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RECONNAISSANCE EVALUATION OF CONTAMINATION IN THE
ALLUVIAL AQUIFER IN THE EAST POPLAR OIL FIELD,
ROOSEVELT COUNTY, MONTANA

by Gary W. Levings

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CONVERSION FACTORS

The following factors can be used to convert inch-pound units in this report to the International System of Units (SI).

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain SI unit*</u>
acre	0.4047	hectare
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
foot	0.3048	meter
inch	25.40	millimeter
micromho per centimeter	100	microsiemens per
at 25° Celsius (micromho)		meter at 25° Celsius
mile	1.609	kilometer
pound per square inch	6895	pascal

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the equation:

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

RECONNAISSANCE EVALUATION OF CONTAMINATION IN THE ALLUVIAL AQUIFER

IN THE EAST POPLAR OIL FIELD, ROOSEVELT COUNTY, MONTANA

by

Gary W. Levings

ABSTRACT

The alluvial aquifer in the East Poplar oil field was studied to determine the occurrence, movement, and chemical quality of ground water and to evaluate contamination in the alluvial aquifer. In the oil field area, shallow water occurs in alluvium beneath the Poplar River valley floor. The general direction in flow of water in the alluvium is from north to south down the Poplar River valley. Localized areas may have directional components of flow toward the river.

Four distinct types of ground water were identified in the study area. Type 1 is sodium bicarbonate water with a range of dissolved-solids concentration of about 490 to 770 milligrams per liter. Type 2 is sodium chloride water with varying quantities of calcium and magnesium and dissolved-solids concentration ranging from about 1,600 to 7,200 milligrams per liter. Type 3 water contains sodium and chloride in significantly larger concentrations than Type 2 water, and dissolved-solids concentrations range from 13,800 to 114,000 milligrams per liter. Type 3 water is from test wells drilled near a brine-disposal well and is similar to Type 4 water, which is the brine being injected. The dissolved-solids concentrations of the brine being injected are 97,900 and 161,000 milligrams per liter.

Contamination of the alluvial aquifer by brine is indicated by a brine/fresh-water interface in the alluvium, and a downstream increase in chloride concentration (20 to 880 milligrams per liter) and change in water type (from sodium bicarbonate to sodium chloride) of the Poplar River. Contamination also may be indicated by the distribution of iron and manganese concentrations in water from wells near a brine-disposal well.

Possible sources of sodium chloride contamination in the alluvium are brine-disposal wells, pipelines, and storage or evaporation pits. The contamination can occur from leaks in the casing of brine-disposal wells or in pipelines caused by the corrosive nature of the brine or from storage or evaporation pits that have been improperly sealed or have sustained tears in the sealing material.

INTRODUCTION

Oil production began in 1952 in the East Poplar oil field, which is located entirely within the Fort Peck Indian Reservation. Since then, brine produced with the oil has been injected into subsurface geologic units by means of brine-disposal

wells or has been directed to storage and evaporation pits. In response to reported increased salinity of ground water used for domestic and stock supply in and near the oil field, the Oil and Gas Branch of the Conservation Division of the U.S. Geological Survey in 1981 requested that a reconnaissance study of the contamination be made. In 1982 the branch function became part of the U.S. Minerals Management Service and in 1983 became part of the U.S. Bureau of Land Management. Additional cooperation was provided by the Office of Environmental Protection of the Fort Peck Assiniboine and Sioux Tribes.

Purpose and scope

The purpose of this report is to describe the results of the reconnaissance study of contamination of the alluvial aquifer in the East Poplar oil field, Roosevelt County, Montana. Specifically, the purpose includes: (1) Description of the occurrence, movement, and chemical quality of water in the alluvial aquifer and (2) evaluation of the contamination of the alluvial aquifer.

Existing wells in the study area were inventoried, water levels measured, and water samples collected. In addition, seven test wells were drilled and cased near a brine-disposal well. Water levels were measured and water samples were collected from the wells. Water samples were collected from the Poplar River and stream discharge was measured along the reach within the study area to give an indication of movement of contaminated ground water to the stream.

Location of the area

The East Poplar oil field is located in northeastern Montana, about 8 miles north-northeast of Poplar (fig. 1). The study area is located in Tps. 28 and 29 N., R. 51 E., along the Poplar River, a tributary of the Missouri River.

Well-numbering system

The local system of numbering wells is based on the rectangular system for the subdivision of public lands (fig. 2). A well number consists of 14 characters and is assigned according to its location within a given township, range, and section. The first three characters consist of the township number and the letter N designating position north of the Montana Base Line. The next three characters consist of the range number and the letter E designating position east of the Montana Principal Meridian. The next two characters indicate the section. The letters following the section number indicate the position of the well within the section. The first letter denotes the quarter section (160-acre tract); the second, the quarter-quarter section (40-acre tract); the third, the quarter-quarter-quarter section (10-acre tract); and the fourth, the quarter-quarter-quarter-quarter section (2.5-acre tract). The subdivisions of the sections are lettered A, B, C, and D in a counterclockwise direction beginning in the northeast quadrant. The next two characters are a sequence number indicating the order of inventory in that tract. For example, well 29N51E32BBBA02 is the second well inventoried in the NE1/4 NW1/4 NW1/4 NW1/4 sec. 32, T. 29 N., R. 51 E.

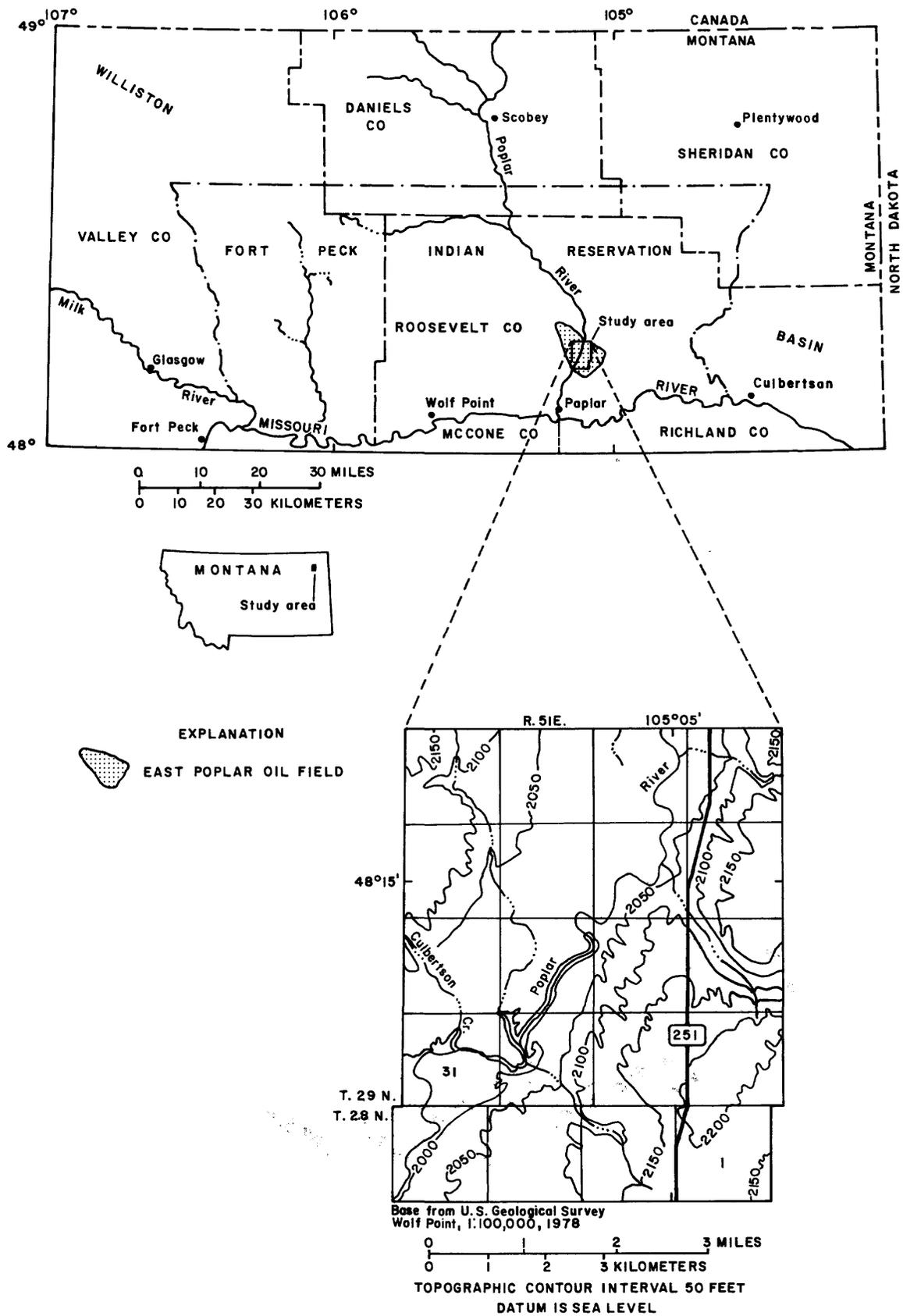


Figure 1.--Location of study area.

