Geohydrology Of The

South Bismarck Area

Burleigh County, North Dakota

By

Steve W. Pusc

North Dakota Ground Water Studies
Number - 90 - Part II
North Dakota State Water Commission

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SOUTH BISMARCK AREA,
BURLEIGH COUNTY,
NORTH DAKOTA

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General Statement

Portions of Bismarck, and the floodplain south of the city, have historically been subject to Missouri River flooding. Because of this flooding, land use on the floodplain had largely been restricted to open use such as agriculture, wildlife, parks, recreation, etc. Construction of the Garrison Dam, 60 miles northwest of Bismarck, has however, eliminated the threat of serious yearly flooding, thus opening up the floodplain to residential and commercial development.

Water levels in the South Bismarck area are known to be rather close to land surface (1-33 feet, Randich and Hatchett, 1966). Specific depth to water in many areas is, however, unknown. Seasonal or long term fluctuations of the water table are not well understood or well documented. A water table close to land surface can have a detrimental effect on certain types of structures, waste disposal facilities and domestic water supplies when waste disposal facilities do not operate properly. To wisely and efficiently manage floodplain development, it is necessary to understand factors which control fluctuations of the water table.

Purpose and Objectives

The purpose of this study was to better understand the geohydrology of the South Bismarck area. The general objective of the study was to collect the necessary data which identifies hydrologic events that cause the greatest change in water level elevation. Information of this type may be especially helpful to those involved in land use planning and zoning by recognizing potential problem areas. Specific objectives were to:

1) Describe and interpret the geohydrologic framework of the South Bismarck area.
2) Evaluate the interrelationships between the ground water and surface water systems in the area.
3) Evaluate the impact that precipitation, evapotranspiration, irrigation pumping, and Missouri River stage have on the water table.
4) Construct a map of the study area illustrating the range of depth to water recorded in the study area.
5) Produce a series of representative water level contour maps illustrating the configuration of the water table at various times of the year.
6) Evaluate the chemical quality of the ground water.

Description of the Study Area

Location

Regionally, the South Bismarck study area lies within the Missouri River Trench District in South Central North Dakota (Fig. 1). Specifically, the study area is situated directly south of Bismarck, North Dakota on the floodplain and terraces of the Missouri River in Burleigh County (Fig. 1). The study area is bounded by the Missouri River to the west and south, Apple Creek to the east and Main Avenue to the north (Fig. 1).

Topography

The South Bismarck area is characterized by a series of broad

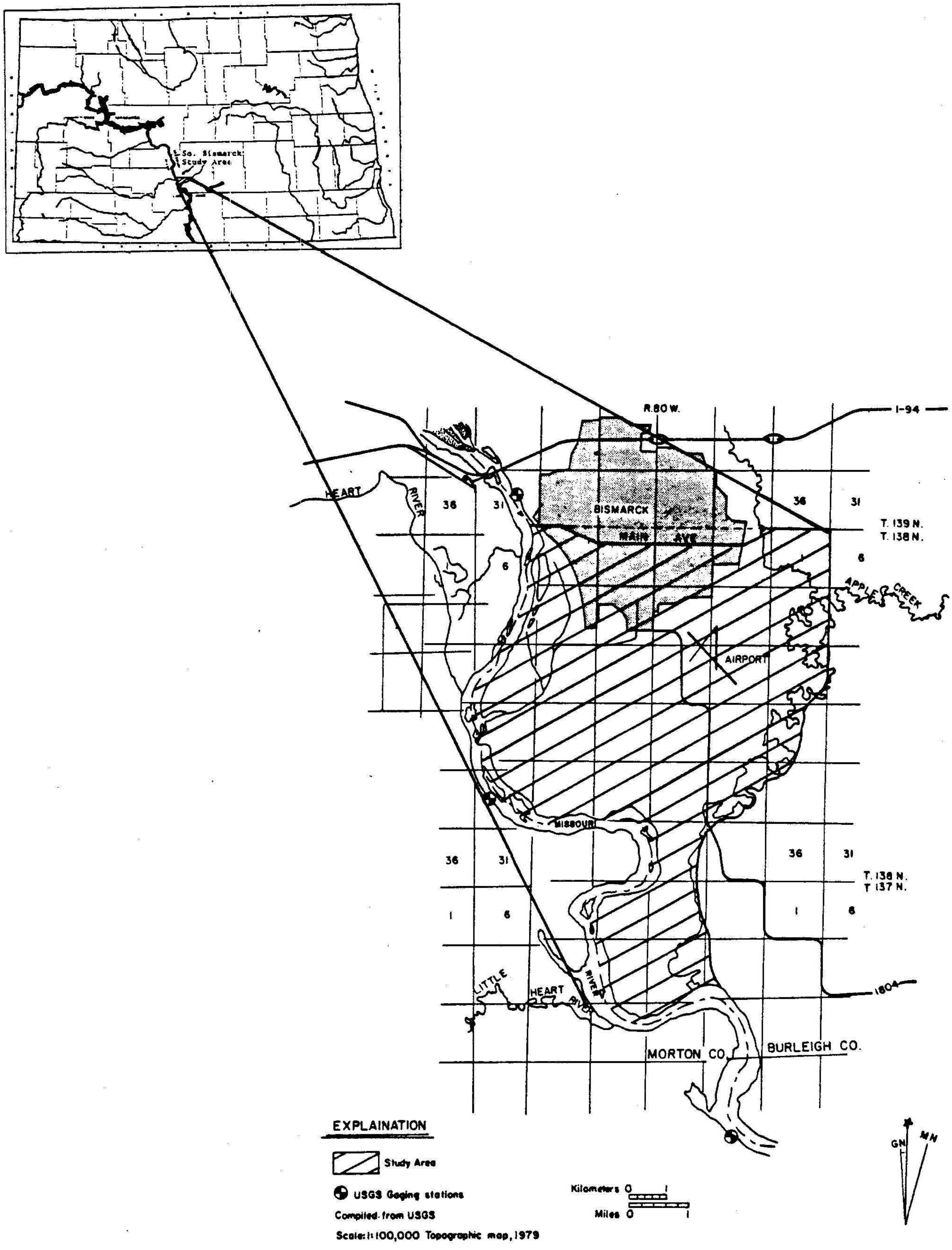


Figure 1. Location of the South Bismarck Study Area
Burleigh County, North Dakota

flat terraces of glacial and alluvial origin. Elevations range from 1680 feet northeast of the Bismarck Municipal airport to 1620 feet along the Missouri River.

Stream Pattern

The Missouri River is the dominant river in the study area (Fig. 1). Tributaries to the Missouri River in the general area include, the Heart River, the Little Heart River and Apple Creek (Fig. 1).

Previous Investigations

The geology and ground-water resources of Burleigh County were first described by Simpson (1929). Simpson's report discussed water supplies at Bismarck and also included a small inventory of private and municipal wells. Limited ground-water quality data from the Bismarck area were also presented.

A ground-water survey of Burleigh County was conducted on a cooperative basis with the North Dakota State Water Commission (NDSWC), North Dakota Geological Survey (NDGS), and the United States Geological Survey (USGS). The report consists of three parts. Part I, Geology, is a comprehensive investigation of the surficial geology and a general study of the subsurface geology (Kume and Hansen, 1965). Part II, Basic Data, includes an inventory of test holes, well logs, water level measurements, and chemical analyses (Randich and Hatchett, 1965). Part III, Ground-Water Resources, presents a general evaluation of the water yielding potential and chemical quality of major aquifers in the bedrock and glacial drift of Burleigh County (Randich and Hatchett, 1966). A general discussion of the location, extent, thickness, lithology and reservoir characteristics of the Bismarck aquifer was included. Information presented in this three part report was used extensively for this study.

A report entitled, "Working Paper, Bismarck Ground Water Study, Bismarck, North Dakota" was prepared by the United States Army Corps of Engineers (Corps) in April, 1980. The report attempted to establish the relationships between ground-water levels, Missouri River stages, and the operation of Lake Oahe. Other factors evaluated were, precipitation, evapotranspiration, and irrigation withdrawals. The report concludes that fluctuations of the water table in the Bismarck aquifer are primarily due to seasonal changes in river stage.

In 1980, Groenewold completed a report entitled, "Geologic and Hydrogeologic Conditions Affecting Land Use in the Bismarck-Mandan Area". Groenewold developed a series of maps detailing geology, ground-water resources, mineral resources, and conditions affecting construction, and waste disposal.

Methods of Study

Hydrogeologic investigation of the South Bismarck area was accomplished by drilling 75 test holes, installing 68 observation wells, measuring and recording depth to water in 75 new and existing observation wells, collecting and analyzing 71 water samples and conducting an inventory of select private wells and test holes.

Test holes were drilled with a hydraulic-rotary drilling rig owned by the NDSWC. Observation wells were constructed of 1¼ inch plastic casing with 3 or 6 foot screens. The observation wells were developed by backwashing and subsequently pumping (airlift) a minimum of 10 hours for development before the measurement of water levels and collection

misleading
where they allowed to recover after pumping?
someone not familier with the operation wouldn't know

of water samples. Location of all test holes and observation wells is presented on Plate 1 (in pocket). Pertinent data on each test hole is presented in "Ground-Water Data for the South Bismarck Area, Burleigh County, North Dakota", North Dakota Ground-Water Studies Number 90, Part I (Pusc 1984). Geologic samples were collected and visually analyzed every five (5) feet. Resistivity and spontaneous potential logs were run in most NDSWC test holes. Copies of geophysical logs run are available for inspection in the office of the North Dakota State Water Commission.

Depth to water measurements were recorded on a monthly basis in a number of observation wells throughout the study area (Pusc, 1984, Part I). Water levels were measured with either a steel tape or continuous recorder. During periods of above average precipitation or high Missouri River stage, all wells or select wells were monitored more frequently. Several wells along the Missouri River were, however, inaccessible during periods of high river stage.

Three continuous water level recorders are presently operating in the South Bismarck area (1984, Plate 1). One recorder is situated on a river terrace, approximately three (3) miles from the Missouri River. Two (2) recorders are situated on the Missouri River floodplain, each within one (1) mile of the river. Water level data collected for this study were coupled with the existing data to determine which variables are affecting the water table.

Water samples were collected from select observation wells during the fall of 1979 and the spring of 1980 to determine the chemical quality of ground water in the area (Pusc, 1984, Part I). Water for samples was obtained from privately owned wells by using the existing pumps and from the NDSWC observation wells by airlift.

Well-Numbering System

Wells and test holes presented on Plate 1 are numbered according to a system based on the location in the public land classification of the United States Bureau of Land Management (Fig. 2). The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located. Letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10 acre tract). For example, well 138-80-15CDD is in the SE¼SW¼SW¼ Section 15, Township 138 North, Range 80 West (Fig. 2). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract.

HYDROGEOLOGICAL FRAMEWORK

Surficial Geology

A generalized surficial geologic map of the South Bismarck study area is presented in Fig. 3. Landforms comprising the area are primarily a result of alluvial and glaciofluvial geologic processes.

Four (4) terrace deposits overlie the South Bismarck area (Fig. 3). Escarpments formed by the terraces trend in a southeast to northwest direction. A summary of each terrace deposit is presented in Table 1.

