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Groundwater Chemistry Analysis of the Saginaw Formation in Delhi Township, Michigan

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GROUNDWATER CHEMISTRY ANALYSIS OF THE SAGINAW FORMATION IN DELHI TOWNSHIP, MICHIGAN

by

Sam L. Kitchin

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
June 1993

GROUNDWATER CHEMISTRY ANALYSIS OF THE SAGINAW FORMATION IN DELHI TOWNSHIP, MICHIGAN

Sam L. Kitchin, M.S.

Western Michigan University, 1993

Groundwater chemistry and well data provided by the Ingham County (Michigan) Health Department were used to evaluate the distribution of inorganic chemical constituents in the groundwater flow system of the Saginaw Formation, in Delhi Township, Michigan. The data also were used to study the distribution of chemical constituents with respect to different rock types of the Saginaw Formation. The data were analyzed to examine if variations in the concentrations of the chemical constituents and the values of other chemical parameters relate to rock-water interactions, groundwater flow systems, or groundwater contamination.

The results indicate that patterns of increasing or decreasing concentrations of chemical constituents along groundwater flow paths are limited to areas encompassing one or two sections of the township. The concentrations of chemical constituents are not controlled by the rock types of the Saginaw Formation or the depth into the formation that water occurs.

ACKNOWLEDGEMENTS

I would like to thank Gary Rowe of the Ingham County Health Department for providing the data used in this study. I would also like to express my appreciation to Dr. Alan Kehew of the Department of Geology at Western Michigan University for his excellent guidance during this project. The efforts of Dr. Thomas Straw and Richard Passero, also of the Department of Geology at Western Michigan University, are recognized.

Sam L. Kitchin

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Kitchin, Sam L., M.S.

Western Michigan University, 1993

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CHAPTER I

INTRODUCTION

Purpose

The purpose of this study was to analyze the inorganic ground-water chemistry of the Saginaw aquifer in Delhi Township, Michigan, by using ground-water chemistry and well record data. The specific objectives were as follows: (a) to map the concentration values of several ground-water chemistry parameters to delineate patterns in the ground-water flow system of the Saginaw aquifer; (b) to examine the concentrations of chemical constituents from the groundwater of the Saginaw aquifer relative to lithology; and (c) to determine if variations in the concentrations of parameters can be explained in terms of rock-water interactions, ground-water flow systems, or ground-water contamination.

The data used for this study were provided by the Ingham County Health Department and consist of well records and chemical analyses of water samples from wells throughout Delhi Township. The data from the Ingham County Health Department along with data from other county health departments in southwest Michigan were compiled by the Southwest Michigan Groundwater Survey into a computerized groundwater database. The Southwest Michigan Groundwater Survey was begun by the Science for Citizens Center at Western Michigan University. The computerized database was used in this study principally because the data could be accessed quickly and easily, and because the database files could be used by other computer software to generate geologic cross sections.

Location

Delhi Township is located in Ingham County, Michigan (Figure 1), which lies in the south-central part of the southern peninsula of Michigan. The northern border of Delhi Township is two miles inside the city limits of Lansing. The city of Holt is located in the central part of the township. Sycamore Creek flows west and northwest through the northeast corner of the township, and the Grand River flows northward through the southwest corner of the township. (See Plate 1 for the location of the rivers.)

Climate

Firouzian (1963) reported that the average annual precipitation in the Lansing area from 1953 to 1962 was 31.08 inches. The lowest average high temperatures occur in January (26 degrees F), and the highest average high temperatures occur in August (78 degrees F). Snowfall occurs from November through March and is approximately 40 inches per year.

Geology Of Delhi Township

Glacial Geology

The geology of Delhi Township includes unconsolidated glacial deposits and consolidated sedimentary strata that underlie the glacial materials. Figure 2 shows the surficial glacial geology of Delhi Township. Surficial map units include moraines, eskers, kames, outwash, alluvium, and muck. The glacial deposits covering Delhi Township are thin, with the average thickness of the drift being approximately 50 feet. Well records indicate that the drift ranges in thickness from 25-75 feet. (See Figure 3.)

Figure 2 shows that moraines are the most common type of glacial landform in Delhi Township. Moraines, which usually are composed of till, range in shape from

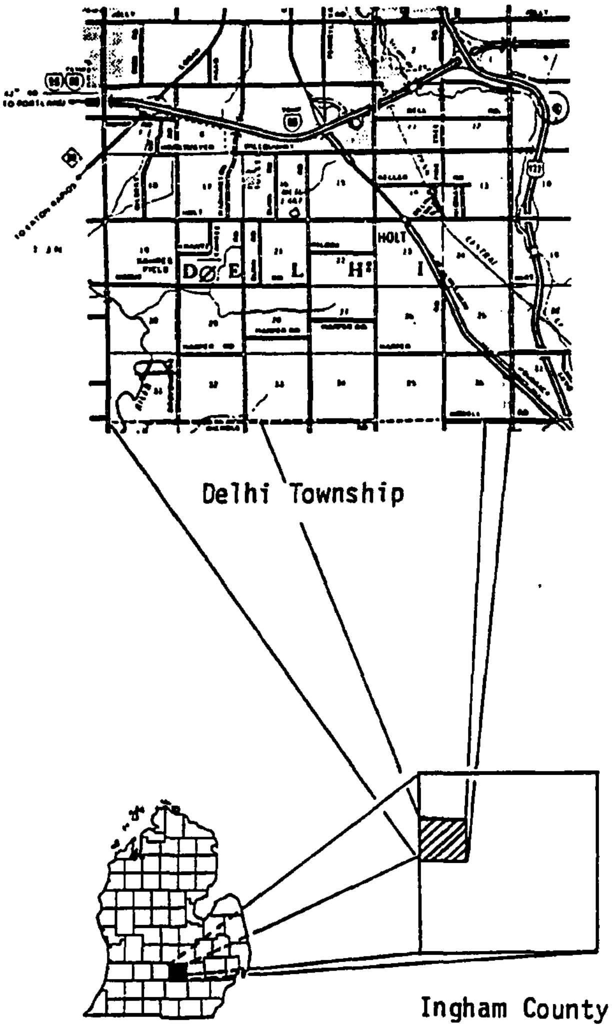


Figure 1. Location of Delhi Township, Michigan.

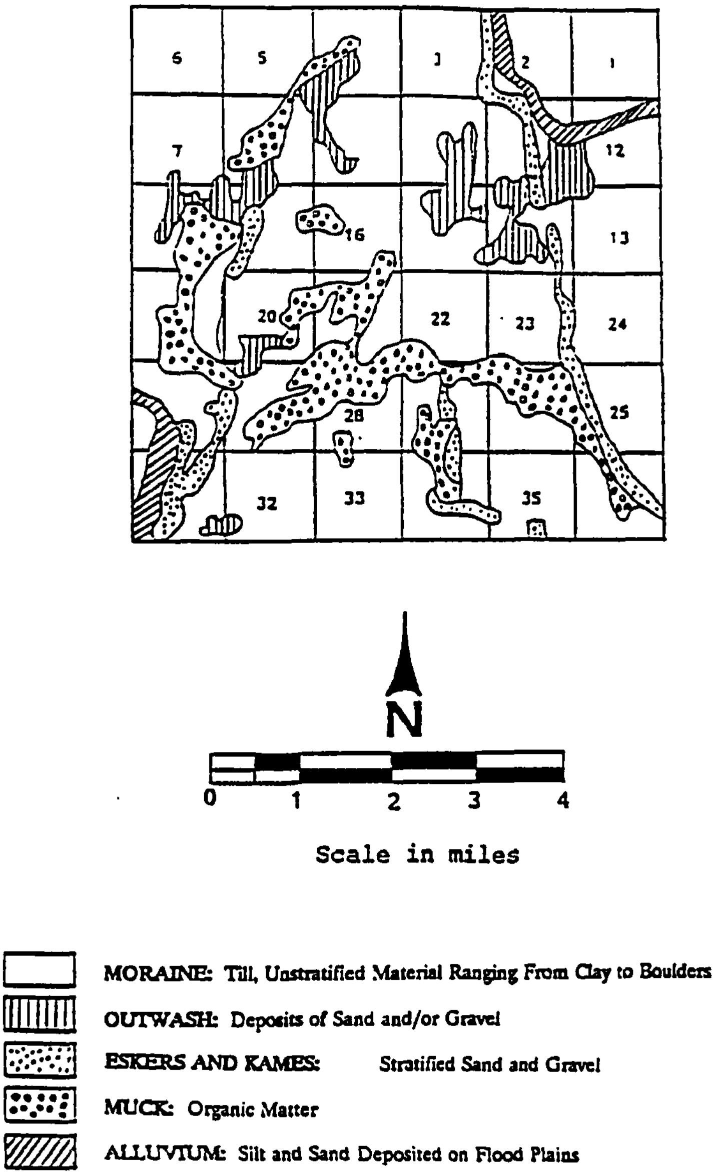


Figure 2. Surficial Geology of Delhi Township (after Tri-County Regional Planning Commission, 1982).

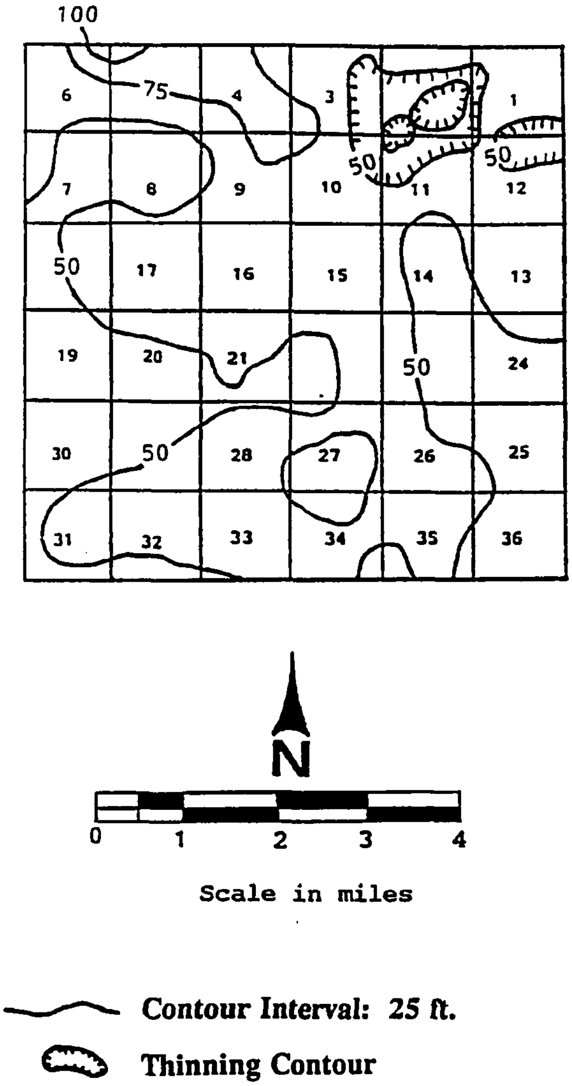


Figure 3. Glacial Drift Thickness in Delhi Township (after Tri-County Regional Planning Commission, 1982).

gently rolling hills with shallow valleys to long, high ridges (Ritter, 1982). Till consists of a unstratified, poorly-sorted mixture of clay, silt, sand, and gravel.

Muck deposits comprise the next most abundant surficial material type in the township (Figure 2). Muck consists of organic material that has accumulated in depressional areas where the water table is close to the ground surface. These deposits usually are located on old glacial lake beds and in kettles. In general, muck deposits occur in the low areas of the township that have little relief and poor drainage (Tri-County Regional Planning Commission - TCRPC, 1982).

Outwash deposits are present in the township and are designated as a surficial unit in Figure 2. Outwash consists of sorted, stratified sand and gravel deposited by glacial meltwater streams (Ritter, 1982).

Alluvial deposits lie on the floodplains along Sycamore Creek and the Grand River. (See Figure 2 and Plate 1.) These deposits consist of silt and fine sand deposited by overbank flow of streams (TCRPC, 1982).

The landforms associated with the outwash deposits include outwash plains and valley train deposits. Valley train deposits consist of sorted, stratified sand and gravel deposited by glacial meltwater streams flowing through a well-defined valley (Ritter, 1982). In the Lansing area, valley train deposits are long and narrow and in many places are only a few feet thick (Snell, 1977). A valley train deposit lies in the eastern half of section 11.

Outwash plains consist of sorted, stratified sand and gravel deposited by several braided glacial meltwater streams over a large, flat area (Ritter, 1982). Outwash plains are located in sections 10 and 15.

Eskers and kames comprise the remaining surficial materials in Delhi Township (Figure 2). Eskers are long, narrow ridges of sorted and stratified sand and gravel

Eskers and kames comprise the remaining surficial materials in Delhi Township (Figure 2). Eskers are long, narrow ridges of sorted and stratified sand and gravel deposited by streams flowing near the base of a glacier (Ritter, 1982). Parts of a well-developed esker exist in the eastern part of the township. This esker trends northwest to southeast between sections 2 and 36. This esker, commonly called the Mason esker, has been mined for sand and gravel, and only a few sections remain (Snell, 1977). Eskers commonly trend parallel to and in contact with bedrock; in other places they overlie other glacial deposits (Snell, 1977).

Kames are mounds of sand and gravel that formed as glacial meltwater streams flowed over the edge of stagnant ice bodies or plunged into moulins in the ice. Generally, the sand and gravel is layered but may not be stratified and sorted as well as outwash deposits (Ritter, 1982). Figure 2 does not show exactly where kames are located since kames and eskers are grouped together as one surficial feature. The kames may show up on a topographic map as a hill or a group of hills.

Figure 2 shows only the glacial materials that exist on the surface. Surface sediments of one particular type usually do not extend to bedrock.

Bedrock Geology

The deep bedrock underlying Delhi Township is composed of Paleozoic sedimentary rocks that include 8000 feet of sandstone, dolomite, limestone, shale, and evaporites. These rocks range in age from Cambrian to Upper Mississippian (Dott, Murray, and Grove, 1954).

Above the Paleozoic rocks lie sedimentary rocks of Pennsylvanian age. The Pennsylvanian sequence in Delhi Township consists of interbedded sandstone, shale, limestone, and coal of the Saginaw Formation. The rocks of the Saginaw Formation

Cross sections (Figure 5 [a] and 5 [b]) were constructed in this study to show the geology of Delhi Township. The locations of the cross sections and the wells used to generate the cross sections are shown in Plate 1.

Hydrology

Surface Water Hydrology

The principal surface water features in Delhi Township are the Grand River and Sycamore Creek. The Grand River flows northward through sections 30 and 31 and continues northward into the city of Lansing (Plate 1). Sycamore Creek flows west through section 12 and then northwest through sections 11 and 2. It then flows northward into the Red Cedar River at Lansing. The Red Cedar flows west and drains into the Grand River approximately 1.5 miles from the confluence with Sycamore Creek.

The Grand River is the largest river in the study area. Figure 6 shows the average monthly discharge of the Grand and Red Cedar Rivers based on data from 1937-1965. The discharge of Sycamore Creek is not on this graph, but its flow is less than that of the Red Cedar River because Sycamore Creek is a tributary of the Red Cedar.

The other surface water features in Delhi Township consist of county drains and ponds formed by gravel pits. The drains, scattered throughout the township, eventually discharge into the Grand River or Sycamore Creek. The ponds formed by the gravel pits are located on the Mason esker, which trends southeast-northwest through sections 36, 25, 24, 23, 14, 11, and 2. The largest ponds are 1/4 mile in length and are about 1/10 mile wide. Some of these ponds lie close to one another, such as those in sections 23 and 24. The drains and gravel pit ponds can be seen on topographic maps (Lansing South, Mason, East Lansing, and Aurelius quadrangles, 7.5 minute series).