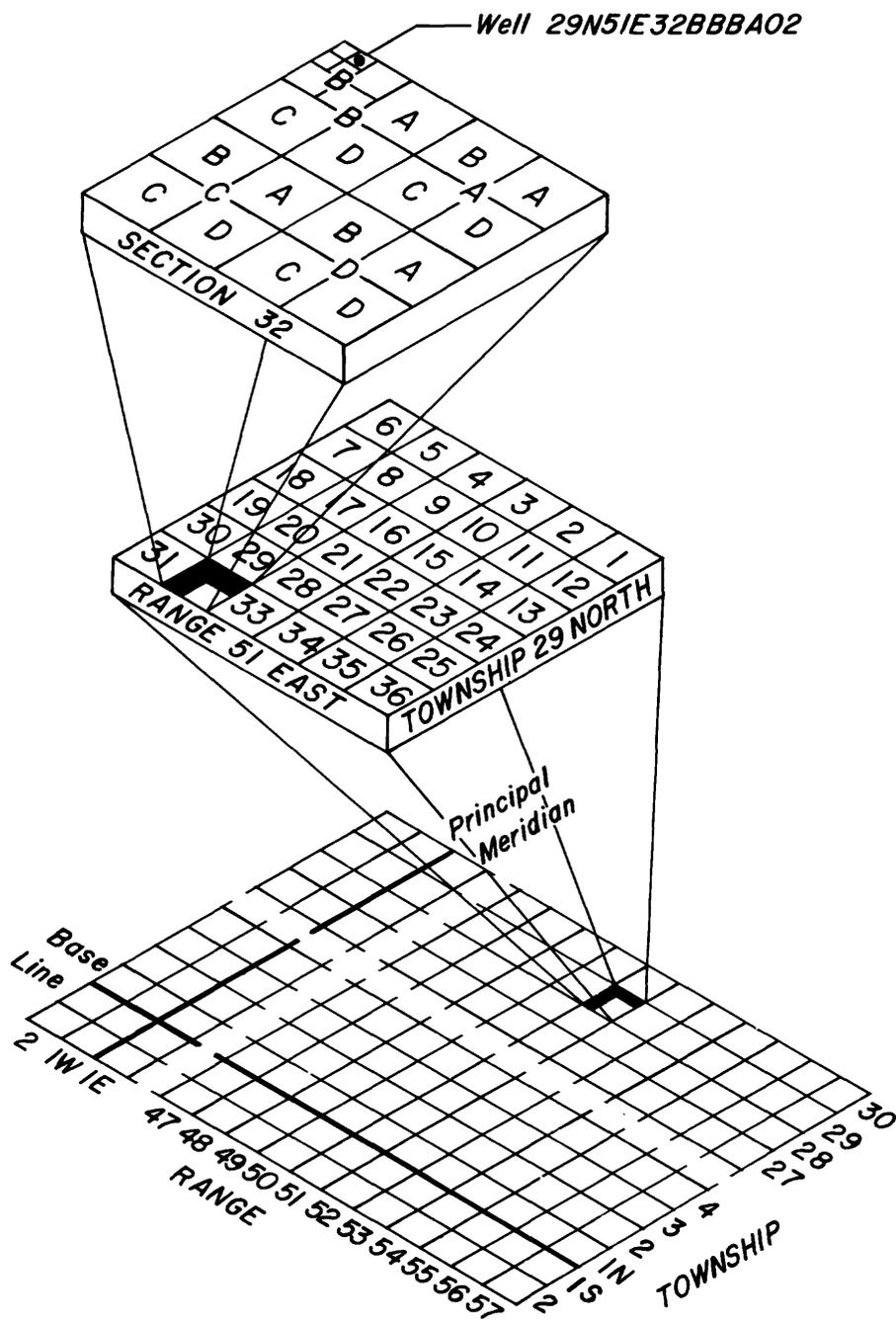


Figure 2.--Numbering system for wells.

DATA COLLECTION

Well inventory

During May and July 1982, wells in the study area were inventoried; where possible the data collected included date completed, depth of hole, depth of well, depth to first opening, and static water level. Data collected during the inventory are listed in table 1 (Supplemental Data at back of report) and the location of all wells inventoried is shown in figure 3. During July 1982, water samples for chemical analysis were collected from six water-supply and unused wells and two brine-disposal wells, SWD-1 and SWD-5. All available water-quality data for wells are presented in table 2 (Supplemental Data at back of report).

Test drilling

Seven test wells, W-10 to W-16, were installed during August 1982 in the area around brine-disposal well SWD-1 (fig. 3). The test wells were augered through the alluvium and into bedrock at each site. The wells were completed with perforated 2-inch plastic casing. Each hole was to be cased to total depth; however, problems in withdrawing the hollow-stem auger flites from the hole without bringing out the casing at the same time generally resulted in the collapse of a few feet of augered hole. The total depth of the hole and the cased depth are included in table 1. The loss of 17 feet of hole in test well W-13 required the drilling of test well W-14, 5.5 feet to the west. This hole was successfully cased to within 0.5 foot of bedrock. The drillers' log for each test well is given in table 3 (Supplemental Data at back of report).

After the casing was installed, each test well was pumped for several hours to prevent clay and silt from plugging the perforations and to develop the well. In November 1982, each test well, except W-13, was pumped for about 2 hours prior to collecting a water sample for chemical analysis (table 2).

GEOLOGY

The East Poplar oil field is located astride the Poplar anticline, which is on the west flank of the Williston Basin of northeastern Montana and North Dakota. The discovery well was completed in 1952 at a depth of about 5,800 feet, with oil production from limestones in the Charles Formation of the Madison Group of Mississippian age. The Charles Formation is at a depth of about 5,300 feet below land surface in the study area.

The oldest formation cropping out in the study area is the Upper Cretaceous Bearpaw Shale. Glaciation and subsequent erosion by the Poplar River have resulted in deposits of Pleistocene till, fan alluvium and colluvium, and dune sand, as well as Holocene alluvium. The sequence and thickness of Pleistocene and Holocene deposits differ throughout the area.

Descriptions of these formations are in reports by Colton (1963a,b) and Howard (1960). The geologic map (fig. 3) shows the areal distribution of the geologic units.

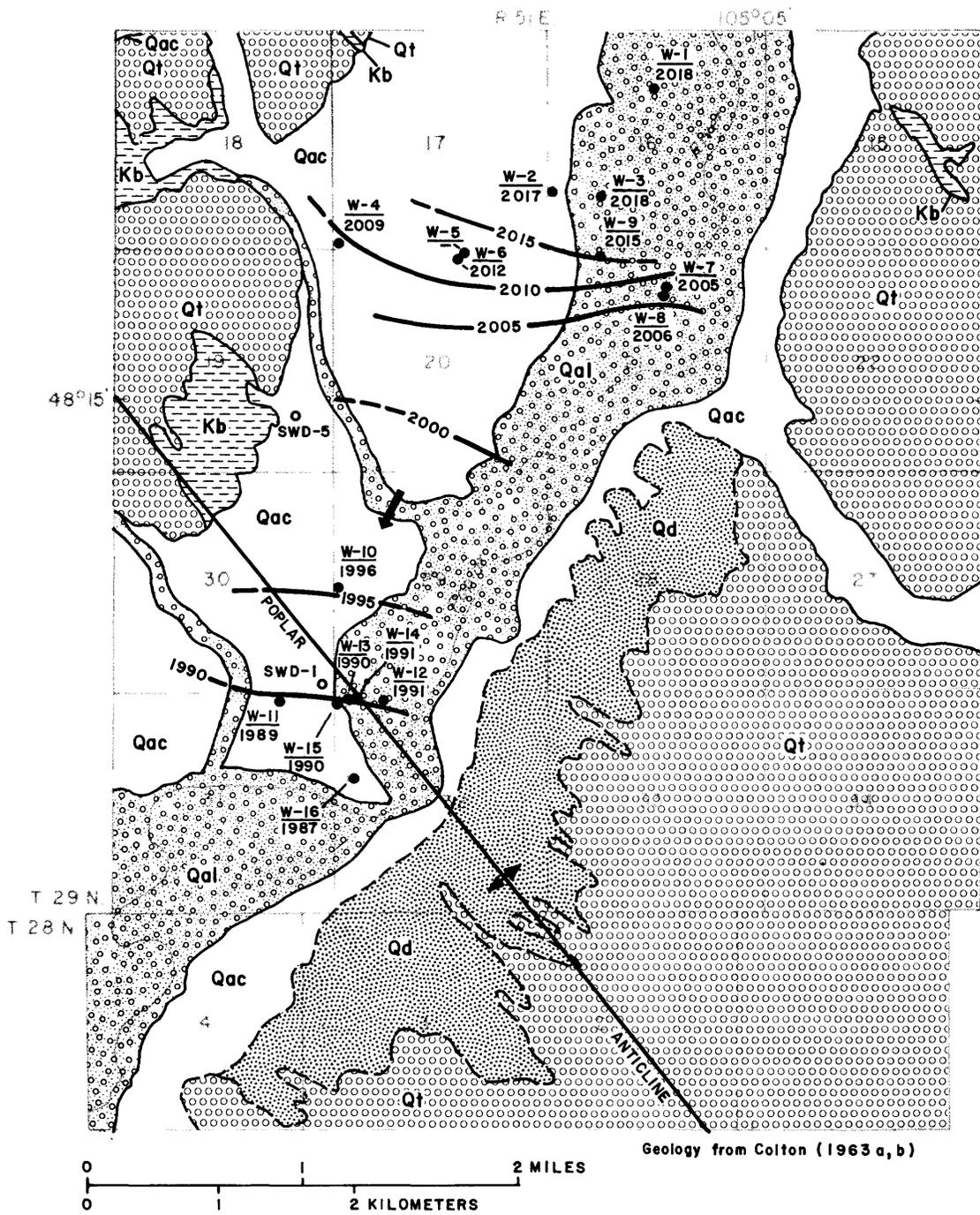
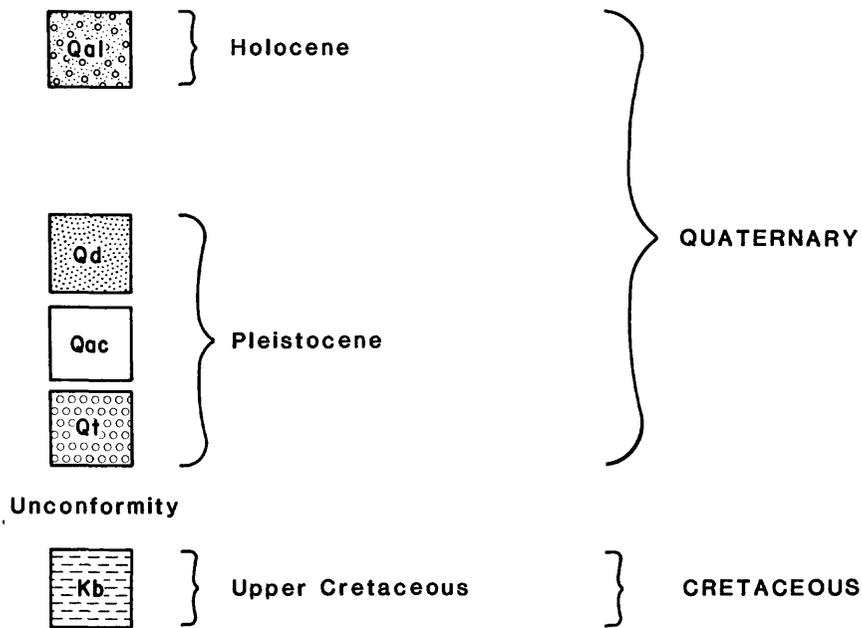