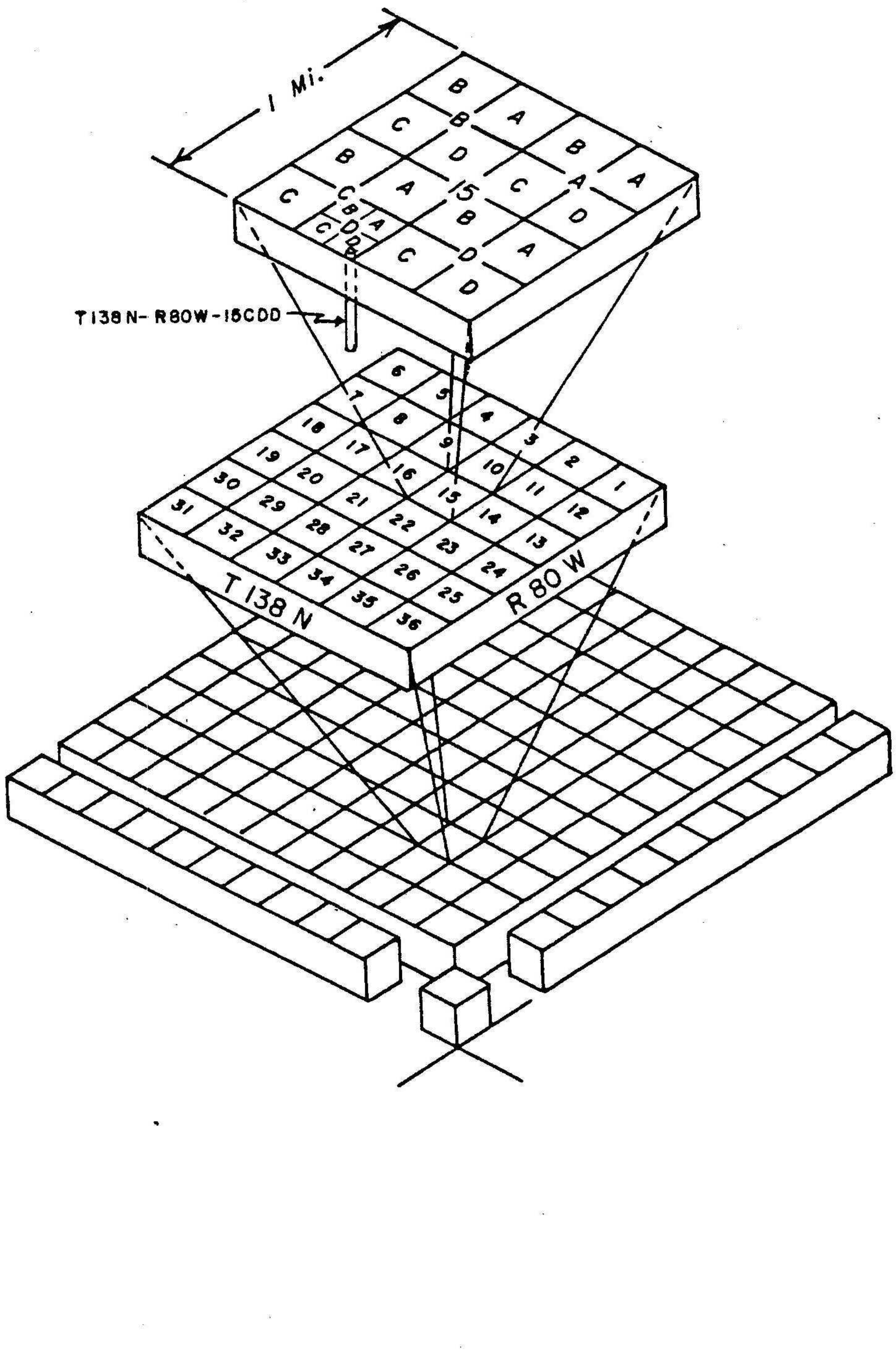


FIG. 2 WELL NUMBERING SYSTEM

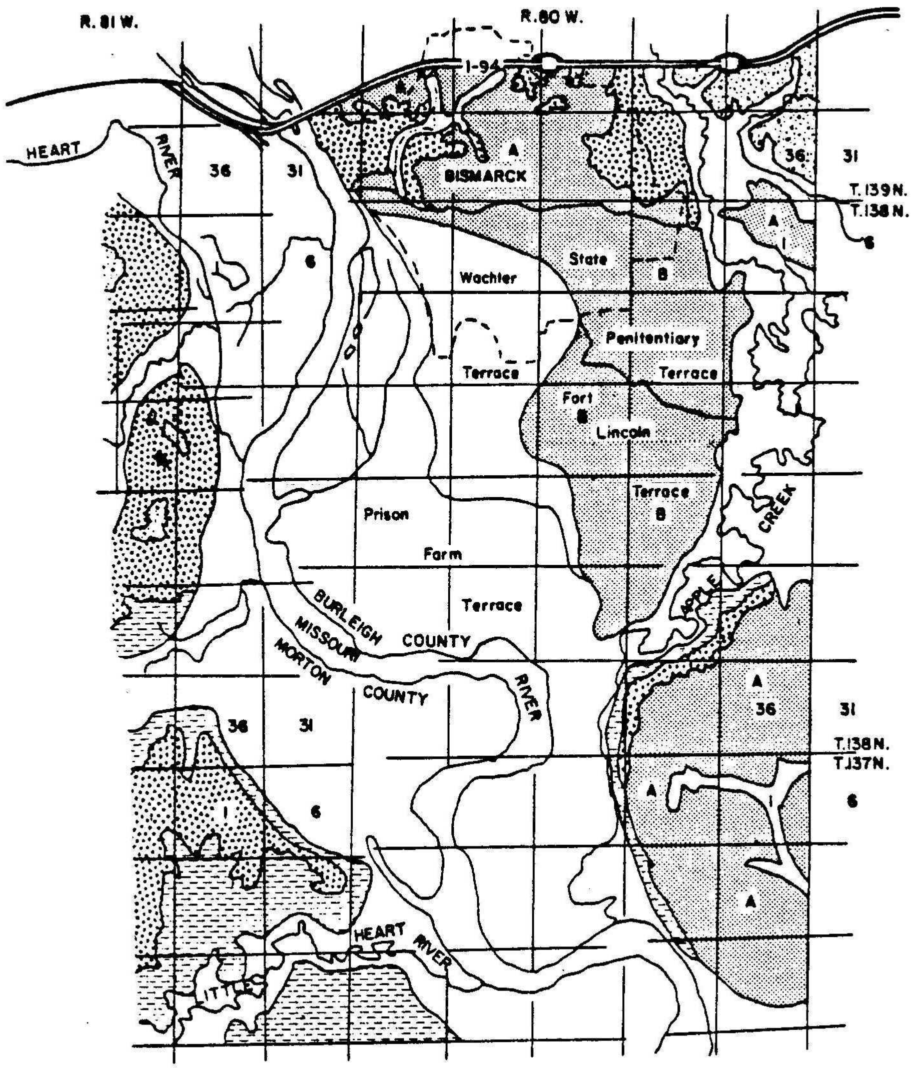
Table 1 - Summary of Terrace Deposits (Modified from Kume and Hansen, 1965, see Figure 3 for Terrace Locations)

Terrace Name	Elevation (feet)	Composition and Comments
State Penitentiary Terrace	1660-1680, 40-60 feet above Missouri River	Glacial outwash terrace, high cut and fill, overlain by windblown silt of the Oahe Formation
Fort Lincoln Terrace	1640-1660, 20-40 feet above Missouri River	Glacial outwash terrace, overlain by windblown silt of the Oahe Formation
Wachter Terrace	1630-1640	Alluvial terrace, rather featureless
Prison Farm Terrace	1620-1630	Alluvial terrace, meander scars, point bar and channel fill deposits

The State Penitentiary and Fort Lincoln Terraces are comprised mainly of poorly sorted sands and gravels overlain by a thin veneer of fine windblown sand and silt of the Oahe Formation. The unsaturated nature of these two terraces make them excellent areas for sand and gravel mining operations.

Vertical accretion deposits, formed by overbank flooding and deposition, overlie much of the Wachter and Prison Farm Terraces (Figure 3). Test hole information indicates that the vertical accretion deposits are composed of approximately 20 feet of very fine grained silt and clay.

Numerous lateral accretion deposits, i.e., point bar, are clearly visible in the study area. Sediment on the concave side of the Missouri River is being eroded away and subsequently deposited as a point bar on the downstream, convex side of the river. Point bar deposits in



Explanation

AGE	MAP SYMBOL	FORMATION	LITHOLOGY	ORIGIN
Quaternary		OAHE	Yellow or gray silt and buff brown well sorted sand	Wind blown sediment, "A" denotes that sediments immediatly overlie bedrock, "B" denotes that sediments immediatly overlie sand, gravel of Oahe & Coleharbor formation
		OAHE & COLEHARBOR	Black, organic clays, silts, sand and gravel	Stream or slope wash sediments
		COLEHARBOR	Yellow brown to olive gray, cobbly, pebbly, sandy, silty clay	Glacial sediments (till)
Cretaceous		CANNONBALL	Gray to yellow brown, sandstone, siltstone and shale	Marine, nearshore sediment
		HELL CREEK	Gray silt, clay, and sandstone	Stream sediment

FIGURE 3. GENERALIZED SURFICAL GEOLOGIC MAP OF THE SOUTH BISMARCK AREA BURLEIGH & MORTON COUNTIES, MODIFIED FROM, KUME 1965 AND GROENWOLD 1980

the area generally consist of very fine to fine grained sand mixed with silt, and clay.

Hydrogeologic Properties of the Area

Bedrock Deposits

General Geology. Bedrock underlying the area primarily consists of consolidated silt, clay, and sandstone units of the Hell Creek Formation. Outcrops of the Hell Creek Formation occur southwest of the study area in Morton County and southeast of the area near Mary College (Figure 3).

Presented in Figure 4 is a structure contour map of the bedrock surface underlying the South Bismarck floodplain and terraces. Erosion by ancient river systems has resulted in several trenches and valleys in the bedrock surface.

Depth to bedrock varies considerably in the area. Near the narrows, between the Missouri River and Apple Creek, bedrock is only nine feet (elevation 1647 feet) below land surface (E½ S.27, T.138N., R.80W., Ridgeview Estates, Figure 4 and Plate 2A). Southwest of the State Penitentiary, bedrock was encountered 170 feet (elevation 1500 feet) below land surface (T.138N., R.80W., 2CCC). Bedrock along the Missouri River is generally 60 to 120 feet (elevation 1562 to 1502 feet) below land surface (Figure 4). The lowest elevation to the top of the bedrock, in the general area, was encountered in a test hole in Morton County (T.138N., R.81W., 24DCD, elevation = 1405 feet).

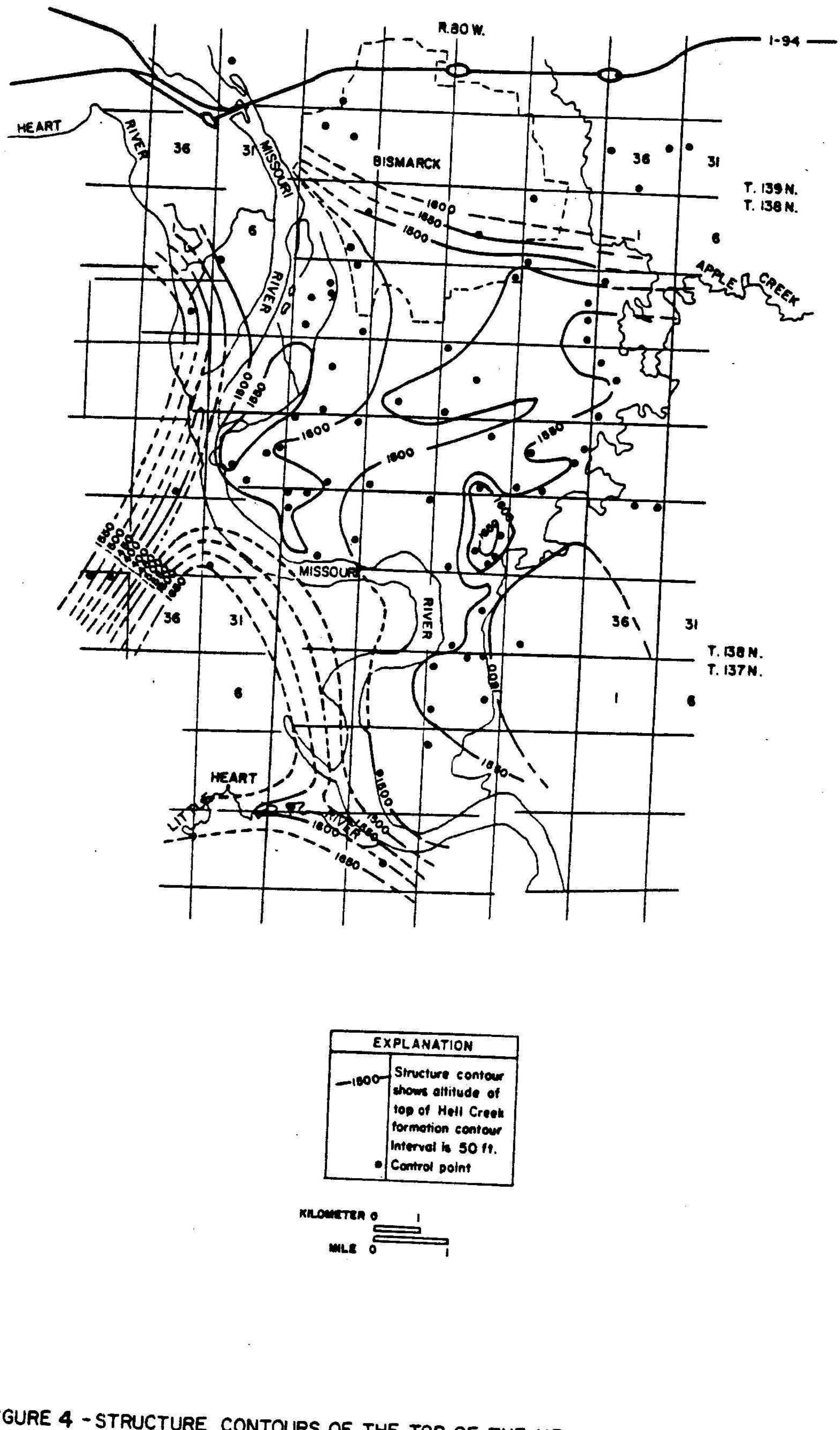


FIGURE 4 - STRUCTURE CONTOURS OF THE TOP OF THE HELL CREEK FORMATION

Hydrology. Limited data are available on the water yielding capability of bedrock units immediately underlying the study area. According to Ackerman, 1980, sandstone beds of the Hell Creek Formation, in Morton County, generally are not laterally extensive and often pinch out within a distance of a few tens of feet. Properly constructed wells may yield 1 to 80 gpm from sandstone units of the Hell Creek Formation (Ackerman, 1980).