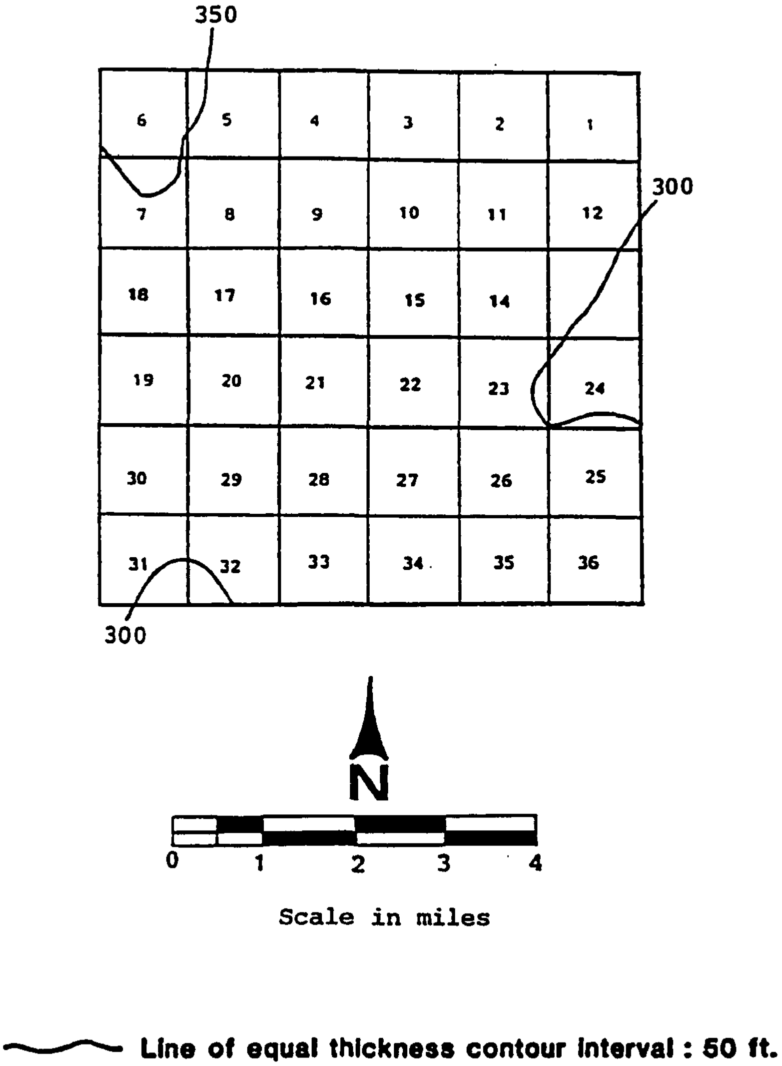


Figure 4. Thickness of the Saginaw Formation in Delhi Township (after Tri-County Regional Planning Commission, 1982).

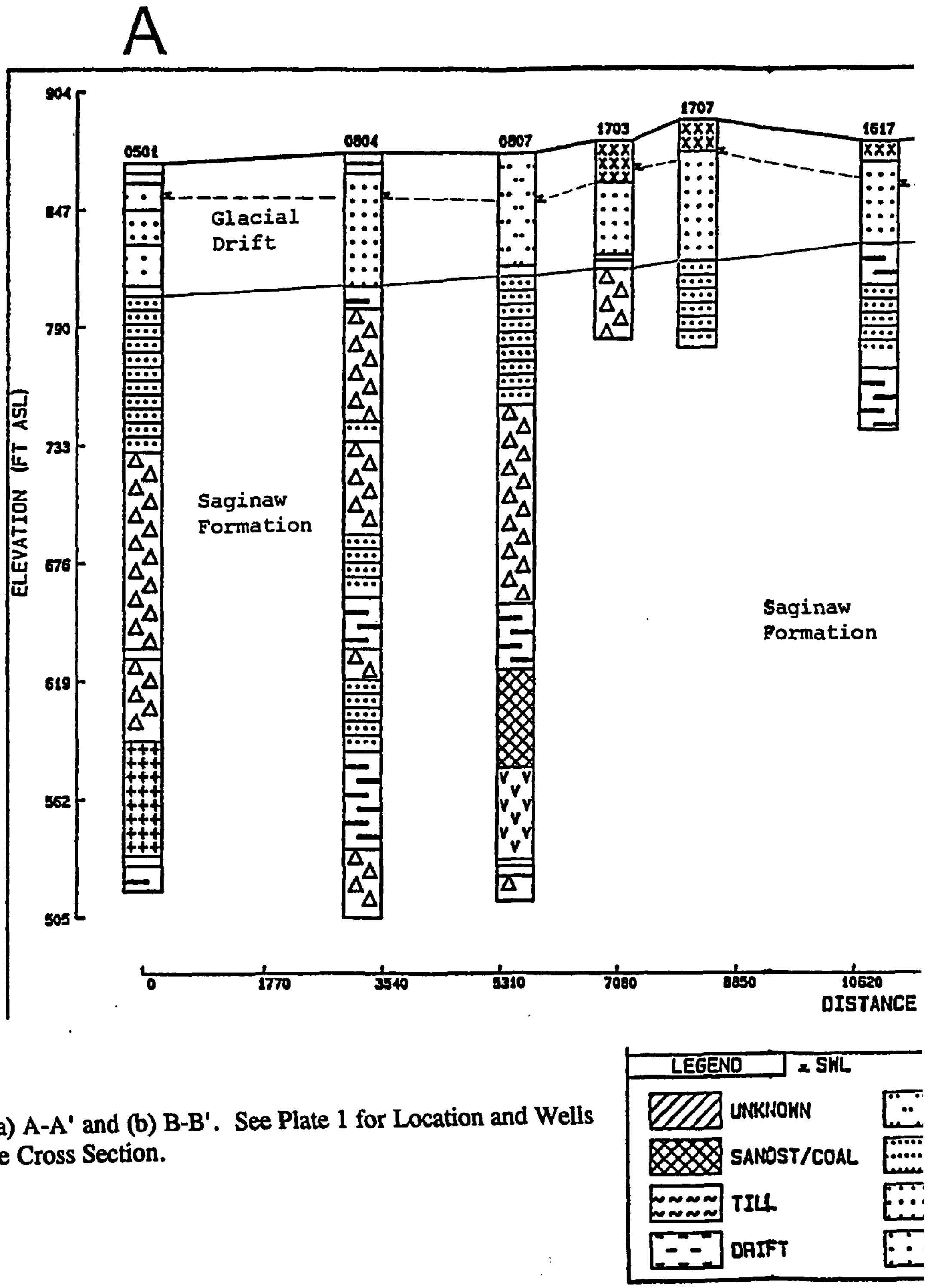
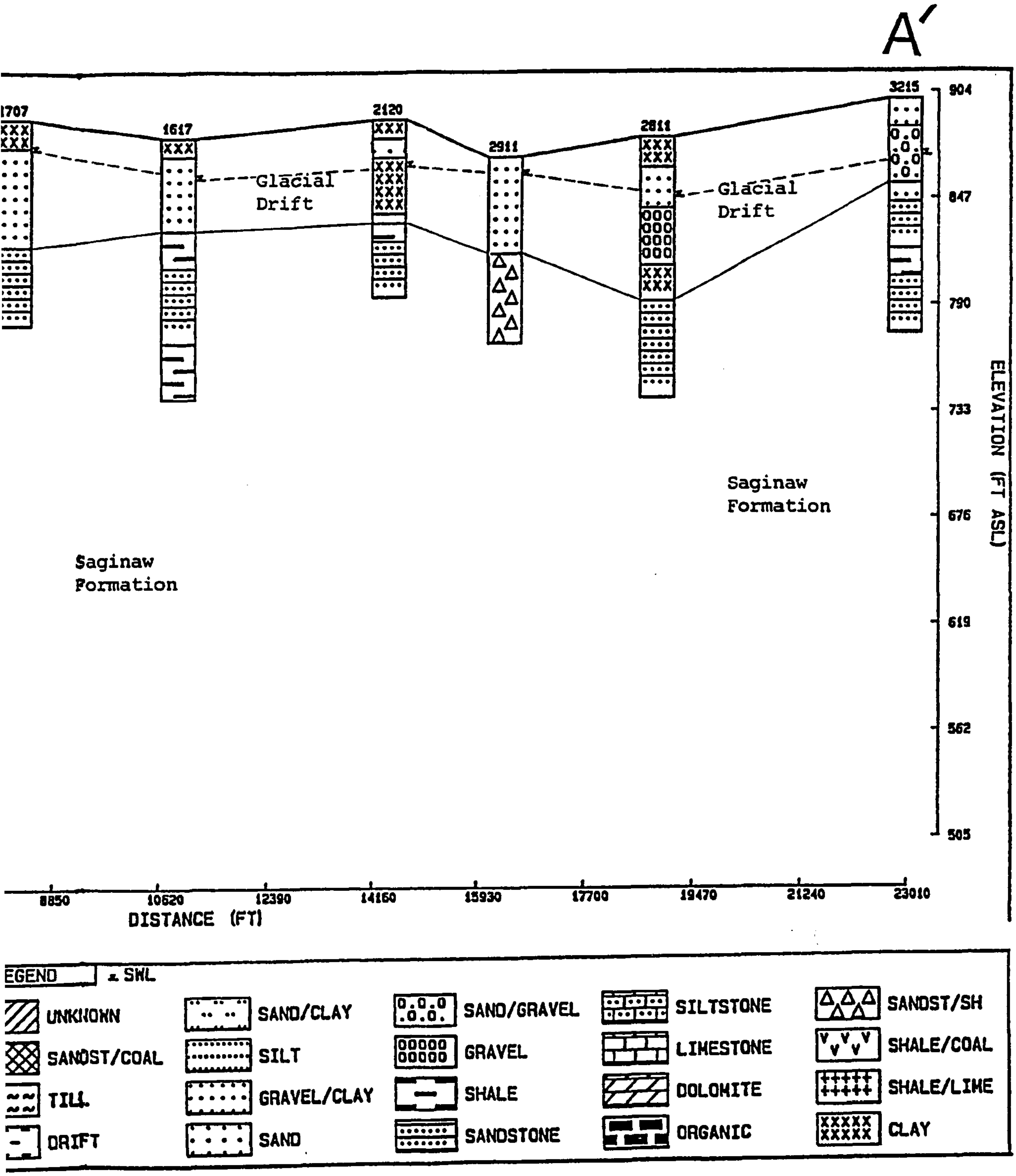
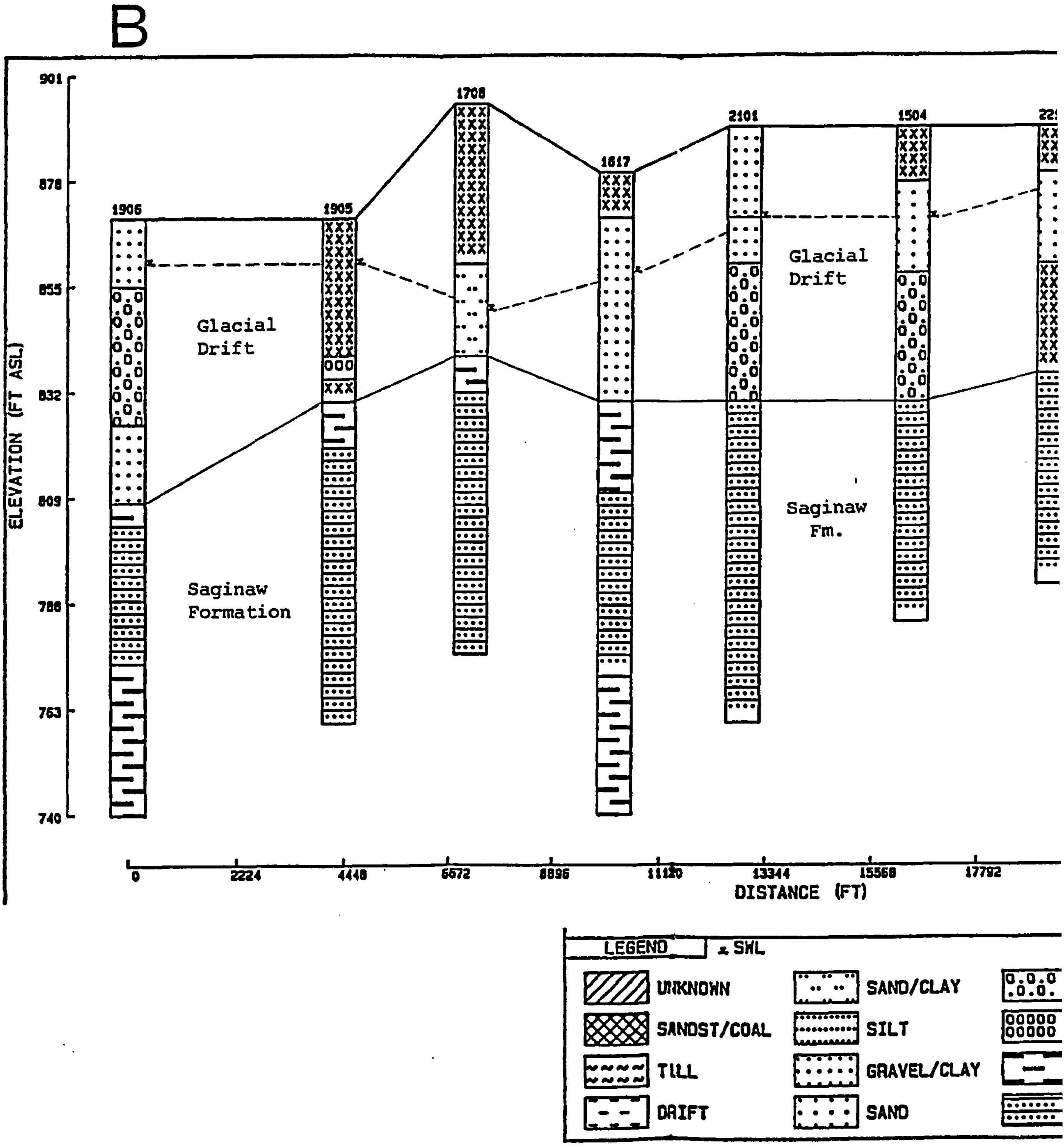
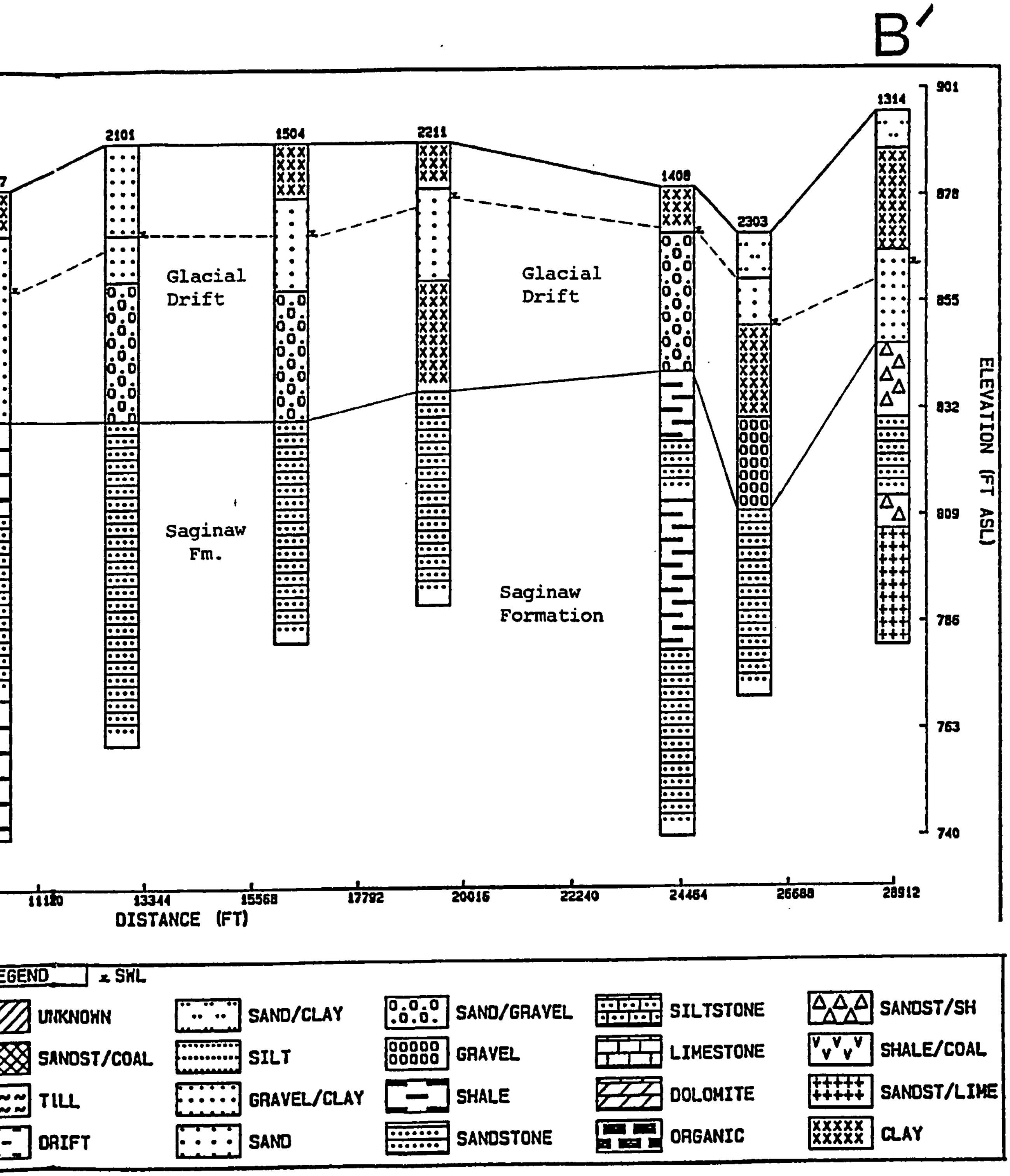


Figure 5. Cross Sections (a) A-A' and (b) B-B'. See Plate 1 for Location and Wells used in building the Cross Section.