Figure 3.--Generalized geology, location of wells, and altitude of water levels in the alluvial aquifer.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS



ALLUVIUM



DUNE SAND



FAN ALLUVIUM AND COLLUVIUM



TILL



BEARPAW SHALE

— — — CONTACT--Dashed where approximately located

—2000— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, 1982. Dashed where approximately located. Contour interval 5 feet. Datum is sea level

➔ GENERAL DIRECTION OF GROUND-WATER FLOW

DATA SITE

W-8
2006 •

Water-supply, unused, or test well--Upper number is well number; lower number, where shown, is altitude of static water level, in feet above sea level

SWD-1 ○

Brine-disposal well and number

HYDROLOGY

Ground water

The alluvium is the source of most of the water from wells W-1 through W-16. Although several wells penetrate a limited thickness of saturated fan alluvium and colluvium, this limited thickness is not sufficient to yield much, if any, water to wells. The underlying Bearpaw Shale is a relatively impermeable bedrock unit that is a barrier to downward movement of water from the overlying units. As a result, all water in the alluvium eventually moves laterally downvalley.

The altitude of static water levels in wells and the generalized direction of ground-water flow are shown in figure 3. The altitude of static water levels indicates that the overall ground-water movement is from north to south down the Poplar River valley. Localized areas may have directional components of flow toward the river.

Based on chemical analyses of water samples collected from wells (table 2), the quality of ground water in the study area is extremely variable. Sodium, bicarbonate, and chloride are the dominant ions in water from most wells.

Dissolved solids, reported in milligrams per liter, is the sum of all dissolved constituents in the water and in reality is the total of the major ions in solution. Dissolved-solids concentrations of ground water sampled in the study area range from 488 to 114,000 mg/L (milligrams per liter).

In analyzing chemical-quality data, graphical methods are used to identify water types by a determination of the ionic compositions. The water type can be identified by use of chemical-constituent diagrams modified from Stiff (1951). These diagrams represent unit concentrations, in milliequivalents per liter, of the major constituents of each analysis plotted to scale. The diagram provides a visual comparison of the ionic content of each analysis.

The range in unit concentration of the major ions in water from the wells in the study area is too large to use the same scale for all diagrams. Chemical-constituent diagrams, at three different scales, for samples collected in 1982, are shown in figure 4. Visual inspection of the diagrams indicates that the water can be separated into four principal types representing different dominant ions and concentrations of dissolved solids.

Type 1 water contains sodium as the dominant cation and bicarbonate as the dominant anion. The dissolved-solids concentration ranges from 488 to 774 mg/L.

Type 2 water differs from Type 1 in that chloride has replaced bicarbonate as the dominant anion; sodium remains the dominant cation. However, the concentrations of calcium and magnesium vary considerably at each of the wells. The dissolved-solids concentration ranges from 1,610 to 7,210 mg/L. Wells W-4, W-6, and W-9 are located in a straight line (fig. 3) about three-quarters of a mile apart. The chemical composition of the water changes from significant quantities of calcium and magnesium in well W-4 to insignificant quantities in well W-9, and the total concentration of all constituents decreases. The unit concentrations of calcium and magnesium in water from well W-10 are almost the same as for sodium.

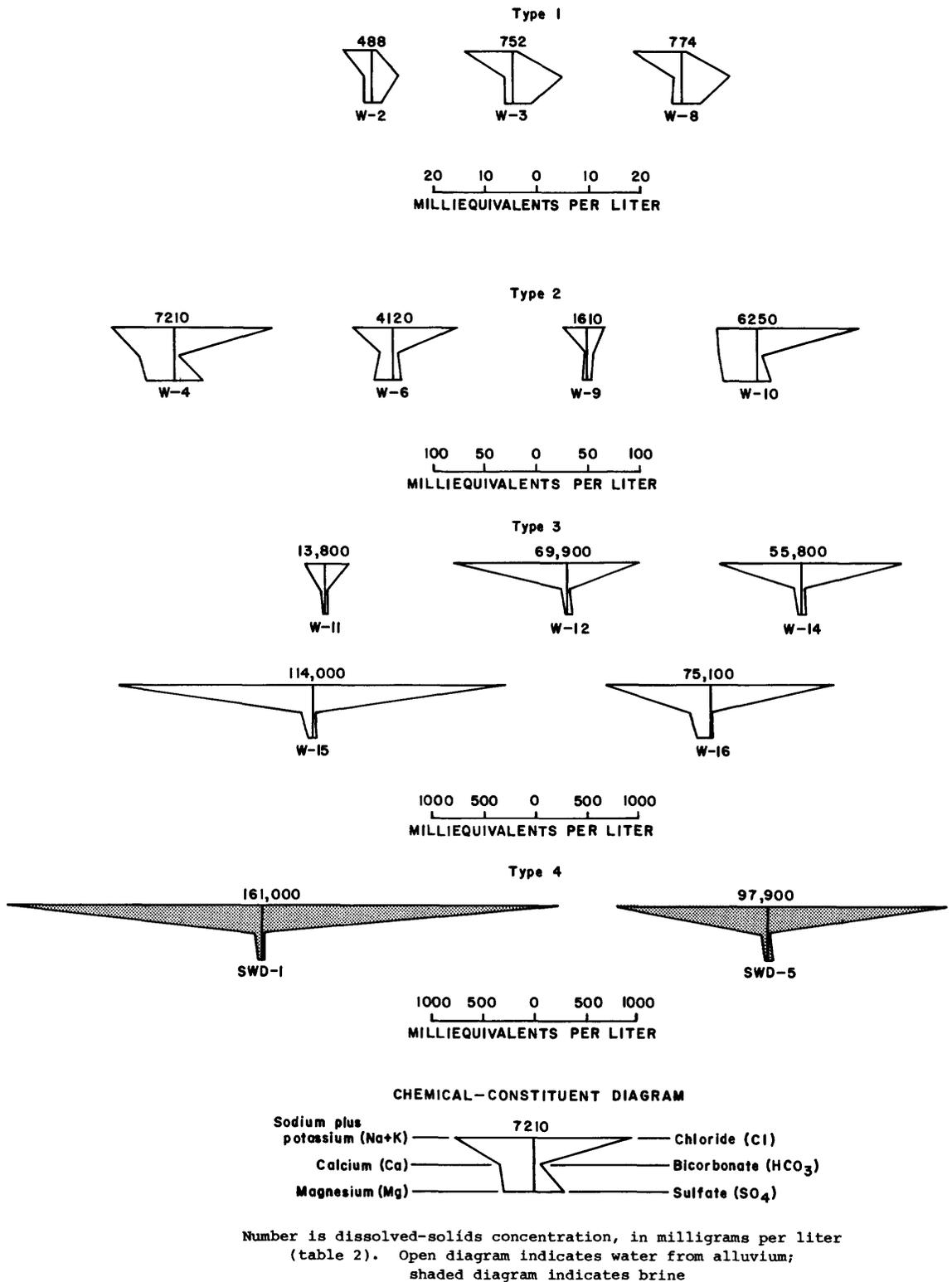


Figure 4.--Chemical-constituent diagrams for water sampled from wells in 1982.

Type 3 water also contains chloride and sodium as the dominant ions; however, the total concentration of constituents is larger than Type 2 water. The dissolved-solids concentration ranges from 13,800 to 114,000 mg/L. These waters are very similar to those of Type 4, which represents the brine being injected into brine-disposal wells SWD-1 and SWD-5. The dissolved-solids concentrations of the brine are 97,900 and 161,000 mg/L. The brine is a mixture of brines from oil-production wells.

The areal distribution of concentrations of sodium, chloride, and sulfate for water from the sampled wells is shown in figures 5-7. The concentrations of sodium (fig. 5) and chloride (fig. 6) in the test wells installed around brine-disposal well SWD-1 reflect the generalized ground-water movement in the area. Water from wells to the south and east have larger concentrations than does water from wells to the north and west. The reason for the smaller concentrations in water from well W-14 than in water from wells W-12 and W-15 is not known. It might be the result of differences in concentration with depth, permeability changes in the alluvium, or localized sources of brine such as pipelines. The concentration of sulfate (fig. 7) does not follow this pattern. Water in well W-16 has a concentration considerably less than water in well W-15. The reason for the decrease is unknown, but the decrease may be caused by geochemical reactions as the water moves through the alluvium.

