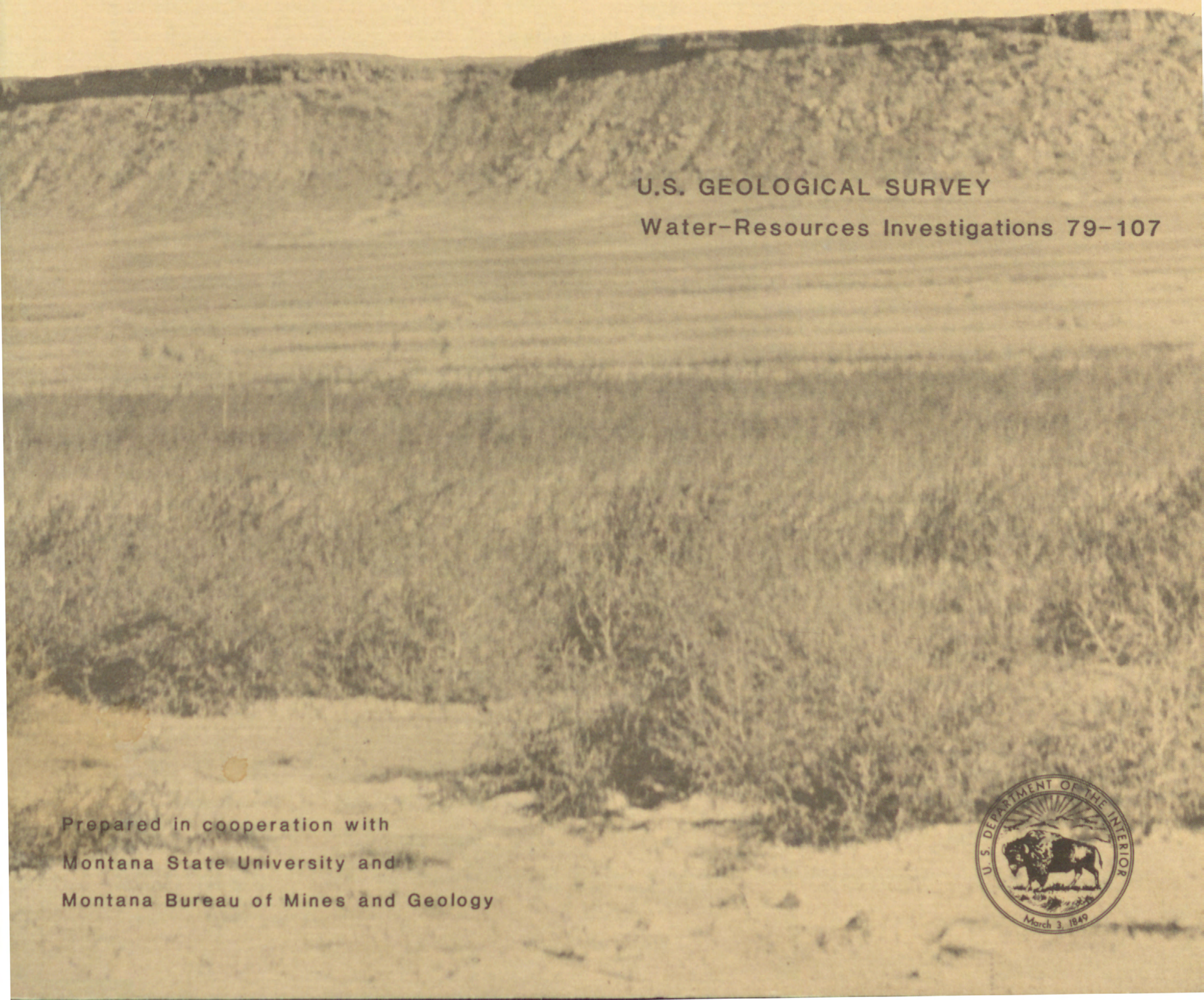
SALINE-SEEP DEVELOPMENT IN THE

HAILSTONE BASIN

NORTHERN STILLWATER COUNTY, MONTANA



U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 79-107

Prepared in cooperation with
Montana State University and
Montana Bureau of Mines and Geology

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.
4. Title and Subtitle SALINE-SEEP DEVELOPMENT IN THE HAILSTONE BASIN, NORTHERN STILLWATER COUNTY, MONTANA			5. Report Date November 1979
			6.
7. Author(s) Barney D. Lewis, Stephan G. Custer, Marvin R. Miller			8. Performing Organization Rept. No. USGS/WRI 79-107
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 428 Federal Building, Drawer 10076 Helena, Montana 59601			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 428 Federal Building, Drawer 10076 Helena, Montana 59601			13. Type of Report & Period Covered Final
			14.

15. Supplementary Notes

Prepared in cooperation with Montana State University and Montana Bureau of Mines and Geology

16. Abstract (Limit: 200 words) As a result of an increase in saline seep occurrence in Montana, a study was begun in 1974 to determine the hydrogeology of saline seeps in the Hailstone basin in south-central Montana. The aquifer is composed of colluvium of Holocene age derived from weathering of Cretaceous rocks. The impermeable Cretaceous Niobrara Formation underlies the saturated zone basinwide. The ground-water system is shallow, unconfined, and locally recharged. Ground-water levels and size of the saline seeps respond rapidly to precipitation in the basin. The appearance and growth of saline seeps are related to precipitation patterns; the agricultural practice of summer fallow; topography; the presence of a shallow, unconfined, and locally recharged ground-water system; and a soluble salt source. Continuous cropping could reduce the amount of water percolating beneath local recharge areas, and thus minimize the water available for seep formation and growth. The lateral variation in chemical quality of water from wells suggests a shallow flow system. The field specific conductance of 29 ground-water samples collected in 1976 ranged from 2,160 to 14,000 micromhos per centimeter and averaged 6,660 micromhos per centimeter. Water from saline seeps in the study area contains principally sodium, magnesium, calcium, and sulfate. The origin of salinity in the water appears to result from weathering of pyrite, carbonate minerals, and clay minerals. Nitrate is present in the ground water in concentrations of as much as 855 milligrams per liter.

17. Document Analysis a. Descriptors

* Saline seep, * hydrology, * geochemistry, * cultivation practices, geologic units, stratigraphy, structural geology, Montana

b. Identifiers/Open-Ended Terms

Hailstone basin, northern Stillwater County, south-central Montana

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution		32
	20. Security Class (This Page)	22. Price

(See ANSI–Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce

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UNITED STATES DEPARTMENT OF THE INTERIOR
CECIL D. ANDRUS, Secretary
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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

The following factors can be used to convert inch-pound units published herein to the International System (SI) of metric units.

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	hectare (ha)
cubic foot (ft^3)	28.32	liter (L)
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
pound per cubic inch (lb/in^3)	27.68	gram per cubic centimeter (g/cm^3)
square mile (mi^2)	2.590	square kilometer (km^2)

temperature, degrees Celsius (°C) = 0.556 (°F-32)

SALINE-SEEP DEVELOPMENT IN THE HAILSTONE BASIN, NORTHERN STILLWATER COUNTY, MONTANA

By

Barney D. Lewis, Stephan G. Custer[1], and Marvin R. Miller[2]

ABSTRACT

Saline seeps are areas where seepage of saline ground water has increased soil salinity and made the soil less agriculturally productive. As a result of an increase in saline seep occurrence in Montana, a study was begun in 1974 to determine the hydrogeology of saline seeps in the Hailstone basin in south-central Montana.

The aquifer is composed of colluvium of Holocene age derived from weathering of Cretaceous rocks. The impermeable Cretaceous Niobrara Formation underlies the saturated zone basinwide. The ground-water system is shallow, unconfined, and locally recharged. Ground-water levels and size of the saline seeps respond rapidly to precipitation in the basin.

The appearance and growth of saline seeps are related to precipitation patterns; the agricultural practice of summer fallow; topography; the presence of a shallow, unconfined, and locally recharged ground-water system; and a soluble salt source. Continuous cropping could reduce the amount of water percolating beneath local recharge areas, and thus minimize the water available for seep formation and growth.

The lateral variation in chemical quality of water from wells suggests a shallow flow system. The field specific conductance of 29 ground-water samples collected in 1976 ranged from 2,160 to 14,000 micromhos per centimeter and averaged 6,660 micromhos per centimeter. Water from saline seeps in the study area contains principally sodium, magnesium, calcium, and sulfate. The origin of salinity in the water appears to result from weathering of pyrite, carbonate minerals, and clay minerals. Nitrate is present in the ground water in concentrations of as much as 855 milligrams per liter. The high nitrate concentrations are interpreted to originate primarily from oxidation of organic material once native sod is broken by cultivation.

INTRODUCTION

A saline seep is an area where seepage of saline ground water has increased soil salinity and made the soil less agriculturally productive.

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A seep is wet, shows depressed crop or grass growth, and may develop white salt crusts. This definition of the modern saline seep excludes saline areas recognized by Lewis and Clark when they traveled through Montana (Bahls and Miller, 1973). These old, naturally occurring saline areas do not spread. In 1974, the Montana Department of State Lands in cooperation with the County Committees for Rural Development estimated that 262,000 acres of Montana land was affected by saline seeps. Of this amount, about 141,000 acres was nonirrigated land.