A'
1707
1617
2120
2911
2811
3215
Glacial Drift
Glacial Drift
Saginaw Formation
Saginaw Formation
904
847
790
733
676
619
562
505
ELEVATION (FT ASL)
8850
10620
12390
14160
15930
17700
19470
21240
23010
DISTANCE (FT)
EGEND
SWL
UNKNOWN
SANDST/COAL
TILL
DRIFT
SAND/CLAY
SILT
GRAVEL/CLAY
SAND
SAND/GRAVEL
GRAVEL
SHALE
SANDSTONE
SILTSTONE
LIMESTONE
DOLOMITE
ORGANIC
SANDST/SH
SHALE/COAL
SHALE/LIME
CLAY


B
901
878
855
832
809
786
763
740
ELEVATION (FT ASL)
1906
1905
1708
1617
2101
1504
22
Glacial Drift
Glacial Drift
Saginaw Formation
Saginaw Fm.
0
2224
4448
6672
8896
11120
13344
15568
17792
DISTANCE (FT)
LEGEND
SWL
UNKNOWN
SANDST/COAL
TILL
DRIFT
SAND/CLAY
SILT
GRAVEL/CLAY
SAND


B′
2101
1504
2211
1408
2303
1314
Glacial Drift
Glacial Drift
Saginaw Fm.
Saginaw Formation
901
878
855
832
809
786
763
740
ELEVATION (FT ASL)
11120
13344
15568
17792
20016
22240
24464
26688
28912
DISTANCE (FT)
EGEND
SWL
UNKNOWN
SANDST/COAL
TILL
DRIFT
SAND/CLAY
SILT
GRAVEL/CLAY
SAND
SAND/GRAVEL
GRAVEL
SHALE
SANDSTONE
SILTSTONE
LIMESTONE
DOLOMITE
ORGANIC
SANDST/SH
SHALE/COAL
SANDST/LIME
CLAY

Ground-water Hydrogeology

Two types of aquifers exist in Delhi Township. The first type includes unconfined aquifers in the unconsolidated glacial deposits. The second type of aquifer is the sandstone-shale units within the Saginaw Formation. In Delhi Township the Saginaw bedrock aquifer supplies most of the water used by homes, industries, and municipalities.

Aquifers in the drift sometimes are confined by clay lenses. Clay layers may also form perched aquifers. These small perched water bodies generally are unimportant except for occassional domestic wells (Mencenberg, 1963)

Glacial aquifers have considerable potential for additional development of water supplies. (Snell, 1977). These aquifers have not been developed already because the bedrock aquifer below the drift has yielded sufficient good-quality water to meet demands. The potential for development of the glacial aquifers is shown in Figure 7. The areas with the greatest potential are associated with the sand and gravel deposits of the Mason esker. Eskers generally are narrow and therefore limited in their potential as water supply sources. However, many eskers are connected hydraulically to water-bearing outwash formations (Snell, 1977). Figure 8 shows the areas of buried outwash, which is present underneath a large portion of the Mason esker. A layer of till covers much of the buried outwash. (See also Figure 2.)

With the exception of a few large-capacity wells in southern Clinton County, the deposits of buried outwash generally are tapped only by wells supplying household needs (Snell, 1977). Even though great potential exists for these buried outwash deposits, little is known about the potential yield of these formations because of the lack of data resulting from little development (Snell, 1977).

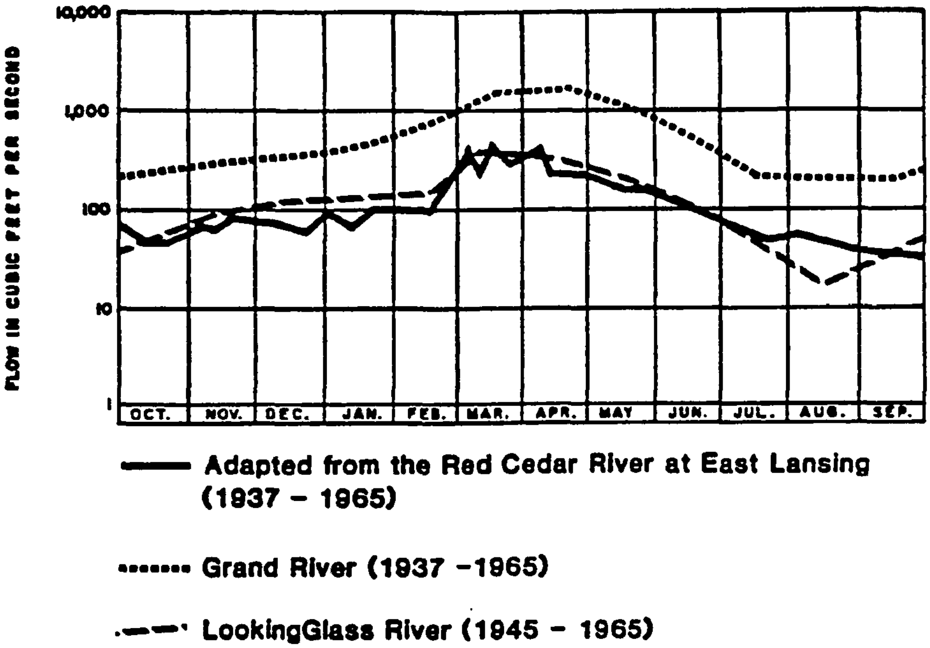


Figure 6. Average Monthly Flow for Major Rivers in the Lansing, Michigan Area (after Tri-County Regional Planning Commission, 1982).

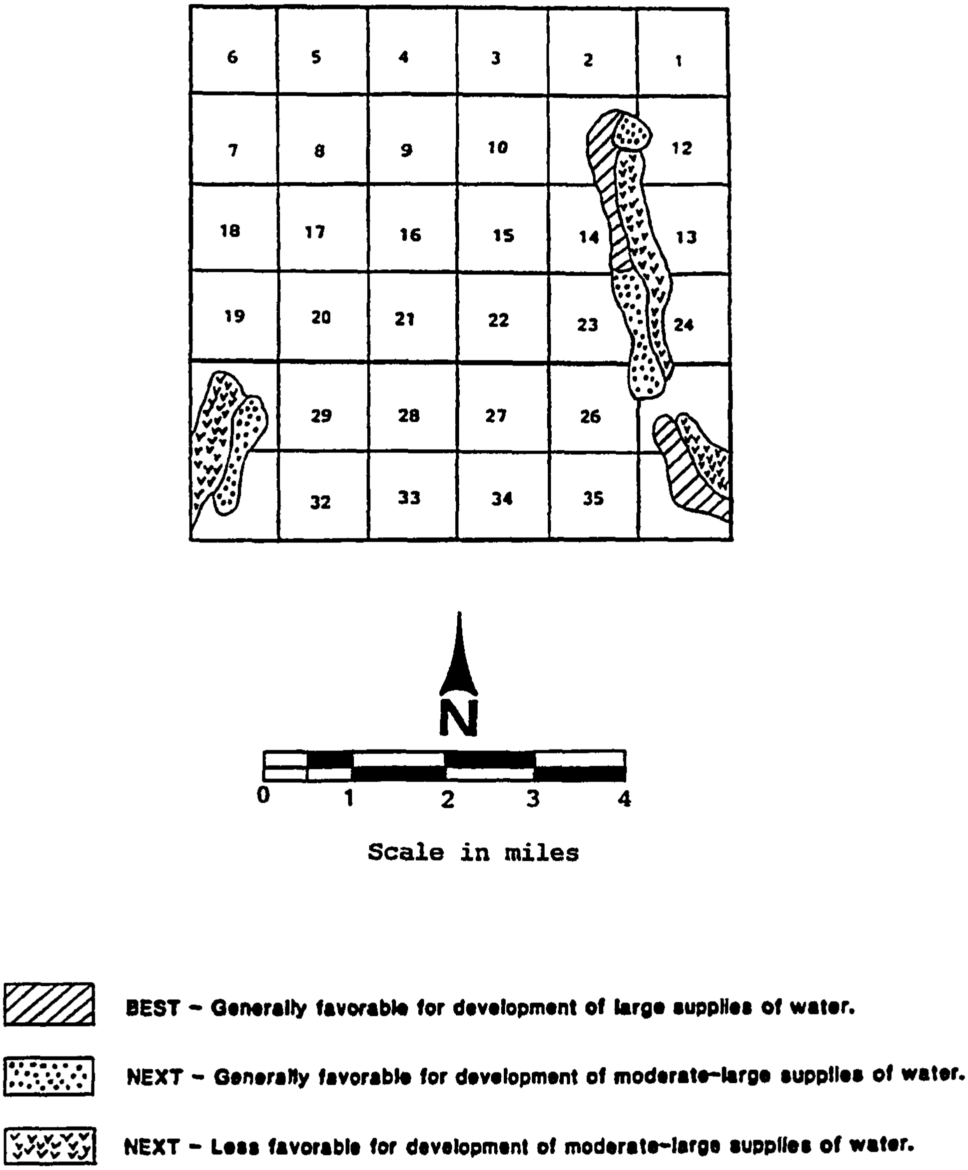


Figure 7. Potential for Development of Water Supplies From Glacial Deposits in Delhi Township (after Tri-County Regional Planning Commission, 1982).

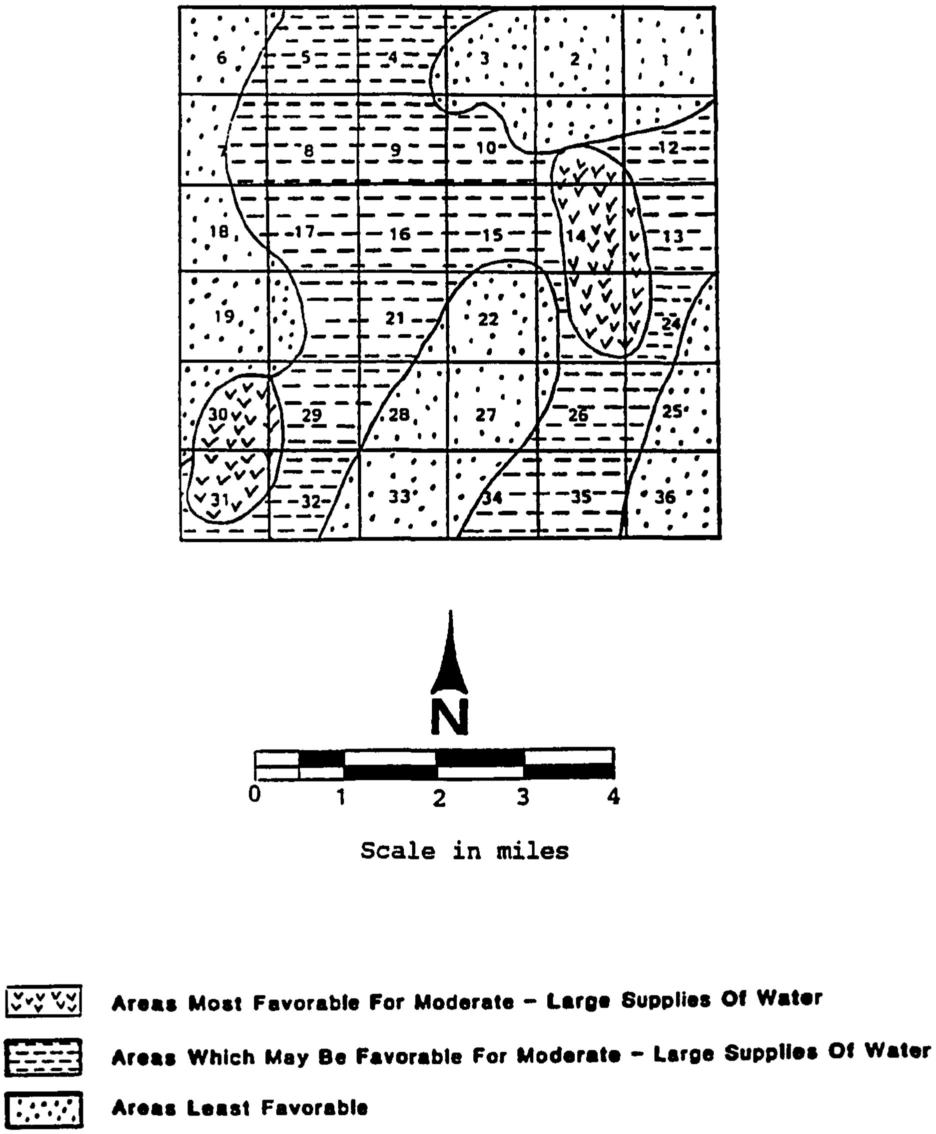


Figure 8. Buried Outwash Deposits in Delhi Township Which May Be Favorable for Water Supply or Recharge (after Tri-County Regional Planning Commission, 1982).

The glacial aquifers are recharged mostly by precipitation. They may also be recharged by the Grand River and Sycamore Creek when the water table in the aquifer drops below the level of the stream beds. Recharge areas in Delhi Township are shown in Figure 9.

The bedrock aquifer in Delhi Township is the sandstone beds of the Saginaw Formation. The aquifer is very productive even though the potentiometric surface has declined substantially over the last 50 years. The underlying Bayport Limestone and Michigan Formation are not used as a source of groundwater because of the high salinity of the water in these formations (TCRPC, 1982). Although the Michigan Formation is not used as a water source, it is important in the hydrologic system. Impermeable shales in the upper part of the formation restrict the upward migration of saline water into the Saginaw Formation (Snell, 1977).

The Saginaw Formation ranges between 300 and 350 feet thick throughout the township (Figure 4). This aquifer is semi- confined because of discontinuous shale layers in the upper part of the Saginaw and because of discontinuous clay layers in the glacial drift. Mencenberg (1963) considers the Saginaw aquifer to be confined with the basinward dip of the strata and the topographic relief generating the artesian head. Mencenberg (1963) also maintains that the overlying shale and clay layers are extensive enough to form local and regional aquicludes.

Recharge to the Saginaw aquifer in Delhi Township occurs by precipitation. The best recharge areas are located where sand and gravel deposits are continuous from the land surface to the bedrock. These areas, which also recharge the glacial aquifers, are shown in Figures 9-11.