Water level data from select wells in the area indicate that ground water in the bedrock occurs under confined conditions.

Unconsolidated Deposits

General Geology. A considerable thickness of multi-layered sediments (clay, silt, sand and gravel) have been deposited in the area (Plates 2 and 2A). Thickest sections of unconsolidated sediments (150-170 feet) occur on the State Penitentiary Terrace, while the thinnest sections occur on the bedrock high in Section 27 (T.138N., R.80W. Plate 2A). Average sediment thickness is 100 to 120 feet.

Unconsolidated sediments of the area can be divided into two groups: alluvial and glacial deposits. Data from test holes indicates that glacial deposits primarily occur in the northeastern one-third of the study area. Glacial materials encountered are generally composed of poorly sorted sand and gravel which are interbedded with silty, sandy, pebbly, clay (till).

Deposits along the Missouri River, however, are mainly alluvial in origin (Fig. 3). Alluvial materials encountered are composed primarily of very fine to coarse sand overlain by and interbedded with clay and silt. Grain size generally increases with depth (Plates 2 and 2A). Glacial till was not detected in any of the test holes drilled on the

Wachter or Prison Farm terraces (Fig. 3).

The classification of sediments in the study area according to mode of deposition is, however, somewhat arbitrary because of gradation between alluvial and glacial materials. Reworking of the sediments also complicates the classification.

Hydrology. Historically, the study area has been divided into two aquifers: the Bismarck aquifer and the lower Apple Creek aquifer (Randich and Hatchett, 1966). Test hole data indicates that generally, sand and gravel deposits in the Apple Creek area occur at the same elevation interval as sand and gravel deposits of the adjoining Bismarck aquifer (Plates 2 and 2A). The bedrock ridge in Section 27, Township 138 North, Range 80 West is the only geologic evidence of a boundary between the Bismarck and Apple Creek aquifers (Fig. 4 and Plate 2A). Because the two aquifers appear to be hydraulically connected, this report considers them as one "aquifer system" and is hereinafter referred to as the South Bismarck Aquifer System.

Saturated sand and gravel deposits of the area range in thickness from only a few feet to well over 100 feet. Thickest sections of aquifer material appear to have been deposited in the ancestral valleys and trenches cut into the bedrock (Plates 2 and 2A). Along the Missouri River, the South Bismarck aquifer system ranges from 30 to 110 feet thick. Channel lag deposits, i.e., coarse sand and gravel, were nearly always detected immediately overlying bedrock. Saturated sand and gravel deposits are, however, absent in the E½ of Section 27, Township

138 North, Range 80 West due to the bedrock high discussed earlier.

Depth to water in the South Bismarck aquifer system is a reflection of land surface elevation. Presented in Plate 3 is a map showing the range in depth to water that was recorded in the area from November 1979 to March 1983. Water levels ranged from less than 1 foot to 10 feet below land surface on the lowlands near the Missouri River (below elevation 1630 feet Prison Farm Terrace). Depth to water was also from 1 to 10 feet in topographically depressed areas on the floodplain away from the river (Plate 4).

As land surface elevation increases, so does depth to water. Thus, areas between 1630 and 1640 feet had depth to water range from 5 to 15 feet below land surface (Wachter Terrace). Depth to water ranged from 15 to 20 feet below land surface in areas between elevations 1640 to 1650. In areas above land elevation 1650, depth to water ranged from 20 to 40 feet below land surface (Plate 4). Test hole and water level data indicate that perched aquifer zones also occur within these higher terraces.

Water level data from the area indicates that ground water in the South Bismarck aquifer system occurs under both artesian (confined) and water table (unconfined) conditions. Overlying floodplain silts and clays (vertical accretion deposits) comprise the confining units. The interbedded nature of the South Bismarck aquifer system may also account for localized confined conditions. On the floodplain, water levels in wells rise only a few feet into the confining unit. Thus, when sufficiently stressed, this portion of the aquifer system will convert to unconfined.

Several irrigation wells have been developed in the South Bismarck aquifer system (Plate 1). Potential yields range from 500 to greater than 2000 gallons per minute. Thus, the alluvial and glacial drift aquifers of the South Bismarck system appear to have a moderate to high hydraulic conductivity while the underlying bedrock aquifer units of the Hell Creek Formation have a low hydraulic conductivity.

Water Quality

A total of 115 ground-water samples have been collected in the South Bismarck area. Chemical analyses available include 110 samples of ground water from the alluvial and glacial drift aquifers and 5 samples from the sandstone units of the bedrock. Analytical results of the analyses are listed in Pusc, 1984, Part I.

A check of the accuracy of the chemical analyses revealed that the difference between the cations and anions exceeded 5% in 11 of the 115 samples. Samples which had a greater than 5% error were not included in the following water quality discussion.

Presented in Table 2 are ranges of values and mean concentrations of the major chemical constituents present in ground water from the alluvial and glacial drift aquifers. Accompanying are water quality standards for irrigation, domestic, and municipal supplies for North Dakota.

Chemical analyses of the ground water shows that recommended drinking water limits for iron (Fe), sodium (Na), bicarbonate (HCO_3), sulfate

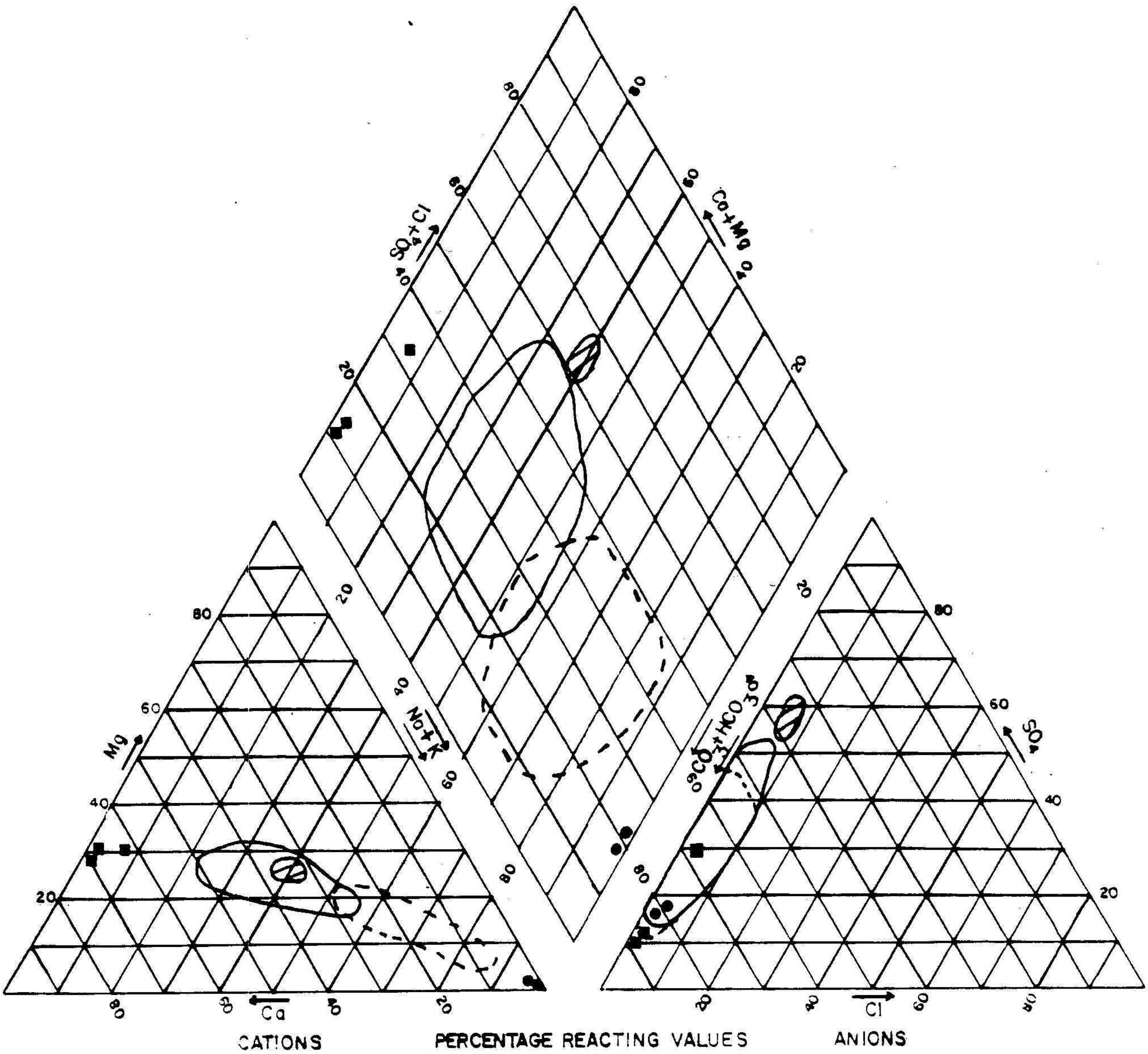
Constituent	Maximum (mg/l)	Minimum (mg/l)	Mean (mg/l)	Recommended* Drinking Water Standards (mg/l)	Recommended+ Irrigation Water Standards (mg/l)
SiO_2	33	15	23	$<$ 50	
Fe	12	.03	2.9	$<$ .5	
Mn	2.6	.04	.9	$<$ .05	
Ca	240	40	117	$<$ 125	
Mg	94	11	41	$<$ 125	
Na	450	3.8	192	$<$ 300	300
K	20	1.4	6		
HCO_3	1100	272	698	$<$ 500	500
CO_3	0	0	0		
SO_4	640	2.9	257	0-300 low 300-700 high $>$ 700 very high	500
Cl	150	.3	28.9	$<$ 250	300
F	2.5	0	.47	.9-1.5 depends on temperature	
NO_3	10	0	1.1	$<$ 45	
B	1.7	0	.4	$<$ 20	.3-3.0 depending on plant
TDS	1780	304	1018	0-500 low 500-1400 average 1400-2500 high $>$ 2500 very high	
$CaCO_3$ (hardness)	910	104	458	0-200 low 200-300 average 300-450 high $>$ 450 very high	
% Na	88%	3%	46%		50%
SAR (sodium adsorption ratio)	15	.1	4.3		8 little effect 8-15 marginal $>$ 15 poor
Specific conductance	3310	497	1500		
RSC (residual sodium carbonate)	10	0	1.8		1.25 safe 1.25-2.5 marginal $>$ 2.5 poor
Temperature °C	18	5	9.5		

*Source: U. S. Environmental Protection Agency, 1975 and NDSWC, 1972
+Source: NDSWC, 1973, and Hem, 1970

Table 2. Range and Mean Concentrations of Major Chemical Constituents Occurring in Ground Water from the South Bismarck Aquifer System (Ground Water from Bedrock units Omitted, see Pusc, 1984, Part I for Water Quality Data)

(SO_4), and hardness ($CaCO_3$) were exceeded in several samples. Water containing more than the recommended concentrations of certain chemical constituents, however, has been used in some areas of North Dakota for many years without noticeable ill effects.

