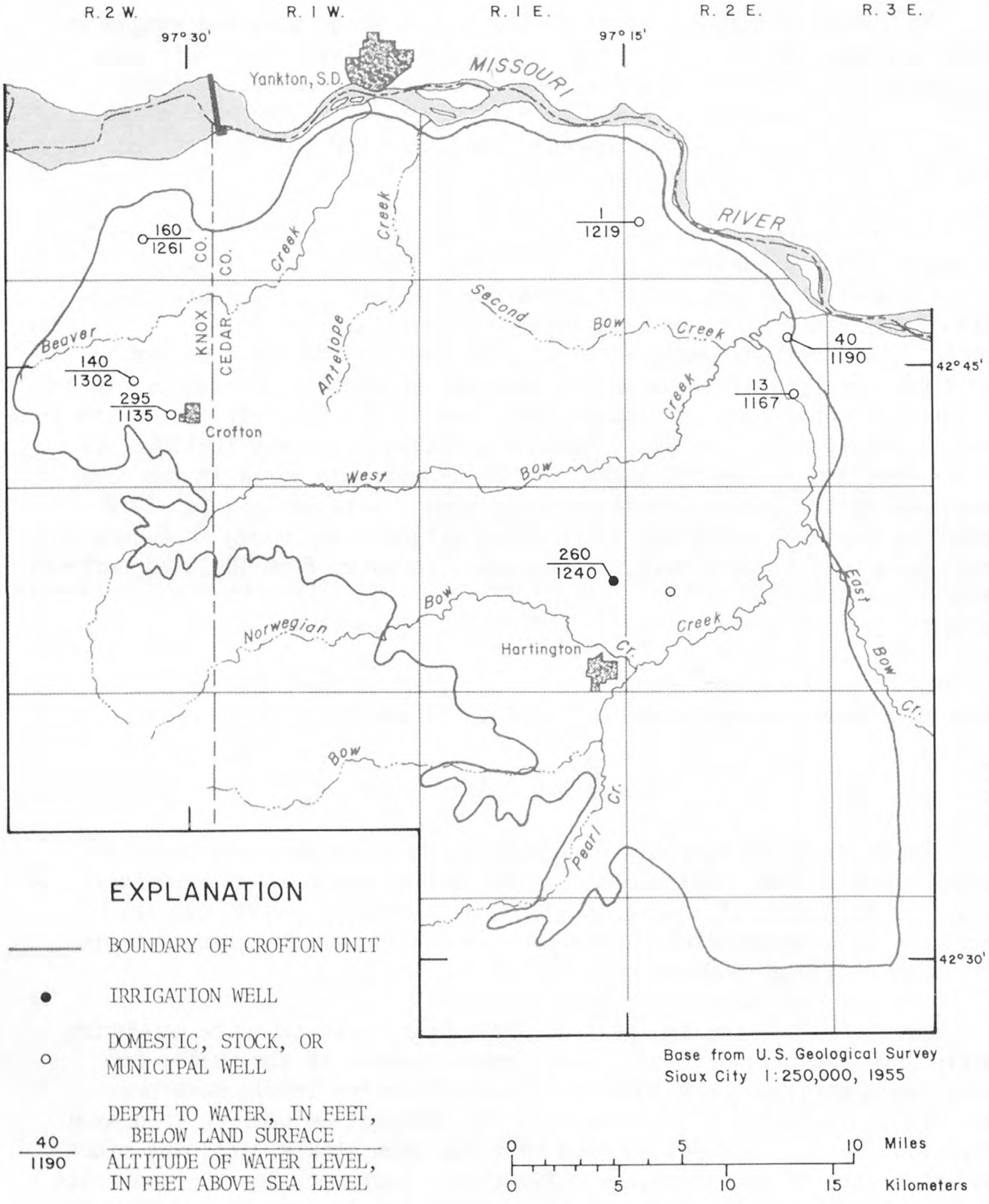



FIGURE 6.--DEPTH TO WATER AND ALTITUDE OF WATER LEVELS DURING 1978 IN WELLS DEVELOPED IN THE DAKOTA FORMATION.

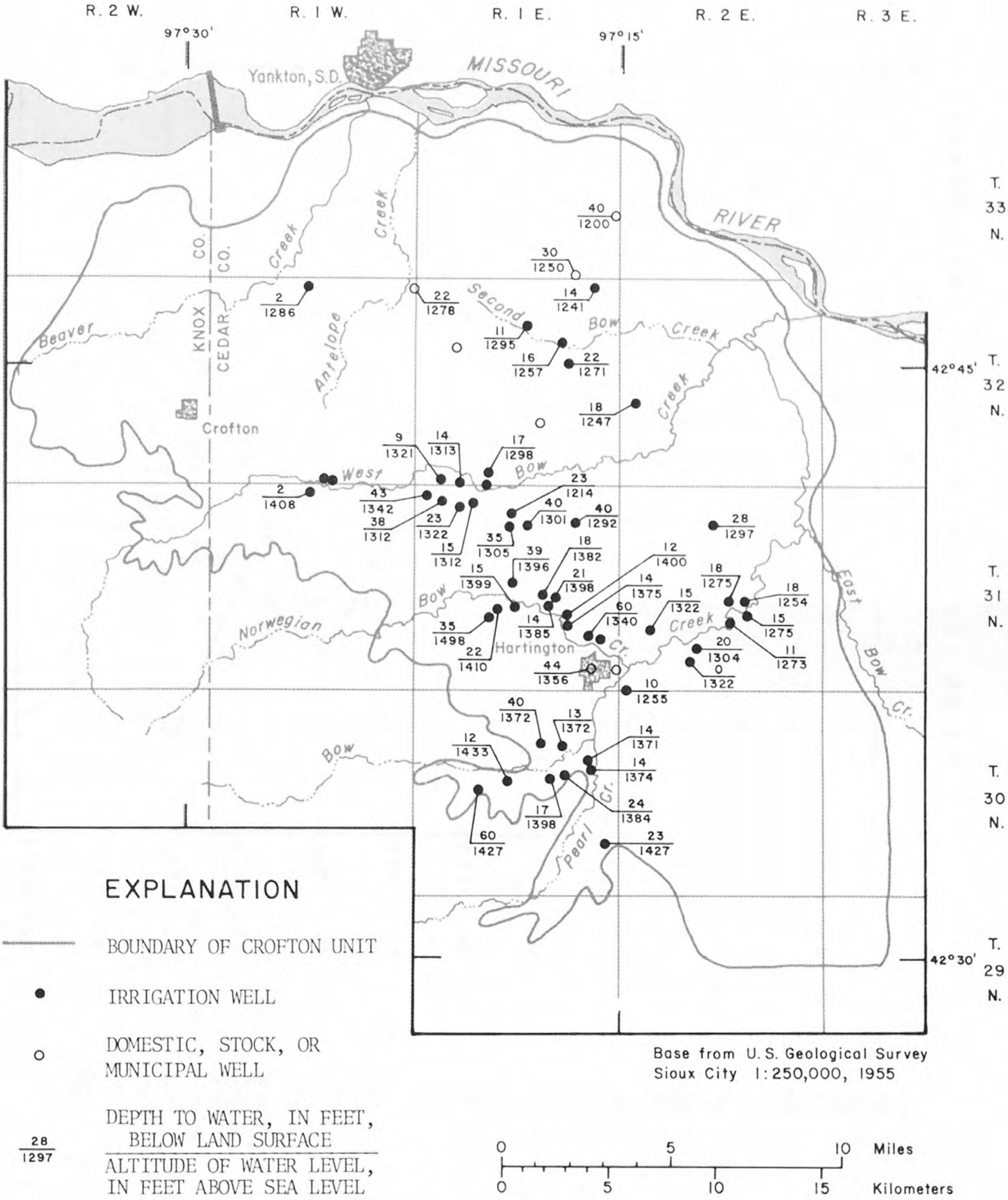



FIGURE 7.--DEPTH TO WATER AND ALTITUDE OF WATER LEVELS DURING 1978 IN WELLS DEVELOPED IN THE NIOBRARA FORMATION.