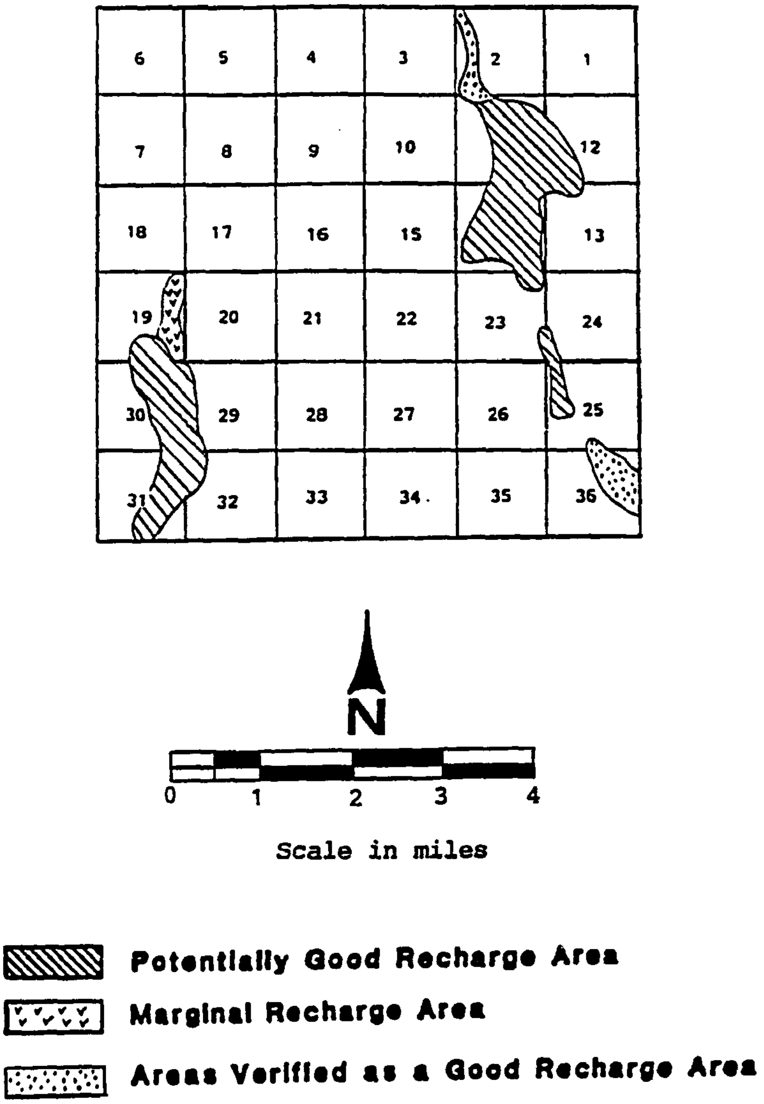


Figure 9. Recharge Areas to the Saginaw Formation and Glacial Aquifers in Delhi Township (after Tri-County Regional Planning Commission, 1982).

1	2	3	4		5		6		7	8	9	10	
1861 Winchell	1876 Rominger	1895 Lane	1901 Lane		1905 Cooper		1908 Cooper		1910 Lane	1912 Smith	1931 Newcombe	1933 Kelly	
Woodville		Woodville			Woodville Absent in Bay County		Woodville Absent in Tuscola County		Woodville Ionia Suggested	Woodville	"Red Beds" Woodville	Grand River Group	"Red Beds" Ionia SS Eaton SS Woodville SS
Coal Measures	Coal Measures	Jackson Coal Group	SAGINAW SERIES	Upper Rider Upper Verne Coal Lower Verne Coal Middle Rider Saginaw Coal Lower Rider Lower Coal	SAGINAW	Salzburg Rider Salzburg Coal Upper Rider Upper Verne Coal Lower Verne Rider Lower Verne Coal Middle Rider Saginaw Coal Lower Rider Lower Coal Bangor Rider Bangor Coal	SAGINAW	Reese Coal Unionville Coal Salzburg Rider Salzburg Coal Upper 1 Rider Lower Verne Rider Lower Verne Coal Middle Rider Saginaw Coal Lower Rider Lower Coal Bangor Rider Bangor Coal	Saginaw	Saginaw	Saginaw	SAGINAW GROUP	Post-Verne Cyclical Formations Verne Pre-Verne Cyclical Formations
Parma		Parma	Parma		Parma		Parma Doubtfully Represented in Tuscola County		Parma	Parma	Parma	Parma Probably Restricted to Southern Area	

Figure 10. Classification of the Pennsylvanian Rock Sequence in Michigan (after Kelley, 1936).

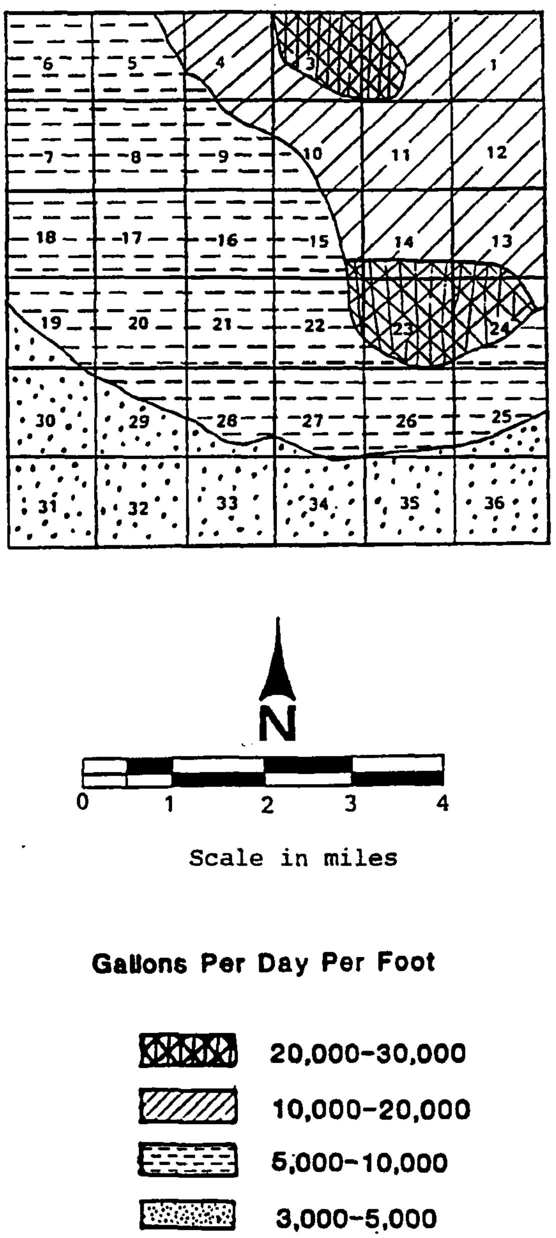


Figure 11. Transmissivity of the Saginaw Formation in Delhi Township (after Tri-County Regional Planning Commission, 1982).

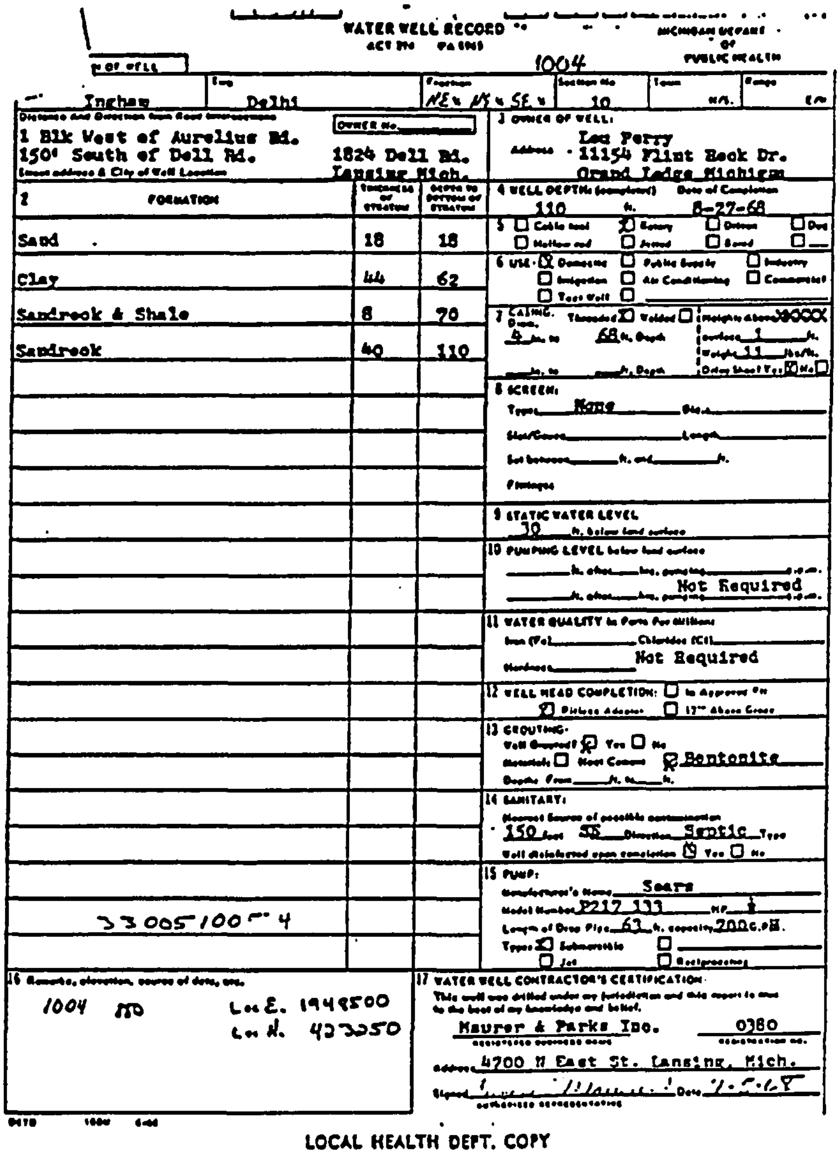
CHAPTER II

REVIEW OF SELECTED LITERATURE

Data Used in the Research

The data used in this research were provided by the Ingham County Health Department and consist of well records and chemical analyses of water samples from wells throughout Delhi Township. Well records are completed by drilling contractors then submitted to the Michigan Department of Public Health. Copies of the records then go to the appropriate county health department. These records contain a variety of information including the static water level in the well and the type and thickness of the lithologies that are penetrated. Copies of 450 drillers' well records of wells located in Delhi Township were obtained from the Ingham County Health Department. Figure 12 shows a drillers' well record from a well in Delhi Township, which presents the format of a well record and the various information that appears on a record.

This study uses information from the county health department well records from several southwest Michigan counties to construct a computer database. The Southwest Michigan Groundwater Survey (now the Michigan Groundwater Survey) begun by the Science for Citizens Center at Western Michigan University organized a groundwater monitoring program for approximately 17 counties in Michigan. SMGS used the data management computer program CONDOR (version 2.11) to build a computer database consisting of information from county health department well records and from chemical analyses of water samples obtained during the project. The computerized database was used in this study primarily because the data could be accessed quickly and



WATER WELL RECORD
MICHIGAN DEPARTMENT OF PUBLIC HEALTH

1004

County	Township	Fraction	Section No.	Town	Range
Ingham	Delhi	NE ¼ NE ¼ SE ¼	10	N.	E.

Distance and Direction from Road Intersections: 1 Blk West of Aurelius Rd. 150' South of Dell Rd.
Street address & City of Well Location: 1824 Dell Rd. Lansing Mich.
OWNER No.

3 OWNER OF WELL: Leo Perry
Address: 11154 Flint Rock Dr. Grand Ledge Michigan

2 FORMATION	THICKNESS OF STRATUM	DEPTH TO BOTTOM OF STRATUM
Sand	18	18
Clay	44	62
Sandrock & Shale	8	70
Sandrock	40	110
33005100⌐4		

4 WELL DEPTH (completed) 110 ft. Date of Completion 8-27-68

5 ☐ Cable tool ☒ Rotary ☐ Driven ☐ Dug ☐ Hollow rod ☐ Jetted ☐ Bored ☐

6 USE: ☒ Domestic ☐ Public Supply ☐ Industry ☐ Irrigation ☐ Air Conditioning ☐ Commercial ☐ Test Well ☐

7 CASING: Threaded ☒ Welded ☐ Height above ~~XXXX~~ surface 1 ft.
Diam. 4 in. to 68 ft. Depth
Weight 11 lbs/ft.
in. to ft. Depth
Drive Shoe? Yes ☒ No ☐

8 SCREEN: Type None Diam.
Slot/Gauze Length
Set between ft. and ft.
Fittings

9 STATIC WATER LEVEL 30 ft. below land surface

10 PUMPING LEVEL below land surface
ft. after hrs. pumping g.p.m.
Not Required
ft. after hrs. pumping g.p.m.

11 WATER QUALITY in Parts Per Million
Iron (Fe) Chlorides (Cl)
Hardness Not Required

12 WELL HEAD COMPLETION: ☐ In Approved Pit ☒ Pitless Adapter ☐ 12" Above Grade

13 GROUTING:
Well Grouted? ☒ Yes ☐ No
Material: ☐ Neat Cement ☒ Bentonite
Depth: From ft. to ft.

14 SANITARY:
Nearest Source of possible contamination
150 feet SE Direction Septic Type
Well disinfected upon completion ☒ Yes ☐ No

15 PUMP:
Manufacturer's Name Sears
Model Number P217 133 HP ½
Length of Drop Pipe 63 ft. capacity 200 G.P.H.
Type: ☒ Submersible ☐
☐ Jet ☐ Reciprocating

16 Remarks, elevation, source of data, etc.
1004 [illegible]
Loc E. 1949500
Loc N. 423250

17 WATER WELL CONTRACTOR'S CERTIFICATION
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Maurer & Parks Inc. 0380
Registered Business Name Registration No.
Address 4700 N East St. Lansing, Mich.
Signed Date 9-5-68
Authorized Representative

LOCAL HEALTH DEPT. COPY

Figure 12. Well Record of a Delhi Township Well Completed by Drilling Contractor (Ingham County Health Department, 1987).

easily, and files from this database could be used by other computer software to generate geologic cross sections.

The computerized well records and chemical analyses of the wells in a township form a data set. Data sets of all the townships in southwest Michigan make up the database.

The well records on the computer files contain the same information as on the drillers' well records. However, the information on the computer records is coded and is organized differently from the information on the drillers' well records.

Chemical analyses were performed on groundwater samples from 81 wells in Delhi Township by the Ingham County Health Department for SMGS, then printouts of the 81 chemical analyses were obtained from the Ingham County Health Department. Figure 13 shows the chemical parameters included and the format used in the chemical database.

Each well used by SMGS is assigned a unique number. The complete well number of a well is represented by nine numerals. The first two identify the county, the next three identify the township, the next two identify the section, and the last two identify the well number in the section.

Potentiometric Surface of Delhi Township

A potentiometric surface map of the Saginaw aquifer was constructed to establish groundwater flow directions in Delhi Township. The necessary data from the well records allowed calculation of the elevation of the static water level of each well. Contour lines connecting points of equal elevation of the static water levels complete the map.

LOCATION:	W. No.	330051004wh (cctttssxx)	LAB1 999	LAB2	LAB3
	L. Name	Hamilton		COL. DT	03/05/84

+Values ppm except Con. (MMHOS) *Not Detected as -det.level *Not Tested as 0.00

	Alkalinity	33.000	<	Aluminum	.030		Ammonia	.000
<	Antimony	-.050	<	Arsenic	-.050	<	Barium	-.005
<	Boron	-.010	<	Cadmium	-.010	<	Calcium	106.000
	Chloride	46.000	<	Cobalt	-.010	<	Chromium	-.010
	Conductivity	650.000	<	Copper	-.005		Flouride	.000
	Hardness	375.000	<	Iron	1.600		Iron.2	.000
<	Lead	-.050	<	Magnesium	30.000	<	Manganese	.030
<	Mercury	-.050	<	Molybdenum	-.050	<	Nickel	-.100
	Nitrate	.000		pH	7.500	<	Phosporus	-.100
	Potassium	1.100	<	Selenium	-.050		Silica	.000
	Sodium	.000		Sodium.2	.000		Sulfate	96.000
	Detergents	.000	<	Thallium	.090	<	Zinc	-.005
	TDS	-.050		C V	.000		C1 V1	.000

Note 1 MDPH Fe O. Note 2
Local Health Department Partial CHEM File: Groundwater Project v3.1

Figure 13. Chemical Analysis of a Water Sample from a Well in Delhi Township (Ingham County Health Department, 1987).

The records indicate that all the wells used in this study are completed in the Saginaw Formation. The cross sections in Appendix C indicate that the borehole for all wells extends several feet below the bottom of the casing.

The potentiometric surface map (Plate 2) and the maps of the chemical parameters (Plates 3-17), omit the well numbers, which was necessary to allow adequate space needed in constructing the maps. The well numbers (last four numerals only) appear in Plate 1.

Mapping of Chemical Parameters

Isoconcentration maps of fifteen chemical parameters were constructed for the following reasons: (a) to determine if any relationship exists between the values of each parameter and the locations of the wells in the groundwater flow system, and (b) to locate anomalous concentrations which may be the result of contamination.

The values of the mapped parameters derive from two sources. The values for sodium, magnesium, iron, hardness, calcium, conductivity, chloride, and sulfate are from the chemical analyses provided by the Ingham County Health Department. The values for TDS, saturation index (SI) for calcite, SI dolomite, SI gypsum, and the Ca:Mg ratios were generated by WATEQF (Plummer, 1976) using the chemical analyses as input.