A Piper trilinear diagram for anion and cation facies in terms of major-ion percentages is presented in Figure 5. Generally, ground water from the South Bismarck area can be divided into four major groups. The first group includes ground water obtained from upper perched aquifer zones in the Fort Lincoln and State Prison terrace area. These waters are low in total dissolved solids and can be classified as a calcium-bicarbonate (Ca HCO_3) type. The second group includes ground water from wells that were constructed on the floodplain and are completed in sand and gravel of the South Bismarck aquifer. These waters are generally calcium, magnesium, sodium, bicarbonate (Ca, Mg, Na, HCO_3) types with no cation being dominant. The best water from this second group occurs in that part of the aquifer that is adjacent to the Missouri River and thus receives direct recharge from the river. The third group includes ground water obtained from wells that are either screened just above bedrock or deeper wells located on the Fort Lincoln and State Prison terraces. These waters trend from calcium, magnesium, sodium, bicarbonate (Ca, Mg, Na, HCO_3) types to sodium bicarbonate (Na, HCO_3) types. The fourth group includes sodium bicarbonate (Na, HCO_3) type water which was obtained from two wells that are screened in bedrock. Ground water from these wells was higher in total dissolved solids (TDS) and sodium



EXPLANATION

Missouri River at Bismarck

Ground water from perched zones on Fort Lincoln or prison farm terraces

Ground water from wells located on floodplain (near Missouri River)

Ground water from wells located on the Fort Lincoln or prison farm terraces or wells screened just above bedrock

Ground water from wells screened in bedrock

Figure 5. Piper diagram of Chemical Analyses of Ground Water from the South Bismarck Area as Percentages of Total Equivalents per Liter

(Na) but lower in iron (Fe) and hardness than ground water from overlying sand and gravel deposits. Thus, the evolution of the cations species appears to be from a calcium-magnesium to a sodium dominant water.

The quality of water an individual can use for irrigation depends on seven (7) factors: (1) salinity of the water, (2) sodium concentration of the water, (3) relationship between the amount of sodium to the amount of calcium and magnesium (sodium adsorption ratio, SAR), (4) soil type, (5) drainage, (6) types of plants to be grown, and (7) irrigation practices. Irrigation classifications of all ground-water samples from the area are presented in Figure 6 (USDA, 1954). Generally, ground water from the alluvial and glacial drift aquifers can be classified as C3-S1 or C3-S2 types, indicating a high salinity, low to medium sodium hazard. Because some of the ground water may be marginal for irrigation, a detailed soil-water compatibility test should be conducted before irrigation of a particular area. Ground water obtained from the underlying bedrock is unsuitable for irrigation.

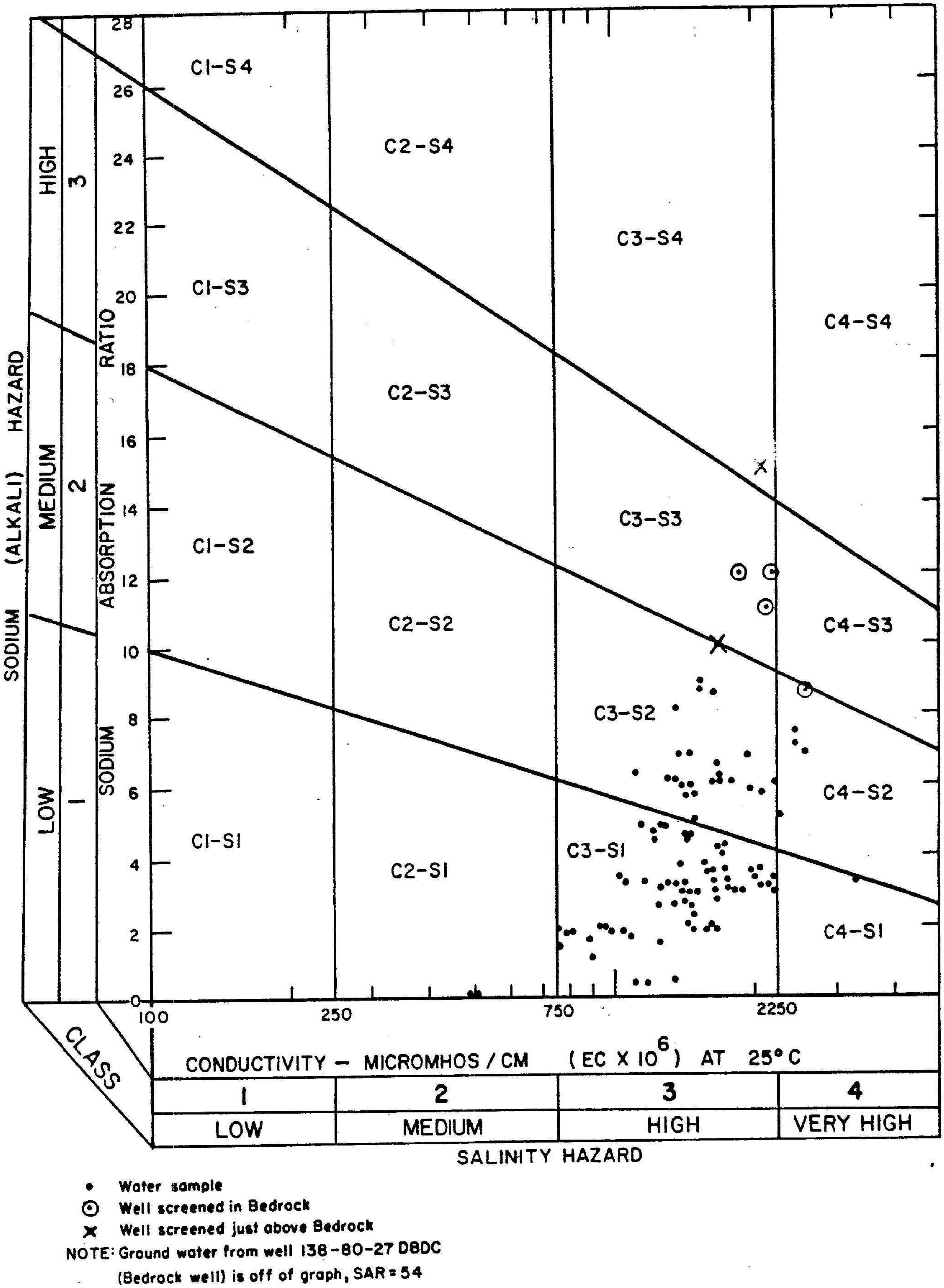


FIGURE 6. IRRIGATION CLASSIFICATION OF GROUND WATER FROM THE SOUTH BISMARCK AREA

FACTORS AFFECTING THE WATER TABLE

Introduction

Ground-water levels rise and fall in response to recharge to and discharge from the South Bismarck aquifer. Factors causing the water table in the South Bismarck area to fluctuate are: stage elevation of the Missouri River, ground-water withdrawals for irrigation, evapotranspiration, precipitation, and leakage from or leakage to adjacent geologic materials.

Hydrographs constructed from water level data were evaluated to determine the influence each factor has on fluctuations of the water table. Because of the large number of observation wells, only hydrographs from representative wells are presented and discussed.

Missouri River Stage

The U. S. Geological Survey has gaged the discharge of the Missouri River at Bismarck since 1928 (Figure 1). Stage recording gages were established in 1966 at River mile 1309 (Mandan Gage) and at River Mile 1297 (Schmidt gage, Figure 1). A summary of streamflow records for the Missouri River at Bismarck is presented in Table 3.

Table 3. Summary of Missouri River Discharge

Years	Annual Average Discharge (ft^3/sec)	Momentary Maximum Discharge (ft^3/sec)	Momentary Maximum Gage Height (ft)	Momentary Minimum Discharge (ft^3/sec)	Momentary Minimum Gage Height (ft)
Pre-Garrison Dam (1929-1953)	21,500	500,000 April 6, 1952	[A]1645.18	1800 January 3, 1940	1618.73
Post Garrison Dam (1954-1983)	23,700	68,900 July 13, 1975	[B]1632.48	4000 1955	?

[A]Maximum stage known, 1649.88 on March 31, 1881 (ice jam)
[B]Backwater from ice jam caused river to rise to a post dam high of 1632.86 on December 18, 1979

Since 1953, discharge of the Missouri River at Bismarck has been controlled by the Garrison Dam. Under normal operating conditions, maximum releases from the reservoir and thus maximum discharge (stage) of the Missouri River occurs during the winter months of December through March (Plate 4). Since construction of the Garrison Dam, peak Missouri River stages at Bismarck have ranged from 1630 to 1632 feet (Plate 4). Infrequent and unpredictable events such as ice jams, rapid melting of snowpack or heavy precipitation also contribute to higher river stages. Generally, a second, lower magnitude peak in stage occurs in April, May or June as a result of the natural spring snowmelt event.

Releases from the reservoir are generally steady throughout the remainder of the year; causing the Missouri River at Bismarck to fluctuate in the 1620 to 1627 foot range. Gage height during these normal to low flow times may vary .5 to 2 feet in a 24 hour period and .5 to 7 feet over a several month time span.

Water Level Response near the Missouri River

Presented in Figure 7 are hydrographs of four (4) wells located near the banks of the Missouri River. Accompanying the hydrographs are stage records for the Missouri River at Bismarck and monthly precipitation values at the Bismarck Municipal airport. Generally, water levels in the observation wells fluctuate with river stage. An increase in river stage causes a corresponding rise in water levels while a decline in river stage results in a decline in water levels (Figure 7). Water levels in wells near the Missouri River fluctuated approximately .6 feet for every 1.0 foot fluctuation in river stage.

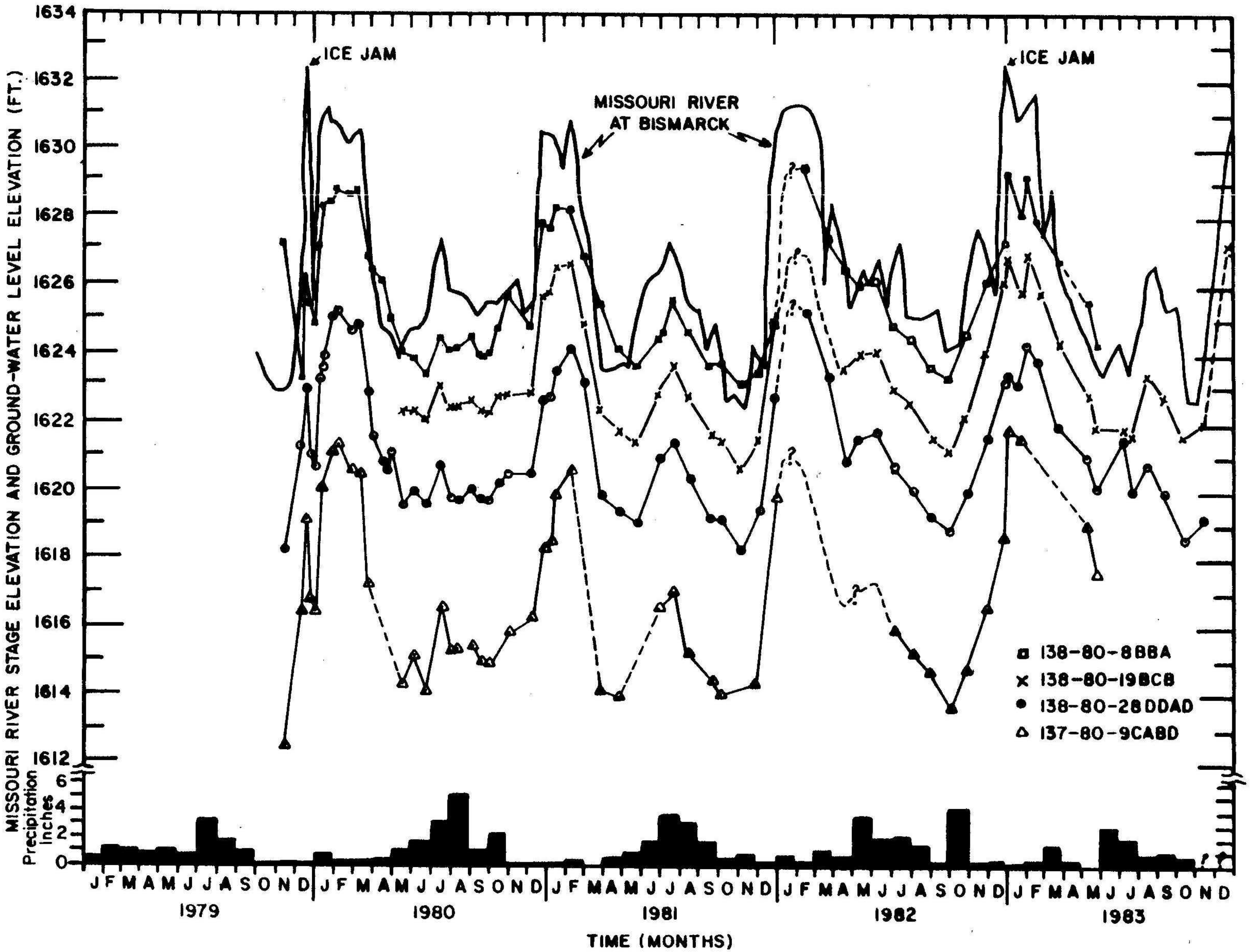


FIGURE 7. HYDROGRAPHS OF WATER LEVELS IN WELLS LOCATED NEAR THE MISSOURI RIVER

Water levels in two wells located near the Missouri River were monitored on a continuous basis. Presented in Figure 8(A) are representative hydrographs of the average daily stage level of the Missouri River at Bismarck and average daily water levels in wells 138-80-17CDD$_1$ and 137-80-03BCC. Again, note that a rise in river stage results in a rise in water levels and vice versa. The continuous record shows that, generally, water levels near the river respond rather quickly to the abrupt December rise in river stage. Ground-water levels slowly rise throughout an entire high river stage event. Following a reduction in river stage, water levels in wells near the river begin to decrease (Figure 8).