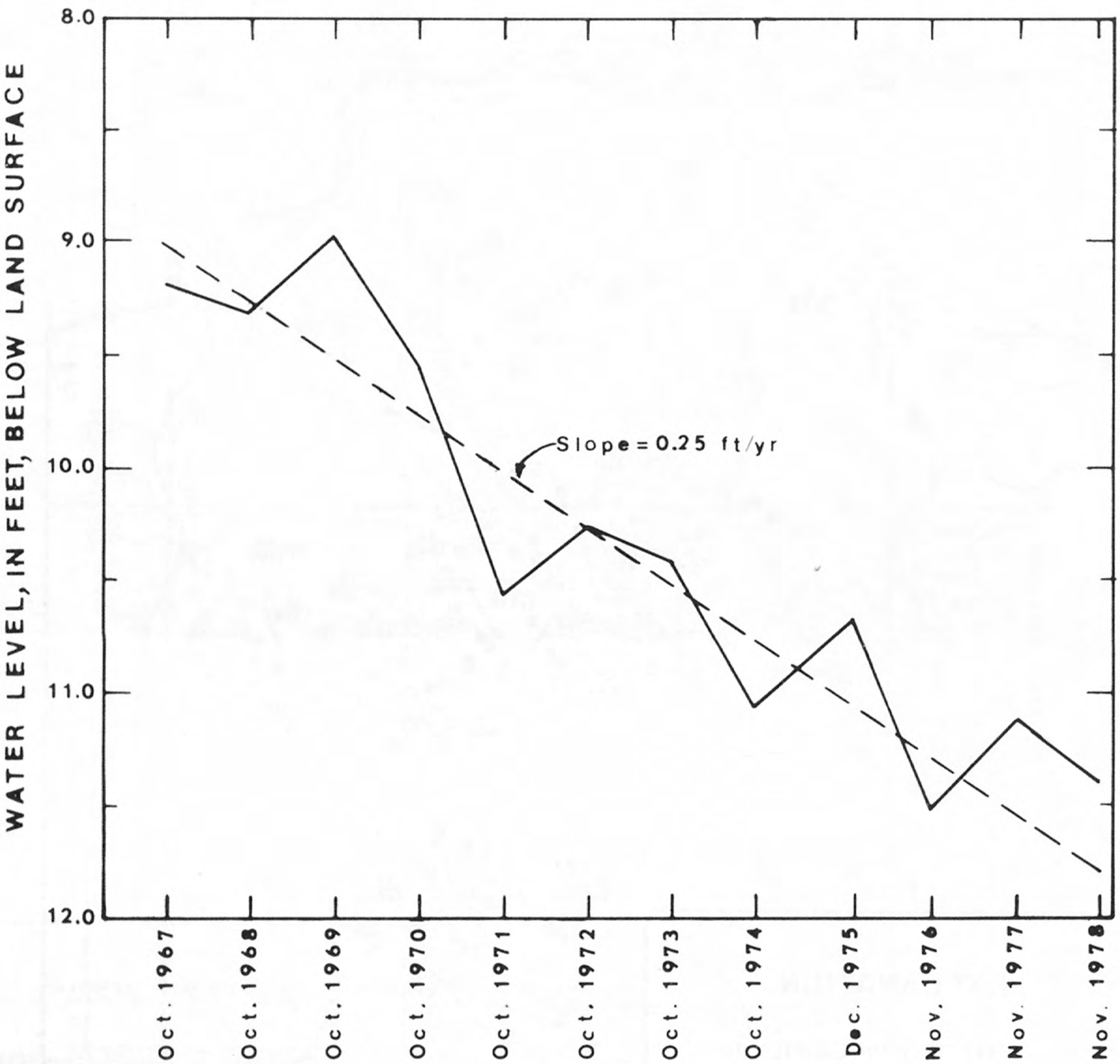



FIGURE 8.--WATER LEVELS IN WELL 31N-2E-31CC, 1967-78.

Table 2.--Water levels in observation wells developed in the Niobrara Formation 1975-78

| Well number | Land surface altitude (feet) | Well depth (feet) | Estimated pre-development depth to water (feet) | Depth to water below land surface (feet) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Fall 1975 | Spring 1976 | Fall 1976 | Spring 1977 | Fall 1977 | Spring 1978 | Fall 1978 |
| 30N-1E-11BD | 1,415 | 89 | 43 | ---- | 45.44 | 49.47 | 46.67 | 49.84 | 45.83 | 49.85 |
| 31N-1E-9AA | 1,340 | 104 | 40 | 48.16 | 42.01 | 56.81 | 50.44 | 55.10 | 41.87 | 45.97 |
| 31N-1E-16DD | 1,435 | 140 | 36 | 40.92 | 37.84 | 46.50 | 41.69 | 48.15 | 40.80 | 43.44 |
| 32N-1E-32CC | 1,325 | 104 | 13 | 16.99 | 14.84 | 18.62 | 16.12 | 17.17 | 15.23 | 16.01 |

The Niobrara Formation yields sufficient water for irrigation wells in the central part of the study area because solution openings and secondary fractures allow the limestone to store and transmit water. The reported yield for 9 irrigation wells ranged from 250 to 1,000 gal/min and averaged 620 gal/min.

Water in the Niobrara Formation locally is confined by either Pierre Shale or glacial till. Recharge to the Niobrara Formation is by percolation through overlying unconsolidated material. Where this material is thin or absent, some recharge probably occurs directly through fractures.

### Pleistocene and Holocene deposits

Pleistocene sand and gravel deposits in the Crofton Unit are widespread in the southern part of the area and underly the Holocene alluvium of the Missouri River flood plain, but are thin or absent in much of the northern part of the area. Holocene alluvial deposits are found along streams throughout the study area. Depth to water during 1978 in Pleistocene and Holocene deposits is shown in figure 9, and the configuration of the water table during 1978 is shown in figure 10. The saturated thickness of the aquifer during 1978 at sites of selected wells assumed to penetrate the entire thickness of the Pleistocene and Holocene deposits is shown in figure 11.

The greatest concentration of wells developed in Pleistocene and Holocene deposits is in that part of the study area south of Bow and Norwegian Bow Creeks. For example, 31 irrigation wells have been drilled in T. 30 N., R. 2 E. The water-level altitudes in these wells during 1978 ranged from 1,349 to 1,474 ft. Saturated thickness during 1978 ranged from 25 to 176 ft in this township and averaged 77 ft. North of Bow and Norwegian Bow Creeks, wells developed in Pleistocene and Holocene deposits are found only in Holocene deposits along small streams or in Pleistocene and Holocene deposits along the Missouri River.

The average water-level altitude during 1978 in the Pleistocene and Holocene wells along bottomlands of the Missouri River was approximately 1,150 ft above sea level. Saturated thickness during 1978 ranged from 34 to 101 ft, with a thickness between 60 and 70 ft most common.