The maps should be viewed with the potentiometric surface map (Plate 2) to identify the groundwater flow directions and parts of the flow system.

Computer Software Utilization

Many kinds of computer software were used to manipulate and interpret the data. Tasks included calculating mineral saturation parameters, calculating Ca^{2+}:Mg^{2+}

ratios, calculating summary statistics, comparing samples, conducting regression analyses, and constructing geologic cross sections.

The computer program WATEQF (Plummer, 1976) was used to calculate the saturation indices of various minerals. The saturation index (SI) of a mineral is expressed as follows:

$$SI = \log (IAP/K_{eq}) \qquad \text{Eq. 3.1}$$

where

SI = saturation index

IAP = ion activity product from a solution

K_{eq} = equilibrium constant of a mineral

The saturation index of a mineral reveals if the water is oversaturated ($SI > 0$), at equilibrium ($SI = 0$), or undersaturated ($SI < 0$) with respect to the mineral. The saturation indices of most interest in this study are calcite, dolomite, and gypsum.

WATEQF also was used to calculate the Ca^{2+}:Mg^{2+} mole ratio of each chemical analysis. The Ca^{2+}:Mg^{2+} ratio is useful in determining the direction of groundwater flow.

The input data used by WATEQF to calculate the saturation indices and the Ca^{2+}:Mg^{2+} ratios are the chemical analyses provided by the Ingham County Health Department. Of the 81 chemical analyses provided, only 60 were analyzed through WATEQF because 21 analyses did not report a pH value. The pH value is important in carrying out several calculations performed by WATEQF.

Summary statistics were calculated on several variables and parameters from the chemical analyses, the well records, or WATEQF procedures. Statistics were performed using the computer program STATGRAPHICS (version 2.1). Figure 14

Total Dissolved Solids
Alkalinity
Chloride
Conductivity
Hardness
Potassium
Sodium
Iron
Magnesium
pH
Barium
Calcium
Silica
Sulfate
Saturation Index (SI) for Calcite
SI for Dolomite
SI for Gypsum
$Ca2+/Mg2+$ ratio
Depth of penetration of borehole into the
    Saginaw Formation (depth)
Depth of penetration of well casing into the
    Saginaw Formation (dpthcas)

Figure 14. Variables and Parameters Used in Statistical Calculations.

Sample Size
Average
Median
Geometric Mean
Variance
Standard Deviation
Standard Error
Minimum
Maximum
Range
Lower Quartile
Upper Quartile
Interquartile Range
Skewness
Standardized Skewness
Kurtosis
Standardized Kurtosis

Figure 15. Statistical Calculations Carried Out on the Variable Parameters Listed in Figure 14.

shows the variables and parameters involved in statistical calculations. Figure 15 shows the calculations carried out on the different variables and parameters.

The mean, median, and mode measure the central tendency of the data while the variance, standard deviation, range, and interquartile range measure the spread. The skewness coefficient measures the asymmetry of the data distribution. Positive skewness values indicate that the upper tail of the curve is longer than the lower tail, whereas negative values indicate that the lower tail is longer.

The kurtosis coefficient reveals how flat or steep the distribution of the data is with respect to a normal (Gaussian) distribution. The kurtosis coefficient is zero for a normal distribution. When the coefficient is less than zero, the curve is flat with short tails. When the coefficient is greater than zero, the curve is either very steep at the center or has long tails.

The standardized skewness and standardized kurtosis coefficients test for significant deviations from a normal distribution. When the values for the standardized skewness and standardized kurtosis are outside the range of -2.0 to 2.0, the data may depart significantly from a normal distribution.

The Ingham County Health Department has categorized the wells with chemical analyses as being contaminated or uncontaminated. Contaminated wells are those having chloride concentrations greater than 26 parts per million (ppm); uncontaminated wells are those with chloride concentrations less than or equal to 26 ppm (Rowe, 1987).

Summary statistics were calculated on all variables variable pairs have a close relationship. For example, calcium can be used as the independent variable and hardness used as the dependent variable. The regression analysis will determine if a change in the hardness concentration (dependent variable) is related to a change in the calcium concentration (independent variable).

A regression analysis calculates two parameters that indicate if a change of the dependent variable is related to a change of the independent variable. The two calculated parameters are the correlation coefficient and the R-squared coefficient.

The correlation coefficient measures the relationship between two variables. The value of the correlation coefficient ranges from -1 to 1. A correlation coefficient of 1 indicates a perfect positive relationship (Bigelow, et al., 1966). In the calcium-hardness example, a correlation coefficient value of 1 means that an increase in the hardness concentration (dependent variable) relates to an increase of the same proportion to the Regression analyses using STATGRAPHICS were performed on all possible pairs of variables and parameters observed in this study. The regression analyses were restricted to variables and parameters from uncontaminated wells because the focus of the study is on analysis of the natural groundwater chemistry. Regression analyses were not done for contaminated wells because the chemistry is believed to be a function of contamination.

The purpose of doing the regression analyses was to find out if variable pairs have a close relationship. For example, calcium can be used as the independent variable and hardness used as the dependent variable. The regression analysis will determine if a change in the hardness concentration (dependent variable) is related to a change in the calcium concentration (independent variable).

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hardness example, a correlation coefficient value of 1 means that an increase in the hardness concentration (dependent variable) relates to an increase of the same proportion to the calcium concentration (independent variable). If the correlation coefficient had a value of -1, the concentration of hardness would decrease in the same proportion that calcium would increase. A correlation coefficient of 0 indicates no relationship between two variables; however, that any data will yield a correlation coefficient value of exactly zero is very unlikely (Bigelow, et al., 1966).

The R-squared coefficient is also useful to see if a relationship exists between two variables. An R-squared value of 100 would indicate that 100 percent of the variability of the dependent variable is accounted for by the independent variable.

Two different computer programs were used to construct geologic cross sections. The computer program CONDOR (version 2.11) was used to build files consisting of geological and spatial information belonging to the wells selected for making the cross sections. The information needed to produce each cross section was gathered from CONDOR well record files. The computer program GSEC (version 6.0) converted the geologic and spatial information organized by CONDOR into the desired cross sections.

Cross sections were constructed to illustrate the subsurface geology of Delhi Township and to examine the areas with abnormally high concentrations of several chemical parameters. The cross sections are helpful in determining if the high concentrations in the contaminated wells are related to geology. They also help to indicate whether an obvious relationship exists between the geology and concentrations of uncontaminated wells.

CHAPTER III

RESEARCH DESIGN AND METHODS

Bedrock Geology

The earliest research on the Pennsylvanian rocks of Michigan (Saginaw and Grand River Formations) was done by Winchell (1861). Winchell divided the Pennsylvanian into the Parma Sandstone (oldest), the Coal Measures, and the Woodville Sandstone (youngest). Since then several geologists have done research on the Michigan Pennsylvanian rocks. Their classifications are shown in Figure 10.

The Parma Sandstone overlies the Bayport Limestone and usually is the basal unit of the Pennsylvanian rock sequence. However, in several places the Parma has been eroded, and the Saginaw Formation unconformably overlies the Bayport Limestone. The map entitled Stratigraphic Succession in Michigan (Michigan Department of Natural Resources, 1972) does not use Winchell's classification. Instead, it assigns all the Pennsylvanian rocks in Michigan either to the Saginaw Formation (early Pennsylvanian) or the Grand River Formation (late Pennsylvanian). It includes the Parma Sandstone and the Coal Measures in the Saginaw Formation, and places the Woodville Sandstone is included in the Grand River Formation.

Perhaps the most detailed study of the Pennsylvanian sequence in Michigan was conducted by Kelley (1936). He described the lithology, stratigraphy, thickness, and correlation of the Parma Sandstone and the other units of the Saginaw Formation.

The lithology of the Parma Sandstone was analyzed first by Winchell (1861). He described the Parma as a white, yellowish quartzose sandstone with occasional fragments of terrestrial vegetation. Kelley adds that the Parma is better cemented and cleaner than the other Saginaw sandstones. The most common heavy minerals are tourmaline and zircon, with beds of dark shale are present. The thickness of the Parma ranges from 0- 200 feet, but the thickness beneath Delhi Township is unknown because most water wells do not penetrate more than 100 feet into the bedrock.

The sandstones in the Saginaw Formation other than the Parma consist of quartz with decomposed feldspar and abundant muscovite (Kelley, 1936). The heavy minerals are tourmaline and zircon and make up less than one percent of the total mineral content. These sandstones usually are fine grained.

Bedding in the Saginaw sandstones other than the Parma is irregular. Where sandstone crops out at Grand Ledge, Michigan, beds are less than 10 feet thick. In the Lansing area, individual beds are more than 100 feet thick.

Kelly (1936) also described the shales in the Saginaw Formation. He classified the shales into three groups: (1) shales with considerable sandy material, (2) shales with little or no sandy material, and (3) underclays.

The sandy shales are an equal mixture of sandstone and shale. Well records for Delhi Township report this lithology as sandstone/shale, with plant fragments occurring in these shales.

Shales with little or no sandy material are dark in color and may or may not contain $CaCO_3$. The non-limy shales usually are structureless and may reach three feet or more in thickness.

The underclays are bedded with the beds having a clay-like or sandy texture. They contain nodules of iron carbonate a few feet from the top of the beds and often lie below coal seams. Coal beds in the Saginaw are thin and laterally discontinuous because they have been truncated by erosion.

Limestones in the Saginaw are thinly bedded. Most of the limestones are fossiliferous and contain more invertebrate fossils than any other Pennsylvanian members.

The beds of sandstone, shale, limestone, and coal in the Saginaw Formation often appear as a random sequence. However, the theory of cyclical sedimentation proposed by Weller (1930) suggests that cyclical deposition of the different lithologies occurred. First sandstone was deposited, followed by sandy shale, gray shale, underclay, coal, black shale, and limestone. These lithologies do not often occur in this order because erosion removed different lithologies in each cycle.

Hydrogeology

The transmissivity of the Saginaw aquifer has been studied by Stuart (1945) and Firouzian (1963). Stuart conducted pump tests on several wells in the Lansing municipal well fields. He calculated the transmissivities using an equilibrium analytical method (Theim formula) and a non-equilibrium analytical method (Theis formula). The average value of transmissivity was 23,400 gallons per day per foot. The highest value, obtained in the North Cedar Street well field, was 79,500 gallons per day per foot. The minimum transmissivity of 4,000 gallons per day per foot was obtained from the Northwest field.

Firouzian (1963) calculated transmissivities using a flow net analysis. He used potentiometric surface data from Stuart's 1945 study to construct a flow net. With this flow net, he calculated the average transmissivity in the city of Lansing to be 14,662 gallons per day per foot. Using data he gathered himself, Firouzian constructed another flow net and found the average value of transmissivity for the city of Lansing to be 23,628 gallons per day per foot. The value of 23,628 gallons per day per foot is close to the average value of 23,400 gallons per day per foot calculated by Stuart using pump tests in 1945. Figure 11 shows the transmissivity of the Saginaw aquifer throughout Delhi Township to range from 3,000-30,000 gallons per day per foot. The transmissivities calculated by Stuart and Firouzian vary throughout the aquifer with changes in the saturated thickness and the hydraulic conductivity.

Discharge by city well fields and industries has created a large decline in the potentiometric surface of the Saginaw aquifer in Lansing, Michigan. Firouzian (1963) points out that between 1945 and 1963 the municipal and industrial pumpage in the Lansing area increased from 17.6 million gallons per day to 27 million gallons per day. Pumpage from the Michigan State University well field increased from 392,000 gallons per day in 1945 to 3 million gallons per day in 1962. This heavy pumpage caused the potentiometric surface to drop as much as 90 feet between 1945 and 1962. The decline of the potentiometric surface decreased as the distance from these pumping areas increased. Since 1962 the decline of the potentiometric surface has probably increased much more since demands for groundwater have increased.

Stuart (1945) calculated that five to nine million gallons of water per day were flowing into the Lansing area through the Saginaw Formation. The 1962 pumping rate of 27 million gallons per day greatly exceeds the recharge rate, and today's pumping rate probably is far greater than the 1962 rate. Large current pumping rates suggest that water is being taken out of storage. However, in 1977 the Saginaw Formation was meeting demands, and little development of the glacial aquifers had taken place (Snell, 1977).

Groundwater Chemistry

The groundwater chemistry of the Saginaw Formation is addressed briefly in a masters thesis by Wheeler (1967). Wheeler states that the chemical quality of groundwater from the Saginaw Formation is fairly consistent throughout the aquifer. Iron concentrations are high and average about 0.2 parts per million (ppm). Total carbonate hardness averages about 350 ppm. Other major anions and cations are present in minor concentrations.

A preliminary study concerning chemical quality of groundwaters throughout the state of Michigan began in 1974 (Cummings, 1980). Laboratory analyses of 86 parameters were made on 152 samples from 113 uncontaminated wells. Of the original 152 samples, 113 were used in the statistical analyses: 39 of the samples were second samples from wells sampled twice. From the 113 original samples analyzed, 10 samples were collected from the Saginaw Formation.

Cummings (1980) points out that the samples from the Saginaw Formation are more highly mineralized than the samples from the other bedrock formations throughout Michigan. In addition, some of the maximum concentrations of trace elements from samples throughout Michigan occur in groundwater from the Saginaw Formation.

Vanlier, Wood, and Brunett (1973) investigated the groundwater chemistry of the Saginaw Formation as part of a larger study concerning water supply and development for Ingham, Eaton, and Clinton counties. Water samples taken from several wells throughout the Saginaw revealed that the water quality varies considerably even though the samples all came from the same depth of penetration into the aquifer. Vanlier et al. (1973) attribute the variability in water chemistry to differences in individual well construction. They maintain that some wells are not sealed properly above the screens, thus providing a pathway for constituents to enter the wells from higher parts of the Saginaw Formation and the glacial drift.

Vanlier et al. (1973) also present chemical analyses of groundwater samples taken from different aquifers throughout Clinton, Ingham, and Eaton counties.

Included in their summary are seven chemical analyses of groundwater from the Saginaw Formation in Delhi Township.

Two-sample comparisons were performed by the Ingham County Health Department (Rowe, 1987). The analyses involved concentrations for each major chemical parameter from recharge and discharge wells. For example, sodium concentrations from wells located in discharge areas were compared with sodium concentrations from recharge areas to determine if the concentrations were possibly from the same population. The parameters analyzed for recharge and discharge comparisons are sodium, chloride, potassium, calcium, magnesium, alkalinity, sulfate, and iron. The Ingham County Health Department performed the comparisons using the computer program STATGRAPHICS (version 2.1) and characterized the wells used in the comparisons as being either recharge or discharge wells. Recharge and discharge wells were identified by using studies done by the Tri-County Regional Planning Commission (TCRPC).

The Ingham County Health Department also performed two-sample comparisons on concentrations from recharge wells and from all other wells not labeled as recharge wells (Rowe, 1987). The parameters analyzed for this category of two-sample comparisons are the same as those analyzed in the two-sample comparisons involving recharge and discharge wells. The results of the two- sample comparisons conducted by the Ingham County Health Department (Rowe, 1987) are shown in Tables 1 and 2. The recharge wells used in the comparisons in Table 2 are the same recharge wells used in Table 1. The non-recharge wells used in Table 2 refer to the discharge wells used in Table 1 plus other wells that were not considered to be either recharge or discharge wells.

Perhaps the most comprehensive study done on the groundwater chemistry of the Saginaw Formation is a doctoral dissertation by Wood (1969). This study describes groundwater in the Saginaw Formation to be calcium-magnesium-bicarbonate type water. Calcium, magnesium, sodium, silica, chloride, bicarbonate, and sulfate make up 98 per cent of the dissolved solids in all samples examined. Iron and potassium make up less than one percent of the total dissolved solids content. Nitrate concentrations greater than 2 mg/L are rare.