Montana has a large potential for saline seep development (Bahls and Miller, 1973). The annual increase in area affected by saline seeps in Montana has been estimated to be 10 percent relative to the first year of measurement (Miller and others, 1976). However, this growth rate of saline seeps cannot continue forever. Topographic considerations suggest that the growth rate should decrease after about 10 to 30 percent of the agricultural land has been affected. The rate may even become negative in response to changes in agricultural practices.

Purpose and scope

As a result of an increasing occurrence of saline seeps in Montana, the U.S. Geological Survey in 1974 began a study to determine the hydrogeology of saline seeps in the Hailstone basin. The study was made in cooperation with Montana State University and Montana Bureau of Mines and Geology, who were already investigating saline seeps in the Hailstone basin. The purposes of this study were to (1) determine the geologic and hydrologic controls on the saline seeps, and (2) determine the chemical quality of ground water in areas of saline seep.

During the summer of 1974, 30 shallow test holes were augered in the basin by the Montana Bureau of Mines and Geology. The holes were then cased and developed by bailing. Water samples were collected and water-level measurements were made at the test wells and at shallow domestic and stock wells in various parts of the basin.

Location and extent of area

The Hailstone basin is located northeast of Rapelje, Mont., in northern Stillwater County (fig. 1). It encompasses an area of 48 mi^2 in south-central Montana. The basin lies on the north edge of tributaries to Cedar Creek, which flows southeast into Big Lake near Molt.

Location numbering system

In this report, locations are numbered according to their geographic position within the rectangular grid system used by the U.S. Bureau of Land Management. The location may consist of as many as 12 characters.

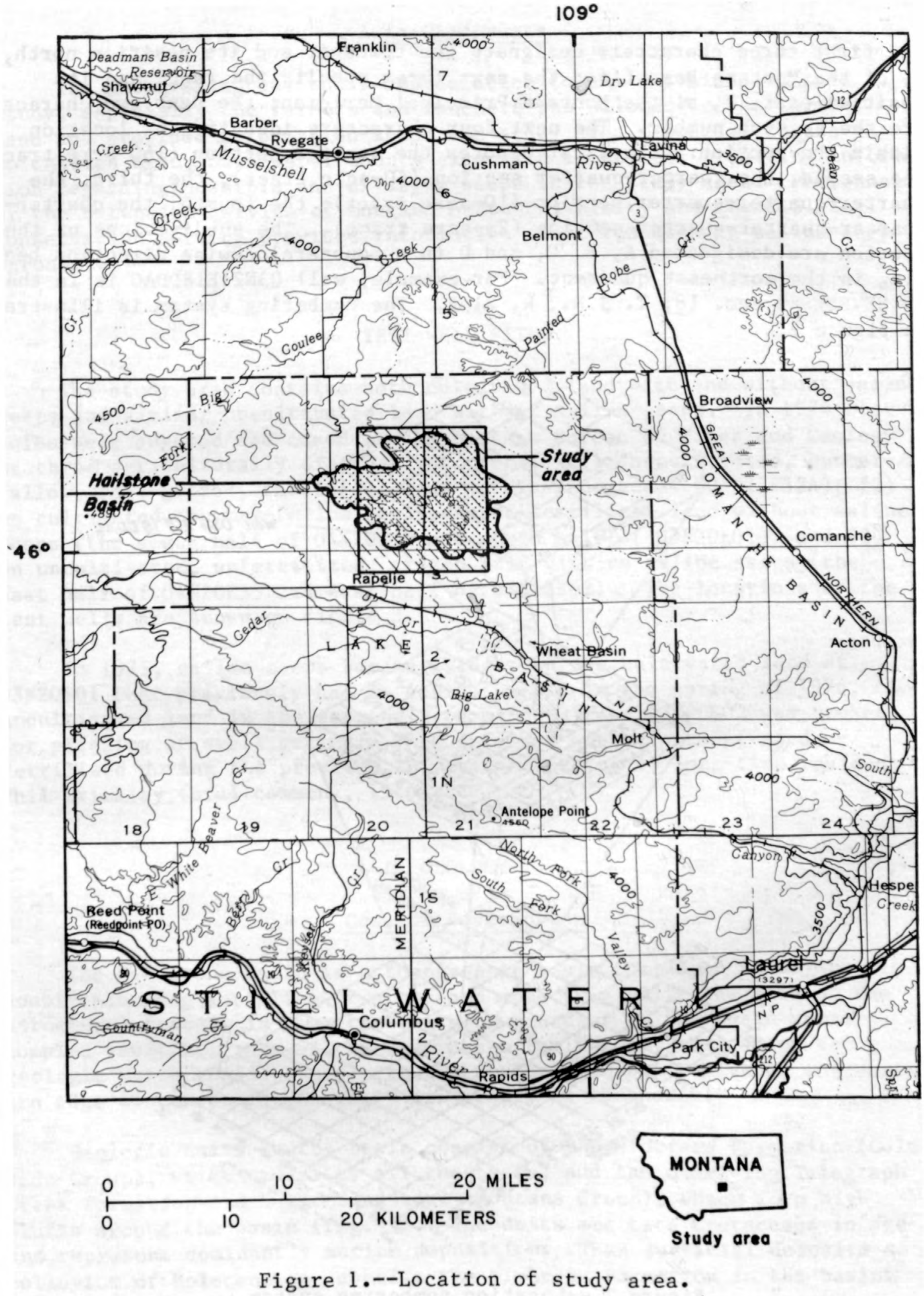


Figure 1.--Location of study area.

The first three characters designate the township and its position north, N, of the Montana Base Line; the next three specify the range and its position east, E, of the Montana Principal Meridian; the next two characters are the section number. The next four characters identify the location within the section: the first 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); the fourth, the quarter-quarter-quarter-quarter section ($2\frac{1}{2}$-acre tract). The subdivisions of the section are designated A, B, C, and D in a counterclockwise direction beginning in the northeast quadrant. For example, well 03N21E18DDAC is in the SW¼NE¼SE¼SE¼ sec. 18, T. 3 N., R. 21 E. The numbering system is illustrated in figure 2.

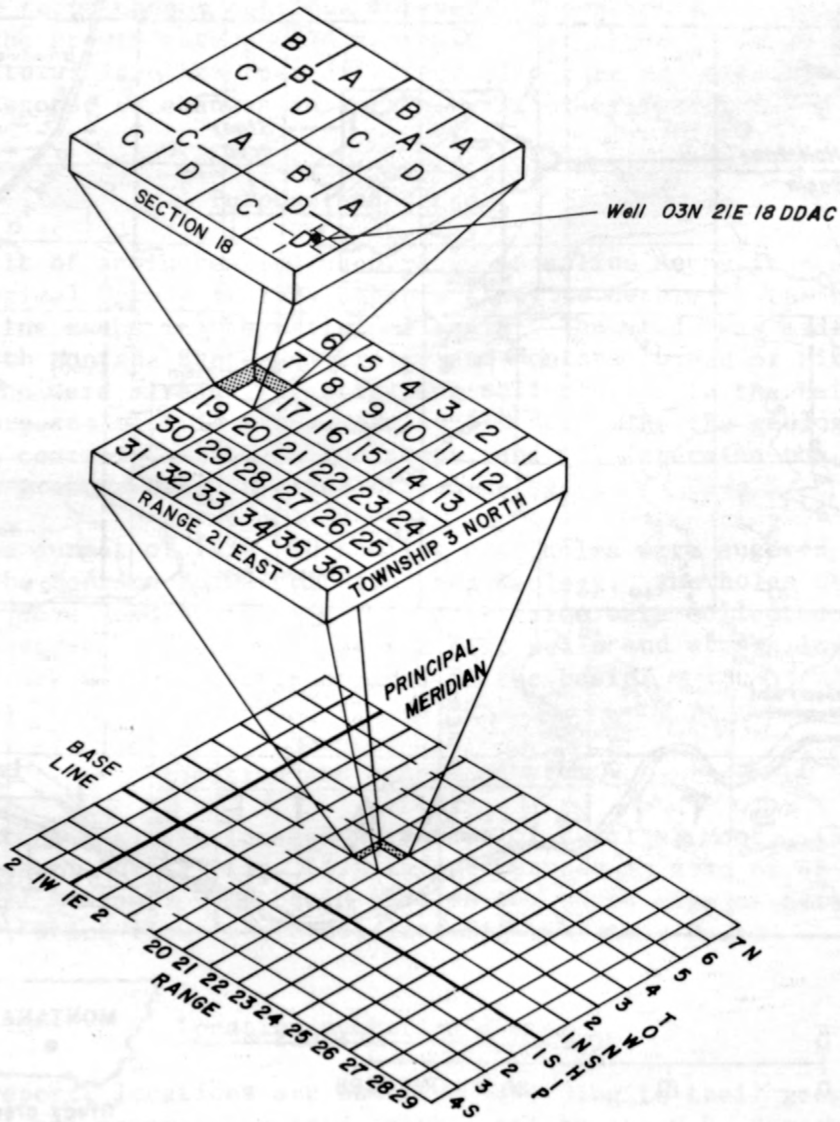


Figure 2.--Location numbering system.