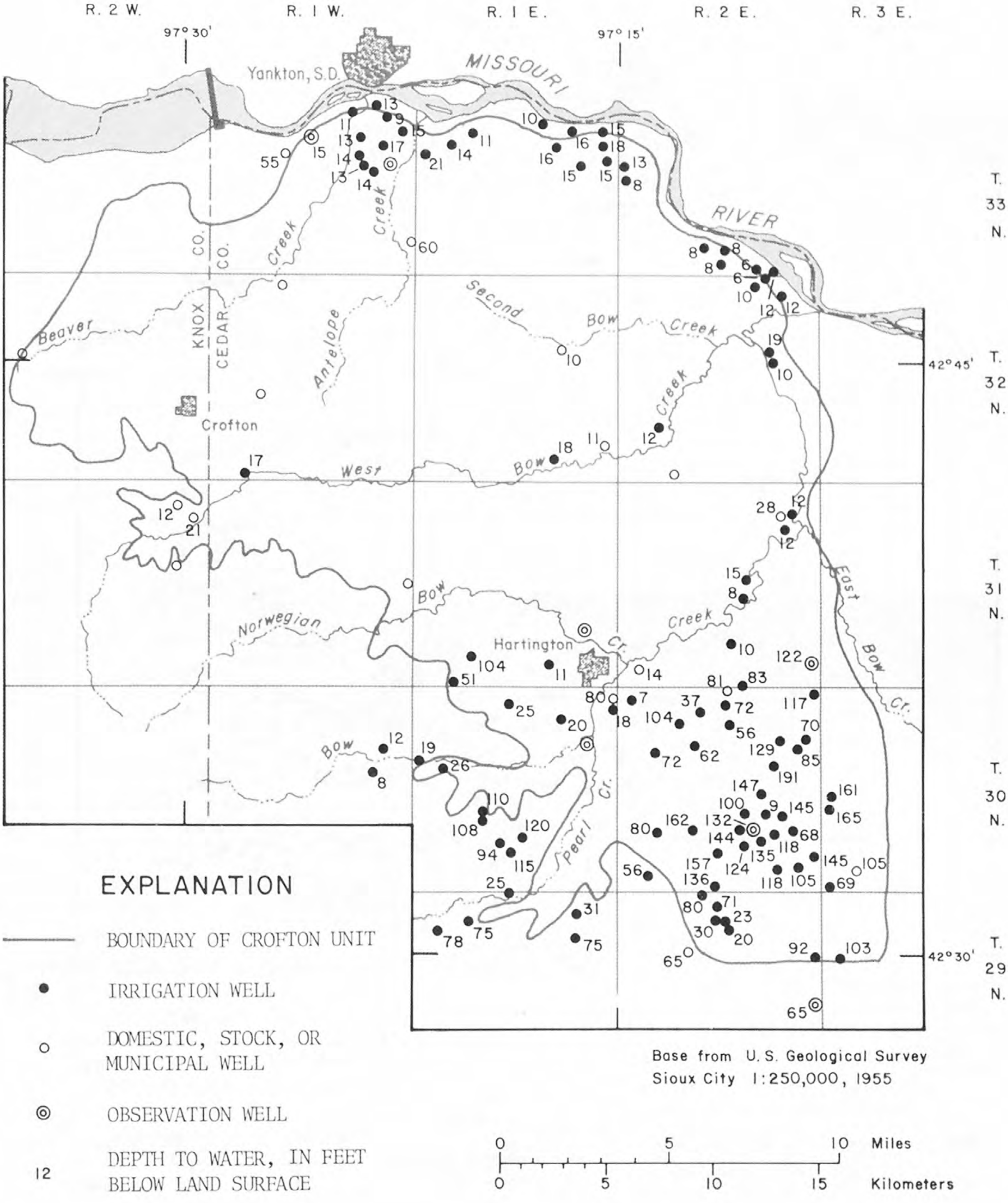



FIGURE 9.--DEPTH TO WATER DURING 1978 IN SELECTED WELLS DEVELOPED IN PLEISTOCENE AND HOLOCENE DEPOSITS, CROFTON UNIT AND SURROUNDING AREA.

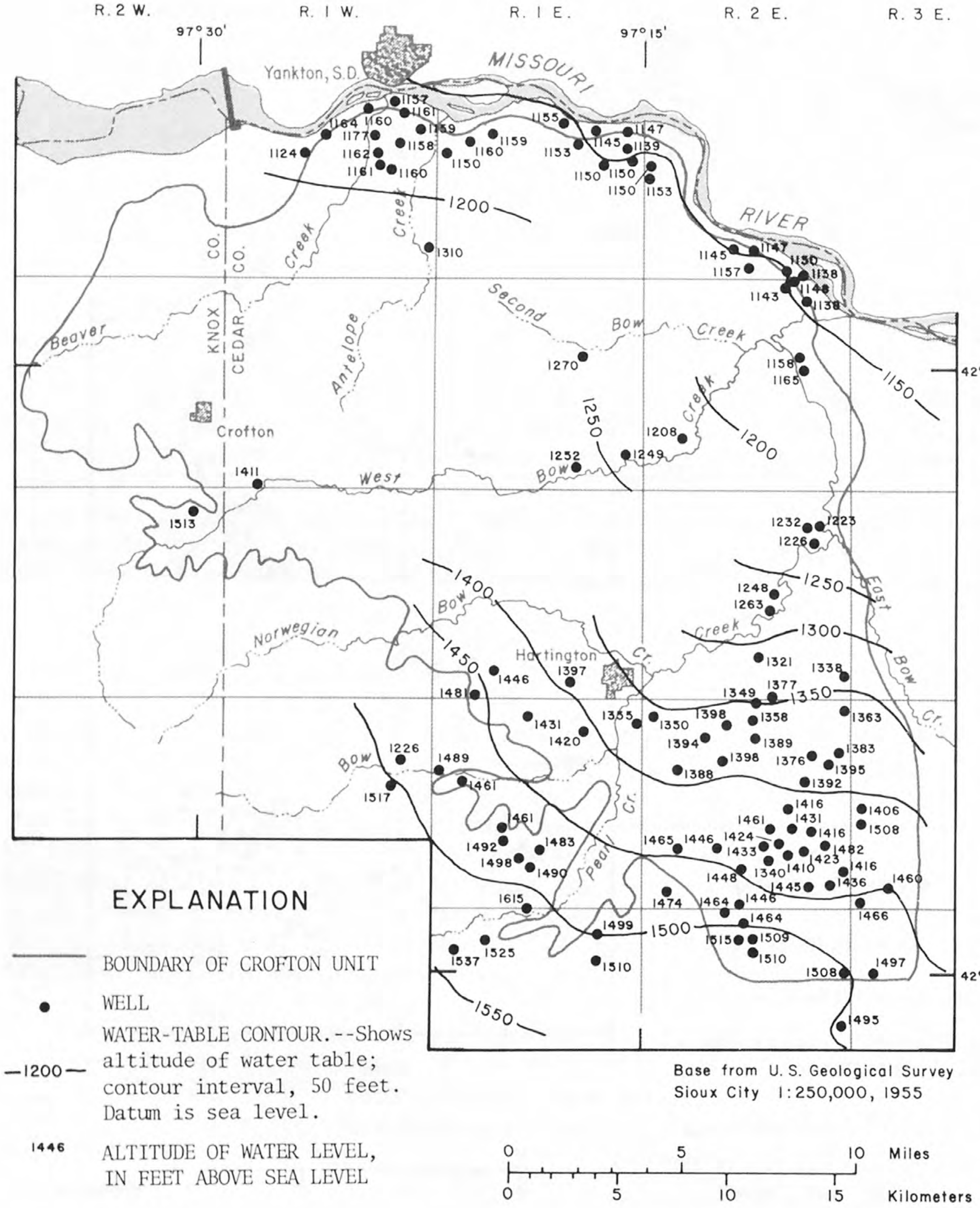



FIGURE 10.--CONFIGURATION OF THE WATER TABLE DURING 1978 IN PLEISTOCENE AND HOLOCENE DEPOSITS, CROFTON UNIT AND SURROUNDING AREA.