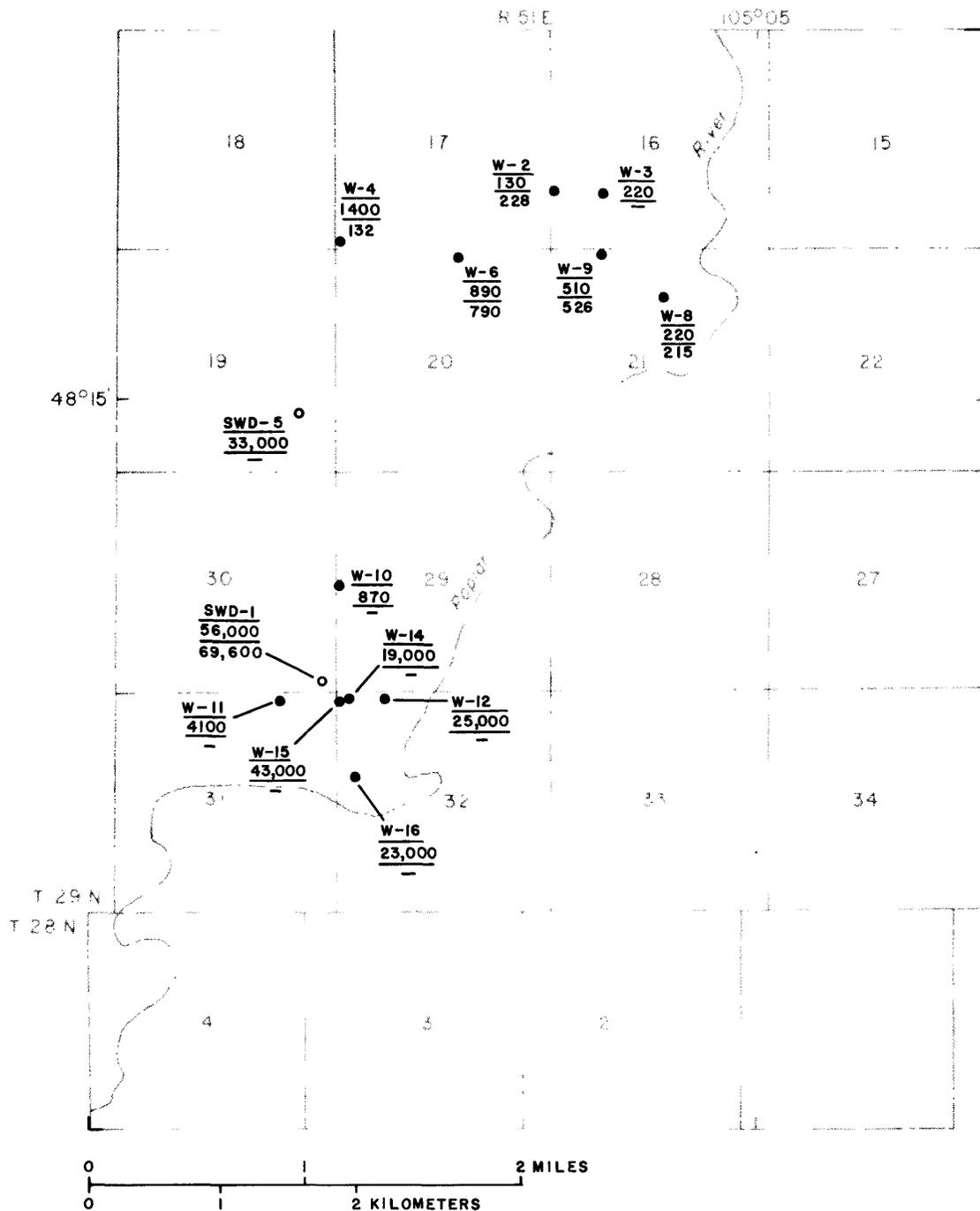
During the sampling of the test wells, the water temperature in well W-15 was 25.0°C, about 15°C greater than in the other test wells. Well W-15 is 238 feet southeast of brine-disposal well SWD-1. The temperature of the injected brine is about 80°-85°C.

Water is a byproduct in the production and recovery of most crude oil. Most of the water comes from the producing zone and represents the quality of water in those zones. In the study area, the Charles Formation is composed of limestone, anhydrite, dolomite, halite, and shale. The halite has been dissolved by the formation water, resulting in the brine produced in the East Poplar oil field. The quality of water in the Charles Formation varies both vertically and laterally throughout the field. The dissolved-solids concentration of samples collected during drill-stem tests, from flows sampled during the drilling process, or from production water ranges from about 16,000 to 201,000 mg/L (Feltis, 1980). The major constituents present in the brine are sodium and chloride.

Surface water

The Poplar River, a tributary to the Missouri River, is a perennial stream in the study area. During September 1981, discharge measurements were made at three of the sites shown in figure 8. Based on these measurements, the reach of the stream between sites PR-1 and PR-5 lost 0.96 ft³/s to the ground-water system. However, a seep along the right bank about 0.6 mile downstream from site PR-3 indicates that the potentiometric surface was above the level of water in the river and was contributing inflow to the river. Although the net effect of the measurements confirms that this is a losing reach, the ground-water system contributes flow to the stream where perched ground water exists.

During the September measurements, water samples were collected at the three measurement sites for standard analysis and at two additional sites for chloride analysis (table 4 in Supplemental Data at back of report). These analyses indicate



EXPLANATION

DATA SITE

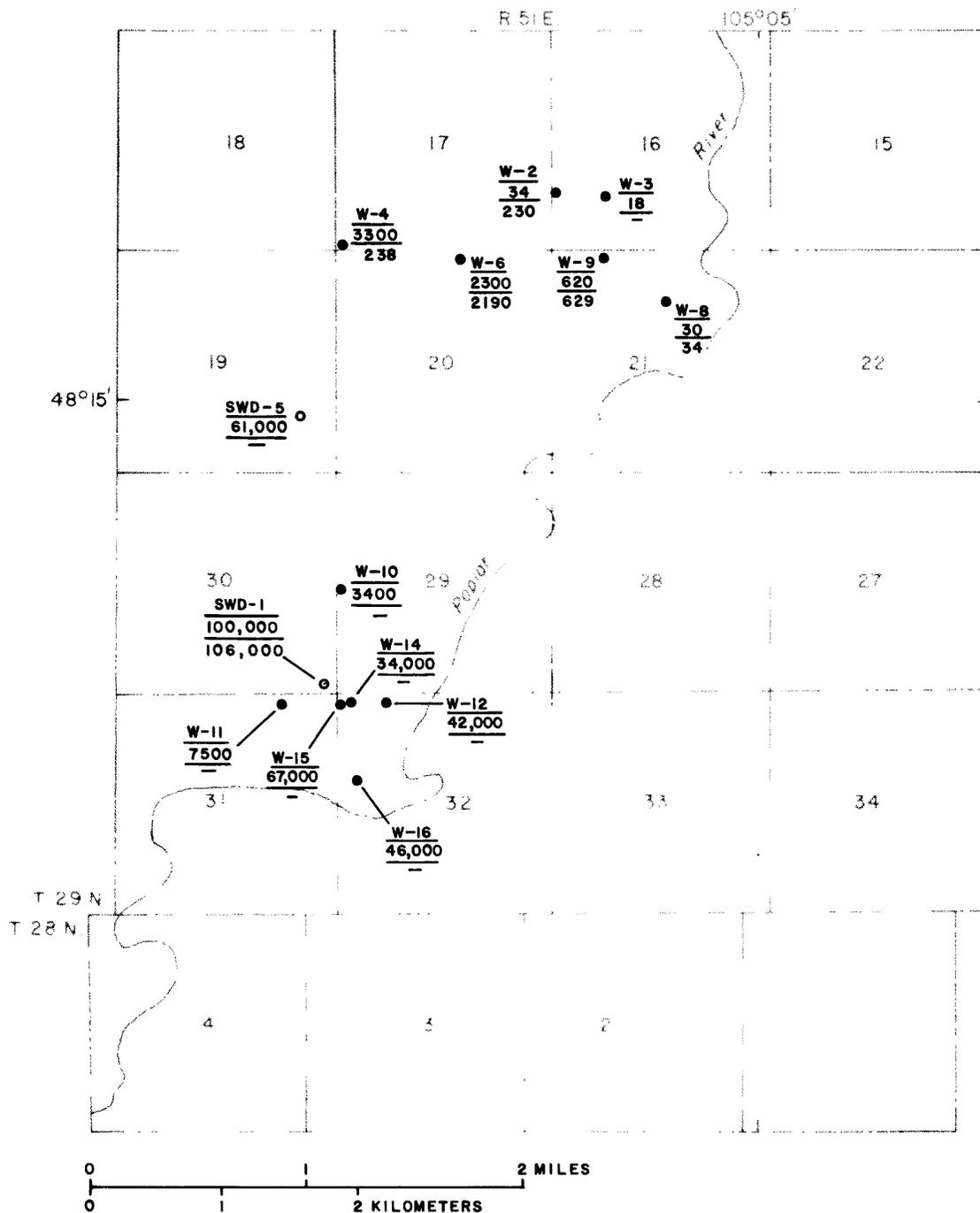
W-4 ●
1400
 132

Water-supply, unused, or test well--Upper number is well number; middle number is sodium concentration, in milligrams per liter, of sample collected in 1982; lower number is sodium concentration, in milligrams per liter, of sample collected in 1979

SWD-1 ○
56,000
 69,600

Brine-disposal well--Upper number is well number; middle number is sodium concentration, in milligrams per liter, of sample collected in 1982; lower number is sodium concentration, in milligrams per liter, of sample collected in 1979

Figure 5.--Sodium concentration of water from wells.