Acknowledgments

The authors express their appreciation to all who aided in this study, especially the farmers and ranchers who allowed access to the land and provided information about the study area. Special thanks go to Charles Egan, Stillwater County extension agent, for providing information regarding possible and existing seeps in the study area. Personnel of the Extension Service of Montana State University and the U.S. Soil Conservation Service provided information about research in saline-seep agronomy.

TEST-WELL SITES

The study area contains both cultivated land with and without saline seeps and similar uncultivated land without saline seeps. In 1974 test holes were augered and cased by the Montana Bureau of Mines and Geology at three agriculturally distinct locations: (1) On cultivated, summer-fallow, fall-grazed, fertilized land with saline seeps (04N21E32A); (2) on cultivated, summer-fallow, fall-grazed fertilized land without saline seeps (the south half of 04N20E36 and north half of 03N20E01); and (3) on uncultivated, unfertilized, grazed land with no saline seeps (the east half of 04N20E35 and east half of 03N20E02). The locations of the test wells are shown on figure 3.

In 1975, saline seeps became evident on the cultivated land at 03N20E01 that previously had no saline seep. In the spring of 1976, the uncultivated land in the east half of 04N20E35 and 03N20E02 was broken for planting of small grains. This land had not been cultivated or fertilized during the previous 70 years according to long-time resident Phil Brickley (oral commun., 1976).

GEOLOGY

General description

The Hailstone basin is a topographic basin formed on an asymmetric doubly plunging anticline or elongated dome (fig. 3). The axis of the structural feature is near the southern boundary of the basin where complex faulting, part of the Lake Basin fault zone, has caused the geologic units to dip steeply to the south. Geologic units on the northern edge of the basin generally dip gently to the north.

Geologic units in the basin consist of the Niobrara Formation (Colorado Group), which underlies all the basin, and the overlying Telegraph Creek Formation and Eagle Sandstone (Montana Group), which form high bluffs around the basin (fig. 3). The units are Late Cretaceous in age and represent dominantly marine deposition. Thin surficial deposits of colluvium of Holocene age overlie the Niobrara Formation in the basin.

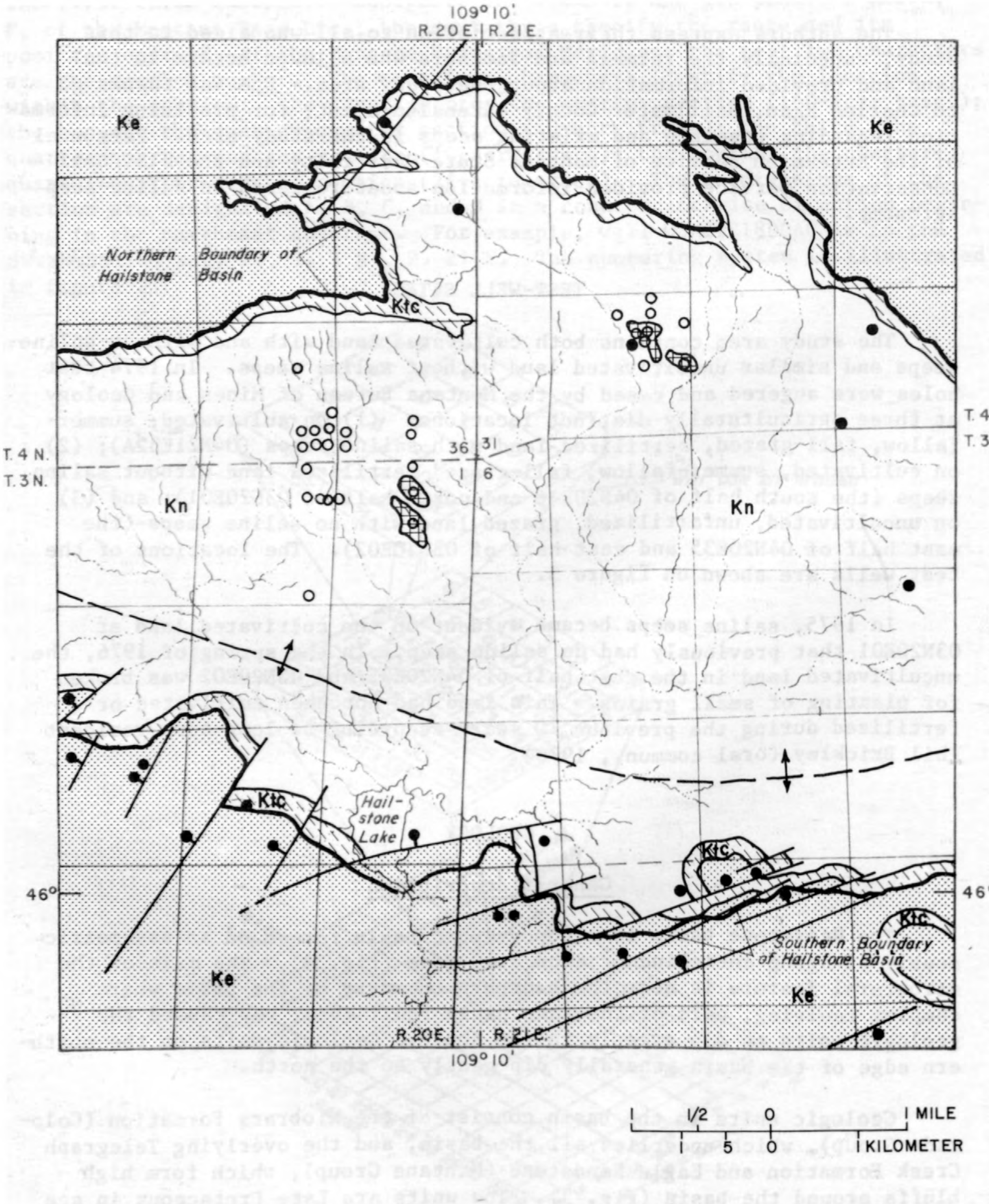
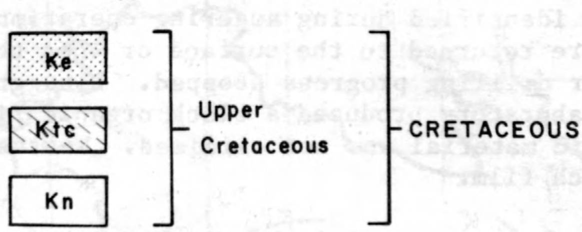


Figure 3.--Generalized bedrock geology (modified from Hancock, 1918).

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS
(Modified from Balster, 1971)

Ke EAGLE SANDSTONE AND YOUNGER UPPER CRETACEOUS UNITS UNDIFFERENTIATED -- Includes Eagle Sandstone, Claggett Shale, Judith River Formation, and Bearpaw Shale of Montana Group (0-2700 feet) -- Primarily marine dark-gray to brownish-gray, partly bentonitic shale with local silty and sandy intervals. Sandstone beds exhibit characteristics and fauna of brackish-water and freshwater deposits; contains some coal and lignite. Conformable contact with underlying unit

Ktc TELEGRAPH CREEK FORMATION -- Lowest formation of Montana Group (0-350 feet) -- Marine grayish-white partly shaly sandstone and sandy shale, and gray shale. Usually thin bedded and weathers to yellow in outcrops. Disconformable(?) with underlying unit

Kn NIOBRARA FORMATION -- Uppermost formation of Colorado Group (100-200 feet) -- Shallow marine deposit of dark-gray to black marly shale which weathers white in outcrop. Locally may almost be a shaly limestone

EXPLANATION

Contact

Fault - Dashed where inferred; bar and ball on downthrown side

Anticline or elongated dome--Approximately located

Saline seep

Test well of Montana Bureau of Mines and Geology

Domestic or stock well

The Niobrara Formation consists of relatively unweathered black shale. It was identified during augering operations when dry, black shale chips were returned to the surface or when the auger tip was inspected for shale after drilling progress stopped. Disaggregation of the black shale in the laboratory produced a black organic film, which suggests that the organic material was not oxidized. Weathered shale or colluvium produced no such film.