Hourly water levels from 138-80-17CDD$_1$ (near river) and 138-80-15CDD (away from river) are presented in Figure 9 to show response times between river stage fluctuations and water level response. December 1977 was chosen because the stage of the Missouri River was very constant for several days prior to the abrupt December 6, 1977 rise in river stage. Also, much of the hourly river stage data from other abrupt river stage events is missing.

Note that the water level in 138-80-17CDD$_1$ (near river) began to respond only 3 to 4 hours following the abrupt rise in river stage. This quick response suggests that a good hydraulic connection exists between the river and aquifer at this location. Also, the water level in observation well 138-80-17CDD$_1$ rises well up into an overlying clay unit, indicating confined conditions. The quick response to river stage fluctuations is probably a reflection of the change in pressure

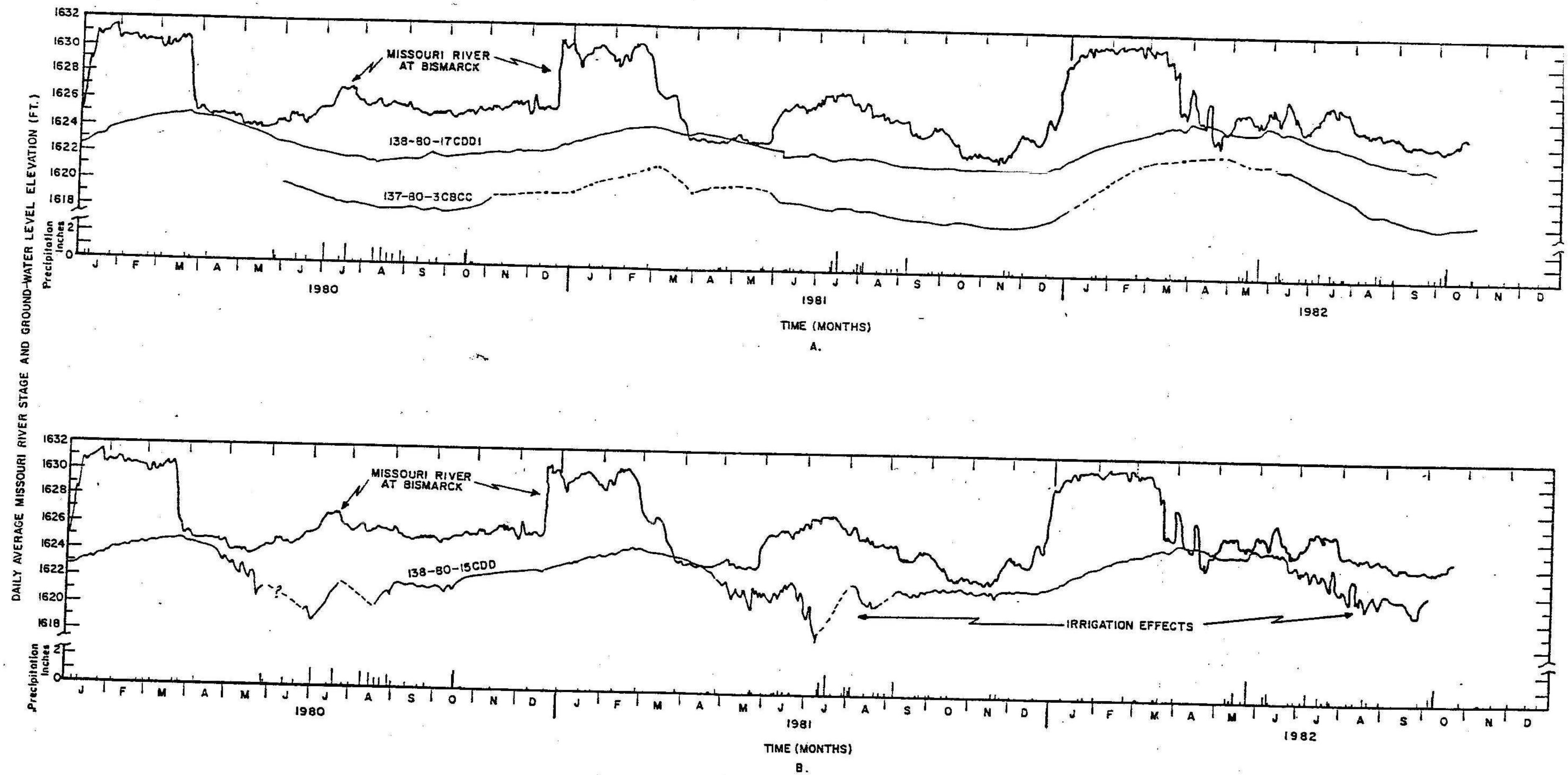


FIGURE 8. HYDROGRAPHS OF THE AVERAGE DAILY RIVER STAGE ELEVATION OF THE MISSOURI RIVER AT BISMARCK VERSUS THE AVERAGE DAILY GROUND-WATER LEVEL ELEVATION IN 138-80-17CDD AND 137-80-3CBCC (A), AND 138-80-15CDD (B) FOR THE PERIOD 1980-1982

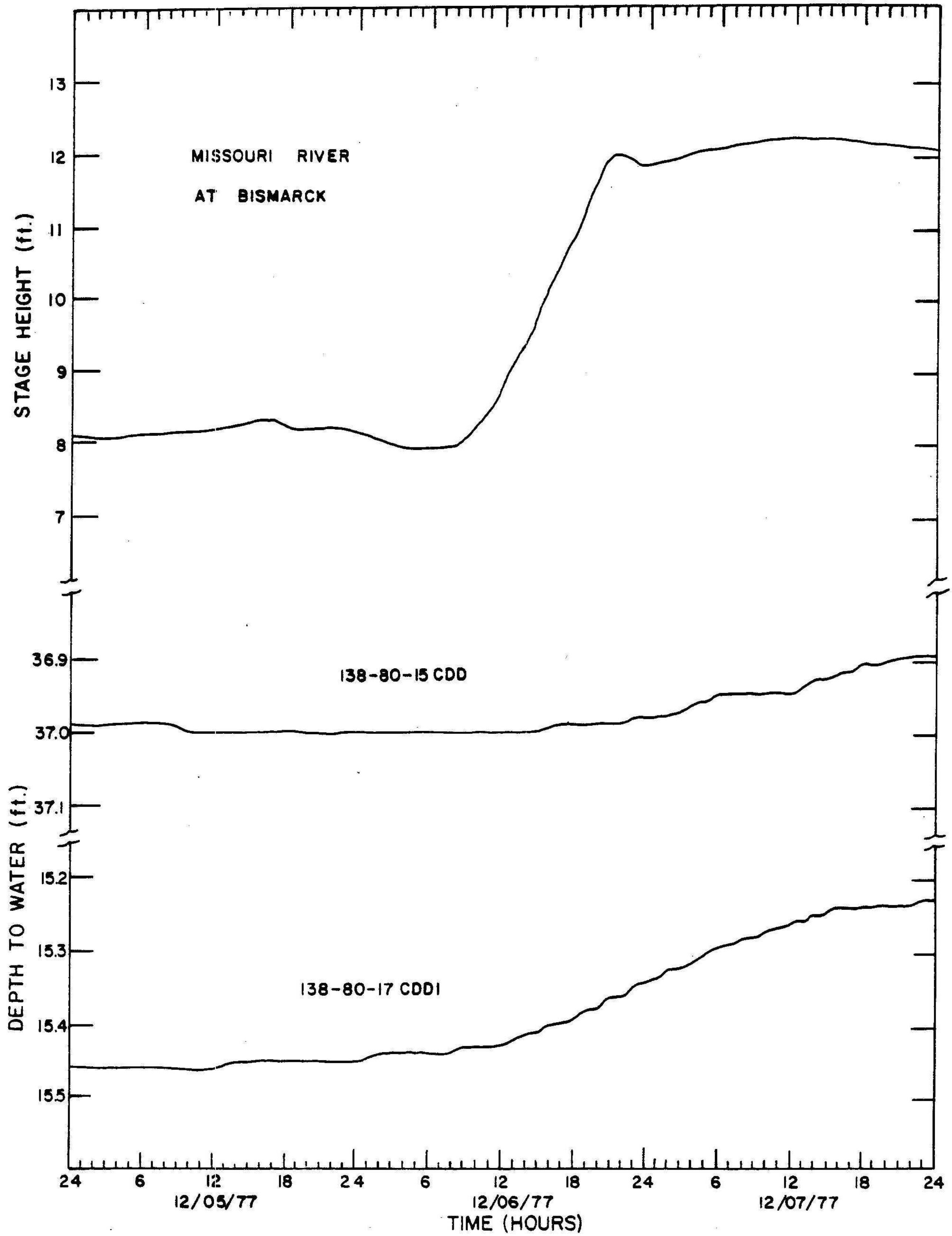


Figure 9. Hourly Ground Water Levels in 138-80-17CDD$_1$ and 138-80-15CDD Showing Water Level Response Time to Fluctuations in River Stage

head within the confined aquifer. In fact, part of the quick response may be due to a loading effect imposed by the river.

Part of the quick response may also be due to the geometry of the Missouri River channel in this area. Approximately ½ mile west of observation well $138\text{-}80\text{-}17CDD_1$ is an oxbow or old river channel that surrounds Fox Island (Plate 1). During high river stage, this channel is flooded, causing the river to be ½ mile from $138\text{-}80\text{-}17CDD_1$ instead of one mile. The reduction in distance to the river, caused by flooding, may explain, in part, the quick response.

Water Level Response Away from the Missouri River

Fluctuations of the water table are also dependent on an observation well's proximity to the Missouri River. Hydrographs from four (4) wells located at 1200 feet, 1700 feet, 7300 feet, and 16,000 feet, respectively from the river at normal stage, are presented in Figure 10. Water levels in all four (4) wells response to fluctuations in river stage. Again, a rise in river stage results in a rise in water levels, and a decrease in river stage results in a decrease in water levels. Water levels in wells nearest to the river respond quicker and have higher peaks than water levels some distance from the river (Figure 10). Water levels away from the river show a slight lag response to fluctuations in river stage. In fact, the continuous record from 15CDD reveals a 1 to 2 day lag response between fluctuations of Missouri River stage and ground-water levels 16,000 feet from the river (Figures 8B & 9). This rather quick response 16,000 feet away from the river confirms the confined nature of portions of the South Bismarck aquifer system.