Table 1

Results of Two-Sample Comparisons Recharge and Discharge Wells (from Ingham County Health Department, 1987)

Parameter Used in the Comparison	Computed T-Statistic	Null Hypothesis Status
Sodium	0.6269	Do not reject
Chloride	-0.2786	Do not reject
Potassium	-0.1667	Do not reject
Calcium	0.6288	Do not reject
Magnesium	0.1216	Do not reject
Alkalinity	0.6401	Do not reject
Sulfate	3.072	Reject
Iron	-0.6761	Do not reject

The source of most of the dissolved solids is the mineral matter in the glacial drift. One experiment examined whether precipitation contributes a significant portion of dissolved solids (Wood, 1969). Results of analyses of rainwater from the Lansing area showed that the rainwater contributes a very small amount of total dissolved solids. Even after large portions of the samples were evaporated to concentrate the dissolved solids, the dissolved solids content in the rainwater samples were still far lower than the

Table 2

Results of Two-Sample Comparisons Involving Recharge Wells and All Other Wells Tested (from Ingham County Health Department, 1987)

Parameter Used in the Comparison	Computed T-Statistic	Null Hypothesis Status
Sodium	0.3518	Do not reject
Chloride	3.046	Reject
Potassium	-2.527	Reject
Calcium	-0.7429	Do not reject
Magnesium	1.1731	Do not reject
Alkalinity	1.748	Do not reject
Sulfate	-1.466	Do not reject
Iron	1.015	Do not reject

dissolved solids content of the Saginaw groundwater. Chloride is the only major ion for which precipitation may be a significant source.

Further evidence supporting the hypothesis that the dissolved solids in Saginaw groundwater originate in the glacial drift is provided by a two-sample comparison survey of river water samples from high flow and low flow stages (Wood, 1969). Wood theorized that during periods of high stream flow most of the water in the streams is surface runoff that has been in contact with the soil zone. During low flow, the water in the streams is baseflow from the glacial drift aquifers. Wood's analysis showed that all major cation and anion concentrations except bicarbonate and sodium were similar in both high stream flow and low stream flow samples.

The results of leaching experiments done by Wood (1969) also suggest that the glacial drift is the source of dissolved solids in Saginaw groundwater. Leaching experiments using deionized water showed that the sandstones of the Saginaw Formation yield small concentrations of dissolved solids. The only rock type from the Saginaw Formation that yields a significant number of dissolved solids is black shale. The black

The results of leaching experiments done by Wood (1969) also suggest that the glacial drift is the source of dissolved solids in Saginaw groundwater. Leaching experiments using deionized water showed that the sandstones of the Saginaw Formation yield small concentrations of dissolved solids. The only rock type from the Saginaw Formation that yields a significant number of dissolved solids is black shale. The black shale is thought to be a calcium and sulfate ion sink for recharging water and not a source of these ions (Wood, 1969).

Wood also conducted leaching experiments on glacial drift samples (Wood, 1969). In his study, drift samples mixed with deionized water were allowed to stand five to seven days. They then yielded water with dissolved solids concentrations similar to water from the Saginaw Formation and the glacial drift.

The leaching experiments, streamflow analyses, and rainwater analyses provide convincing evidence that most dissolved solids in the Saginaw groundwater originate in the glacial drift. The rainwater analyses show that rainwater in the Lansing area is very low in total dissolved solids (TDS). The streamflow analyses show that rainwater in contact with the glacial materials quickly dissolves significant amounts of mineral matter present in the glacial materials. The leaching experiments show that the sandstones (the major rock type) and the other rock types in the Saginaw Formation do not yield significant amounts of dissolved solids. Moreover, the leaching experiments also show that the TDS content of the groundwater in the glacial drift is similar to that of the Saginaw Formation. Good evidence that dissolved solids do not flow upward into the Saginaw Formation from lower formations supports the idea that the source of most of the dissolved solids in Saginaw groundwater is the glacial drift. The conclusion is that Saginaw groundwater previously passed through glacial materials. That the

Saginaw Formation is the uppermost bedrock formation in the Lansing area and that the Lansing area is completely covered with glacial drift support this conclusion.

Wood (1969) lists the chemical constituents that appear in Saginaw groundwater as a result of the dissolution of several minerals. Calcium and sulfate in the Saginaw Formation groundwater derives from the dissolution of anhydrite and gypsum in the glacial drift. Dissolution of limestone and dolomite by carbonic acid produces calcium, magnesium, and bicarbonate. Chloride and sodium ions derive from the dissolution of halite in the glacial drift and from precipitation (rainwater). Sodium also is obtained by ion exchange with calcium from clay minerals.

Wood (1969) addresses the role of the Bayport Limestone in protecting the groundwater quality of the Saginaw Formation. The Bayport Limestone lies directly below the Saginaw Formation and acts as a hydrologic barrier between the Saginaw Formation and the underlying formations. The Bayport Limestone prevents groundwaters from the Saginaw Formation and the glacial materials from mixing with groundwaters that contain larger amounts of dissolved solids beneath the Bayport.

One way in which more highly mineralized groundwaters beneath the Bayport Limestone infiltrate into the Saginaw Formation is through poorly plugged wells (Wood, 1969). The cone of depression in the city of Lansing is not mineralized except near an abandoned brine well that had been drilled into a deep formation and was not sealed properly.

In addition to a high total dissolved solids (TDS) content, the sulfate/chloride ratio also indicates whether water from deeper formations is moving upward into the Saginaw Formation. A ratio less than 4 indicates that flow derives from the lower formations.

Groundwater in the Saginaw Formation has a lower TDS concentration than the groundwater in the glacial drift. However, the sulfate/chloride ratio was found to be the same in the Saginaw Formation and the glacial drift (Wood, 1969). Wood (1969) discusses several possibilities for the higher TDS in the glacial drift, but only one is considered to be valid. Shales of the Saginaw Formation filter out certain ions as water from the glacial aquifers moves downward.

Concentrations of the major chemical species in groundwater of the Saginaw Formation were observed to vary over several orders of magnitude (Wood, 1969). Sodium, which is the only major constituent contributed by the Saginaw Formation, is the only species that displayed a consistent pattern when mapped.

The major chemical constituents were plotted on maps in known areas of recharge and discharge to determine if correlations exist between concentration and recharge or discharge area (Wood, 1969). This procedure failed to define significant differences between recharge and discharge areas.

Statistical analyses were conducted to determine if the large range in concentrations of the major chemical constituents is a function of the depth of penetration into the Saginaw Formation of sampled wells (Wood, 1969). Yet, no statistically significant differences were observed. In contrast, large differences in the concentrations of some parameters often occurred between wells of the same depth that were within a few hundred feet of each other.

The groundwater in the Saginaw Formation generally is saturated or supersaturated with respect to calcite and dolomite and greatly undersaturated with respect to gypsum and anhydrite (Wood, 1969). No relationship appears to exist between the degree of saturation and whether the sampled well is located in a recharge or discharge area (Wood, 1969). Moreover, no apparent difference in saturation exists between glacial wells and wells in the Saginaw Formation. By using an Eh-pH analysis, Wood (1969) found that siderite was the iron mineral most likely in equilibrium with the groundwater.

Chemical Processes

Many chemical processes are active in groundwater. Cherry, Gillham, and Barker (1984) summarize precipitation and solubility controls, hydrolysis and chemical speciation, oxidation and reduction, and mineral dissolution and acid consumption. Toth (1984) discusses hydration, attack by acids, ion exchange, and membrane filtration.

Considering the many processes that can occur in groundwater, determining which processes are active in a given hydrogeologic environment is sometimes difficult. However, the factors that control the chemical composition of groundwater give clues as to which chemical processes may be occurring. Important factors are element mobility, temperature, pressure, contact area between rock and water, contact time, length of flow path, type of flow system (local, intermediate, or regional), amounts and distribution of soluble salts in rocks, and the antecedent water quality (Toth, 1984).

The chemical process that predominately shapes the groundwater chemistry of the Saginaw aquifer is dissolution. As discussed earlier, Wood (1969) found that most mineral matter present in the Saginaw groundwater comes from the dissolution of minerals present in the overlying glacial drift, and this process does not occur significantly within the Saginaw Formation itself. Conversely, precipitation does not significantly contribute to the gross chemical makeup of the groundwater in the Saginaw Formation. Calcite and dolomite may be precipitating in the Saginaw Formation; Wood (1969) found that Saginaw groundwater generally is saturated or supersaturated with respect to calcite and dolomite.

Whether a mineral will dissolve or precipitate in a given hydrogeologic environment depends on the activity of the mineral species in groundwater and the equilibrium constant (K_{eq}) of the solid phase of the spiecies' parent compound. The equilibrium constants for many compounds at 25 degrees centigrade have been calculated.

Ion exchange noticeably may influence the groundwater chemistry of the Saginaw Formation although it may do so to a much less extent than dissolution. Clays in the glacial drift and shales in the Saginaw could possibly release Na^+ ions into the groundwater while adsorbing Ca^{2+} and Mg^{2+} ions from the groundwater.

Most geologic materials have the capacity to exchange ions on their surfaces with ions in solution. Ion exchange involves mostly cations. The geologic materials most capable of ion exchange are clay minerals such as kaolinite, montmorillonite, illite, chlorite, and vermiculite. The ions most readily adsorbed by clay minerals are Ba^{2+}, Sr^{2+}, Ca^{2+}, and Mg^{2+}. These ions tend to replace K^+, Na^+, and Li^+ that initially are present on the surface of clay minerals.

Wood (1969) believes that Na^+ releases into the glacial drift aquifers through the dissolution of halite; however, the abundance of halite in the glacial drift aquifers was not addressed. Ion exchange occurring within the clays in the glacial drift and within the Saginaw shales may be responsible for the majority of Na^+ ions in Saginaw groundwater.

Wood (1969) also states that membrane filtration (also called hyperfiltration) accounts for a lower TDS content in Saginaw groundwater than in the glacial drift water. Membrane filtration presumably occurs as clay and shale layers act as imperfect semi-permeable membranes in aquifers. These clay and shale layers are believed to filter out ions as groundwater passes through them. Wood (1969) believes that hyperfiltration occurs in the glacial drift filters mineral matter from the groundwater as it passes into the Saginaw. If this hypothesis is correct, then the process of hyperfiltration is significant in shaping the chemistry of Saginaw groundwater.

Freeze and Cherry (1979) point out that membrane filtration most likely occurs in sedimentary deposits at depths greater than 500 meters, and that laboratory experiments conducted on the membrane properties of clays and shales have shown that large stresses are necessary to achieve significant filtering efficiencies. Freeze and Cherry (1979) conclude that if hyperfiltration were to occur commonly at shallower depths, then the postulated increase of dissolved solids concentrations along flow paths would be invalid in many areas.

The observation by Wood (1969) that the TDS content in the Saginaw groundwater is lower than that of the glacial groundwater is the only convincing evidence he presents to support the hypothesis that hyperfiltration is occurring in either the glacial drift or the Saginaw Formation. He plotted the concentrations of the major chemical constituents in known areas of recharge and discharge in the Saginaw Formation (1969) and found no significant differences present in the concentrations of the constituents in recharge and discharge zones, which suggests that the shales in the Saginaw are not filtering ions. This observation, in turn, leads to speculation that if the shales (which are under greater stress) do not seem to be filtering ions, then that the clays in the drift do so would appear unlikely .

In summary, the chemical process that shapes the groundwater chemistry of the Saginaw Formation is dissolution. Ion exchange may be significant but not to the extent as is dissolution. Hyperfiltration is most likely not occurring in the glacial drift or in the Saginaw shales. The lower TDS in Saginaw groundwater than in glacial groundwater is good evidence that ion filtration is taking place in the drift, but other evidence (Freeze and Cherry, 1979 and Wood, 1969) suggests that filtration is not occurring in the glacial drift or the Saginaw shales. Perhaps the TDS content is lower in the Saginaw groundwater than in the glacial groundwater because greater dispersion occurs in the Saginaw Formation. To be sure, chemical processes other than the ones discussed are active in the glacial drift and the Saginaw, but they most likely do not contribute significantly to the chemical makeup of groundwater in the Saginaw Formation.

CHAPTER IV

FINDINGS AND INTERPRETATION

Ground-Water Flow

The potentiometric surface map for the Saginaw aquifer in Delhi Township (Plate 2) shows that ground-water flow in the township generally occurs northward. The highest static water levels are in the southernmost sections (34, 35, 36). Groundwater flows eastward in sections 13, 24, and 25 and westward in sections 20, 21, 27, 28, 29, 30, 31, and 32. Groundwater flows toward Sycamore Creek and the Grand River, suggesting that these streams may be discharge areas for the Saginaw Aquifer. The map also indicates that a ground-water divide is present between the Grand River and Sycamore Creek. The general northward flow results from the following conditions: (1) the northward dip of the Saginaw Formation (Mencenburg, 1963), and (2) the greatest decline in the potentiometric surface occurs in the city of Lansing, which is mostly north of Delhi Township (Firouzian, 1963).

Mapping of Chemical Parameters

Table 3 is a summary of basic information given by the isoconcentration maps and the potentiometric surface map (Plates 2 - 17). Patterns of increasing or decreasing concentrations along ground-water flow paths are limited to areas encompassing one or two sections of the township. Even with limited data, there is a good indication that patterns of increasing and decreasing concentrations are not continuous throughout the entire flow system in Delhi Township. Areas exist where almost all the parameters in

Table 3

Summary of Information Given by Plates 2-17

	Sections where concentration decreases in direction of decreases in direction of groundwater flow	Sections where concentration increases in direction of groundwater flow	Sections where plumes containing anomalous values exist	Sections where single high values exist	Are remaining values (concentrations of parameters not covered in the first four headings) uniform throughout township?
Iron	11, 12	15, 19, 25, 36	10, 11, 21	14, 32	NO
Chloride	22	14	10, 11, 21	15, 19, 32, 36	YES (Around 5 ppm or > 20 ppm)
Conductivity	13, 14, 19	NI	10, 11, 21, 25, 32	36	NO
Calcium	13,14, 19, 36	NI	10, 11, 21, 22, 25, 36	NI	NO
Hardness	11,13,14,19	36	10, 11, 21, 25	NI	YES (300 to 400 ppm)
Sodium	19	13, 14	10, 11, 21	32, 36	YES (Usually <10 ppm)
Alkalinity	11,12,13,14,19,20,22	21, 36	25	NI	Somewhat (around 300 ppm)
Sulfate	14, 25, 36	19, 20	10, 11, 21, 25	NI	NO
Magnesium	19, 14	32, 33	10, 11, 25	NI	YES (20 to 40 ppm)
Total Dissolved Solids	11,13,14,16,17,19,36	15, 22, 33	10, 11, 21	31, 32, 36	YES (500 to 700 ppm)
Ca:Mg ratio	10,11,16,17,19,25,36	13, 14, 16, 21, 22	NI	NI	NO
SI Calcite	16, 19,31,36	13, 14, 23, 24	NI	NI	NO
SI Dolomite	16, 31	19, 23, 24	NI	NI	YES (Southern 1/3 and northern 1/3 of twp. values neg., mid 1/3 values pos.)
SI Gypsum	11, 16,36	14, 19, 21, 25	NI	NI	YES

NI = Not indicated by the data
SI = Saturation Index

Table 3 increase in the direction of flow, and other areas are present where all the parameters decrease in the direction of flow.

Primary Constituents

Table 3 indicates that the values of most of the primary constituents (iron, chloride, conductivity, calcium, hardness, sodium, alkalinity, sulfate, magnesium, and TDS) decrease in the direction of ground-water flow in more sections than they increase. Sodium is the only primary constituent that increases in more sections than it decreases.

For the primary constituents, two significant conditions exist for the observed increases and decreases of concentrations in the direction of ground-water flow. First, the observation that there are more areas where the primary constituents decrease rather than increase in the direction of ground-water flow suggests that hydrodynamic dispersion readily occurs in the Saginaw Formation in Delhi Township. Areas where the primary constituents increase in the direction of ground-water flow may be explained by the following circumstances: (a) the entrance of more highly mineralized water into the Saginaw from the glacial aquifers through sealed poorly wells (Wood, 1969), and (b) point sources of contamination may be sources of highly mineralized water.

Second, the only area where the data indicate that ion exchange is possibly taking place is in sections 13 and 14. In this area, calcium concentrations decrease in the ground-water flow direction whereas sodium concentrations increase. Thus, ion exchange may not be as significant a chemical process in the Saginaw aquifer in Delhi Township as originally thought (Chapter II). Therefore, ion exchange may not be a significant contributor of Na^+ ions to Saginaw groundwater. Wood (1969) states that the major sources of Na^+ ions in Saginaw groundwater are the dissolution of halite in the glacial drift and ion exchange (Chapter II); however, Wood (1969) did not address the abundance of halite in the glacial drift. That not much halite exists in the drift is likely. Since the glacial drift contains many particles of igneous rocks, perhaps the major source of Na^+ ions in Saginaw groundwater is the dissolution of albite in the glacial drift rather than the dissolution of halite in the drift or ion exchange.