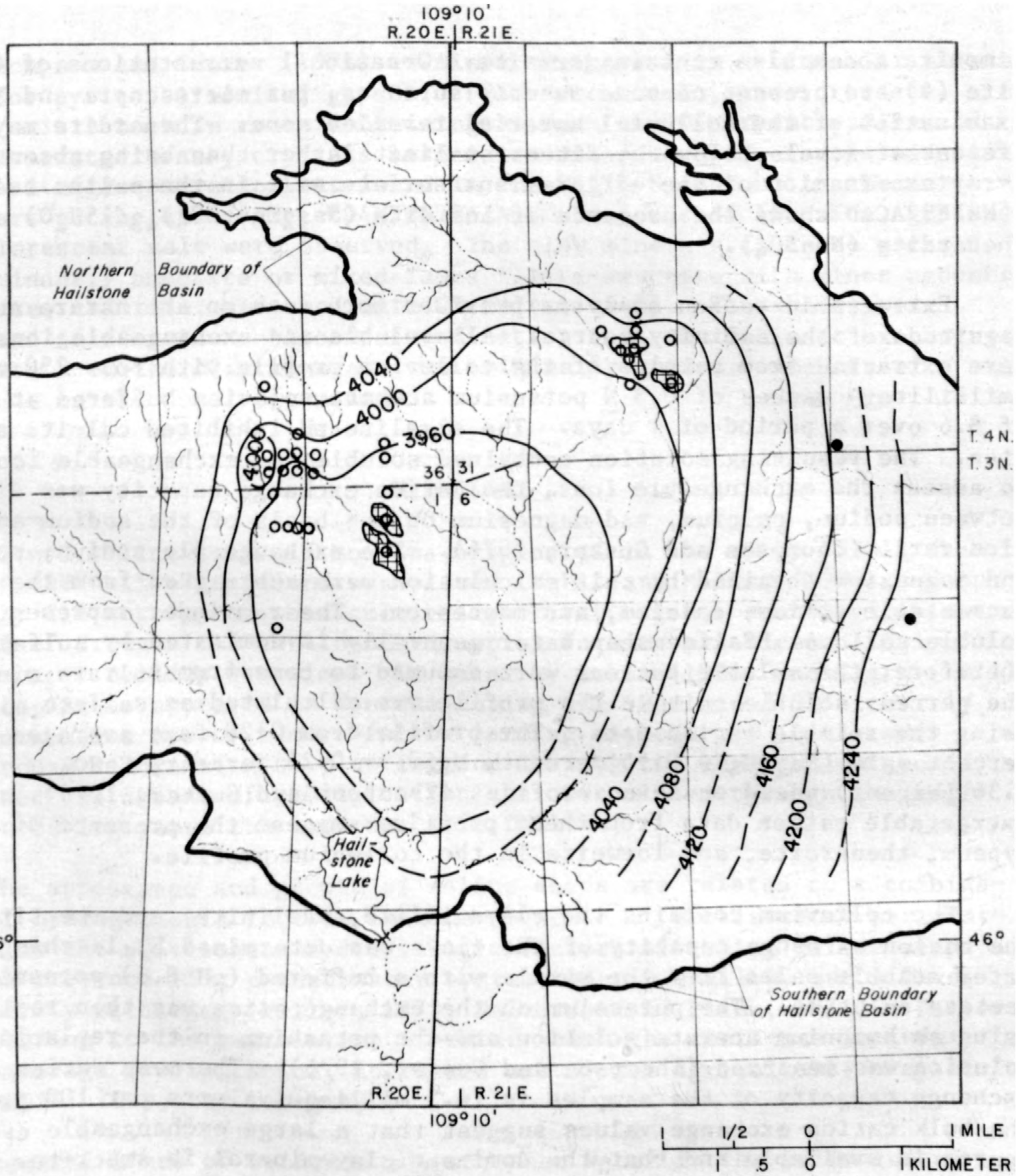
The black shale is overlain by weathered brown silty shale and brown silty to very fine sandy colluvium. The colluvium is derived from an escarpment of Telegraph Creek Formation and Eagle Sandstone on the north edge of the basin (Gieseker, 1957). The colluvium contains limonite and gypsum-rich stringers similar to those in outcrops at 04N21E29. The weathered shale and colluvium at many locations cannot be distinguished in auger samples and hence will be referred to collectively as colluvium.

The contact between colluvium and unweathered shale is irregular and has resulted from a complex history of weathering, erosion, and deposition. For example, at 04N20E35DDAB adjacent to an intermittent stream, the auger penetrated 50 feet of silty colluvium and then entered unweathered clayey shale. At 04N20E35DDCA unweathered shale is present within 8 feet of the surface. The contact between colluvium and unweathered shale slopes broadly to the south near the test wells (fig. 4), which is the reverse of the regional dip reported by Hancock (1918). The southward slope and basinal configuration of the unweathered shale of the Niobrara Formation at the study area are related to weathering and erosion and not to structure.

Mineralogy

A soluble salt source appears to be available throughout much of the area in Montana affected by saline seeps. The area is underlain by rocks of the Colorado and Montana Groups (Early and Late Cretaceous age) and the Fort Union Formation (Paleocene age) or their equivalents. Although these units do not contain evaporites, many investigators (for example, Knechtel and Patterson, 1956) have noted alkali (Na_2SO_4) in the outcrops. Sodium sulfate also occurs in the glaciated parts of northern Montana (Cole, 1926). This salt was probably redistributed by glaciers as they passed over alkali-rich outcrops.

The source of salinity in the Hailstone basin can be determined by analysis of the mineralogy of the surficial and subsurface material. The colluvium profile contains 2-30 percent carbonate minerals (Sonderegger and Miller, 1977). The high carbonate percentages occur in the Cca soil horizon. The high carbonate levels are from secondary deposits, which do not reflect the carbonate content of the bedrock. Outcrops at 04N21E31A and 04N21E31B in the escarpment north of the saline seeps and colluvium in the subsurface at 04N20E35DDCA contain zones of gypsum 0.04-0.12 inch thick below discontinuous limonite-rich zones about 6 inches thick. The



EXPLANATION

—4000— — STRUCTURE CONTOUR--Shows altitude of unweathered shale surface of Niobrara Formation. Dashed where approximately located. Contour interval 40 feet. National Geodetic Vertical Datum of 1929

Saline seep

○ Test well of Montana Bureau of Mines and Geology

● Domestic or stock well

Figure 4.--Configuration of the unweathered shale surface.

limonite zones also contain jarosite. Occasional encrustations of thenardite (?) are present on some outcrop surfaces, but microscopic and X-ray examination of the colluvial material revealed none. Thenardite may be present at levels below the detection limit rather than being absent. X-ray examination of the efflorescent surface salt in the saline seep at 04N21E32ACAD shows the presence of loeweite ($Na_{12}Mg_7(SO_4)_{13} \cdot 15H_2O$) and thenardite ($Na_2SO_4$).

Extractable cation analysis provides more data on the nature and magnitude of the salinity source. All soluble and exchangeable ions were extracted from samples of the colluvium profile with four 250 mL (milliliter) washes of 0.3 N potassium acetate solution buffered at a pH of 8.6 over a period of 4 days. The alkaline pH inhibited calcite solution. The resulting solution contained soluble and exchangeable ions. To assess the exchangeable ions, the cation exchange capacity was divided between sodium, calcium, and magnesium on the basis of the sodium-adsorption ratio (Thompson and Custer, 1976). The exchangeable sodium, calcium, and magnesium obtained by this calculation were subtracted from the extractable sodium, calcium, and magnesium. The remainder represents soluble cations. Saline-seep water generally is dominated by sulfate; therefore, the soluble cations were assumed to come from sulfate minerals. The percent soluble salt in the profile was calculated as sulfate minerals using the soluble cation data. The profile from 0-20 feet averages 2.75 percent salt (Na_2SO_4 = 0.15 percent, $MgSO_4$ = 0.24 percent, $CaSO_4$ = 2.36 percent) based on seven profiles (Thompson and Custer, 1976). The extractable cation data from these profiles suggest the presence of gypsum, thenardite, and loeweite in the colluvium profile.

The colluvium contains the clays illite, kaolinite, and smectite. The cation exchange capacity of the clays was determined by leaching the water soluble salts from the sample with a buffered (pH=8.6) potassium acetate solution. The potassium on the exchange sites was then replaced using an ammonium acetate solution and the potassium in the replacing solution was measured (Thompson and Custer, 1976). The mean cation exchange capacity of the samples is 14.3 milliequivalents per 100 grams. The bulk cation exchange values suggest that a large exchangeable cation source is available and that the dominant clay mineral is smectite.

The mineralogy of the unweathered material is more difficult to document, because of the solubility of the minerals produced by weathering and the scarcity of cored shale samples from depths greater than 650 feet. The best deep core is from the Gorr 3-10 well (02N20E10), approximately 5 miles southwest of the study area. This core is important because it is relatively continuous from 394 to 1,270 feet and includes both sandstone and shale. The core includes strata identified as Claggett Shale and Eagle Sandstone rather than the Niobrara Formation; however, the lithology and environment of deposition of the Claggett Shale are grossly similar to the Niobrara Formation at the study site (Gill and Cobban, 1973).