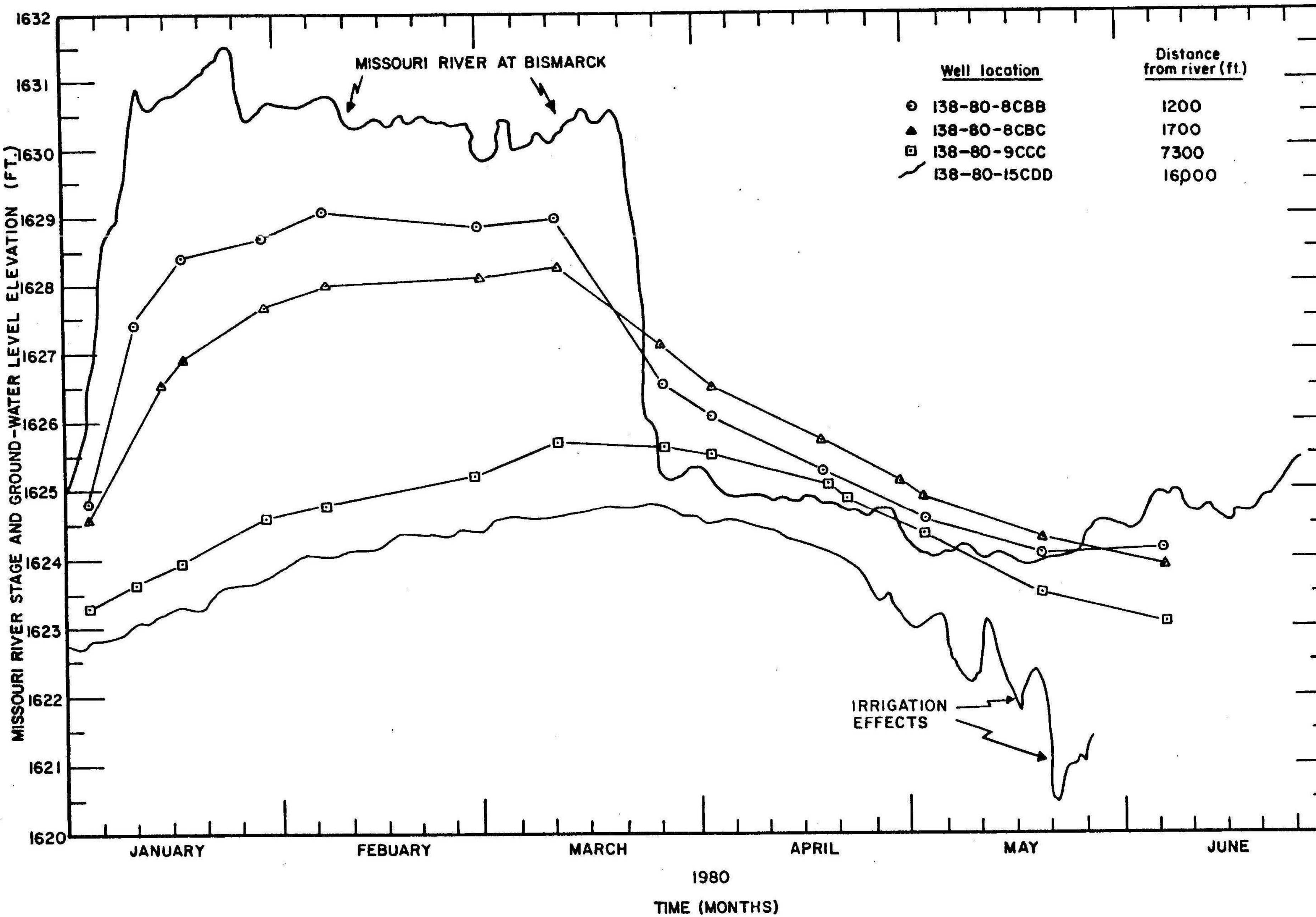


FIGURE 10. HYDROGRAPHS OF WATER LEVELS IN WELLS LOCATED AT INCREASING DISTANCES FROM THE MISSOURI RIVER

Water levels in all observation wells monitored in the area appear to respond to fluctuations in Missouri River discharge. The degree of water level response appears dependent on several factors: (1) magnitude of river stage event, (2) duration of river stage event, (3) hydraulic connection between the river and aquifer (4) transmissivity and storage coefficient of the aquifer, and (5) proximity to the river.

Irrigation Effects

Effects on the water table by irrigation withdrawals are represented by observation well 138-80-15CDD in Plate 4 and in Figures 8B and 9. Water levels in the vicinity of operating systems generally declined .5 to 6 feet in response to irrigation; while water levels a mile or more away from an operating production well declined very slightly or not at all. Following the irrigation season, water levels slowly recovered back to their pre-irrigation position (Plate 4). This suggests that recharge to the aquifer system is sufficient to replace water discharged from irrigation wells in the area.

Based on the available data, the withdrawal of ground water from irrigation wells during the growing season (May-August) causes localized declines in the water table. Fluctuations are, however, rather minor when compared to fluctuations of the water table caused by changing Missouri River stages.

Evapotranspiration

Evapotranspiration (ET) is a combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants. The natural discharge of water into the atmosphere by ET can cause a decline in ground-water levels. ET effects on the water table are generally strongest in the summer months of May through September.

The daily water level record of observation wells 138-80-17CDD$_1$ and 137-80-3CBCC reveal that fluctuations of the water table follow very closely fluctuations in river stage (Figure 8A). Note however, that during the high ET months of each year, water levels in 138-80-17CDD$_1$ and 137-80-3CBCC were decreasing despite relatively steady Missouri River stages. Water level declines during the summer months appear to be due in part to ET.

In September, when ET effects diminish, water levels began a gradual upward trend. Water levels following the maximum ET period then trend at the same slope as the river stage elevation (Figure 8A).

Presented in Figure 11 are hourly water levels from observation well 138-80-17CDD$_1$ during the period, July 10, 1980 to July 15, 1980. Note that a daily decline in water levels occurred during the sunlight hours when ET losses are the greatest. Water levels declined on an average of .04 feet during a daily high ET period. Water levels slowly recovered or stabilized during the evening and morning when ET losses were low. Large cottonwoods and other phreatophytes in the area probably account for the principal ET effects. Note also the general downward slope to the water levels during this time period despite a relatively stable river stage.

ET does appear to affect the water table. Fluctuations caused by ET are, however, very minor when compared to fluctuations of the water table caused by changing Missouri river stages.

Precipitation, Snowmelt

Accompanying Figures 7 and 8 are histograms of precipitation at the Bismarck municipal airport. Generally, infiltration from precipitation

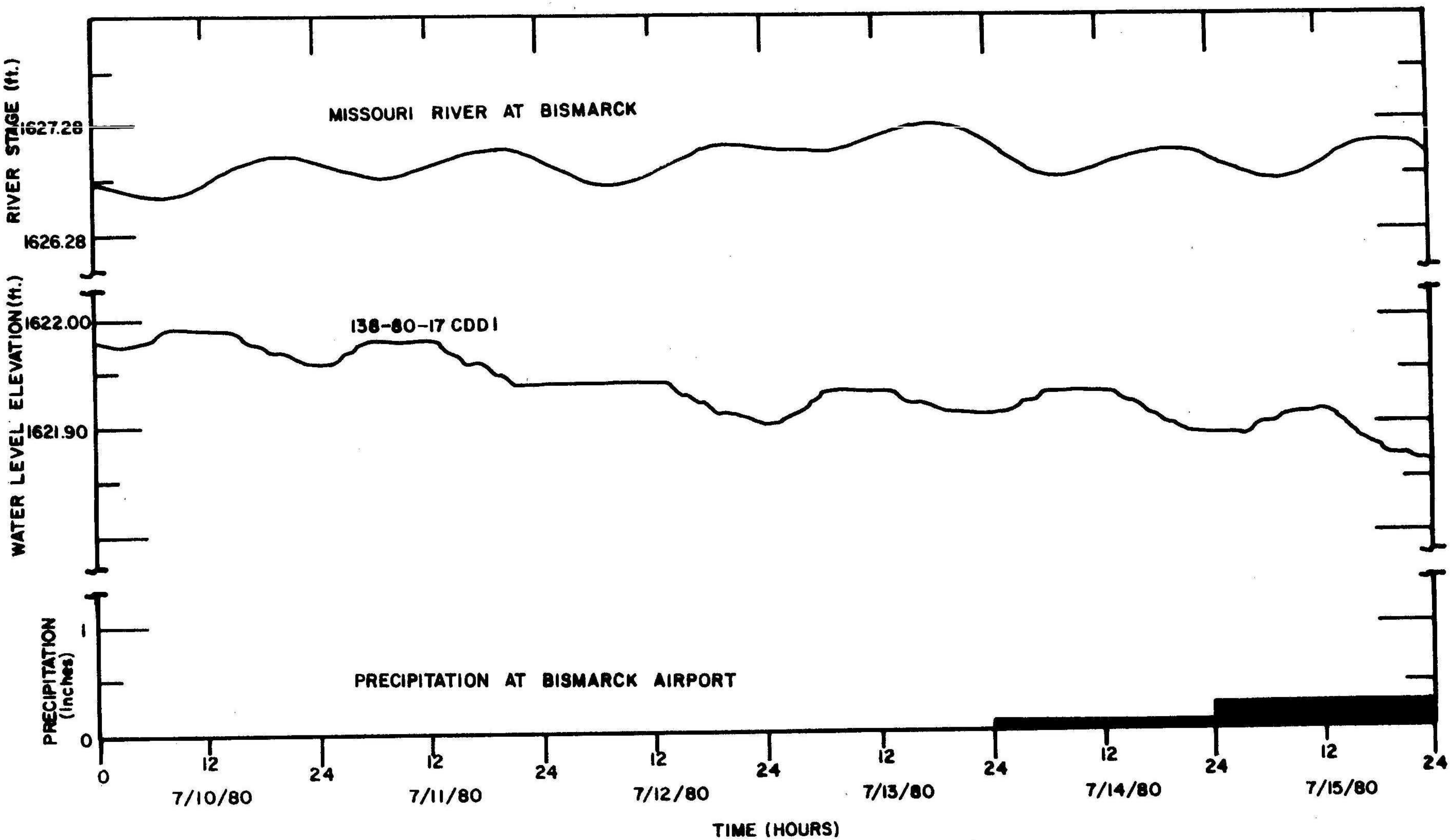


FIGURE 11. HOURLY WATER LEVELS IN OBSERVATION WELL 138-80-17 CDD FOR THE PERIOD 7/10/80 TO 7/15/80 SHOWING THE EFFECTS OF EVAPOTRANSPIRATION

events appear to have a minor influence on the water table. In fact, during high ET periods, precipitation has little or no effect on ground-water levels (Figure 8A). Precipitation and local spring snowmelt events also correlate to a rise in river stage, making it difficult to determine whether precipitation and snowmelt are recharging the aquifer directly, or whether rising ground-water levels are the result of a rising river stage. Consequently, the aquifer is influenced more by river stage fluctuations than local precipitation and snowmelt events.

Long Term Water Level Trends

Presented in Plate 4 are long term hydrographs for observation wells $17CDD_1$ (15 years) and 15CDD (21 years) (Township 138 North, Range 80 West) and the gage height of the Missouri River at Bismarck.

Response of water levels in both wells confirms that fluctuations of Missouri River stages cause fluctuations of the water table. Highest ground-water levels occur during periods of highest river stage (December-March). Note that the highest and most sustained ground-water levels occur in years which had higher than average winter river stage readings coupled with above normal river stage in the summer and fall months (Plate 4, e.g. 1972, 1975, 1976, 1978, 1979, and 1982).

Lowest water levels were recorded in years which had a slightly lower than normal winter river stage readings coupled with years of low summer and fall river stage (Plate 4, e.g. 1973 and 1977). On the floodplain, away from irrigation, water levels reach their yearly minimum in September as a result of low river stage and evapotranspiration (Plate 4B). Near irrigation developments, water levels reach their lowest point in June, July, or August (Plate 4A).

GROUND-WATER MOVEMENT

Introduction

Ground-water movement was determined by plotting water level elevations for select time periods on base maps of the South Bismarck study area. Contours of equal water level elevation were then interpolated from the data. Ground-water contours represent lines of equal ground-water elevation, thus flow must be perpendicular to the contours. Time periods for the water-level contour maps were selected on the basis of season of the year and significant natural hydrologic or man induced events. Only general patterns of ground-water movement will be discussed. Localized variations in direction of ground-water movement are illustrated with arrows (Figures 12, 13, 14 and 15)..

Water Level with Depth Relationships

Water level with depth was measured at twelve (12) multiple well sites in the study area (Table 4 and Plate 1). This relationship is important to determine because it is not possible to construct water level contour maps if there are significant vertical head components in a particular aquifer.