The area represented by sections 13 and 14 is a common decreasing zone for a majority of the primary constituents. In addition to calcium, iron, conductivity, hardness, alkalinity, sulfate, and TDS decrease in the ground-water flow direction in this region, whereas sodium increases. Another common decreasing zone is section 19. Conductivity, calcium, hardness, sodium, alkalinity, and magnesium decrease in this section whereas iron and sulfate increase. A common increasing zone is section 36, in which the concentrations of iron, hardness, and alkalinity increase.

No firm conclusion arises concerning the relationship of the common increasing and decreasing sections and the location of recharge and discharge zones in Delhi Township. Table 3 along with Figure 9 indicate that the common decreasing sections (13, 14, and 19) exist within or next to areas designated as recharge zones by the Tri-County Regional Planning Commission (TCRCP). The common increasing section (36) also exists in a TCRP-designated recharge zone. Based on the potentiometric surface map (Plate 2), it appears that groundwater discharges out of the Saginaw aquifer into the Grand River and Sycamore Creek. Therefore, the assignment of recharge areas by the TCRPC may be questionable. Since the assigned recharge zones in Figure 9 are questionable, it may be possible that the true recharge zones contain groundwater whereby the concentrations of most of the primary constituents either decrease or increase in the direction of ground-water flow.

Table 3 shows that all the primary constituents except alkalinity exist in abnormally high concentrations in two particular areas: sections 10 and 11 and section

21. These two particular areas may be contamination sites, such as an abandoned landfill or dump. According to Rowe (1993), an abandoned landfill (Gun Road Landfill) is located in section 21. This site was shut down 10 to 15 years ago and is currently on the State of Michigan's list (Act 307 list) of sites assigned top priority in cleanup efforts. Rowe (1993) stated that the high concentrations appearing in sections 10 and 11 are the result of heavy applications of roadsalt in this area, which lies next to two major freeway interchanges. In addition, Table 3 shows that five of the primary constituents (iron, chloride, conductivity, sodium, and TDS) have isolated single wells with high values. These wells may be near point-source contamination sites. The water in these wells may have high concentrations of constituents because these wells have been sealed poorly, allowing more dissolved solids to enter the well from the point sources in the glacial drift.

The remaining concentration values of the primary chemical constituents (values not from contamination sites, isolated single wells with high values, or areas that show a pattern) are fairly consistent throughout the township for some constituents but range considerably for others. Remaining concentrations of chloride, sodium, hardness, alkalinity, magnesium, and TDS are distributed fairly evenly throughout the township, while the rest of the primary constituents (iron, conductivity, calcium, and sulfate) have wide-ranging values.

The remaining values of the primary constituents in Table 3 partially agree with Wheeler's (1967) statement that the chemical quality of groundwater from the Saginaw Formation is fairly consistent throughout the aquifer (Chapter II). Table 3 indicates that concentrations of five of the nine primary constituents are fairly consistent throughout the township with hardness being 300-400 ppm. Wheeler (1967) points out that total carbonate hardness averages about 350 ppm. He also states that iron concentrations are uniform throughout the Saginaw Formation and average 0.2 ppm. Table 3 shows that iron concentrations are not uniform throughout Delhi Township.

Ca^{2+}:Mg^{2+} Ratio

Table 3 and Plate 3 indicate that the Ca^{2+}:Mg^{2+} ratio decreases in the direction of ground-water flow in sections 10, 11, 16, 17, 19, 25, and 36. Ratios increase in the direction of ground-water flow in sections 13, 14, 16, 21, and 22. The number of sections where this ratio increases nearly equals the number of sections where it decreases. Thus To'th's (1984) generalization that the Ca^{2+}:Mg^{2+} ratio decreases in the direction of ground-water flow was not observed in Delhi Township.

The observation that the Ca^{2+}:Mg^{2+} ratio increases in the direction of ground-water flow in sections 13 and 14 suggests that the calcium concentration gradient is less steep across this area than that of magnesium, since both calcium and magnesium decrease in this area (see Plates 4 and 5). As mentioned previously, Na^+ concentrations increase in this area and ion exchange may be occurring. The significance of this observation is that Mg^{2+} may have a greater tendency to participate in the ion exchange process in the Saginaw aquifer in Delhi Township than Ca^{2+}.

Saturation Indices

SI Calcite

Wood (1969) states that groundwater in the Saginaw Formation generally is saturated to supersaturated with respect to calcite. Assuming that saturation of groundwater with respect to calcite occurs when SI calcite $= 0 \pm 0.2$, 12 percent of the 60 wells that were subject to saturation index calculations in this study are at equilibrium with calcite, 40 percent are oversaturated, and 48 percent are undersaturated, as indicated by Plate 6 (SI calcite). Positive values are concentrated in sections 13, 16, 19, 21, and 22, whereas negative values dominate in sections 26, 31, and 36. Plate 6 also indicates that sections 11, 13, and 14 may contain groundwater at equilibrium with respect to calcite; however, more data are needed to verify this observation.

Table 3 shows that the saturation indices for calcite decrease in the direction of ground-water flow in sections 16, 19, 31, and 36. Plates 6 and 2 show that the SI values in sections 16 and 19 are positive, indicating that calcite may be precipitating in these sections in the direction of ground-water flow. In sections 31 and 36 the decreasing values are negative, suggesting that calcite saturation lessens with ground-water flow.

SI values for calcite increase in the direction of groundwater flow in sections 13, 14, 23, and 24. In these sections, the values are negative in the upgradient portion of this area and are positive in the downgradient portion. This observation suggests that groundwater is becoming more saturated with respect to calcite in the ground-water flow direction.

Since the areas designated as recharge and discharge zones by the TCRPC (Figure 9) are questionable, no firm conclusions can be made regarding whether groundwater becomes more saturated or less saturated with respect to calcite in the direction of ground-water flow in recharge or discharge zones. However, Plate 2 indicates that the Grand River and Sycamore Creek may be discharge areas for the Saginaw aquifer in Delhi Township. Plates 6 and 2 suggest that groundwater becomes less saturated in the direction of ground-water flow near the Grand River in Section 31. Groundwater becomes less saturated with respect to calcite as the pH increases. Plate 17 along with Plate 2 show that the pH increases in the direction of ground-water flow in Section 31.

SI Dolomite

Wood (1969) states that groundwater in the Saginaw Formation generally is saturated to supersaturated with respect to dolomite. The SI dolomite distribution in this study suggests that 12 percent of the 60 wells analyzed were at equilibrium with respect to dolomite, 33 percent were oversaturated, and 55 percent were undersaturated as indicated by Plate 7 (SI dolmite). The high percentage (55 %) of undersaturated wells observed in this study may be attributed to a higher pH in the groundwater than when Wood conducted his study.

Plate 7 shows that negative SI values are dominate in the northern third and southern third of the township, whereas the middle third is dominated by positive values.

The SI dolomite values increase in the direction of ground- water flow in sections 19, 23, and 24. In section 19, the increasing SI values are positive, suggesting that the groundwater is becoming increasingly oversaturated in the direction of ground-water flow with respect to dolomite. In sections 23 and 24, the increasing SI values are negative, suggesting the groundwater is becoming more saturated with respect to dolomite. The SI dolomite values decrease in the direction of ground- water flow in sections 16 and 31. In section 16, the decreasing SI values are positive, suggesting that dolomite may be precipitating in this area. In section 31, the SI values are negative, which indicates that the groundwater is becoming less saturated with respect to dolomite.

As with calcite, the data (Plates 7 and 2) indicate that the groundwater becomes less saturated with respect to dolomite in the direction of ground-water flow in the discharge area of section 31. The pH increases in the direction of ground-water flow in section 31 (see Plates 17 and 2), which may explain why the groundwater becomes less saturated with respect to dolomite in this area.

SI Gypsum

Wood (1969) found that Saginaw groundwater is greatly undersaturated with respect to gypsum. All 57 wells that were subject to SI gypsum calculations in this study are noticeably undersaturated with respect to gypsm (all less than -1.0), which is consistent with Wood's (1969) findings. Plate 8 shows the distribution of the 57 SI gypsum values. The low saturation of gypsum in Saginaw groundwater may result from the low quantity of gypsum in the glacial drift.

Table 3 shows that the saturation indices for gypsum decrease in the direction of ground-water flow in sections 11, 16, and 36. Plate 8 (SI gypsum) shows that the decreasing values are negative in these sections, suggesting that the groundwater becomes less saturated with respect to gypsum in the direction of ground-water flow.

The SI gypsum values increase in the direction of groundwater-flow in sections 14, 19, 21, and 25. In all these sections, the increasing values are negative, which suggests that the groundwater is becoming more saturated in the flow direction with respect to gypsum.

As with calcite and dolomite, gypsum saturation decreases in the direction of ground-water flow in section 31, a discharge zone. Gypsum saturation also decreases in the ground-water flow direction at the other discharge area (section 11). However, the pH appears to decrease in the flow direction (see Plates 18 and 2) in section 11, whereas it increases in section 31. Gypsum saturation is not dependent on pH as is the saturation of calcite and dolomite.

Statistical Analyses

Summary Statistics

The results of the summary statistics performed in this study (see Figures 15 and 16) are found in Table 4 and Appendix A. Table 4 contains basic summary statistics; Appendix A contains all other summary statistics.

Table 4 suggests that a significant difference exists between the concentrations of parameters in uncontaminated and contaminated wells. The average values for chloride, conductivity, sodium, and sulfate are much higher in the contaminated wells than in the uncontaminated wells. The average values for TDS, hardness, potassium, iron, magnesium, and calcium are higher in the contaminated wells, but the difference in the average values between the contaminated and uncontaminated wells for these constituents is less than those for chloride, conductivity, sodium, and sulfate.

Two-Sample Comparisons

The results of the two-sample comparison and the non- parametric two-sample comparison between chloride concentrations from contaminated wells and chloride concentrations from uncontaminated wells are shown in Table 5. The non-parametric two-sample comparison was done in addition to the regular two-sample comparison because the standardized coefficients of the chloride concentrations from the uncontaminated wells (see Table 4) are greater than 2.0, which indicates that the samples do not come from a Gaussian distribution.

The two-sample comparison suggests that the values of chemical constituents from the contaminated wells are from a different population than those from the uncontaminated wells because the null hypothesis is rejected. The non-parametric two-sample comparison provides additional support because the probability of equalling or exceeding Z is very small.

The two-sample comparisons conducted by the Ingham County Health Department (Chapter I) involving recharge and discharge wells (Table 1) show that the null hypothesis is rejected for seven of the eight chemical constituents tested. Overall, the comparisons indicate that no significant difference exists between the concentrations from recharge and discharge wells.

Regression Analyses

As stated in Chapter III, regression analyses were performed on all possible pairs of variables and parameters used in this study for the uncontaminated wells only. The most significant results (correlation coefficient > 0.50) are found in Table 6. The remainder of the regression analyses performed in this study are presented in Appendix B. The best correlations are between conductivity and calcium, hardness and magnesium, hardness and calcium, pH and silica, pH and the saturation index (SI) for calcite, pH and SI dolomite, SI calcite and SI dolomite, silica and SI calcite, silica and SI dolomite, and TDS and calcium.

The high correlation between conductivity and hardness reflects that most of the dissolved solids are calcium and magnesium. The high correlation between total dissolved solids and calcium supports this observation. As expected, high correlations exist between hardness and magnesium and hardness and calcium because hardness is a measure of calcium and magnesium.

The well-known fact that the pH controls the solubilities of calcite and dolomite is supported by the regression analyses. The best correlations in Table 6 are those between pH and SI calcite, pH and SI dolomite, and SI calcite and SI dolomite.

The regression analyses indicate that none of the values of the parameters or other variables correlate well with the depth of well penetration into the Saginaw Formation (depth) or the depth into the Saginaw Formation the well casings are set (dpthcas). (See Appendix B for the values of the correlation coefficient that apply to these variables.) These poor correlations support Wood's (1969) findings (Chapter III) that the large range in concentrations of the major chemical constituents is not a result of the depth of penetration into the Saginaw Formation of sampled wells.

Literature Comparison

The average concentrations of chemical parameters from the groundwater of the Saginaw Formation from Cummings (1980), Van Lier, et al. (1973), Wood (1969), and this study appear in Table 7. The purpose of this table is to compare the values of chemical parameters used in this study with those of previous work involving the ground-water chemistry of the Saginaw Formation. It is necessary to point out that the values of pararameters reported in Van Lier, et al. (1973) were taken from Wood (1969).

The average concentration values from this study and from Wood (1969) correspond to samples from the Saginaw Formation in Delhi Township. The locations of the wells Cummings (1980) used to gather his data were not included in his report. Therefore, the samples may have been taken from a portion of the Saginaw aquifer that contains water much more highly mineralized than is the water of the Saginaw Formation in Delhi Township.

The values from this study are slightly higher than those reported by Wood (1969) and Van Lier, et al. (1973). The values given by Cummings (1980) are substantially higher than the values reported by Wood (1969) and those presented in this study.

Cross Sections

In addition to illustrating the subsurface geology, cross sections were used to examine two sites in Delhi Township that have high concentrations of several parameters to see if correlations exist between geology and the concentrations of the parameters in contaminated and uncontaminated wells. The first site is located in Section 21; the second site is in sections 10 and 11. The locations of the cross sections and the wells used in building the cross sections are displayed in Plate 1. North-south (C-C') and east-west (D-D') cross sections were constructed for eight parameters at the section 21 site, while an east-west (E-E') cross section was constructed for the eight parameters at the section 10-11 site. In total, 24 cross sections were constructed to study the two sites. The cross sections are provided in Appendix C.

The parameters studied are chloride, magnesium, sodium, iron, conductivity, sulfate, calcium, and hardness. For example, wells 2116, 2115, 2114, 2127, 2113, and 2126 were used to build a north-south cross section for the section 21 site to study chloride concentrations. Each well in the cross section is labeled to indicate whether the well is contaminated or uncontaminated. In addition, the chloride concentration of the water sample from each well is labeled next to the well. In each cross section, glacial and bedrock lithologies above the well screens, bedrock lithologies across the screened intervals of the wells, and concentrations were analyzed meticulously.

The lithologies above the screened intervals in the cross sections most likely do not contribute to concentrations in the wells because ground-water flow across the screened intervals is horizontal unless these areas are confirmed to be located in recharge zones where downward flow into the wells would likely occur. Therefore, verification of these areas as being or not being recharge zones would be very useful.