EXPLANATION

DATA SITE

- W-4 ●

3300

238

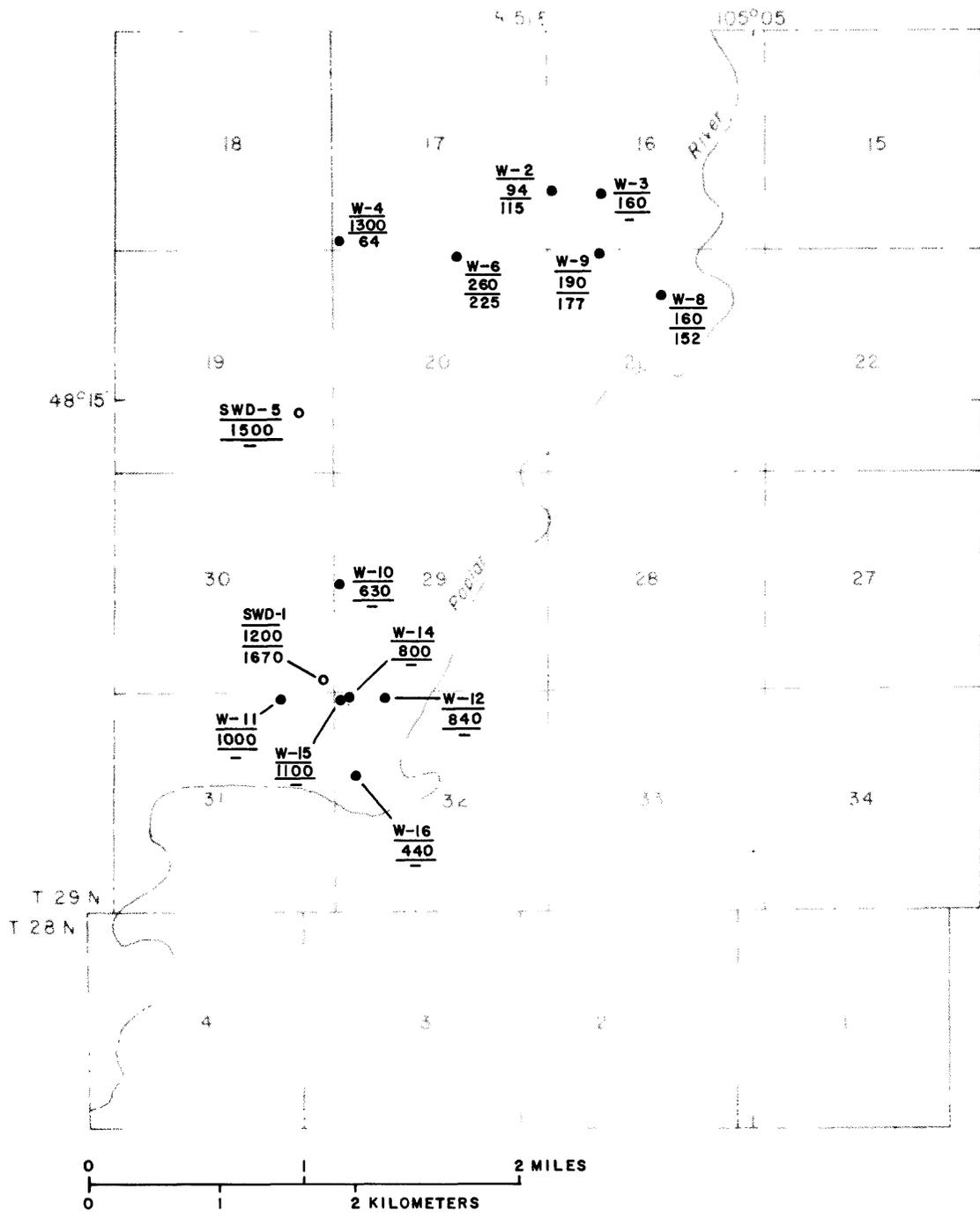
Water-supply, unused, or test well--Upper number is well number; middle number is chloride concentration, in milligrams per liter, of sample collected in 1982; lower number is chloride concentration, in milligrams per liter, of sample collected in 1979
- SWD-1 ○

100,000

106,000

Brine-disposal well--Upper number is well number; middle number is chloride concentration, in milligrams per liter, of sample collected in 1982; lower number is chloride concentration, in milligrams per liter, of sample collected in 1979

Figure 6.--Chloride concentration of water from wells.



EXPLANATION

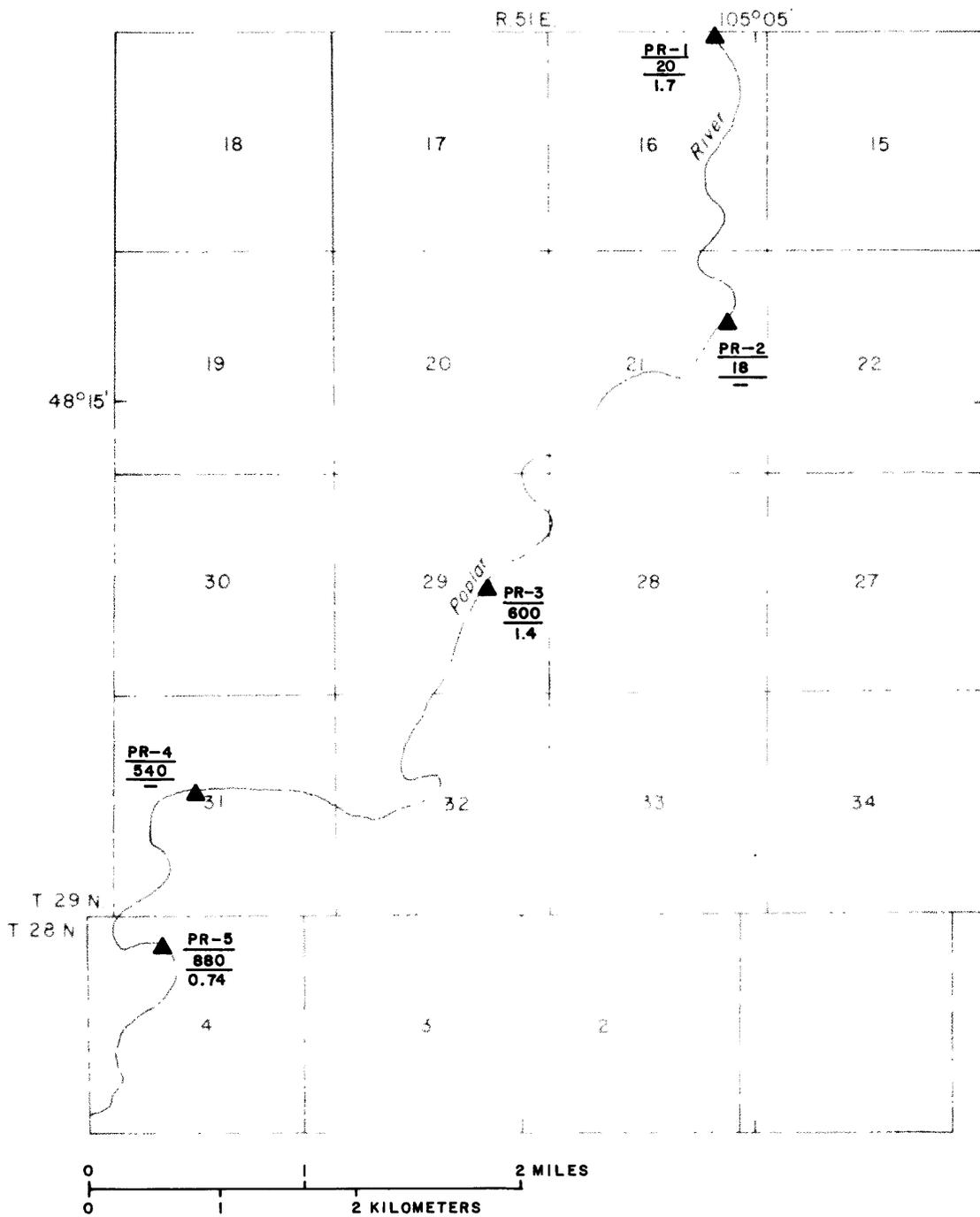
DATA SITE

- $\frac{W-4}{1300}$ ●

Water-supply, unused, or test well--Upper number is well number; middle number is sulfate concentration, in milligrams per liter, of sample collected in 1982; lower number is sulfate concentration, in milligrams per liter, of sample collected in 1979
- $\frac{SWD-1}{1200}$ ○

Brine-disposal well--Upper number is well number; middle number is sulfate concentration, in milligrams per liter, of sample collected in 1982; lower number is sulfate concentration, in milligrams per liter, of sample collected in 1979

Figure 7.--Sulfate concentration of water from wells.



PR-1
20 ▲
 1.7

EXPLANATION

STREAM MEASUREMENT SITE--Upper number is the site number; middle number is chloride concentration, in milligrams per liter; lower number is discharge, in cubic feet per second

Figure 8.--Discharge and chloride concentration at sites along the Poplar River, September 1981.

a significant increase in chloride concentration between sites PR-2 (18 mg/L) and PR-3 (600 mg/L) (fig. 8). From site PR-3 to PR-4, the concentration decreases, then increases again at site PR-5.

Analysis of the major constituents of the stream water indicates that the water is a sodium bicarbonate type at site PR-1 (similar to Type 1 ground water) and changes to a sodium chloride type at sites PR-3 and PR-5 (similar to Type 2 ground water) (fig. 9). The dissolved-solids concentration increases from 970 mg/L at PR-1 to 2,310 mg/L at PR-5.