Generally, there is a slightly decreasing water level with depth relationship at seven (7) of the twelve (12) multiple well locations. At four (4) of those seven (7) sites, the difference was very minor and could be due to measurement error (Table 4). One (1) of the sites has the deeper well screened in bedrock, thus explaining the water level difference (T138-R80-3CAD$_1$ and $_2$). The two (2) remaining paired

TABLE 4. Water Level with Depth Relationships

Obs. Well	Increasing With Depth	Decreasing with Depth	Magnitude (ft.)	Comment
T.138-R.80				
2DDD$_{1\&2}$		X	.1 - .2	Difference within measurement error
3CAD$_{1\&2}$		X	5 - 7	Deep well screened in bedrock
5ADD$_{1\&2}$	X	X	0 -+ .4	Both wells respond to river. Shallow well has higher water level during high river stage Deeper well has higher water level during normal flow of river.
8ABA$_{1\&2}$				No difference.
10CDAD$_{1\&2}$		X	1 - 2	Shallower well is screened in perched system
15CAAA$_{1\&2}$		X	0 - .1	Difference within measurement error.
16DCC$_{1\&2}$				No difference
17CDD$_{1\&2}$		X	0 - .2	Difference within measurement error
19DCC$_{1\&2}$				No correlation, one well screened in clay
23ADC$_{1\&2}$				No difference
28AAA$_{1,2\&3}$				No difference
29BCB$_{1\&2}$		X	less than .1	Difference within measurement error

wells appear to have the shallower well screened in a thin perched aquifer zone (Table 4). Water level and test hole data indicate that perched zones are more prevalent on the State Penitentiary and Fort Lincoln terraces. Wells that were screened in perched zones were not included on the water level contour maps. No significant difference in water level with depth was detected in the remaining five (5) paired wells. Thus, water levels do not appear to vary significantly with depth.

Significant variations in water level with depth were not detected between wells on the floodplain. Therefore, most wells in the area are believed to yield representative water level elevations for the South Bismarck aquifer. Thus, the following water level contour maps are based on wells that are screened in various depth intervals within the South Bismarck aquifer system.

Winter of the Year, High River Stage

During the months of December to March, the level of the Missouri River rises well above the adjoining ground-water levels. It was shown earlier that water levels in the South Bismarck aquifer rise in response to the increase in river stage. Thus, from December through March water from the Missouri River provides recharge to the South Bismarck aquifer (Figure 12).

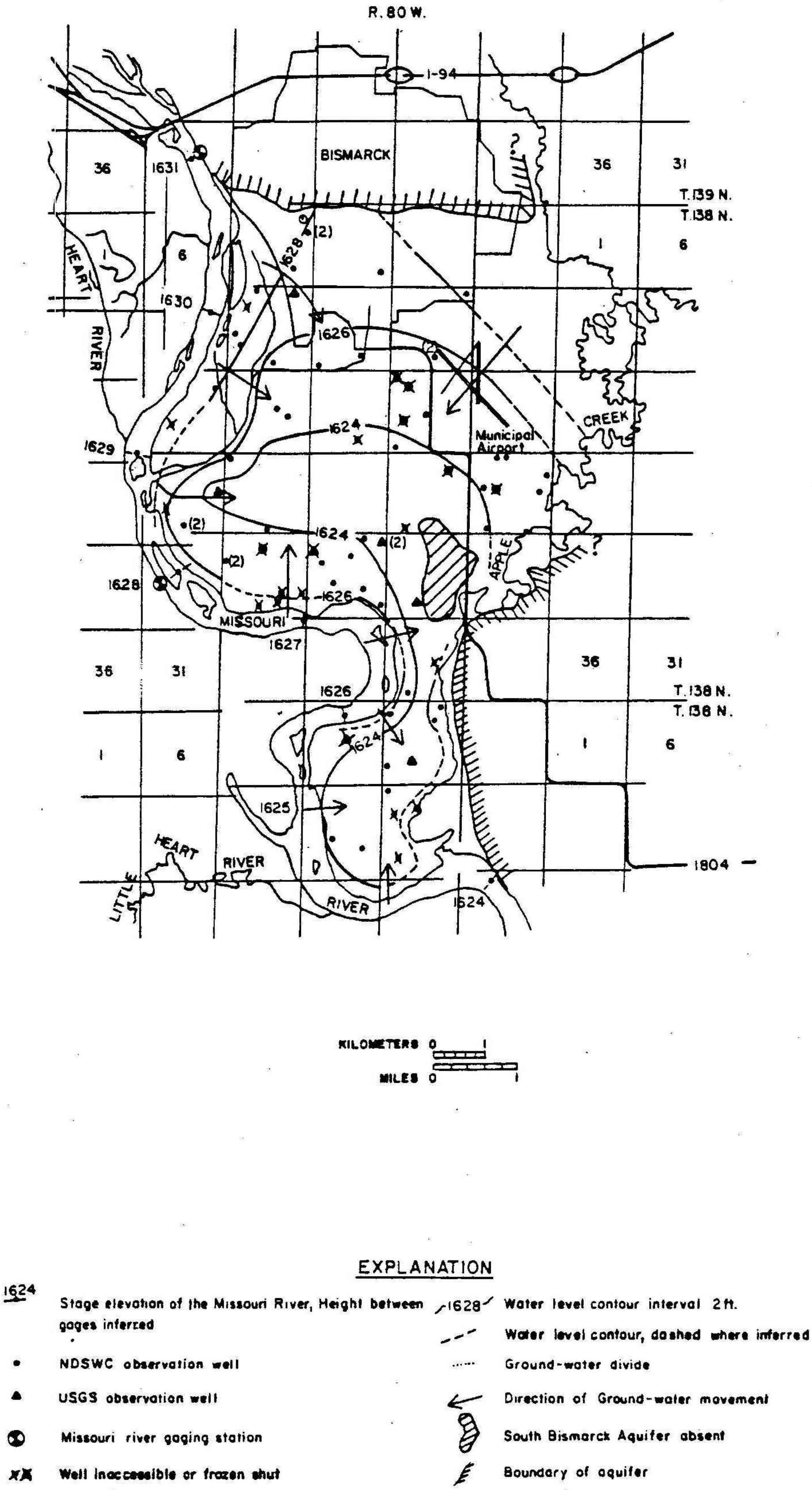


Figure 12. Water Level Contour Map of the South Bismarck Aquifer System During the Winter of the Year, High River Stage (Feb. 7 & 8, 1980)

Recharge from the meandering river into the aquifer causes ground water in the South Bismarck aquifer to move in several directions. In the northwest and southeast portions of the study area, ground water moves from the northwest to the southeast (Figure 12). Recharge from the river to the aquifer in Sections 28 and 29, Township 138 North, Range 80 West and Sections 9 and 10, Township 137 North, Range 80 West, imposes a north to northeast direction to ground-water flow (Figure 12). In areas where the river trends from north to south, ground-water movement is to the east, away from the river. Ground-water movement in the northeastern portion of the study area is from the north and east to the south and west.

Near the river, the hydraulic gradient was approximately 4 feet/mile; while out on the floodplain the gradient was relatively flat (Figure 12).

Spring of the Year, Normal to Low River Stage

Because of the winter, high river stage recharge event, water levels in the South Bismarck aquifer rise. Recharge from the Missouri River to the aquifer creates bank storage mounds along the river (Figure 13). These mounds are hinge zones representing the areas most impacted by fluctuations in river stage. When river stage suddenly decreases, ground water from portions of the bank storage mounds moves back towards the river (Figure 13). In some areas, a ground-water divide is formed. Ground water on the aquifer side of the ground-water divide moves from the north-northwest to the south-southeast and is subsequently discharged back into the Missouri River (Figure 13).

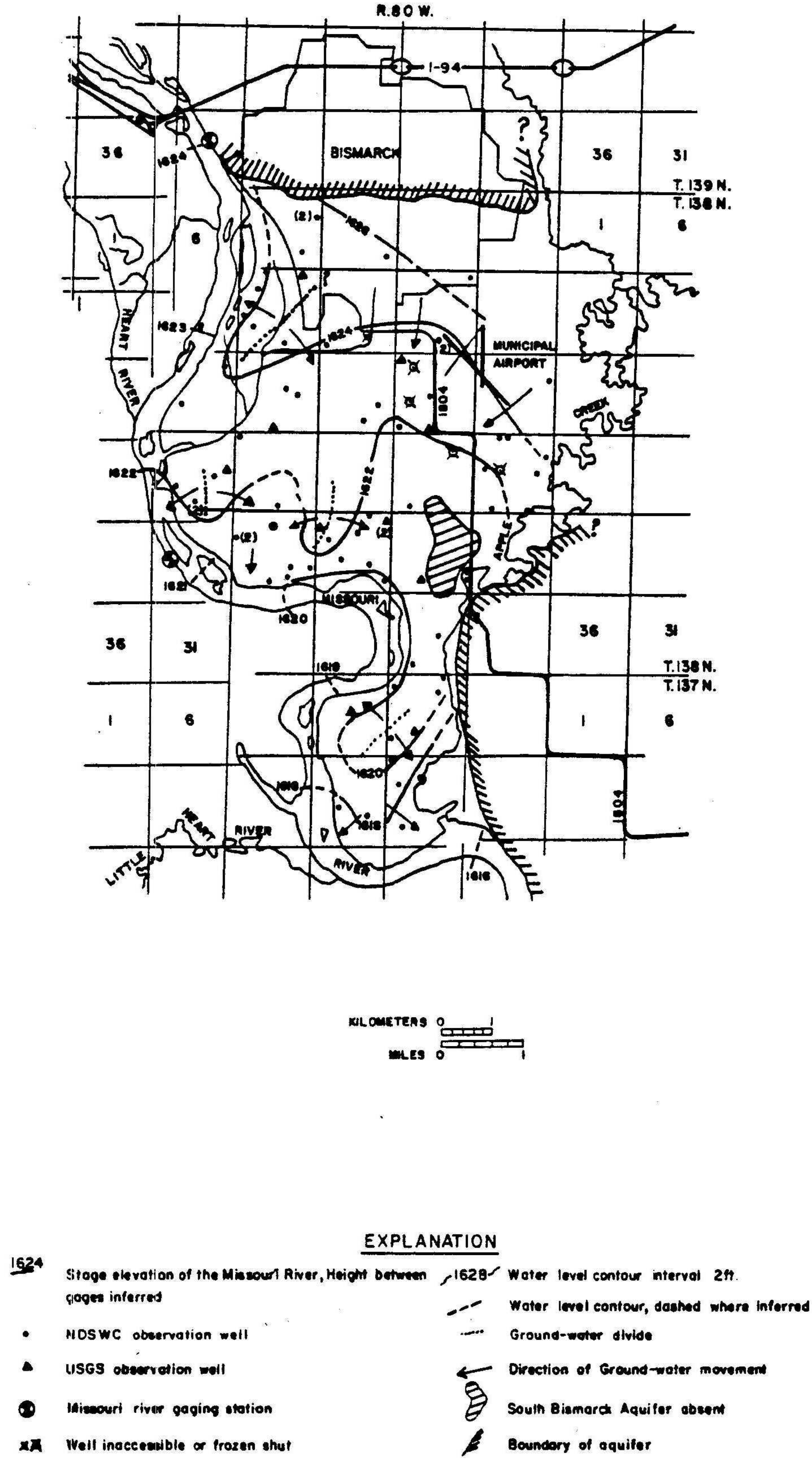


Figure 13. Water Level Contour Map of the South Bismarck Aquifer System During the Spring of the Year, Normal River stage (May 19-20, 1980)

Late Summer, Normal to Low River Stage, Irrigation Season

Presented in Figure 14 is a water table contour map of the study area during the 1980 irrigation season. Discharge of ground water from irrigation wells has resulted in several localized cones of depression. Areas of largest declines are near operating irrigation wells in Sections 15, 23, and 29, Township 138 North, Range 80 West.

Ground-water movement is in several directions during the irrigation season. Near operating irrigation wells, ground-water flow is directed toward the cones of depression (Figure 14). Along the Missouri River, the bank storage mound discussed earlier has subsided, resulting in recharge from upstream portions of the river into the aquifer. Generally, ground-water movement along the river is from the northwest to the southeast.

Fall of the Year, Normal to Low River Stage

During the fall of the year, ground-water flow appears to be directed across meanders in the Missouri River in response to the head differential between the upstream and downstream portions of each meander (Figure 15). On the upstream side of the river, heads in the river are at times higher than the adjoining ground-water levels. Thus, water moves from the river into the aquifer. Ground water in this case moves in a south to southeasterly direction. On downstream portions of the river, heads in the aquifer are higher than the river, thus ground water moves from the aquifer back into the river (Figure 15).

During the fall of the year, the stage of the Missouri River can fall below the adjoining ground-water levels. In this case, bank storage mounds would be formed with flow assuming the patterns shown in Figure 13.