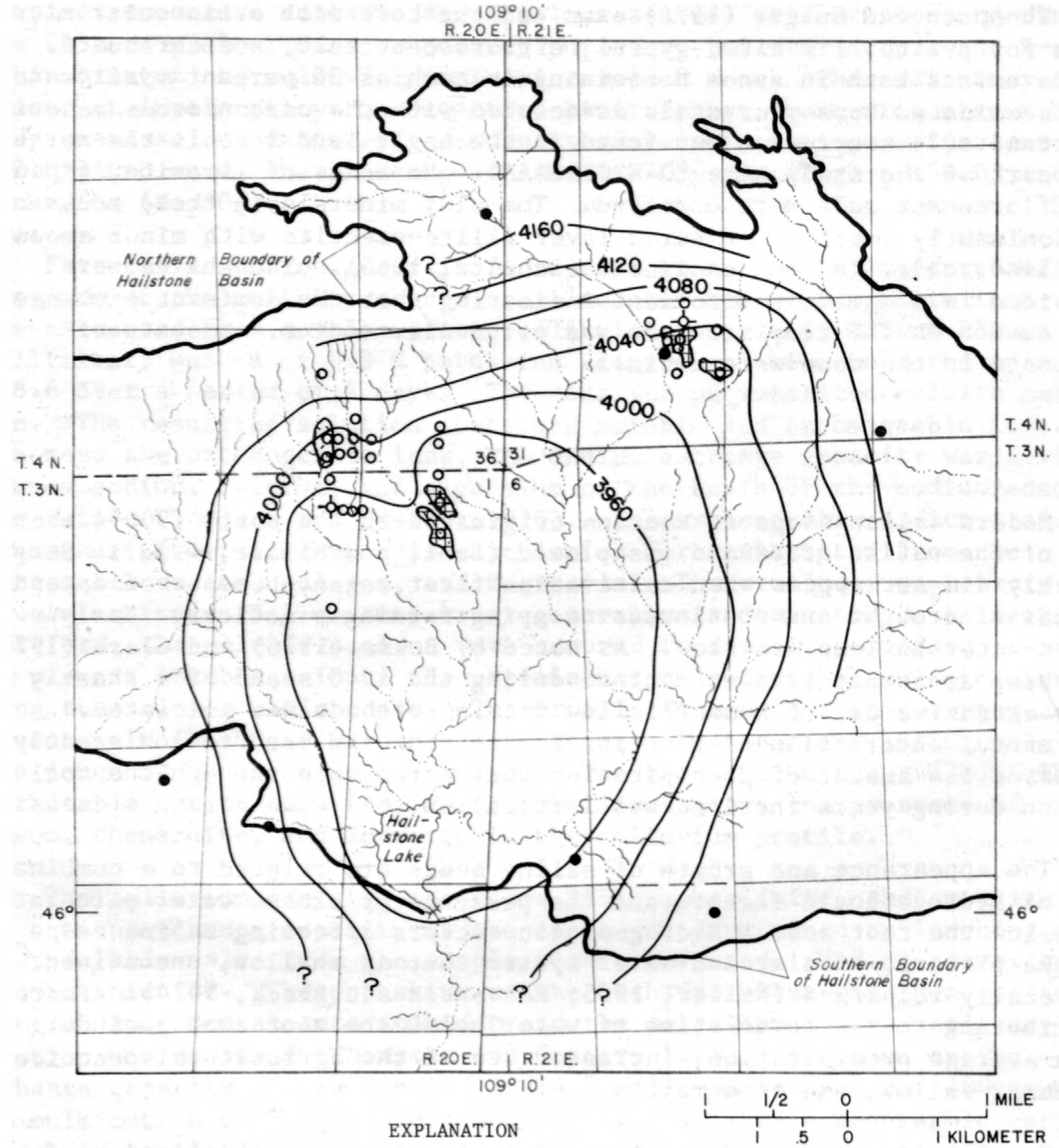
Thompson and Custer (1976) examined the core with a binocular microscope for pyrite, limonite, gypsum, efflorescent salt, and carbonate. Pyrite exists both in zones containing as much as 20 percent pyrite and as disseminated brassy crystals associated with the carbonaceous material. A marcasite(?) concretion was found in the Eagle Sandstone in the northwest part of the study site (04N20E22AAA). No zones of limonite, gypsum, or efflorescent salt were observed. The clay minerals in these rocks are dominantly smectite or mixed layer illite-smectite with minor amounts of illite, chlorite, and kaolinite (Schultz, 1965). The shales were deposited in a marine environment indicating that the dominant exchangeable cation on the clay minerals was originally sodium. Amounts of carbonate in the core were minimal.

HYDROLOGY

Modern saline seeps in Montana originated in the early 1900's when much of the native grassland was plowed (Bahls and Miller, 1973). Seeps probably did not appear when cultivation first began, because of extended periods of drought and continuous-cropping farming practices. Early ground-water buildup was slow. As noted by Bokma (1976) and Clark (1971), many seep areas appeared in Montana during the 1940's and 50's shortly after extensive use of summer-fallow farming methods was initiated. This annual alternation of planting and leaving the land fallow greatly increased the amount of precipitation that percolated through the soil horizon during years the land was left fallow.

The appearance and growth of saline seeps are related to a combination of hydrogeologic factors and the presence of excess water percolating below the root zone. Hydrogeologic factors affecting saline seeps are the presence of a ground-water system that is shallow, unconfined, and locally recharged (Miller, 1975; Halvorson and Black, 1974). Factors contributing to the percolation of water below the root zone include: above-average precipitation, increased use of the agricultural practice of summer fallow, and topography.

Several lines of evidence suggest that water in the colluvium of the study area is shallow, unconfined, and locally recharged. The auger penetrated wet (10-25 percent moisture) colluvium and entered dry (5-10 percent moisture) black shale at less than 59 feet in all test holes (Thompson and Custer, 1976). This indicates an unconfined ground-water system above the impermeable black shale, which is at a relatively shallow depth throughout the basin. The fact that the configuration of the water table (fig. 5) closely parallels the configuration of the land surface and the water levels are near land surface shows that the system is shallow and locally recharged. The water table also reflects the configuration of the unweathered shale surface within the confines of the basin boundaries. The structurally high anomaly on the unweathered shale surface at 04N20E35D (fig. 4) corresponds closely to the area of no shallow ground water on figure 5, which is also evidence of a shallow



EXPLANATION

——4000——? WATER-TABLE CONTOUR--Shows altitude of water table. Queried where doubtful. Contour interval 40 feet. National Geodetic Vertical Datum of 1929

Area of no shallow ground water

Saline seep

Test well of Montana Bureau of Mines and Geology

Observation test well of Montana Bureau of Mines and Geology used to construct water-level hydrographs (figs. 6-8)

Domestic or stock well

Figure 5.--Approximate configuration of the water table, summer 1976.

ground-water system.

Additional evidence that the ground-water system is shallow and locally recharged is the effect of precipitation. In 1975 the precipitation near Rapelje was 70 percent above normal (National Oceanic and Atmospheric Administration, 1976) and the saline seep at 04N21E32ACA nearly doubled in size. During the same year two saline seeps appeared at 03N20E01ABC and 03N20E01ACC for the first time. Hydrographs for three test wells (figs. 6, 7, and 8) show that the water levels rise sharply in response to rainfall during the spring and early summer when the snowpack has melted and evapotranspiration rates are low.

Test well 03N20E02AACD (fig. 6) was drilled in an area of uncultivated native sod that was plowed for the first time in the early spring of 1976. The water-level curve shows a rapid response to heavy spring and early summer precipitation in 1975, even though a heavy cover of native sod was present. Following initial tillage in 1976, the water level remained fairly constant, with a slight rise being registered after spring and early summer precipitation. The consumptive water use of the newly planted spring grains appears to have effectively minimized the amount of water percolating to the shallow ground-water system.

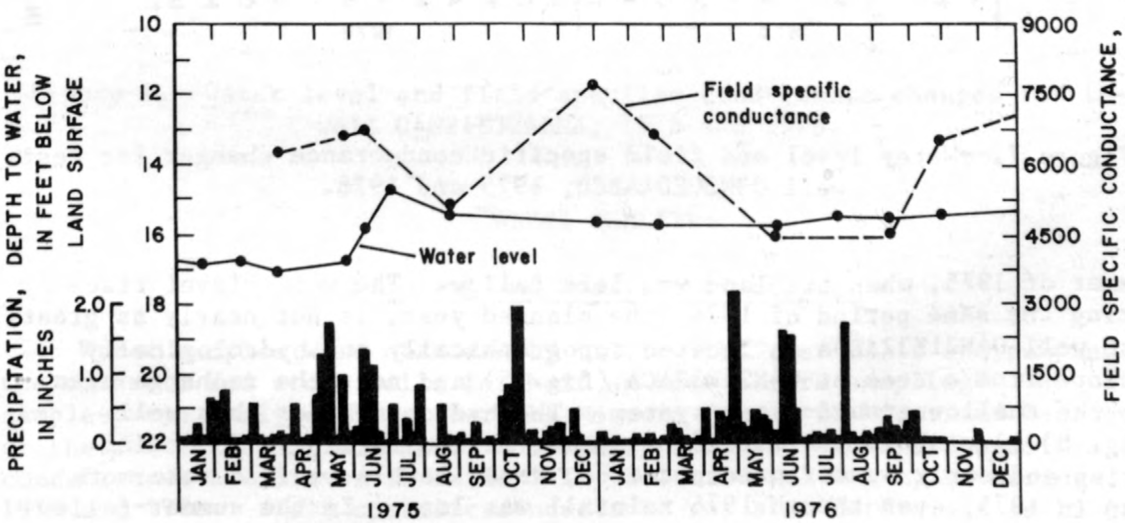


Figure 6.--Water level and field specific conductance changes for test well 03N20E02AACD, 1975 and 1976.