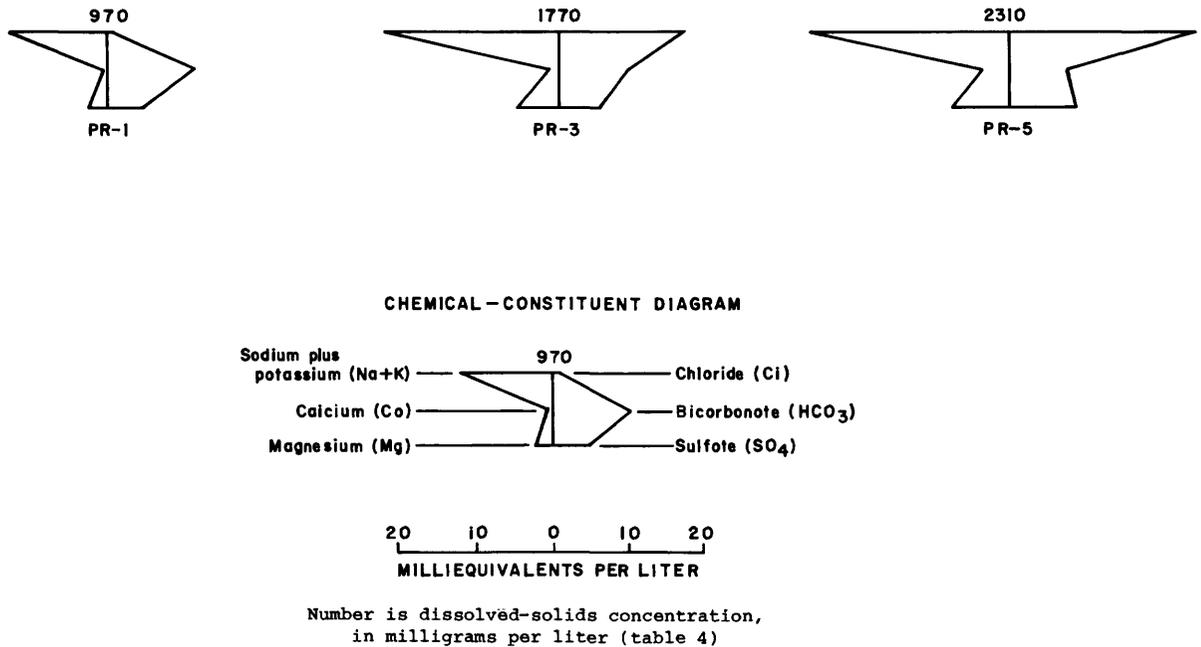


Figure 9.--Chemical-constituent diagrams for water from the Poplar River, September 1981.

In 1979, stream discharge was measured and a water sample was collected at site PR-1 (table 4). Comparison with the 1981 data does not indicate any significant differences in water quality even though the discharge was considerably greater in 1979.

CONTAMINATION OF THE ALLUVIAL AQUIFER

Indication of contamination

Contamination of the alluvial aquifer is indicated by analysis of chemical-quality data for water samples from wells and the Poplar River. A brine/fresh-water interface appears to exist between uncontaminated water in alluvium to the north (wells W-2 and W-3) and brine-contaminated water in alluvium to the south (wells W-6 and W-9), based on the difference in type of water (fig. 4). The concentrations of sodium, sulfate, and chloride in water from well W-2 decreased from 1979 to 1982

(table 2). This decrease may have resulted from the interface moving south, the direction of ground-water movement. If the source of contamination has been decreased, the water moving into this area from the north will begin to mix with, and dilute, the contaminated water. The significant increase in all major constituent concentrations in well W-4 from 1979 to 1982 indicates that no recharge is occurring in this part of the aquifer or the well may be close to a source of contamination or both.

Another water-quality change that may indicate contamination is an increase in concentration of iron and manganese in ground water in the area around brine-disposal well SWD-1. The concentration of iron in the brine is 1,400 µg/L (micrograms per liter) in brine-disposal well SWD-1 and 730 µg/L in well SWD-5 (fig. 10). The concentration of iron in water from the test wells near brine-disposal well SWD-1 ranges from 9,500 to 55,000 µg/L and increases with distance to the south and east. The manganese concentrations are less but have a similar pattern. The geochemical reaction resulting in the increase in iron and manganese concentrations cannot be determined with the data available; however, the variables that affect solubility include the pH and redox potential (Eh) and the dissolved carbon dioxide and sulfur species.

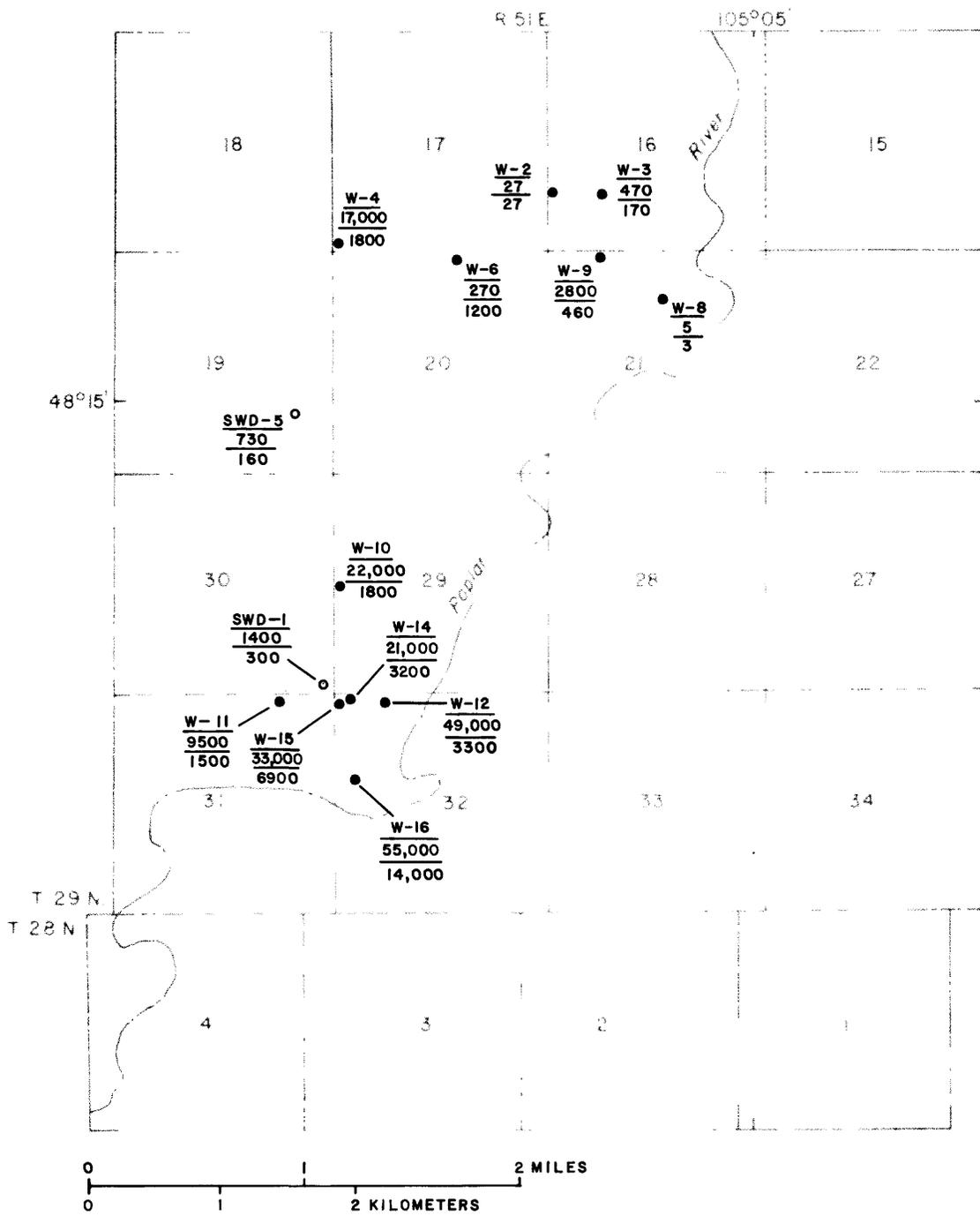
The downstream increase in chloride concentration between sampling sites PR-2 and PR-3 is an indication of brine-contaminated ground-water flow to the Poplar River. The change from sodium bicarbonate water at site PR-1 to a sodium chloride type at PR-3, coupled with a downstream increase in dissolved-solids concentration, is further indication that brine-contaminated ground water is entering the stream.

Possible sources of contamination

The two most common means of disposal of brine produced in the East Poplar oil field are brine-disposal wells and storage or evaporation pits. Brine-disposal wells are used for two purposes: (1) The disposal of brine into non-producing subsurface formations and (2) the disposal of brine into the producing zones for pressure maintenance to increase the quantity of oil recovered from the formation. To date (1982), brine has been injected into the Upper Cretaceous Judith River Formation (about 700 feet deep), the Lower Cretaceous Dakota Formation (about 3,300 feet deep), and the Mississippian Charles and Mission Canyon Formations (about 5,300 feet deep), for disposal, and into the Charles Formation for pressure maintenance.

The brine-disposal wells can become a source of contamination because of the corrosive nature of the brine. The chemical composition and heat of the brine combined with an injection pressure of several hundred pounds per square inch can corrode and rupture steel casing or pipe, resulting in leakage into adjacent formations. Wells in the oil field produce water having temperatures ranging from 93° to 104°C (Sonderegger and Bergantino, 1981). Leakage can also occur in pipelines transporting brine from production wells to tank batteries and then to brine-disposal wells.

Storage or evaporation pits are used to hold brine either for evaporation of the water or as storage reservoirs during periods when a brine-disposal well is inoperative. These pits are usually bulldozed into the alluvium near a brine-disposal well but may be located near tank batteries or production wells. They may or may not be lined with plastic or clay to prevent infiltration of water into the alluvium. Where plastic is used, it is susceptible to punctures or tears, allowing



EXPLANATION

DATA SITE

$\frac{W-15}{33,000}$ ● Water-supply, unused, or test well--Upper number is well number; middle number is iron concentration, in micrograms per liter, of sample collected in 1982; lower number is manganese concentration, in micrograms per liter, of samples collected in 1982
 $\frac{6900}$

$\frac{SWD-1}{1400}$ ○ Brine-disposal well--Upper number is well number; middle number is iron concentration, in micrograms per liter, of sample collected in 1982; lower number is manganese concentration, in micrograms per liter, of sample collected in 1982
 $\frac{300}$

Figure 10.--Iron and manganese concentrations of water from wells.

brine to infiltrate the underlying formation.

The location of all evaporation or storage pits, pipelines, wells, and tank batteries that have existed in the oil field is unknown. In the study area, as many as 11 wells are known to have periodically been used for disposal of brine. All these wells are assumed to have had storage or evaporation pits at one time. During the study, pits were in use at brine-disposal wells SWD-1 and SWD-5. The area is interlaced with pipelines connecting oil wells to tank batteries, which may be connected to brine-disposal wells.