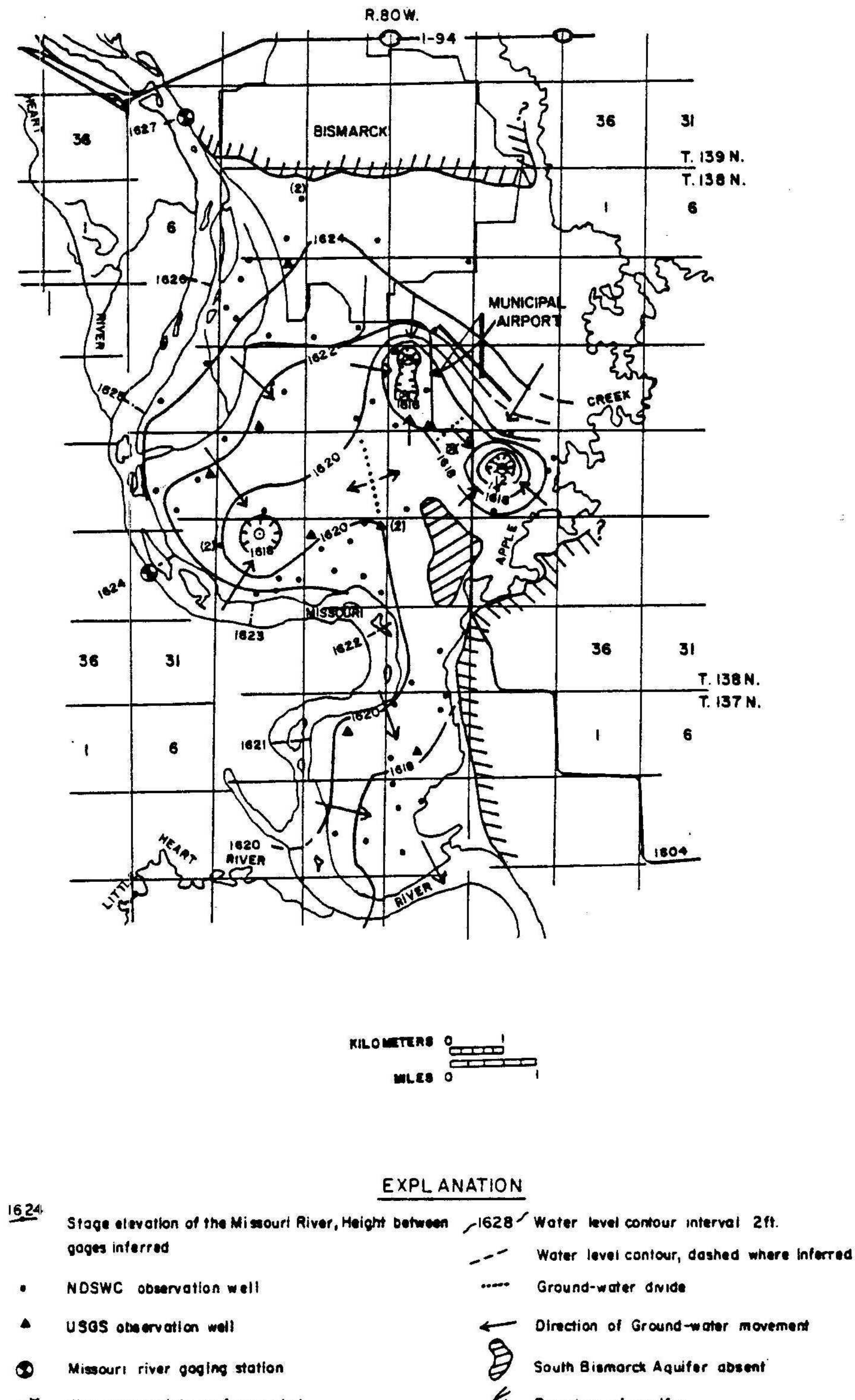


Figure 14. Water Level Contour Map of the South Bismarck Aquifer System During Late Summer, Normal to Low River Stage, Irrigation Season (July 17-18, 1980)

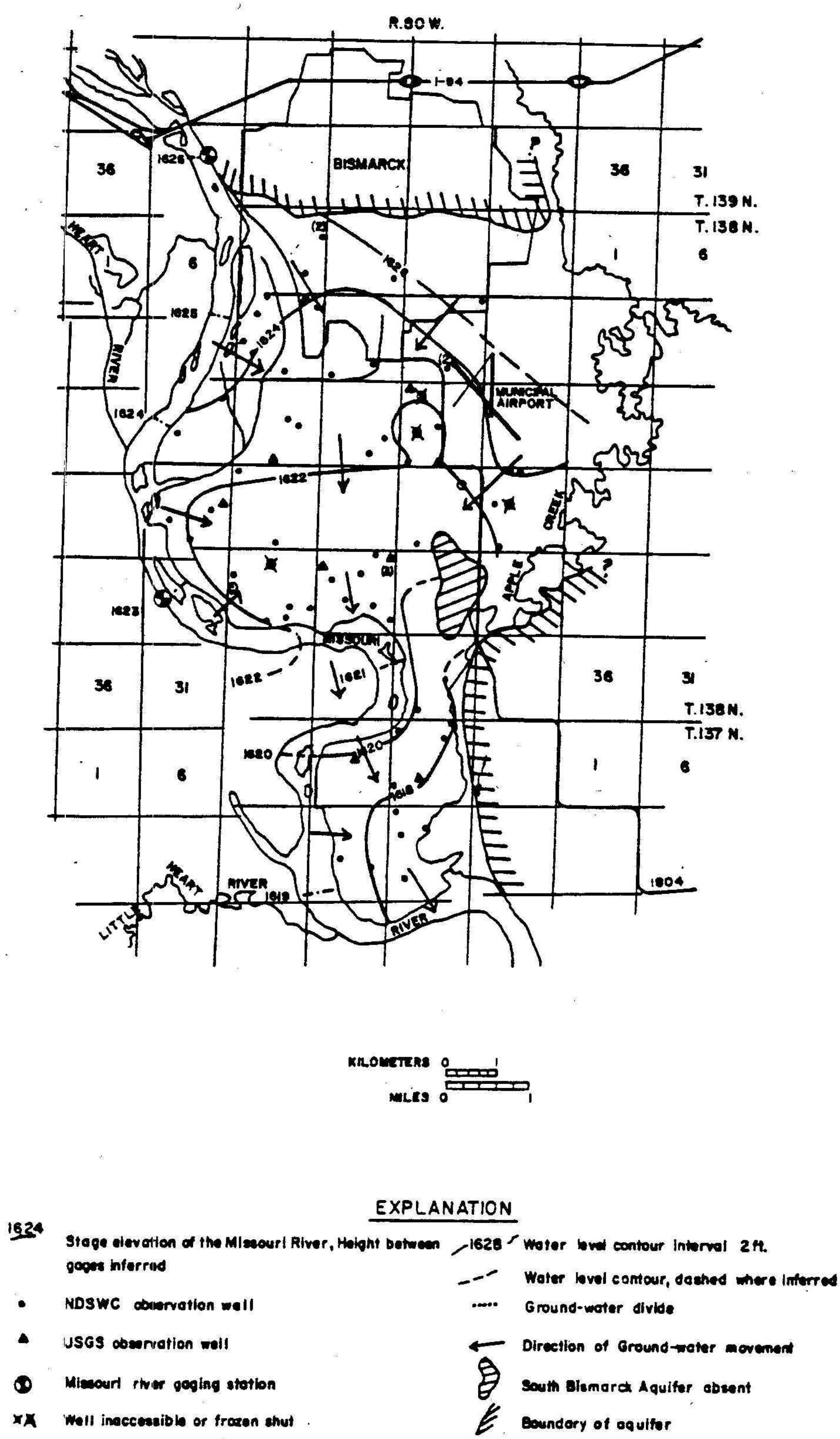


Figure 15. Water Level Contour Map of the South Bismarck Aquifer System During the Fall of the Year, Normal to Low River Stage (November 3, 1980)

In the northern portion of the study area, the hydraulic gradient is very flat, ranging from 1½ to 2 feet/mile (Figure 15, Township 138 North, Range 80 West). In the southern portion, the gradient increases slightly to 2½ to 3 feet/mile. The increase in hydraulic gradient is the result of a decrease in cross-sectional area from north to south across the study area.

Depressions, or warping of contour lines in Section 15, Township 138 North, Range 80 West are due to residual drawdown from prior irrigation activities.

Ground-water movement in the northeastern portion of the study area is from the north and east to the south and west. Thus, the Apple Creek aquifer supplies some recharge to the South Bismarck aquifer.

CONCLUSIONS

1) Ground-water occurrence and movement in the South Bismarck area is controlled by the complex geohydrologic setting existing in the region. The floodplain and terraces south of Bismarck consist primarily of fine to coarse sand and gravel which are overlain by and interbedded with clay and silt. Grain size generally increases with depth. Saturated sand and gravel deposits range in thickness from only a few feet to well over 100 feet. Along the Missouri River, the South Bismarck aquifer ranges from 30 to 100 feet thick.

Sand and gravel deposits of the area exhibit a moderate to high hydraulic conductivity. Well yields from the South Bismarck aquifer range from 500 to 2000 gpm.

2) Bedrock underlying the area consists of consolidated silt, clay, and sandstone units of the Hell Creek Formation. These units exhibit a very low hydraulic conductivity in comparison to the sand and gravel units of the overlying South Bismarck aquifer system.

3) Ground water in the South Bismarck aquifer system occurs under both artesian (confined) and water table (unconfined) conditions. On the floodplain, the confining unit consists of approximately 20 feet of overlying clay and silt.

Depth to water in the area is a reflection of the elevation a particular point is above mean sea level. In areas below land elevation 1630 feet, depth to water ranges from less than 1 foot to 10 feet below land surface (Prison Farm terrace). Depth to water ranges from 5 to 15 feet below land surface in areas between elevation 1630 and 1640 feet (Wachter terrace). Between land elevation 1640 to 1650 feet, depth to water ranges from 15 to 20 feet below land surface. Areas above land elevation 1650 feet have depth to water in the 20 to 40 foot range. Perched aquifer zones were also detected in these higher terraces.

4) Fluctuations of the South Bismarck water table are primarily due to stage fluctuations of the Missouri River. A rise in river stage results in a rise in water levels, while a decrease in river stage results in a decline in water levels. Highest ground-water levels usually occur during the months of December through March in response to maximum stage of the Missouri River. A second, lower magnitude peak in water levels occurs in April through June as a result of the natural spring runoff event.

On the floodplain, lowest water levels occur in late September as a combined result of low river stages and evapotranspiration. Near irrigation developments lowest water levels generally occur in June, July, and August.

Precipitation, evapotranspiration, and irrigation activities have very minor influences on the water table in comparison to changes imposed by river stage fluctuations.

The response of the water table to changes in Missouri River stage also depends on the magnitude and duration of river stage fluctuations and proximity to the river. Generally, the higher and more sustained the river flow, the higher and more sustained ground-water levels will be. Water levels in wells nearest the river respond quicker and have higher peaks than water levels in wells some distance away from the river. The further an observation well is from the river the more dampened the response is to the changing river stage. Ground-water levels in the area are either influenced directly by the river, or are responding to the change in gradient imposed by the river.

5. Major recharge to and discharge from the South Bismarck aquifer system is controlled by the Missouri River. When river stage is below the elevation of the adjoining water table, the direction of ground-water movement is toward the river. When river stage is higher than the adjoining water table, the direction of flow is from the river to the aquifer. When river stage suddenly drops below the level of the adjoining water table, ground-water mounds and divides are found, with ground-water moving both towards the river and the aquifer.

6. Generally, ground-water flow in the South Bismarck aquifer system appears to be directed across meanders in the Missouri River in response to the head differential between the upstream and downstream portion of each meander. The net direction of ground-water movement roughly parallels the flow of the Missouri River; north to south or northwest to southeast. Localized flow patterns resulting from site specific stratigraphy, topography, bank storage mounding and irrigation have minor influences on the regional flow patterns.

Ground water also moves from the Apple Creek aquifer into the South Bismarck system. Water levels in the Apple Creek area appear to be controlled in part by the Missouri River.

7. Ground water from the South Bismarck aquifer can generally be classified as a sodium-magnesium-calcium-bicarbonate (Na-Mg-Ca-HCO_3) type with no cation being dominant. Recommended drinking water limits for iron (Fe), sodium (Na), bicarbonate (HCO_3), sulfate (SO_4), and hardness ($CaCO_3$) were exceeded in several samples. Ground water from sandstone units of the underlying Hell Creek Formation is higher in total dissolved solids (TDS) and sodium (Na) but lower in iron (Fe) and hardness than ground water from the South Bismarck aquifer system.

For irrigation purposes, ground water from the South Bismarck aquifer system can be classified as C3-S1 or C3-S2 types; indicating a high salinity, low to medium sodium hazard. A soil-water compatibility test should be conducted before irrigation development takes place.

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