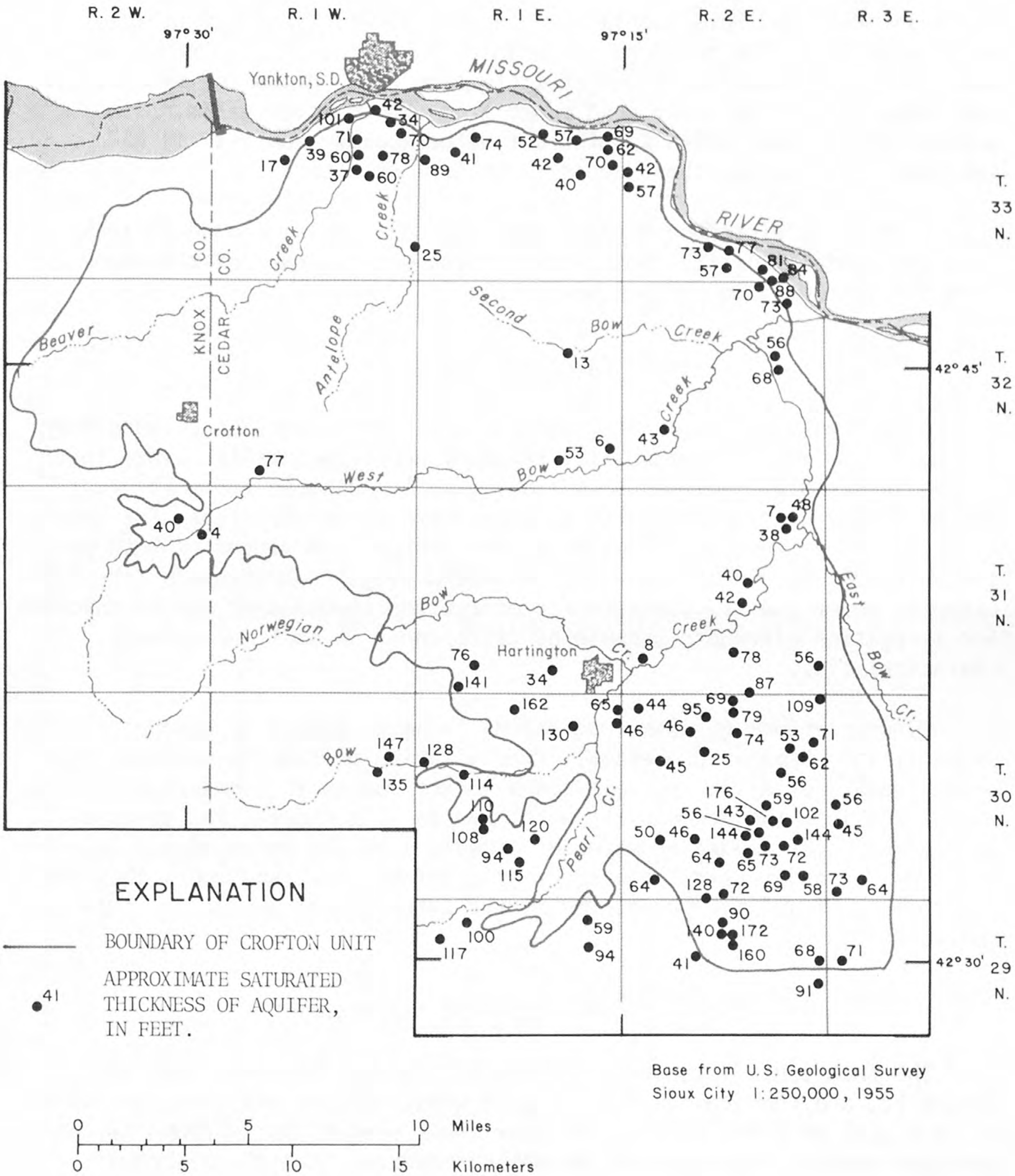



FIGURE 11.--APPROXIMATE SATURATED THICKNESS DURING 1978 OF PLEISTOCENE AND HOLOCENE DEPOSITS, CROFTON UNIT AND SURROUNDING AREA.

Water levels for 1975-78 in established observation wells developed in Pleistocene and Holocene sand and gravel are presented in table 3. Sufficient data have not been accumulated to determine any trends in the water levels. Reported yields of irrigation wells producing from Pleistocene deposits in the study area range from 550 to 1,500 gal/min; the average for 13 such wells sampled for water-quality analyses is 857 gal/min. Recharge of these deposits is from precipitation.

Water in Pleistocene deposits may be confined or perched by less permeable glacial drift. Some wells in the central part of the study area are developed in perched aquifers.

## WATER QUALITY

Dissolved chemical constituents in water are important because they determine the water's suitability for many uses. Generally, water that is low in dissolved solids is considered to be suitable for most uses; whereas, very mineralized water is considered to be unsuitable for many uses. However, this may be an arbitrary designation depending both on the intended use of the water and on geohydrologic conditions. For example, water that is suitable for irrigation in one area may be unsuitabl for irrigation elsewhere because of differences in soil and subsoil characteristics.

Concentrations of dissolved solids in water depend on several physical and chemical processes. Precipitation ordinarily contains only small amounts of dissolved solids and gases; but as it runs off or percolates into the ground, the water reacts with mineral and organic substances. The amount of material dissolved by the water depends upon the chemical and physical characteristics of the soil and rocks that the water contacts and the properties of the water itself during the time of contact.

### Chemical Composition of the Water

The locations of the 41 wells sampled during 1978 are shown in figure 12, and the chemical analyses of these samples are shown in table 4. For most of these wells, the water comes predominantly from only one geologic source. For some of the wells, however, both the Niobrara Formation and Pleistocene deposits contribute significant amounts of water.

Table 3.--Water levels in observation wells developed in Pleistocene deposits, 1975-78

| Well number | Land surface altitude (feet) | Well depth (feet) | Estimated pre-development depth to water (feet) | Depth to water below land surface (feet) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Fall 1975 | Spring 1976 | Fall 1976 | Spring 1977 | Fall 1977 | Spring 1978 | Fall 1978 |
| 29N-1E-19CD | 1,780 | 347 | 245 | ----- | 246.26 | 246.35 | 246.35 | 246.83 | 246.27 | 247.80 |
| 29N-2E-13AD | 1,560 | 156 | 63 | ----- | 64.00 | 65.85 | 63.65 | 65.57 | 62.79 | 65.58 |
| 30N-1E-21CB | 1,600 | 170 | 117 | ----- | ------ | ------ | ------ | 121.52 | 118.09 | ------ |
| 30N-2E-27AA | 1,555 | 188 | 128 | ----- | 129.18 | 131.00 | 129.97 | 130.99 | 130.25 | 132.17 |
| 31N-1E-25BC | 1,400 | 100 | 44 | 47.69 | 45.27 | 48.28 | 46.22 | 47.19 | 44.72 | 46.04 |
| 31N-2E-36A | 1,460 | 178 | 121 | ------ | ------ | 124.32 | 123.73 | 124.28 | 124.12 | 124.14 |
| 33N-1W-10CC | 1,180 | 54 | 15 | 17.77 | 16.55 | 16.72 | 18.37 | 17.80 | 18.44 | 15.44 |
| 33N-1W-13CA | 1,176 | 88 | 13 | 14.86 | 13.67 | 15.58 | 15.09 | 15.96 | 14.69 | 15.57 |