Hydrographs for test wells 03N20E01ABCD and 04N21E32ABDA (figs. 7 and 8, respectively) also illustrate the effect of plant growth on the amount of shallow ground-water recharge. Well 03N20E01ABCD is located in one of the saline seeps that first appeared in 1975. The hydrograph (fig. 7) shows a large rise in water level during the spring and early

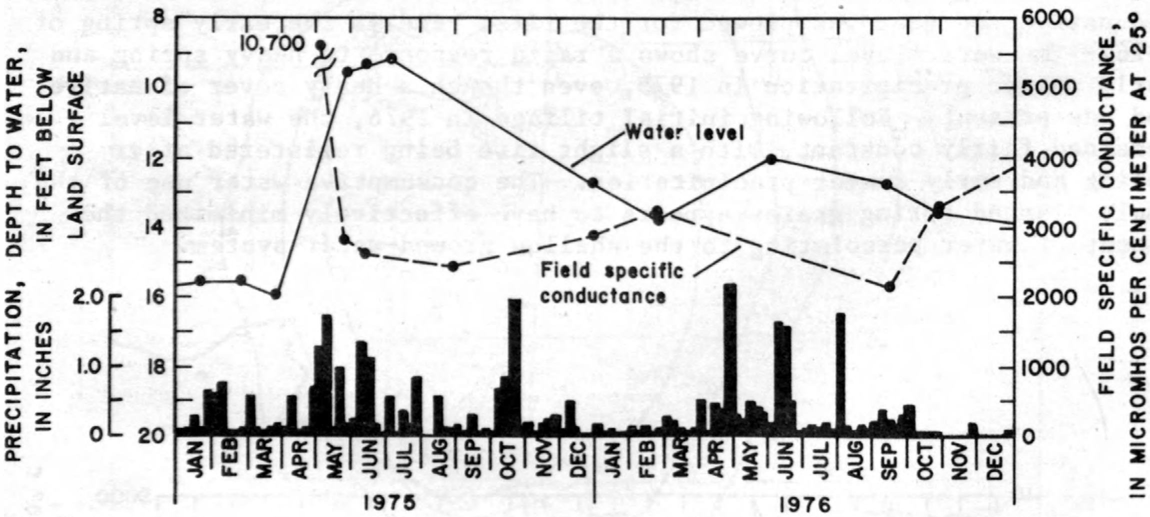


Figure 7.--Water level and field specific conductance changes for test well 03N20E01ABCD, 1975 and 1976.

summer of 1975, when the land was left fallow. The water-level rise during the same period of 1976, the planted year, is not nearly as great. Test well 04N21E32ABDA is located topographically and hydrologically upslope from a seep at 04N21E32ACA (fig. 5) and near the recharge area for the shallow ground-water system. The hydrograph for this well (fig. 8) also shows the effect of summer-fallow farming. Following spring and early summer precipitation, water levels in 1976 rose more than in 1975, even though 1976 rainfall was less. In the summer-fallow sequence, 1975 was the planted year and 1976 was the fallow year.

From the foregoing discussion it appears that the amount of precipitation percolating through the soil to the shallow ground-water system could be effectively controlled by plant utilization of percolating water in the local recharge areas. Reduction in the amount of percolating water, which would minimize the water available for seep formation and growth, could be accomplished by continuous cropping in these local areas.

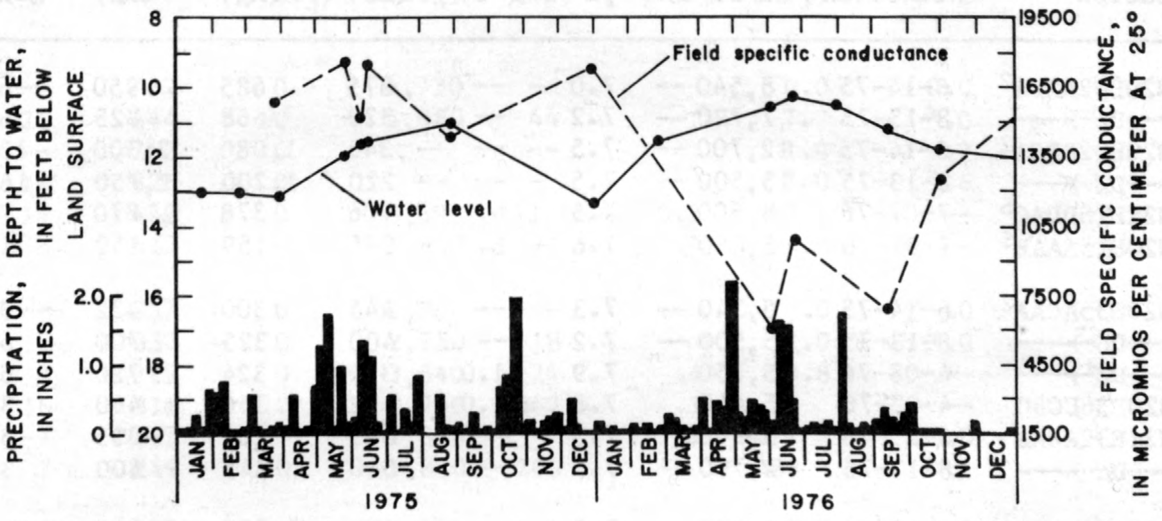


Figure 8.--Water level and field specific conductance changes for test well 04N21E32ABDA, 1975 and 1976.

WATER QUALITY

Sampling and analysis procedures

Water samples were obtained by bailing the test wells and pumping the domestic and stock wells for half an hour before sampling. The samples were analyzed by either the Montana Bureau of Mines and Geology or the University of Montana. Laboratory analyses and field specific conductances are listed in table 1 for selected wells sampled during 1975 and 1976. Field specific conductance was also determined in 1976 at 29 additional sites (table 2).

Both laboratories used the same procedures for calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, and fluoride. The cations were analyzed on water passed through a 0.45 micrometer (micron) filter using an atomic absorption spectrophotometer. Carbonate and bicar-

Table 1.--Chemical analyses of water from selected wells
[Constituents are dissolved and in milligrams per liter unless indicated otherwise]

Well[1] location	Date of collection	Field specific conductance (µmho/cm at 25°C)	Laboratory pH	Field temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sodium adsorption ratio (SAR)
03N20E02AABA[2]	6-14-75	8,540	7.0	--	375	685	950	6.7
-----Do-----	8-13-75	7,720	7.2	--	320	668	825	6.0
03N20E02DDCA[2]	6-14-75	12,700	7.5	--	345	1,080	2,300	13.7
-----Do-----	8-13-75	15,500	7.5	--	220	1,200	2,750	16.1
03N21E18DDAC[5]	7-07-76	8,500	7.5	6.0	406	378	870	7.5
04N20E25AAAB[5]	7-07-76	3,050	7.6	8.0	295	159	150	1.8
04N20E35ACAA[2]	6-14-75	5,340	7.3	--	445	300	432	3.9
-----Do-----	8-13-75	5,500	7.2	--	400	325	700	6.3
-----Do-----	4-08-76	5,750	7.9	11.0	376	324	720	6.6
04N20E36CCBC	4-08-76	5,440	7.8	12.0	472	356	460	3.9
04N21E32ABAA	6-25-75	5,200	7.3	--	545	250	395	3.5
-----Do-----	8-13-75	4,790	7.3	--	540	245	400	3.6
04N21E32ABDA	8-13-75	17,000	7.7	--	435	1,780	2,430	11.5
04N21E32ACAB	4-08-76	12,700	8.0	7.0	196	1,060	2,250	14.0
04N21E32ACAD	6-14-75	9,470	7.2	--	420	500	1,380	10.7
-----Do-----	8-13-75	9,210	7.3	--	390	480	1,390	11.1
04N21E34CCCC[5]	7-07-76	13,100	7.9	8.0	430	592	1,820	13.4

[1]Shallow wells representing highest water-table conditions. Wells are cased test holes except as indicated.
[2]Well drilled on land uncultivated until spring 1976.
[3]S. G. Custer, using facilities of the University of Montana.
[4]Sample acidified.
[5]Domestic or stock well.
[6]Montana Bureau of Mines and Geology.

Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Nitrogen ammonia (NH_4)	Analysis by
--	762	0	4,730	--	--	0.0	0.0	([3])
21	644	0	4,980	44	--	[4].7	[4].0	([3])
--	762	0	--	--	--	1.4	.2	([3])
18	826	0	--	--	--	[4].0	[4].8	([3])
14	476	0	3,690	117	0.2	49	--	([6])
6	413	0	1,330	24	.4	.8	--	([6])
--	337	0	2,960	--	--	.0	.0	([3])
8	333	0	2,750	18	--	[4]1.0	[4].0	([3])
8	219	0	3,540	24	.4	3.8	--	([6])
16	318	0	2,760	302	.1	76	--	([6])
--	257	0	1,810	--	--	172	.0	([3])
7	249	0	1,820	205	--	[4]33	[4].1	([3])
23	475	0	12,400	161	--	[4]7.7	[4].0	([3])
14	498	0	8,640	260	.5	117	--	([6])
--	457	0	4,920	--	--	78	.9	([3])
13	463	0	5,020	194	--	[4]33	[4].0	([3])
13	497	0	6,150	208	.3	468	--	([6])

Table 2.--Field specific conductance of ground water, summer 1976

[Measurements made in September by Montana Bureau of Mines and Geology except as noted]

Well location	Field specific conductance (µmho/cm at 25°C)	Field temperature (°C)
03N20E01ABBB	9,080	9.0
03N20E01ABCD	2,160	9.5
03N20E01ACCA	2,530	11.0
03N20E01BCBB	14,000	10.0
03N20E02AABA[1]	4,760	10.5
03N20E02AACD	4,520	10.0
03N20E02AADC	10,730	11.0
03N20E02AADD	13,300	11.5
03N20E02DDCA	10,900	11.0
03N21E18DDAC[2]	8,500	6.0
04N20E25AAAB[2]	3,050	8.0
04N20E35DADA	3,970	11.0
04N20E35DDAA	2,240	10.0
04N20E35DDAB	2,260	10.0
04N20E35DDDA	3,250	10.0
04N20E35DDDB	2,600	10.0
04N20E36CCBA	8,910	10.0
04N20E36CCBC	3,760	9.0
04N20E36DBCC	7,150	11.0
04N20E36DCBB	8,400	9.0
04N21E32AADD	5,200	9.5
04N21E32ABCB	9,630	11.0
04N21E32ABDA	6,970	12.0
04N21E32ACAA[1]	9,390	12.0
04N21E32ACAB	6,500	13.5
04N21E32ACAD	6,670	10.0
04N21E32ACDC	3,300	10.0
04N21E32ADDD	6,460	11.0
04N21E34CCCC[2]	13,100	8.0

[1] Measurement by Montana Bureau of Mines and Geology, June 1976.
[2] Measurement by U.S. Geological Survey, July 1976.

bonate were measured using unfiltered samples and the acid titration procedure described by Brown, Skougstad, and Fishman (1970); samples were analyzed within 48 hours of sampling. Chloride was measured using the mercuric nitrate method (American Public Health Association and others, 1975). Fluoride was measured using a fluoride specific-ion electrode. Different methods were used to analyze for sulfate. The Montana Bureau of Mines and Geology used the thorin method (Brown, Skougstad, and Fishman, 1970). The University of Montana used an electrochemical lead titration procedure (Goertzen and Oster, 1972).

Nitrate was determined by different methods in 1975 and 1976, owing to the fact that the samples were analyzed by different laboratories (table 3). In 1975, the samples were acidified with concentrated sulfuric acid in the field to a pH of 2 and analyzed for nitrate within 48 hours in the University of Montana laboratory using the micro-kjeldahl procedure of Bremner and Keeney (1966). In 1976, the samples were acidified, frozen, and analyzed for nitrate by the Soil, Plant, and Irrigation Water-Testing Laboratory at Montana State University 4 months after sampling by the chromotropic acid method of West and Ramachandran (1966).

Analytical interpretations

The chemical analyses tend to support the concept that the ground-water system in the basin is shallow, unconfined, and locally recharged. The support is mainly in the form of field-determined specific conductance of well water, field temperature of well water, and contrast in water-quality types.

Field specific conductance was determined periodically at three test wells (figs. 6-8). Following periods of major precipitation, conductance increased or decreased depending on seasonal and agricultural variations. The changes were not directionally consistent but responded rapidly to precipitation. The conductance curve of test well 03N20E02AACD (fig. 6) suggests that values do not vary significantly from precipitation on native sod (1975) versus newly cropped soil (1976). Specific conductance values decrease with rising water levels, indicating dilution of the existing ground water by fresher water produced by recent precipitation. This relationship may be due to minimal transit time for water percolating through the highly permeable soil above the colluvium. Water from test well 03N20E01ABCD (fig. 7), which is located in a saline seep, also shows decreasing conductance with rising water levels. This relationship appears to be true regardless of whether the land is planted or left fallow. Topographically and hydrologically upslope from a seep, test well 04N21E32ABDA exhibits a slightly differing specific-conductance curve (fig. 8). During 1975, the planted year, the conductance values remained high even though the water level increased slightly. This result indicates that very little water percolated through the soil to the shallow ground water. In 1976 the conductance values were reduced by dilution as the land surface was left fallow and water levels increased. All the curves demonstrate that as the time of residence for the diluted ground water increases, the concentrations of dissolved constituents increase approximately to their previous levels.

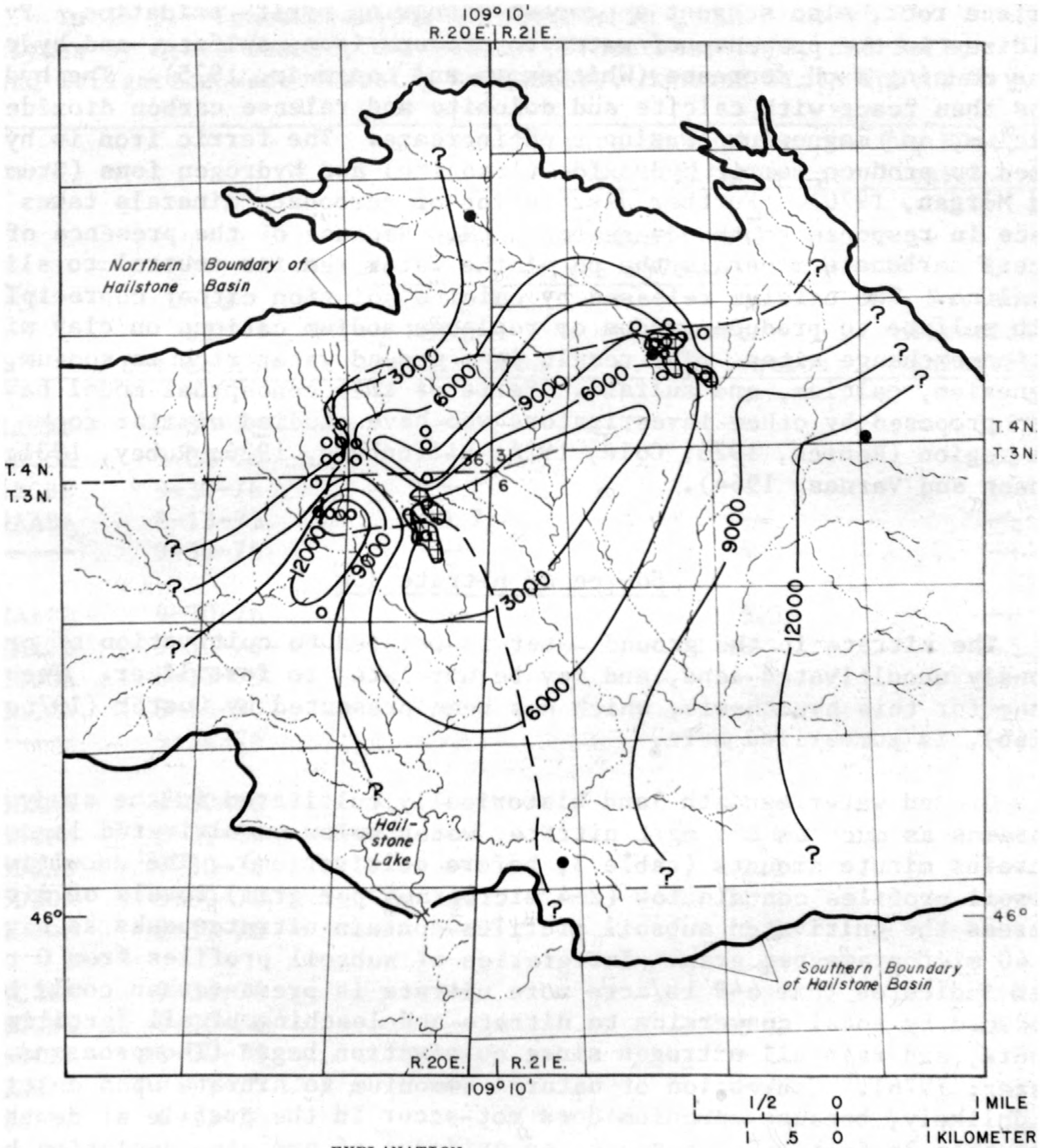
Field specific conductance tends to be highly varied over short lateral distances (fig. 9). Conductance values of 29 ground-water samples collected in 1976 ranged from 2,160 to 14,000 μmho/cm (micromhos per centimeter) and averaged 6,660 μmho/cm (table 2); water having the highest values generally occurs in places topographically higher than the saline seeps (fig. 9). The specific-conductance curve of figure 7 also shows that before seep formation in 1975 at 03N20E01ABCD, the conductance was three to five times greater than that after seep formation. These relationships are unexpected because concentration by evapotranspiration and the location of the seep at the low end of the ground-water flow system should result in the highest specific conductance values being in the saline seeps.

Several hypotheses for the observed conductance relationships are possible. The ground-water flow system may be stagnant in local depressions on the unweathered shale surface in some areas. Water in the depressions would have a longer residence time and, therefore, a higher concentration of dissolved solids. Also, density of water becomes greater with increasing concentrations of dissolved solids. Thus, lighter less-concentrated ground water could flow over and leave undisturbed the denser water in subsurface depressions. Perhaps the water in the saline seep could be moving in semiconfined zones that contain water of differing quality. The test wells are perforated from the bottom of the hole to about 3 feet below the land surface; therefore, water samples are composites of the saturated zone, and the hypotheses cannot be substantiated. Regardless of the transporting mechanism, the heterogeneous array in water quality is not indicative of a more homogeneous regional flow system.