NEED FOR ADDITIONAL STUDY

The results of this reconnaissance study indicate that brine from oil-field production is the probable source of sodium chloride contamination in the alluvial aquifer. Additional data collection is necessary to determine the areal extent of the contamination, rates of movement of brine in the alluvium, geochemical reactions that may occur between the brine and alluvium resulting in precipitates, and changes in water quality with depth in the alluvium.

Answers to some of these unknowns may be possible by using resistivity and electromagnetic geophysical techniques to isolate probable sources of the contamination plumes. To supplement these data, the location of all producing and disposal wells, dry holes, tank batteries, pipelines, and storage or evaporation pits needs to be determined. The quantity of brine and period of time that brine was injected in each disposal well also need to be determined.

An analysis of these data could isolate the point sources of contamination throughout the oil field. A detailed drilling and sampling program could then be undertaken to determine the magnitude of contamination and its lateral and vertical distribution from these point sources.

If sufficient data are obtained, contaminant transport models might be used to simulate the system. Depending on the degree of simulation that is achieved, the model could be useful in predicting the movement and residual effects of the contaminant through the alluvium downvalley from the oil field.

SUMMARY AND CONCLUSIONS

In the East Poplar oil field, shallow water occurs in the alluvium beneath the valley floor. The general direction of ground-water flow is from north to south down the Poplar River valley. Localized areas may have directional components of flow toward the river. The alluvium is underlain by the Bearpaw Shale, which is relatively impermeable, preventing downward movement of water and forcing water in the alluvium to move laterally downvalley.

Seven test wells, bottomed in the Bearpaw Shale, were installed around brine-disposal well SWD-1. These wells were sampled, along with several existing wells, to determine the quality of ground water in the study area. Depending on the well location, four distinct types of water exist. Type 1 is a sodium bicarbonate water with dissolved-solids concentration ranging from about 490 to 770 mg/L. Type 2 is sodium chloride water with varying quantities of calcium and magnesium and dissolved-solids concentration ranging from about 1,600 to 7,200 mg/L. Type 3 is also

sodium chloride water; however, the concentrations of sodium and chloride are significantly larger than in Type 2. The dissolved-solids concentration ranges from 13,800 to 114,000 mg/L. The wells producing Type 3 water are test wells drilled around brine-disposal well SWD-1. Type 3 water is very similar to Type 4 water, which represents the brine being injected into two disposal wells. The dissolved-solids concentrations of the brine being injected were 97,900 and 161,000 mg/L.

Contamination of the alluvial aquifer by brine is indicated by analysis of chemical-quality data for water samples from wells and the Poplar River. A brine/fresh-water interface appears to exist in the alluvium between wells W-2 and W-3 and wells W-6 and W-9. A downstream increase in chloride concentration (20 to 880 mg/L) and downstream change in water type from sodium bicarbonate to sodium chloride are indications of brine-contaminated ground-water inflow to the Poplar River. Contamination also may be indicated by the distribution of iron and manganese concentrations around brine-disposal well SWD-1.

The probable source of sodium chloride contamination of the alluvial aquifer is by brines from the production of oil in limestones of the Charles Formation of the Madison Group of Mississippian age. The brines contain dissolved-solids concentrations ranging from about 16,000 to 201,000 mg/L. Brine-disposal wells and storage or evaporation pits have been used in the disposal of the brine. The contamination of water in the alluvium can occur from leaks in casing or pipelines caused by the corrosive nature of the brine or from leakage in storage or evaporation pits that have been improperly sealed or have sustained tears in the sealing material.

Additional data collection is necessary to determine the areal extent of contamination. Rates of movement of brine in the alluvium, geochemical reactions that may occur between the brine and alluvium resulting in precipitates, and changes in water quality with depth in the alluvium also could be determined by analysis of additional data.

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SUPPLEMENTAL DATA

Table 1.--Records of water-supply, unused, test, and brine-disposal wells

[Local number--numbering system in text. Depth of hole--in feet below land surface. Depth of well--in feet below land surface. Finish--P, perforated; X, open hole. Depth to first opening--in feet below land surface. Use of site--D, brine disposal; O, observation; U, unused; W, withdrawal. Use of water--H, domestic; Z, other. Altitude of land surface--in feet above sea level. Water level--in feet below land surface. Remarks--C, chemical analyses in table 2; L, well log in table 3.]

Well No. (fig. 3)	Local No.	Date completed (month-day-year)	Depth of hole (feet)	Depth of well (feet)	Casing diameter (inches)	Finish	Depth to first opening (feet)	Use of site	Use of water	Principal aquifer	Altitude of land surface (feet)	Water level (feet)	Date water level measured (month-day-year)	Remarks
W-1	29N51E16BDA01	--	110	52.6	5.5	--	--	U	--	Alluvium	2,027	9.14	07-20-82	--
W-2	29N51E16CBC01	--	--	25	6	P	21	U	--	do	2,030	13.48	05-04-82	C
W-3	29N51E16CAA01	--	--	23	6	P	19	W	Z	do	2,027	9.31	05-04-82	C
W-4	29N51E17CCC01	--	--	87	5.5	P	83	U	--	do	2,065	55.66	05-04-82	C
W-5	29N51E20ABBA01	--	--	48	--	--	--	U	--	do	2,035	--	--	--
W-6	29N51E20ABBA02	--	--	44	5.5	--	--	U	--	do	2,037	24.67	07-27-82	C
W-7	29N51E21ABCB01	--	210	197	4.5	X	100	U	--	do	2,016	11.37	05-04-82	--
W-8	29N51E21ABCC01	60	--	12	12	--	--	W	H	do	2,016	9.51	05-04-82	C
W-9	29N51E21BBAA01	--	20	17.4	5.5	P	13.4	U	--	do	2,024	9.40	05-04-82	C
W-10	29N51E29CBBB01	08-30-82	46	45.3	2	P	13.3	O	--	do	2,007	11.23	08-31-82	C,L
W-11	29N51E31AABB01	08-28-82	55	54	2	P	15	O	--	do	2,009	19.55	08-31-82	C,L
W-12	29N51E32BBAA01	08-29-82	44	42.4	2	P	12.4	O	--	do	1,999	8.37	08-31-82	C,L
W-13	29N51E32BBBA01	08-26-82	48	31	2	P	11	O	--	do	2,000	9.50	08-31-82	L
W-14	29N51E32BBBA02	08-27-82	48	47.5	2	P	7.5	O	--	do	2,000	9.48	08-31-82	C,L
W-15	29N51E32BBBB01	08-29-82	49	49	2	P	19	O	--	do	2,000	10.21	08-31-82	C,L
W-16	29N51E32BCCA01	08-27-82	46	39.7	2	P	19.7	O	--	do	1,996	8.84	08-31-82	C,L
SWD-1	29N51E30DDDD01	09-12-57	3,465	3,310	5.5	X	3,146	D	--	Dakota	2,005	--	--	C
SWD-5	29N51E19DDBA01	02-22-76	3,583	3,583	7	P	3,190	D	--	do	2,040	--	--	C

Table 2.--Chemical-quality data for water from wells and for injection brines

[Values are reported in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g/L}$), degrees Celsius ($^{\circ}\text{C}$), and micromhos per centimeter at 25 $^{\circ}$ Celsius (micromhos). <, constituent present at concentration smaller than detection limit of applied analysis. Agency analyzing sample--MDHES, Montana Department of Health and Environmental Sciences, Water Quality Bureau; USGS, U.S. Geological Survey]

Well No. (fig. 3)	Local No.	Date of sample (month-day-year)	Geologic unit	Onsite specific conductance (micromhos)	Lab specific conductance (micromhos)	Onsite pH (standard units)	Onsite water temperature ($^{\circ}\text{C}$)	Hardness (mg/L as CaCO_3)	Hardness, noncarbonate (mg/L as CaCO_3)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
W-2	29N51E16CBCC01	07-23-79	Alluvium	--	1,612	--	--	260	0	47	35
		07-26-82	do	900	850	7.9	9.0	150	0	30	18
W-3	29N51E16CCAA01	07-20-82	do	1,140	1,170	7.7	9.5	160	0	27	22
W-4	29N51E17CCCC01	07-23-79	do	--	1,070	--	--	170	100	40	17
		07-27-82	do	9,100	11,500	7.4	9.5	3,100	2,800	700	320
W-6	29N51E20ABBA02	07-23-79	do	--	7,300	--	--	1,800	--	340	242
		07-26-82	do	6,300	7,430	7.5	--	1,600	1,400	290	220
W-8	29N51E21ABCC01	07-23-79	do	--	1,240	--	--	190	--	38	24
		07-20-82	do	1,200	1,240	7.6	9.5	180	0	36	22
W-9	29N51E21BBAA01	07-23-79	do	--	3,070	--	--	230	--	39	32
		07-26-82	do	3,100	2,850	7.5	--	220	0	39	30
W-10	29N51E29CBBB01	11-03-82	do	10,000	10,200	6.9	10.0	3,500	3,300	750	400
W-11	29N51E31AABB01	11-03-82	do	17,000	21,100	7.1	10.0	2,500	2,100	670	210
W-12	29N51E32BBAA01	11-02-82	do	70,000	86,300	6.8	12.0	4,700	4,400	1,300	350
W-14	29N51E32BBBA02	11-02-82	do	58,000	72,000	6.7	10.5	4,700	4,400	1,400	300
W-15	29N51E32BBBB01	11-03-82	do	120,000	127,000	6.6	25.0	7,800	7,600	2,500	380
W-16	29N51E32BCCA01	11-02-82	do	70,000	92,000	6.8	10.0	16,000	15,000	4,100	1,300
SWD-1	29N51E30DDDD01	07-23-79	--	--	100,000	--	--	4,300	--	1,480	141
		07-22-82	--	170,000	150,000	6.6	--	6,000	5,900	2,000	250
SWD-5	29N51E19DBBA01	07-22-82	--	130,000	111,000	6.4	--	4,600	4,500	1,500	200