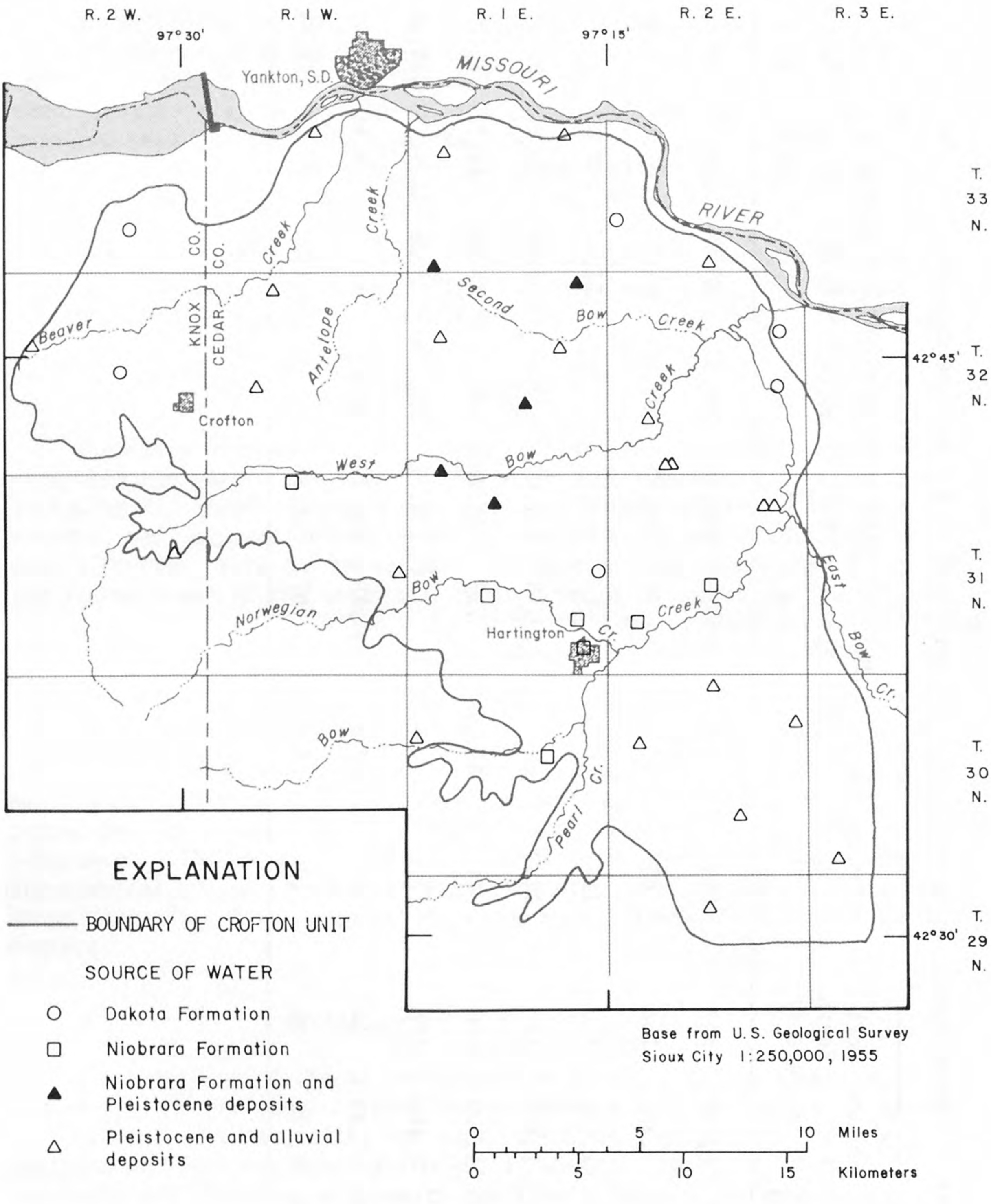



FIGURE 12.--LOCATION OF WELLS SAMPLED DURING 1978, CROFTON UNIT AND SURROUNDING AREA.

Table 4.--Chemical quality of ground water, 1978

[umhos = micromhos per centimeter at 25 degrees Celsius; mg/L - milligrams per liter; Mg/L = micrograms per liter]

| Well number | Date of sample | Total depth of well (feet) | Specific conductance (umhos) | pH (units) | Hardness (mg/L as $CaCO_3$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Sodium adsorption ratio | Potassium, dissolved (mg/L as K) | Bicarbonate (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, residue at 180° C., dissolved (mg/L) | Nitrogen, $NO_2$+$NO_3$, dissolved (mg/L as N) | Boron, dissolved (ug/L as B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water from the Dakota Formation | | | | | | | | | | | | | | | | |
| 31N-1E-13DDB1 | 78-08-09 | 820 | 1,760 | 7.3 | 770 | 240 | 41 | 130 | 2.0 | 24 | 266 | 750 | 58 | 1,330 | 0.06 | 410 |
| 32N-2E-12CBC1 | 78-08-22 | 520 | 1,610 | 7.3 | 770 | 240 | 42 | 51 | .8 | 18 | 83 | 730 | 55 | 1,320 | .01 | 110 |
| 32N-2E-24BC1 | 78-07-27 | 288 | 1,510 | 7.5 | 770 | 240 | 42 | 42 | .7 | 19 | 180 | 650 | 43 | 1,210 | .57 | 160 |
| 32N-2W-15DC1 | 78-08-09 | 746 | 1,560 | 7.4 | 820 | 260 | 41 | 59 | .9 | 17 | 211 | 690 | 54 | 1,230 | .01 | 140 |
| 33N-2E-30BD2 | 78-07-27 | 515 | 1,560 | 7.3 | 830 | 260 | 44 | 44 | .7 | 17 | 196 | 690 | 48 | 1,250 | .13 | 140 |
| 33N-2W-27DAC1 | 78-08-09 | 900 | 1,420 | 7.3 | 780 | 240 | 44 | 60 | .9 | 21 | 220 | 630 | 61 | 1,140 | .36 | 360 |
| Water from the Niobrara Formation | | | | | | | | | | | | | | | | |
| 30N-1E-14BCB1 | 78-08-02 | 105 | 644 | 7.3 | 330 | 93 | 23 | 18 | .4 | 8.3 | 378 | 57 | 4.5 | 359 | .29 | 80 |
| 31N-2E-22BCDD1 | 78-08-02 | 87 | 879 | 7.0 | 480 | 160 | 19 | 19 | .4 | 6.0 | 474 | 120 | 8.7 | 592 | .17 | 100 |
| 31N-2E-30ADA1 | 78-08-03 | 77 | 740 | 7.2 | 390 | 140 | 10 | 6.3 | .1 | 4.5 | 368 | 100 | 2.8 | 447 | .15 | 50 |
| 31N-1E-21CAA1 | 78-08-02 | 100 | 619 | 7.3 | 310 | 90 | 21 | 14 | .3 | 7.5 | 344 | 61 | 2.8 | 347 | .42 | 70 |
| 31N-1E-25BCB1 | 78-08-01 | 100 | 637 | 7.2 | 320 | 94 | 21 | 18 | .4 | 5.4 | 343 | 75 | 5.3 | 307 | .06 | 80 |
| 31N-1E-36BB1 | 78-07-26 | 84 | 739 | 7.5 | 350 | 100 | 25 | 21 | .5 | 7.5 | 345 | 92 | 20 | 470 | .20 | 60 |
| 31N-1W-4ABAD1 | 78-07-26 | 98 | 695 | 6.9 | 330 | 95 | 23 | 21 | .5 | 10 | 294 | 140 | 2.1 | 452 | .06 | 120 |
| Water from both the Niobrara Formation and Pleistocene deposits | | | | | | | | | | | | | | | | |
| 31N-1E-4DDB1 | 78-08-08 | 104 | 1,650 | 6.7 | 1,000 | 380 | 19 | 18 | .2 | 4.9 | 502 | 630 | 2.7 | 1,100 | .27 | 80 |
| 32N-1E-1BBD1 | 78-08-08 | 100 | 1,970 | 6.9 | 1,300 | 420 | 49 | 29 | .4 | 12 | 376 | 970 | 5.2 | 1,710 | .70 | 260 |
| 32N-1E-22DCCC1 | 78-07-27 | 100 | 2,040 | 6.6 | 1,300 | 480 | 26 | 28 | .3 | 10 | 642 | 810 | 6.2 | 1,760 | .11 | 190 |
| 32N-1E-32CCD1 | 78-08-07 | 105 | 1,310 | 7.0 | 590 | 190 | 29 | 22 | .4 | 9.5 | 445 | 270 | 5.0 | 640 | .25 | 120 |
| 33N-1E-30DDD1 | 78-08-09 | 85 | 1,840 | 6.8 | 1,100 | 370 | 42 | 29 | .4 | 12 | 520 | 680 | 26 | 1,270 | .85 | 180 |