Field-measured temperatures of well water (table 2) also vary greatly over small horizontal distances. The variability is indicative of a shallow ground-water system wherein some measuring points are contiguous to local recharge areas.

The water-quality types observed in the study area are generally inconsistent with deep regional or subregional flow systems. Water from deep wells (greater than about 400 feet) penetrating rocks of the Montana or Colorado Group is of the sodium chloride or sodium bicarbonate type (Thompson and Custer, 1976). Water from saline seeps in the study area contains principally sodium, magnesium, calcium, and sulfate.

The mineralogy and water chemistry suggest that the probable origin of salinity in the region is weathering of pyrite, carbonate minerals, and clay minerals. Jarosite is a common weathering product of pyrite (Warshaw, 1955). The presence of pyrite and absence of gypsum in the deep bedrock, and the absence of pyrite and presence of gypsum in the



EXPLANATION

—6000—? LINE OF EQUAL SPECIFIC CONDUCTANCE--Queried where doubtful. Interval 3000 micromhos per centimeter. Data given in table 2

— — — ? LINE OF NITRATE CONCENTRATION of 45 milligrams per liter. Queried where doubtful. Concentration is higher east of line and lower west of line

Saline Seep

o Test well of Montana Bureau of Mines and Geology

• Domestic or stock well

Figure 9.--Field specific conductance and generalized nitrate concentration of shallow ground water, summer 1976.

surface rock, also suggest a process involving pyrite oxidation. Pyrite oxidizes in the presence of water to produce iron, sulfate, and hydrogen ions causing a pH decrease (Whittemore and Langmuir, 1975). The hydrogen ions then react with calcite and dolomite and release carbon dioxide, calcium, and magnesium causing a pH increase. The ferric iron is hydrolyzed to produce ferric hydroxide (limonite) and hydrogen ions (Stumm and Morgan, 1970). Further dissolution of carbonate minerals takes place in response to the decrease in pH. Because of the presence of excess carbonate minerals the pH of the water remains neutral to slightly alkaline. The calcium released by calcite solution either coprecipitates with sulfate to produce gypsum or replaces sodium cations on clay mineral cation-exchange sites. The result is a ground water rich in sodium, magnesium, calcium, and sulfate. Parts of this conceptual model have been proposed by other investigators who have studied similar rocks in the region (Renick, 1925; Cole, 1926; Riffenburg, 1926; Rubey, 1931; Jensen and Varnes, 1964).

Source of nitrate ion

The nitrate in the ground water is related to cultivation of previously uncultivated land, and may be unrelated to fertilizer. The evidence for this hypothesis, which has been presented by Custer (1976a; 1976b), is summarized here.

Ground water beneath land historically cultivated in the study area contains as much as 855 mg/L nitrate; water below uncultivated land contains minute amounts (table 3, before cultivation). The uncultivated subsoil profiles contain low (2-4 micrograms per gram) levels of nitrate, whereas the cultivated subsoil profiles contain nitrate peaks as high as 40 micrograms per gram. Integration of subsoil profiles from 0 to 25 feet indicates that 649 lb/acre more nitrate is present than could be produced by total conversion to nitrate and leaching of all fertilizer, manure, and rainfall nitrogen since cultivation began (Thompson and Custer, 1976). Conversion of natural ammonium to nitrate upon cultivation is unlikely, because ammonium does not occur in the profile at depths of less than 36 feet. Furthermore, no evidence of ammonium depletion below cultivated land was documented. The only source that appears to quantitatively account for the nitrate excess is conversion of organic nitrogen in the A soil horizon to nitrate by micro-organisms in response to increased aeration and moisture content due to cultivation of native sod (Custer, 1976b).

Cultivation of the previously uncultivated land in 1976 provided new evidence supporting the hypothesis that cultivation leads to an increase of nitrate in ground water. Since cultivation, nitrate has appeared in the ground water where previously only small amounts were present (table 3). Also, the location of the line of 45 mg/L (milligrams per liter) nitrate concentration (fig. 9) is nearly identical to the location of the cultivated/uncultivated land-use boundary which existed before 1976.

Table 3.--Concentrations of nitrate in ground water[1]
[Analyses by Steve Custer, University of Montana, 1975, and Soil, Plant, and Irrigation Water-Testing Laboratory, Montana State University, 1976]

Well location	Date of collection	Nitrate concentrations (as NO_3), in milligrams per liter: Surface cultivated only since 1976: Before cultivation	Nitrate concentrations (as NO_3), in milligrams per liter: Surface cultivated only since 1976: After cultivation	Nitrate concentrations (as NO_3), in milligrams per liter: Surface historically cultivated
03N20E01ABBB	9-30-76	--	--	368
03N20E01ACCA	9-30-76	--	--	12
03N20E01BCBB	9-30-76	--	--	66
03N20E02AABA	8-13-75	0.7	--	--
-----Do-----	9-30-76	--	34	--
03N20E02AACD	9-30-76	--	5.3	--
03N20E02AADD	9-30-76	--	--	265
03N20E02DDCA	8-13-75	.0	--	--
04N20E35ACAA	8-13-75	1.0	--	--
-----Do-----	9-30-76	--	14	--
04N20E35DADA	9-30-76	--	71	--
04N20E35DDAA	9-30-76	--	4.4	--
04N20E35DDAB	9-30-76	--	2.2	--
04N20E35DDDA	9-30-76	--	11	--
04N20E35DDDB	9-30-76	--	2.2	--
04N20E36CCBA	9-30-76	--	--	855
04N20E36CCBC	9-30-76	--	--	285
04N20E36DCBB	9-30-76	--	--	332
04N21E32ABAA	8-13-75	--	--	33
04N21E32ABDA	8-13-75	--	--	7.7
04N21E32ACAD	8-13-75	--	--	33

[1] All samples acidified in the field.

Nitrate concentrations exceeding 45 mg/L occur east of the boundary, which is the area historically cultivated. The 45 mg/L nitrate (as NO_3) concentration is the recommended limit for domestic consumption as defined by the U.S. Environmental Protection Agency (1976).

The newly cultivated land received fertilizer having the composition 18 percent nitrogen, 40 percent phosphorus, and 6 percent potassium at a rate of 61 lb/acre. The contribution of nitrate from the fertilizer to the ground water was evaluated using a mass balance calculation. The general procedure adopted was to calculate the volume of water in the ground-water system in the area, assume addition of the fertilizer to the ground water as nitrate, and compare the value obtained with the measured nitrate concentrations. This calculation was possible because the land was unfertilized before 1976 and the nitrate concentration in ground water was measured 6 months after the fertilizer was added. The following assumptions were made: (1) All nitrogen in the fertilizer was converted to nitrate and leached into the ground water (48 lb/acre nitrate), and (2) the mean saturated thickness in the area is represented by the average difference between the static water level and the depth to dry shale (20 ft).

The measured mean bulk density of the soil profile is 0.07 lb/in^3, and the mean measured water content of the saturated zone is 17 percent (Thompson and Custer, 1976). Thus, 1 acre contains 2.6×10^5 ft^3 of water from 0 to 20 feet. If fertilizer were the sole source of the nitrate, the concentration in the ground water would be about 3 mg/L. However, the observed mean concentration of nitrate in the ground water was 18 mg/L. Thus, fertilizer is probably not the sole source of nitrate in the ground water.

The reason for high nitrate concentrations (table 3) in water beneath land that has been cultivated for a long time is not known with certainty. One hypothesis is that the release of nitrate from organic material is gradual and that the nitrate is stored below the root zone until it is transported into the ground-water system during deep percolation (Custer, 1976a; 1976b).

SUMMARY

1. The aquifer in the study area is composed of colluvium, which is derived from an escarpment of the Telegraph Creek Formation and Eagle Sandstone plus weathered shale at the top of the Niobrara Formation. Unweathered shale of the impermeable Niobrara Formation underlies the saturated zone basinwide.

2. The appearance and growth of saline seeps are related to precipitation patterns; the agricultural practice of summer fallow; topography; the presence of a shallow, unconfined, and locally recharged ground-water system; and a soluble salt source.

3. The ground-water system in the study area is shallow, unconfined, and locally recharged. The configuration of the water table closely parallels the configuration of the land surface and the unweathered shale surface of the Niobrara Formation. Ground-water levels and the size of the saline seeps respond rapidly to precipitation.

4. Reduction in the amount of water percolating to the ground-water system, which would minimize the water available for seep formation and growth, could be accomplished by continuous cropping in local recharge areas.

5. The field specific conductance of 29 ground-water samples collected in 1976 ranged from 2,160 to 14,000 μmho/cm and averaged 6,660 μmho/cm; water having the highest values generally occurs in places topographically higher than the saline seeps.

6. The mineralogy and water chemistry suggest that the probable origin of salinity in the region is weathering of pyrite, carbonate minerals, and clay minerals.

7. High nitrate concentrations of as much as 855 mg/L in the ground water are interpreted to originate primarily from organic material once native sod is broken by cultivation.

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