Table 2.--Chemical-quality data for water from wells and for injection brines--Continued

Well No. (fig. 3)	Date of sample (month-day-year)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio (SAR)	Potassium, dissolved (mg/L as K)	Bicarbonate, fet-lab (mg/L as HCO ₃)	Carbonate, fet-lab (mg/L as CO ₃)	Alkalinity, lab (mg/L as CaCO ₃)	Sulfate, dissolved (mg/L as SO ₄)
W-2	07-23-79	228	--	6.1	--	389	0.0	319	115
	07-26-82	130	65	5.2	3.8	--	--	250	94
W-3	07-20-82	220	75	8.7	4.1	--	--	473	160
W-4	07-23-79	132	--	4.4	--	80	.0	66	64
	07-27-82	1,400	50	11	12	--	--	234	1,300
W-6	07-23-79	790	--	8.0	--	310	.0	254	225
	07-26-82	890	54	9.6	11	--	--	213	260
W-8	07-23-79	215	--	6.7	--	554	.0	454	152
	07-20-82	220	72	8.0	4.1	--	--	474	160
W-9	07-23-79	526	--	15	--	381	.0	312	177
	07-26-82	510	83	15	6.1	--	--	323	190
W-10	11-03-82	870	35	6.4	12	--	--	246	630
W-11	11-03-82	4,100	78	35	20	--	--	395	1,000
W-12	11-02-82	25,000	92	159	250	--	--	245	840
W-14	11-02-82	19,000	90	120	89	--	--	301	800
W-15	11-03-82	43,000	92	221	150	--	--	172	1,100
W-16	11-02-82	23,000	76	80	97	--	--	126	440
SWD-1	07-23-79	69,600	--	457	--	171	.0	140	1,670
	07-22-82	56,000	94	314	910	--	--	153	1,200
SWD-5	07-22-82	33,000	93	212	550	--	--	76	1,500

Table 2.--Chemical-quality data for water from wells and for injection brines--Continued

Well No. (fig. 3)	Date of sample (month-day-year)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO ₂)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO ₂ +NO ₃ dissolved (mg/L as N)	Arsenic, dissolved (µg/L as As)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)
W-2	07-23-79	230	--	--	1,464	--	--	--	--	--
	07-26-82	34	.5	10	488	3.9	1	<.5	<1	<10
W-3	07-20-82	18	.4	15	752	<.10	--	--	--	--
W-4	07-23-79	238	--	--	452	--	--	--	--	--
	07-27-82	3,300	.1	14	7,210	.10	7	<10	20	10
W-6	07-23-79	2,190	--	--	4,100	--	--	--	--	--
	07-26-82	2,300	.2	16	4,120	<.10	--	--	--	--
W-8	07-23-79	34	--	--	880	--	--	--	--	--
	07-20-82	30	.4	14	774	.27	1	<.5	<1	<10
W-9	07-23-79	629	--	--	1,780	--	--	--	--	--
	07-26-82	620	.4	14	1,610	<.10	--	--	--	--
W-10	11-03-82	3,400	.1	16	6,250	<.10	--	--	--	--
W-11	11-03-82	7,500	.2	16	13,800	.62	--	--	--	--
W-12	11-02-82	42,000	<.1	7.9	69,900	<.10	--	--	--	--
W-14	11-02-82	34,000	<.1	11	55,800	<.10	2	<10	130	60
W-15	11-03-82	67,000	<.1	12	114,000	<.10	5	<.5	1	100
W-16	11-02-82	46,000	<.1	6.8	75,100	<.10	--	--	--	--
SWD-1	07-23-79	106,000	--	--	--	--	--	--	--	--
SWD-5	07-22-82	100,000	4.6	57	161,000	<.10	<1	<10	290	130
	07-22-82	61,000	4.4	52	97,900	<.10	<1	<10	170	120

Table 2.--Chemical-quality data for water from wells and for injection brines--Continued

Well No. (fig. 3)	Date of sample (month-day-year)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Zinc, dissolved (µg/L as Zn)	Agency analyzing sample
W-2	07-23-79 07-26-82	-- <10	-- 27	-- <100	-- 27	-- <.1	-- <100	-- 4	-- 44	MDHES USGS
W-3	07-20-82	--	470	--	170	--	--	--	--	USGS
W-4	07-23-79 07-27-82	-- 30	-- 17,000	-- 200	-- 1,800	-- <.1	-- 200	-- <1	-- 40	MDHES USGS
W-6	07-23-79 07-26-82	-- --	-- 270	-- --	-- 1,200	-- --	-- --	-- --	-- --	MDHES USGS
W-8	07-23-79 07-20-82	-- <10	-- 5	-- <100	-- 3	-- <.1	-- 100	-- <1	-- 320	MDHES USGS
W-9	07-23-79 07-26-82	-- --	-- 2,800	-- --	-- 460	-- --	-- --	-- --	-- --	MDHES USGS
W-10	11-03-82	--	22,000	--	1,800	--	--	--	--	USGS
W-11	11-03-82	--	9,500	--	1,500	--	--	--	--	USGS
W-12	11-02-82	--	49,000	--	3,300	--	--	--	--	USGS
W-14	11-02-82	70	21,000	600	3,200	.1	500	<1	140	USGS
W-15	11-03-82	<10	33,000	1,600	6,900	.5	1,600	<1	220	USGS
W-16	11-02-82	--	55,000	--	14,000	--	--	--	--	USGS
SWD-1	07-23-79	--	--	--	--	--	--	--	--	MDHES
SWD-5	07-22-82	200	1,400	4,000	300	<.1	3,200	<1	110	USGS
	07-22-82	140	730	1,300	160	<.1	2,700	<1	80	USGS

Table 3.--Drillers' logs of test wells

[Thickness is in feet. Depth is in feet below land surface]

	<u>Thickness</u>	<u>Depth</u>
<u>29N51E29CBBB01 (W-10)</u>		
Topsoil	5	5
Clay, moist	8	13
No returns, easy drilling	3	16
Fine, silty sand, saturated	7	23
Silty sand and some gravel	7	30
Gravel	9	39
Gravel, fairly moist	6	45
Bearpaw Shale	1	46
<u>29N51E31AABB01 (W-11)</u>		
Topsoil	3	3
Hardpan	2	5
Clay, silt	14	19
Sandy gravel	2	21
Clay with small amount of gravel	33	54
Bearpaw Shale	1	55
<u>29N51E32BBAA01 (W-12)</u>		
Topsoil	7	7
Sand	1	8
Moist sand and silt	.5	8.5
Gravel and sand, moist	7.5	16
Saturated	5	21
Moist	5	26
Saturated	17	43
Bearpaw Shale	1	44
<u>29N51E32BBBA01 (W-13)</u>		
Soil	7	7
Gravel	9	16
Gravel; water at 16 feet	32	48
Bearpaw Shale	--	48
<u>29N51E32BBBA02 (W-14)</u>		
Soil	7	7
Gravel	9	16
Gravel; water at 16 feet	32	48
Bearpaw Shale	--	48
<u>29N51E32BBBB01 (W-15)</u>		
Topsoil	6	6

Table 3.--Drillers' logs of test wells--Continued

	<u>Thickness</u>	<u>Depth</u>
<u>29N51E32BBBB01 (W-15)--Continued</u>		
Sand, moist with some gravel	5	11
Sandy gravel	1	12
Moist sand	2	14
Sandy gravel	2	16
Mostly sand, little more moist	2	18
Gravel	2	20
Sand-some gravel	2	22
Gravel and sand	3	25
Gravel and sand, saturated	4	29
Same, hard drilling	5	34
Same, easier drilling	5	39
Hard drilling, no returns	9	48
Bearpaw Shale	1	49
<u>29N51E32BCCA01 (W-16)</u>		
Soil	12	12
Gravel	34	46
Bearpaw Shale	--	46

Table 4.--Chemical quality of water in the Poplar River

[Values are reported in cubic feet per second (ft³/s), micromhos per centimeter at 25° Celsius (micromhos), degrees Celsius (°C), milligrams per liter (mg/L), and micrograms per liter (µg/L). Analyses by U.S. Geological Survey.]

Site designation (fig. 8)	Date of sample (month-day-year)	Stream flow, instantaneous (ft ³ /s)	Onsite specific conductance (micromhos)	Onsite pH (standard units)	Onsite water temperature (°C)	Hardness (mg/L as CaCO ₃)	Hardness, noncarbonate (mg/L as CaCO ₃)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
PR-1	10-25-79	22	1,380	8.8	7.0	190	--	24	31
	09-09-81	1.7	1,560	9.0	20.0	140	0	12	27
PR-2	09-09-81	--	1,590	9.0	--	--	--	--	--
PR-3	09-09-81	1.4	3,090	8.6	23.0	360	0	36	66
PR-4	09-09-81	--	3,620	8.5	--	--	--	--	--
PR-5	09-09-81	.74	3,790	8.4	25.0	590	220	80	95

Site designation (fig. 8)	Sodium, dissolved (mg/L as Na)	Percent adsorption	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, lab (mg/L as CaCO ₃)	Sulfate, dissolved (mg/L as SO ₄)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO ₂)	Solids, sum of constituents, dissolved (mg/L)	Iron, dissolved (µg/L as Fe)
PR-1	280	76	8.9	7.4	--	250	12	0.4	7.1	918	10
	320	82	14	8.5	560	240	20	.5	1.9	970	21
PR-2	--	--	--	--	--	--	18	--	--	--	--
PR-3	530	75	12	11	460	250	600	.4	2.5	1,770	30
PR-4	--	--	--	--	--	--	540	--	--	--	--
PR-5	610	69	11	13	370	400	880	.4	5.2	2,310	30