Table 4.--Chemical quality of ground water, 1978--Continued

| Well number | Date of sample | Total depth of well (feet) | Specific conductance (umhos) | pH (units) | Hardness (mg/L as $CaCO_3$) | Calcium, dissolved (mg/L as Ca) | Magnesium, dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Sodium adsorption ratio | Potassium, dissolved (mg/L as K) | Bicarbonate (mg/L as $HCO_3$) | Sulfate, dissolved (mg/L as $SO_4$) | Chloride, dissolved (mg/L as Cl) | Solids, residue at 180° C., dissolved (mg/L) | Nitrogen, $NO_2$+$NO_3$, dissolved (mg/L as N) | Boron, dissolved (ug/L as B) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water from Pleistocene or Holocene deposits | | | | | | | | | | | | | | | | |
| 29N-2E-3CCCC1 | 78-07-26 | 195 | 755 | 7.2 | 380 | 110 | 26 | 18 | 0.4 | 6.0 | 351 | 110 | 4.8 | 486 | 5.4 | 60 |
| 30N-3E-31ADD1 | 78-08-07 | 169 | 979 | 7.3 | 340 | 96 | 24 | 26 | .6 | 4.8 | 220 | 41 | 2.2 | 529 | 49 | 80 |
| 30N-2E-3BBD1 | 78-08-22 | 150 | 589 | 7.3 | 280 | 81 | 18 | 15 | .4 | 6.0 | 261 | 75 | 2.4 | 393 | 5.9 | 40 |
| 30N-2E-8CCCD1 | 78-08-01 | 117 | 659 | 7.2 | 340 | 96 | 25 | 19 | .4 | 5.6 | 320 | 110 | 2.8 | 445 | 2.9 | 70 |
| 30N-2E-12ACC1 | 78-08-03 | 147 | 863 | 7.2 | 350 | 100 | 25 | 19 | .4 | 4.8 | 221 | 110 | 3.0 | 512 | 28 | 60 |
| 30N-2E-27AAA1 | 78-07-26 | 188 | 622 | 7.1 | 300 | 84 | 21 | 19 | .5 | 4.9 | 316 | 66 | 2.5 | 386 | 3.5 | 60 |
| 30N-1E-7CCD1 | 78-08-01 | 147 | 701 | 7.4 | 350 | 95 | 27 | 16 | .4 | 15 | 350 | 100 | 3.8 | 430 | 1.6 | 100 |
| 31N-2E-1CCC1 | 78-08-22 | 60 | 1,390 | 7.1 | 680 | 210 | 38 | 18 | .3 | 17 | 421 | 370 | 7.1 | 979 | .17 | 140 |
| 31N-2E-2DDC1 | 78-08-22 | 35 | 1,165 | 7.2 | 630 | 200 | 32 | 22 | .4 | 17 | 497 | 270 | 4.3 | 722 | 1.5 | 140 |
| 31N-1W-13DDD1 | 78-07-26 | 80 | 667 | 7.8 | 320 | 92 | 22 | 20 | .5 | 5.4 | 347 | 59 | 6.3 | 435 | 4.4 | 40 |
| 31N-2W-13BCB1 | 78-08-09 | 120 | 1,190 | 7.0 | 610 | 170 | 46 | 38 | .7 | 10 | 419 | 330 | 7.3 | 880 | 3.2 | 90 |
| 32N-2E-29BDB1 | 78-08-08 | 55 | 1,650 | 6.8 | 1,000 | 360 | 27 | 24 | .3 | 8.1 | 421 | 670 | 15 | 1,230 | 2.3 | 130 |
| 32N-2E-32DAC1 | 78-08-01 | 65 | 1,910 | 6.7 | 1,200 | 380 | 67 | 26 | .3 | 33 | 704 | 710 | 4.3 | 1,440 | .13 | 680 |
| 32N-2E-32DAC2 | 78-08-01 | 100 | 2,620 | 6.7 | 1,700 | 560 | 70 | 37 | .4 | 17 | 627 | 1,100 | 67 | 2,370 | 9.4 | 300 |
| 32N-1E-8CCD1 | 78-08-08 | 100 | 509 | 7.3 | 250 | 78 | 13 | 12 | .3 | 2.1 | 262 | 24 | 2.7 | 314 | 9.3 | 20 |
| 32N-1E-14BAB1 | 78-08-22 | 23 | 1,070 | 7.2 | 580 | 200 | 20 | 17 | .3 | 7.8 | 314 | 310 | 14 | 792 | 7.9 | 60 |
| 32N-1W-4BCC1 | 78-08-23 | 35 | 1,470 | 6.7 | 800 | 290 | 18 | 17 | .3 | 9.8 | 456 | 450 | 3.1 | 986 | .08 | 190 |
| 32N-1W-20ACBB1 | 78-07-26 | 22 | 894 | 7.4 | 400 | 120 | 25 | 23 | .5 | 4.6 | 244 | 41 | 26 | 705 | 50 | 30 |
| 32N-2W-18ACA1 | 78-08-09 | 65 | 970 | 7.1 | 520 | 89 | 72 | 38 | .7 | 9.8 | 437 | 120 | 34 | 645 | 23 | 110 |
| 33N-2E-34CBC1 | 78-08-08 | 65 | 1,220 | 7.3 | 660 | 170 | 56 | 72 | 1.2 | 9.4 | 508 | 370 | 10 | 777 | 2.1 | 170 |
| 33N-1E-11DCA1 | 78-08-08 | 73 | 1,358 | 7.4 | 630 | 170 | 49 | 83 | 1.4 | 12 | 532 | 340 | 12 | 901 | 4.1 | 190 |
| 33N-1E-17BBD1 | 78-07-27 | 55 | 1,170 | 7.3 | 610 | 180 | 39 | 23 | .4 | 8.3 | 465 | 270 | 5.6 | 782 | .09 | 120 |
| 33N-1W-10CCB1 | 78-08-09 | 54 | 1,146 | 7.1 | 630 | 200 | 32 | 27 | .5 | 9.0 | 444 | 310 | 4.0 | 720 | 2.5 | 110 |

One of several ways of schematically expressing water quality is by use of pattern diagrams. Such diagrams are useful in showing, by similarities or differences in shape and in area enclosed, similarities or differences in chemical characteristics of water from different sources. Diagrams representative of several types of water found in the study area are shown in figure 13.

In constructing the diagrams in figure 13, concentrations of major chemical constituents, in milligrams per liter, such as given in table 4, are converted to concentrations in milliequivalents per liter. Concentrations of major cations for a given sample are plotted to the left of the vertical axis of the diagram, and major anions are plotted to the right. Diagrams for water samples whose ratios of major ions are nearly the same are similar in shape. The larger the area within the diagram, the greater the dissolved-solids concentration of the water. Individual diagrams are discussed later in relation to geologic source.

## Suitability of the Water for Irrigation

Classification of the water for irrigation as indicated by the electrical conductivity or specific conductance, in micromhos per centimeter (umhos/cm) at 25 degrees Celcius, and by the sodium-adsorption ratio (SAR) of the water is shown in figure 14. Specific conductance and SAR values for water from all 41 wells sampled during 1978 in the study area plot within the shaded area of the diagram.

Conductivity is related to the dissolved-solids concentration of water and can be used to indicate the salinity hazard involved in the use of the water. Water having a conductivity of less than 750 umhos/cm has a low to medium salinity hazard and is classified as C1 or C2 in figure 14. With adequate drainage, this type of water is suitable for irrigating most crops without special practices for salinity control. A conductivity of 750 to 2,250 umhos/cm indicates a high salinity hazard (C3); water with such conductivity adversely affects both soils and crops where drainage is restricted. Where drainage is good and salt-tolerant crops (table 5) are grown, use of such water is satisfactory, although some special management practices for salinity control, including proper drainage and leaching, may be necessary. Conductivities greater than 2,250 umhos/cm indicate water with a very high salinity hazard (C4). Such water is unsuitable for continued irrigation under ordinary conditions. However, under special circumstances of very permeable soil, good drainage, and very salt-tolerant crops, such water may be used satisfactorily if applied in excess to prevent salt buildup in the soil.

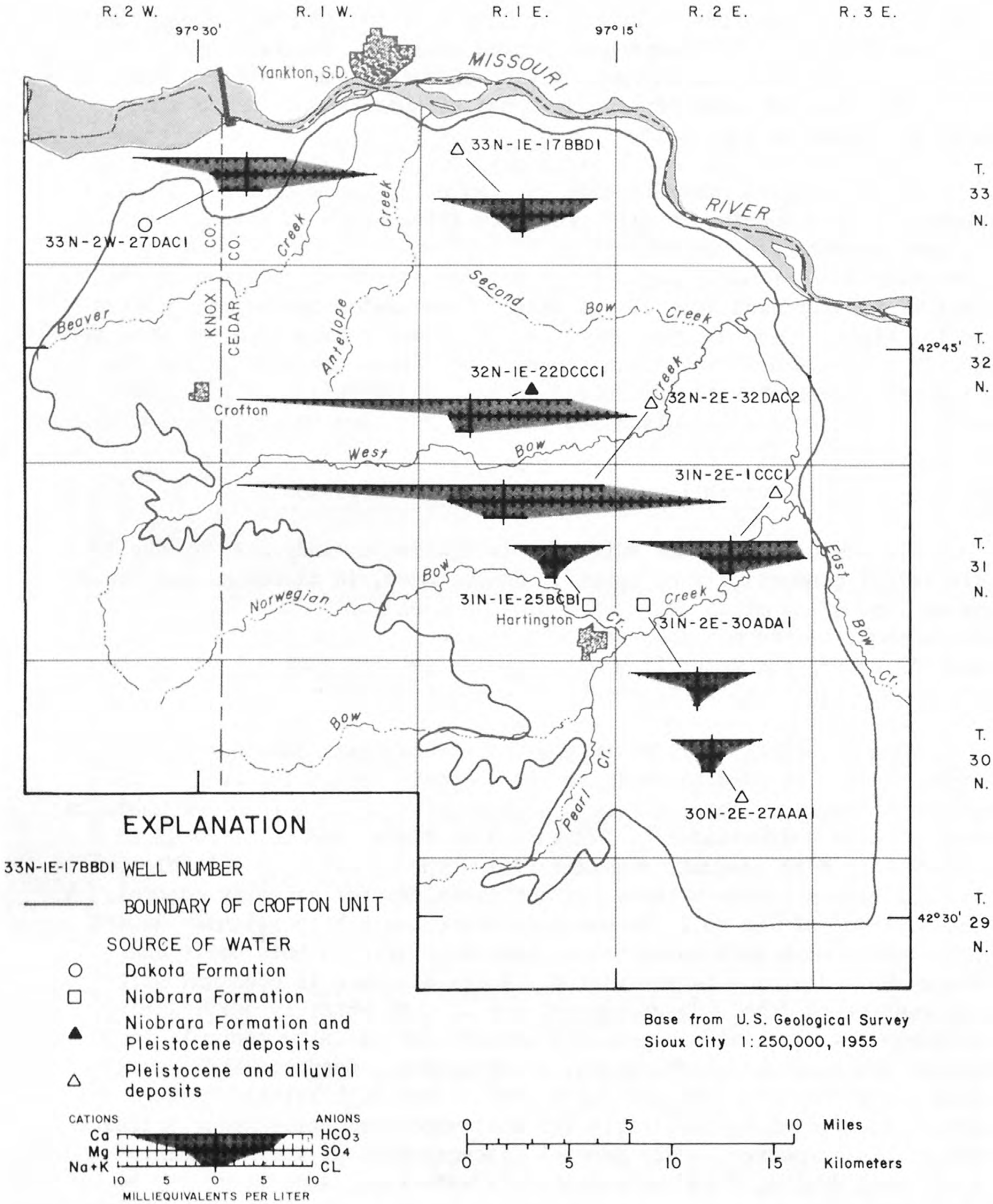



FIGURE 13.--DIAGRAMS REPRESENTING QUALITY OF WATER FROM DIFFERENT GEOLOGIC SOURCES.

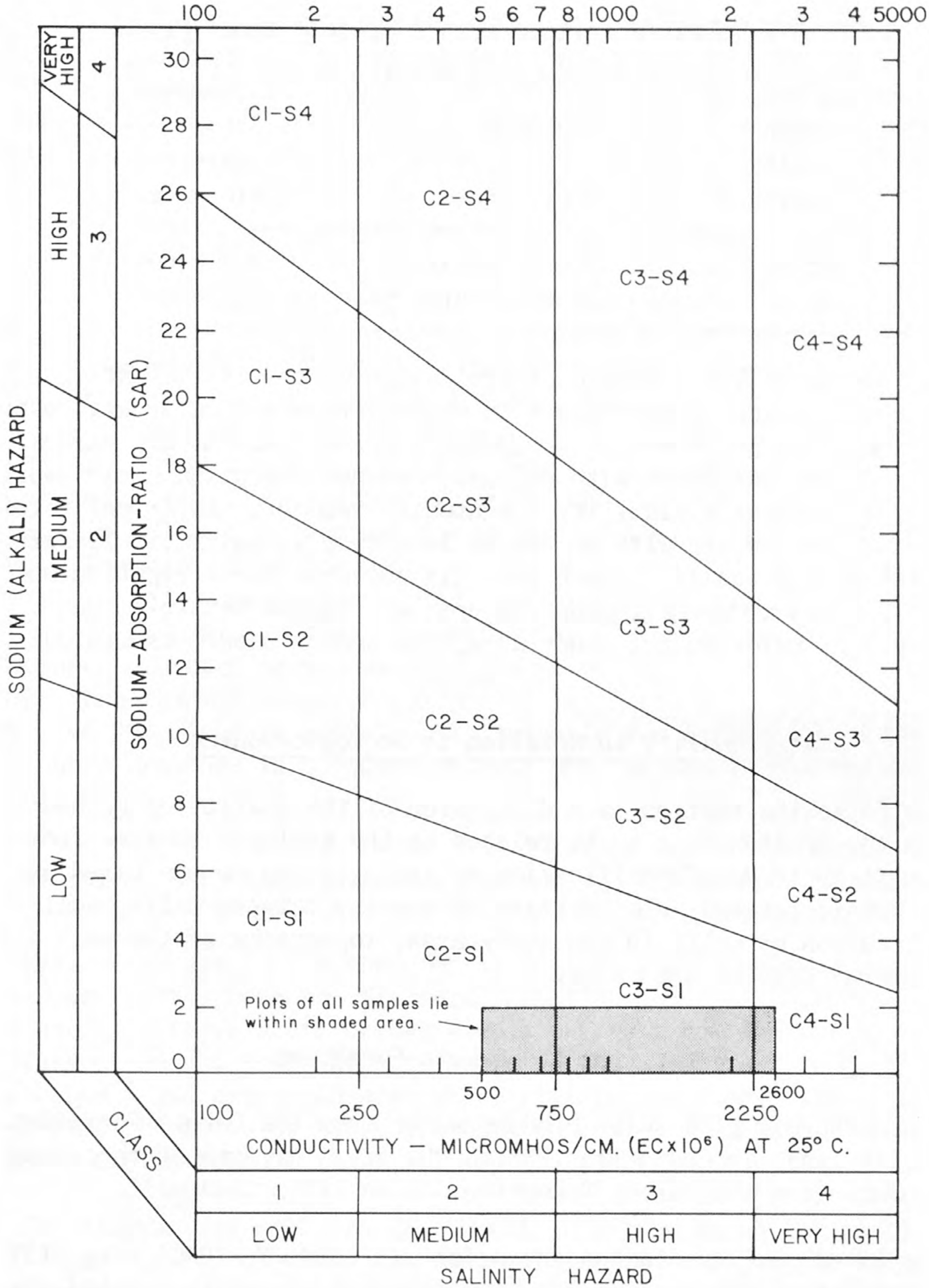



FIGURE 14.--CLASSIFICATION OF GROUND WATER FOR IRRIGATION (DIAGRAM FROM RICHARDS, 1954).

Table 5.--Relative salt-tolerance of some crops grown in the Crofton Unit

| High salt-tolerance | Medium salt-tolerance | Low salt-tolerance |
|---|---|---|
| Barley | corn, alfalfa, wheat, oats, milo | soy beans |

The sodium (alkali) hazard of irrigation waters is indicated by the SAR. The SAR indicates the extent to which irrigation water will enter into cation exchange, that is, replacing adsorbed calcium and magnesium on soil and clay particles with sodium. Sodium adsorption causes soil swelling and reduces tillability, eventually rendering soils unfit for crop production. Water with an SAR of less than 10 units is classified as S1 (low sodium hazard). Such water is suitable for irrigation on almost all soils and of all crops except very sodium-sensitive ones. For all ground water in the study area, the sodium hazard is minimal (fig. 14).

## Water Quality in Relation to Geologic Source

The following section is a discussion of the quality of ground water in the Crofton Unit as it relates to the geologic sources from which it is derived. Classification by geologic source was based on several considerations--similarities of quality between wells, well depth, location of wells in the study area, topography of the well site, and drillers' logs of the wells.

### Water from the Dakota Formation

Six of the sampled wells produce water from the Dakota Formation. These wells range in depth from 288 to 900 ft. Only one of those sampled that produce from the Dakota Formation was an irrigation well.

The water-quality diagram shown for well 33N-2W-27DAC1 (fig. 13) is representative of the quality of water from all six wells sampled that produce from the Dakota Formation. The water is a calcium sulfate type and has a classification for irrigation of C3-S1, or high salinity and low sodium. Water from the Dakota Formation probably never will be used extensively for irrigation because its high salinity will necessitate burdensome salinity-control measures for successful continued long-term use. Only the most salt-tolerant crops could be grown and even then use of the water would require good drainage and rapid application rates. The Dakota Formation will continue to be an acceptable source for domestic and stock supplies where sufficient water supplies of adequate quality do not exist at shallower depths.

## Water from the Niobrara Formation

With a few exceptions, concentrations of chemical constituents in samples of water from seven wells producing from the Niobrara Formation are relatively uniform (table 4). The water is a calcium bicarbonate type. Nitrite and nitrate nitrogen, as N, averaged 0.19 mg/L (milligrams per liter), indicating that very little nitrogen, such as in fertilizer or septic-system effluent, has moved from surface sources into the aquifer. Two diagrams represent the quality of water from the Niobrara in figure 13; they are for wells 31N-1E-25BCB1 and 31N-2E-30ADA1. The water from all wells is classified as C2-S1 (medium-salinity hazard - low-sodium hazard) for irrigation, except that from well 31N-2E-22BCDD1, which is classified as C3-S1. However, the specific conductance of water from that well was 879 umhos/cm, only slightly greater than the 750 umhos/cm maximum for a C2 classification. Accordingly, water from the Niobrara Formation is suitable for irrigation of most crops where drainage is adequate without special management for salinity control.

## Water from both the Niobrara Formation and Pleistocene Deposits

Five wells sampled in the central part of the study area probably produce water from both the Niobrara Formation and Pleistocene deposits. Three are in valleys along creeks (two along West Bow and one along a tributary of Second Bow) where recharge to the Niobrara through alluvium is probable. Two are in an area where Pleistocene deposits are thick enough that the wells probably are open to inflow from both Pleistocene deposits (at the base of the till) and the Niobrara.

The diagram for well 32N-1E-22DCCC1 in figure 13 is representative of all five samples of water produced partly from each of the two aquifers. The water is a calcium sulfate type and has a relatively large concentration of dissolved solids as compared to water from the Niobrara Formation alone. Water from all of the five wells is classified for irrigation as C3-S1 (high-salinity hazard - low-sodium hazard). While use of this water for irrigation is not likely to cause alkali problems, salinity problems could result unless the fields to which the water is applied are well drained and salt-tolerant crops are grown.

## Water from Pleistocene or Holocene Deposits

The quality of water from Pleistocene or Holocene deposits is highly variable. This variableness is accounted for in large part by the stratigraphic position of the sand and gravel beds that supply water to the wells and by the amount of circulation of flow through the beds. If the position of the beds is such that recharge to them is mostly through till, commonly rich in soluble materials, the water is likely to have relatively large concentrations of dissolved solids, whose chemical composition varies with the chemical composition of the till. Conversely, absence of overlying till and direct recharge by precipitation or stream seepage results in water likely to have relatively small concentrations of dissolved solids. Even if overlying till is absent, however, if the circulation of flow through the beds is very slight, leaching of such salts as do enter the beds may be almost nil, so that concentrations of dissolved solids may be large. The variableness in water quality, therefore, is understandable if one considers how variable the physical setting of the beds that produce the water may be.

Four diagrams in figure 13 represent different types of quality in water from Pleistocene or Holocene deposits. The first is for water from the southern part of the study area as indicated by the analysis for well 30N-2E-27AAA1. Most wells in this part of the study area are developed in thick sands and gravel beds, some of which may have been deposited in glacial stream channels. Till is thin or absent above these beds. The quality of water from the other six wells in this same area is very similar. This water is a calcium bicarbonate type and is classified as C2-S1 for irrigation. The medium-salinity hazard and the low-sodium hazard involved in using this water means that the water is suitable for most soils and for moderately salt-tolerant crops.

Many wells developed in the Pleistocene deposits in the central part of the study area obtain water from thin sand and gravel deposits at the base of the till or from isolated beds within the till. Water from well 31N-2E-1CCC1 probably is derived from deposits at the base of the till. This water is a calcium sulfate bicarbonate type and is about twice as mineralized (979 mg/L of dissolved solids) as water from wells in the southern part of the study area. This water has an irrigation classification of C3-S1. Because of its high salinity hazard, successful, long-term use of this water for irrigation will require good drainage and crops with good salt tolerance.

Well 32N-2E-32DAC2, also in the central part of the study area, obtains water from an isolated sand or gravel bed in the till. To reach this bed, the water has percolated through till and has been exposed to considerable soluble material in the till. Water from this well has the largest dissolved-solids concentration of any wells sampled in the study area. The water is the same chemical type (calcium sulfate bicarbonate) as that from well 31N-2E-1CCC1; however, it has a greater percentage of sulfate. Water from the two wells is the same type because the water from both wells had significant contact with till.

The quality of water from different beds within the till is unpredictable. That from the bed supplying well 32N-2E-32DAC2 is of the C4-S1 class for irrigation and is therefore too saline for continued irrigation under almost any conditions.

Wells near the northern edge of the study area are developed in Holocene deposits beneath the Missouri River flood plain. The quality of water from these deposits is represented in figure 13 by the diagram for well 33N-1E-17BBD. There is little variation in quality of the water from the four wells sampled in this area, because recharge to this aquifer is mainly seepage from the Missouri River. Water from this area is a calcium bicarbonate type and is rated for irrigation as C3-S1. Use of the water for irrigation would require growing a salt-tolerant crop in a well-drained area.

Nitrite plus nitrate nitrogen, as N, exceeded the U.S. Environmental Protection Agency's (1976) drinking-water standard of 10 mg/L in water from four wells producing from Pleistocene deposits and almost equaled the limit in water from two other wells (9.3 and 9.4 mg/L). These constituents are the only ones analyzed in this study that are considered toxic to humans and animals. Concentrations of nitrite plus nitrate-N in excess of 10 mg/L have been shown to cause methemoglobinemia, a blood disorder, in infants. The concentrations of nitrite plus nitrate-N almost equaling or exceeding the standard are most likely due to contamination at the well site, perhaps from a nearby feedlot, fertilizer nitrogen, or an improperly constructed septic system.

# SUMMARY

The Dakota Formation and Niobrara Formation of Cretaceous age and deposits of Pleistocene and Holocene age are all aquifers in the study area. Because the Dakota Formation is at least 400 ft below land surface and water from it is slightly saline, it is used as a source of water only when sufficient supplies are not available at shallower depths. The Niobrara Formation yields sufficient water for the development of irrigation in the central part of the study area. Pleistocene and Holocene deposits are developed for irrigation in both the southern part of the study area and in the northern part near the Missouri River.

Water from both the Dakota Formation and from Pleistocene sand and gravel deposits in glacial till commonly is very mineralized and would require burdensome salinity-control measures for successful irrigation use. Water from the Niobrara Formation is suitable for irrigation of most crops. Water from Pleistocene deposits in the southern part of the study area is suitable for irrigation on most soils and of most crops. Water from Holocene deposits along the Missouri River is suitable for irrigation of salt-tolerant crops on well-drained soils. Water from isolated Pleistocene sand and gravel deposits in glacial till is highly variable, but commonly is very mineralized and unsuited for irrigation.

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