Table 4

Basic Summary Statistics for Contaminated, Uncontaminated, and Contaminated and Uncontaminated Wells

	Alkalinity o	Chloride o	Conductivity o	Hardness o	Potassium o	Sodium o	Iron o	Magnesium o	pH o	Barium o
Contaminated and Uncontaminated Wells										
Sample Size	81	62	81	81	81	76	80	81	69	56
Average	307.3	25.15	671.6	357.6	1.67	11.9	1.86	30.4	7.2	0.096
Median	307	5	619	332	1.5	5.2	1.45	29	7.1	0.1
Standard Deviation	50.14	40	250.3	120.1	0.97	25.2	1.66	10.3	0.35	0.05
Minimum	189	1	390	160	0.8	2.5	0.3	9.5	6.1	0
Maximum	499	385	1890	1113	8.4	209	11	95.4	8.8	0.20
Standardized Skewness	2.2	7.31	10.01	12.96	17	23.7	10	13.8	2.21	1.46
Standardized Kurtosis	4.06	7.79	17.4	35.6	54	90.4	20.5	38.4	0.82	1.09
Uncontaminated Wells										
Sample Size	67	48	67	67	67	63	66	67	57	45
Average	311.6	7.01	594.1	328.4	1.54	5.67	1.67	28.2	7.17	0.3
Median	310	5	566	319	1.5	4.8	1.25	27.5	7	0.1
Standard Deviation	51.4	5.62	113.7	57	0.62	3.43	1.55	4.48	0.53	0.05
Minimum	189	1	390	227	0.8	2.5	0.3	18	6.1	0
Maximum	499	24	902	477	4.5	20	11	42.6	8.2	0.2
Standardized Skewness	1.92	6.34	2.47	1.91	6.38	7.67	12	2.53	1.44	1.4
Standardized Kurtosis	3.85	5.44	0.49	0.006	10.9	9.49	32.1	1.76	-0.74	1.14
Contaminated Wells										
Sample Size	14	14	14	14	14	13	14	14	12	11
Average	287	87.4	1042	497	2.26	42.1	2.77	40.9	7.35	0.08
Median	284	84.5	906	440	1.9	28	2.11	36.4	7.2	0.1
Standard Deviation	30.3	44.9	375.7	216.7	1.82	52.3	1.87	20.2	0.64	0.05
Minimum	223	28	650	160	1.1	5.6	0.6	9.5	6.65	0
Maximum	353	185	1890	1113	8.4	209	6	95.4	8.8	0.20
Standardized Skewness	0.047	1.04	1.92	2.65	5.11	4.6	1.38	2.37	1.63	0.8
Standardized Kurtosis	-0.62	0.23	0.53	3.78	9.14	7.7	-0.49	2.84	0.49	1.06

	Calcium o	Silica o	Sulfate o	SI Calcite +	SI dolomite +	SI gypsum +	Ca/Mg ratio +	TDS +	Depth *	Dpthcas *
Contaminated and Uncontaminated Wells										
Sample Size	81	25	74	69	69	4	69	69	81	81
Average	95.4	9.66	75.27	0.012	-0.36	-1.63	1.92	614.7	76.8	15.84
Median	88	7.6	52.5	-0.14	-0.62	-1.57	1.88	600.5	71	9
Standard Deviation	35.7	4.71	105.2	0.542	1.09	0.44	0.29	175.2	34.67	26.5
Minimum	32	5.4	0	-1.07	-2.51	-2.68	1.05	383.4	23	0
Maximum	314	20.8	776	1.63	2.93	-0.26	2.72	1720	226	193
Standardized Skewness	13.5	3.24	17.2	2.24	2.3	-1.04	0.54	13.86	5.80	16.87
Standardized Kurtosis	35.3	0.95	50.3	0.19	0.16	3.13	2.34	38.8	7.38	48.3
Uncontaminated Wells										
Sample Size	67	20	60	57	57	52	57	57	67	67
Average	87.56	9.73	51.48	-0.017	-0.42	-1.72	1.92	573.3	78.97	17.07
Median	84.8	7.75	47	-0.153	-0.82	-1.65	1.88	572.6	73	11
Standard Deviation	15.58	4.5	36.12	0.312	1.03	0.40	0.27	79.92	36.4	28.8
Minimum	59	5.4	0	-1.075	-2.5	-2.86	1.05	383.4	23	0
Maximum	139.4	20.8	166	1.41	1.94	-1.07	2.72	831.7	226	193
Standardized Skewness	0.95	2.94	2.99	1.49	1.58	-3.86	0.59	1.87	3.33	14.14
Standardized Kurtosis	-1.35	1.03	1.56	-0.62	-0.71	1.42	3.51	1.70	3.98	34.81
Contaminated Wells										
Sample Size	14	5	14	12	12	12	12	12	14	14
Average	133	9.36	177.2	0.13	-0.077	-1.27	1.92	811.5	66.43	9.93
Median	112	6.7	90.5	0.093	-0.226	-1.31	1.95	698.3	61	6
Standard Deviation	69.2	6.06	205.9	0.67	1.37	0.431	0.38	325.8	22.95	7.97
Minimum	32	6.5	48	-0.74	-1.91	-1.90	1.30	503.9	38	0
Maximum	314	20.2	776	1.627	2.93	-0.264	2.54	1720	112	26
Standardized Skewness	2.35	2.04	3.52	1.30	1.27	1.83	0.15	3.37	0.75	1.18
Standardized Kurtosis	2.29	2.28	4.03	0.48	0.51	1.51	-0.187	4.09	-0.28	-0.54

SI = Saturation Index
TDS = Total Dissolved Solids
depth = Depth of penetration of the borehole into the Saginaw Form
dpthcas = Depth of penetration of well casing into the Saginaw Formation

o Parameters from the chemical analyses. Values are in ppm except conductivity (µmhos) and pH (pH units)
+ Parameters generated by WATEQF. Values are dimensionless except TDS (ppm)
* Parameters generated by the well records. Values are in feet.

zones where downward flow into the wells would likely occur. Therefore, verification of these areas as being or not being recharge zones would be very useful.

If the wells in in cross sections C-C', D-D', and E-E' are not located in recharge areas, one possible way that lithologies above the well screens could contribute to concentrations involves whether the wells are not sealed properly. Generally, a plug consisting of bentonite is placed in the annular space of each well directly above the well screen. The plug, if properly constructed, provides a seal which prevents water above the well screen from traveling along the well casing and entering into the well. Knowing if the wells were properly sealed would be extremely helpful.

If the wells are not located in a recharge area and they are sealed properly, then the cross sections of the contaminated sites in sections 10 and 11 and section 21 show no overall obvious patterns between the concentrations of the constituents in the contaminated and uncontaminated wells and the geology. However, patterns are present in some individual cross sections, but they are not consistent from cross section to cross section. For example, the north-south cross section (C-C') from section 21 suggests that chloride concentrations in wells 2116 and 2126 (uncontaminated) are equal, and the lithology across the screened intervals is sandstone. The other uncontaminated well in this cross section (2113) exhibits a higher chloride concentration than in wells 2116 and 2126, but the lithology across the screened interval in 2113 is different from that in 2116 and 2126. This pattern is not seen in cross section D-D'. In this cross section, the chloride concentrations of the 2118 and 2119 are the same, but the lithology across the screened interval is different (sandstone in 2118 and sandstone/shale in 2119).

Regarding the contaminated wells in cross section C-C', wells 2114, 2115, and 2127 are screened in sandstone. Samples from 2115 and 2127 exhibited the same chloride concentration (83 ppm), but 2114 relinquished a sample exhibiting a chloride concentration of 129 ppm.

The cross sections of the other parameters also indicate that, overall, patterns are not obvious between concentrations and geology. If patterns are present, they are limited to individual cross sections and are not consistent from cross section to cross section.

Conclusions and Recommendations for Further Study

The main conclusions of this study are as follows:

1. Patterns of increasing or decreasing concentrations of chemical parameters along ground-water flow paths are limited to one or two sections of the township.
2. Certain sections in the township where most constituents decrease in concentration in the ground-water flow direction rather than increase, which suggests that hydrodynamic dispersion is active in the Saginaw Formation.
3. Concentrations of the chemical constituents in the contaminated wells belong to a different population than do the concentrations from the uncontaminated wells.
4. No correlation exists between concentrations of the Saginaw Formation.
5. No significant correlations were detected between geology and concentrations of constituents in contaminated and uncontaminated wells.

Variations in concentrations of constituents in the groundwater of the Saginaw Formation most likely result from several years of cultural activities. For example, road salt used each winter as a deicing agent contributes to higher chloride concentrations in wells located along roads. Point sources of contamination such as that in section 21 probably cause higher concentrations of several constituents in the wells at these locations compared with concentrations in wells away from these sources.

Recommendations for further work in Delhi Township include performing chemical analyses annually on more wells throughout the township, checking the sampled wells to see if they are sealed properly, verifying recharge and discharge areas, and conducting a hydrochemical facies analysis.

An annual sampling program on a larger number of wells in the township may possibly reveal concentration patterns that could not be detected from the chemical analyses performed in this study. The analyses used in this study are useful; however, a long-term sampling program would provide more accurate information regarding concentration patterns throughout the ground-water flow system.

An examination of the sampled wells in the township to determine if they are sealed properly would provide valuable information in accurately analyzing correlations (if actually present) between geology and concentrations of constituents in groundwater. A properly sealed well allows water to enter the well from the screened portion of the aquifer. A well not sealed properly can take in water from formations above the screened interval. If whether a well is sealed properly is not known, then detecting correlations between concentrations and geology at the screened intervals is difficult. The concentrations may be a function of the lithologies encountered throughout the vertical extent of the well rather than the lithologies at the screened interval.

Verification of recharge and discharge zones would help to determine if any correlation exists between concentrations and locations of wells in recharge and discharge areas. Rowe (1987) suggests that no significant difference occurs between concentrations of chemical constituents in recharge and discharge wells. However, the recharge and discharge areas studied by Rowe were designated as such by the TCRPC and are questionable.

Finally, a hydrochemical facies analysis (described by Back, 1966) would be valuable because it would provide another way to characterize the ground-water chemistry in the township. An analysis of this type could indicate if there are zones in Delhi Township whereby the concentrations of various parameters exist in certain proportions to one another. Several piper trilinear diagrams would need to be constructed.

Table 5

Results of the Two-Sample Comparison and the Non-Parametric Two-Sample Comparison of Chloride Concentrations From Contaminated and Uncontaminated Wells

Two Sample Analysis: Chloride

	Uncontaminated Wells	Contaminated Wells	Contaminated and Uncontaminated
Number of obs.	48	14	62
Average	7.01	87.36	25.15
Variance	31.62	2011.94	460.69
St. Dev.	5.62	44.85	21.46
Median	5	84.5	5

Hypothesis test for null hypothesis: computed t−statistic = −12.3237
Status: reject null hypothesis

Two−Sample Analysis: Chloride (Non−Parametric Methods)

Test based on pairs
Average rank of uncontaminated wells = 24.5 based on 48 values
Average rank of contaminated wells = 55.5 based on 14 values
Large sample test statistic z = 3.02E−10

Table 6

Results of Regression Analyses From Uncontaminated Wells Where Correlation Coefficient is Greater Than or Equal to 0.05

dpthcas: depth of penetration of the well casing into the Saginaw Formation

depth: depth of penetration of the borehole into the Saginaw Formation

SI: saturation index

TDS: total dissolved solids

Analysis (independent variable listed first)	Correlation Coefficient	R-squared Coefficient
chloride vs. sodium	0.568	32.25%
conductivity vs. hardness	0.715	51.15%
conductivity vs. magnesium	0.677	45.83%
conductivity vs. calcium	0.743	55.27%
conductivity vs. sulfate	0.553	30.62%
hardness vs. magnesium	0.813	66.06%
hardness vs. calcium	0.766	58.73%
hardness vs. sulfate	0.503	25.31%
magnesium vs. calcium	0.730	53.36%
pH vs. silica	0.812	65.8%
pH vs. SI calcite	0.981	96.31%
pH vs. SI dolomite	0.983	96.55%
calcium vs. sulfate	0.676	47.75%
calcium vs. SI gypsum	0.636	40.48%
silica vs. SI calcite	0.735	54.01%
silica vs. SI colomite	0.766	60.15%
SI calcite vs. SI dolomite	0.998	99.63%
dpthcas vs. depth	0.567	32.10%
TDS vs. alkalinity	0.693	42.87%
TDS vs. conductivity	0.515	26.49%
TDS vs. hardness	0.515	26.54%
TDS vs. magnesium	0.655	42.87%
TDS vs. calcuim	0.731	53.38%

Table 7

Average Concentrations of Chemical Parameters of the Saginaw Formation in Delhi Township From This Study and the Literature

	Silica	Iron	Ca	Mg
Wood, 1969 and Van Lier et al., 1973	13.5	0.86	72.5	26.9
Cummings, 1980	14	2.4	119	36
This study	9.73	1.67	87.6	28.2

	Na	K	Sulfate	Cl–
Wood, 1969 and Van Lier et al., 1973	4.4	1.14	21.9	3.8
Cummings, 1980	128	4.3	233	165
This study	5.7	1.5	51.5	7

	TDS	Hardness as CaC03	Conductivity	pH
Wood, 1969 and Van Lier et al., 1973	305	292	523	7.4
Cummings, 1980	1583	447	1363	7.6
This study	573	328.4	594.1	7.12

	SI gypsum	SI calcite	SI dolomite
Wood, 1969 and Van Lier et al., 1973	–2.57	0.0746	–0.072
Cummings, 1980	----	----	----
This study	–1.72	–0.017	–0.42

Values apply to samples from uncontaminated wells and are in ppm except conductivity (mmhos) and pH (pH units)

SI = Saturation Index

Appendix A

Summary Statistics

ALKALINITY

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	303.35	307.421	284.601
VARIANCE	2513.62	2638.49	1540.87
STANDARD ERROR	5.571	6.275	10.491
RANGE	310	310	130
LOWER QUARTILE	281	287	256
UPPER QUARTILE	333	333	323
INTERQUARTILE RANGE	52	46	67
SKEWNESS	0.6	0.576	0.031
KURTOSIS	2.21	2.307	−0.811

CHLORIDE

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	10.314	5.754	76.292
VARIANCE	1600.14	31.625	2011.94
STANDARD ERROR	5.08	0.812	11.988
RANGE	184	23	157
LOWER QUARTILE	5	5	50
UPPER QUARTILE	24	5	108
INTERQUARTILE RANGE	19	0	58
SKEWNESS	2.273	2.241	0.684
KURTOSIS	4.844	3.85	0.298

CONDUCITIVITY

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	639.666	583.978	989.147
VARIANCE	62,666.80	12,917.80	141,153
STANDARD ERROR	27.815	13.885	100.411
RANGE	1500	512	1240
LOWER QUARTILE	536	505	769
UPPER QUARTILE	733	652	1270
INTERQUARTILE RANGE	197	147	501
SKEWNESS	2.726	0.74	1.256
KURTOSIS	9.450	0.291	0.694

HARDNESS

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	343.789	323.707	458.553
VARIANCE	14,432.50	3248.28	46,986.40
STANDARD ERROR	13.348	6.963	57.933
RANGE	953	250	953
LOWER QUARTILE	294	287	393
UPPER QUARTILE	391	371	585
INTERQUARTILE RANGE	97	84	192
SKEWNESS	3.527	0.573	1.737
KURTOSIS	19.371	0.005	4.953

POTASSIUM

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	1.519	1.444	1.938
VARIANCE	0.935	0.388	3.319
STANDARD ERROR	0.107	0.076	0.487
RANGE	7.60	3.70	7.30
LOWER QUARTILE	1.10	1.10	1.60
UPPER QUARTILE	1.90	1.90	2.00
INTERQUARTILE RANGE	0.80	0.80	0.40
SKEWNESS	4.619	1.909	3.350
KURTOSIS	29.732	6.531	11.965

SODIUM

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	6.751	5.028	28.146
VARIANCE	637.452	11.742	2734.00
STANDARD ERROR	2.896	0.432	14.502
RANGE	206.50	17.50	203.40
LOWER QUARTILE	4.00	4.00	17.00
UPPER QUARTILE	10.00	6.10	36.00
INTERQUARTILE RANGE	6.00	2.10	19.00
SKEWNESS	6.664	2.366	3.120
KURTOSIS	50.806	5.857	10.471

IRON

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	1.392	1.261	2.214
VARIANCE	2.741	2.417	3.50
STANDARD ERROR	0.185	0.191	0.500
RANGE	10.70	10.70	5.400
LOWER QUARTILE	0.8	0.80	1.200
UPPER QUARTILE	2.45	2.09	4.400
INTERQUARTILE RANGE	1.65	1.29	3.200
SKEWNESS	2.738	3.621	0.773
KURTOSIS	11.233	19.344	-0.904

MAGNESIUM

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	29.238	27.909	36.53
VARIANCE	106.172	20.104	409.60
STANDARD ERROR	1.145	0.548	5.409
RANGE	85.90	24.60	85.900
LOWER QUARTILE	25.00	25.00	30.00
UPPER QUARTILE	33.10	30.00	44.40
INTERQUARTILE RANGE	8.10	5.00	14.40
SKEWNESS	3.758	0.752	1.55
KURTOSIS	20.897	1.051	3.721

pH

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	7.183	7.153	7.327
VARIANCE	0.300	0.279	0.409
STANDARD ERROR	0.066	0.070	0.185
RANGE	2.70	2.10	2.150
LOWER QUARTILE	6.80	6.80	6.855
UPPER QUARTILE	7.50	7.50	7.70
INTERQUARTILE RANGE	0.70	0.70	0.845
SKEWNESS	0.651	0.469	1.156
KURTOSIS	0.143	−0.479	0.979

BARIUM

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	N/A	N/A	N/A
VARIANCE	0.0026	0.0025	0.003
STANDARD ERROR	0.0068	0.0074	0.016
RANGE	0.20	0.20	0.200
LOWER QUARTILE	0.075	0.08	0.030
UPPER QUARTILE	0.10	0.10	0.10
INTERQUARTILE RANGE	0.025	0.02	0.070
SKEWNESS	0.478	0.510	0.593
KURTOSIS	0.712	0.833	1.565

CALCIUM

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	91.027	86.201	118.135
VARIANCE	1277.80	242.798	4789.430
STANDARD ERROR	3.972	1.904	18.496
RANGE	282.00	60.40	282.00
LOWER QUARTILE	76.40	76.00	106.00
UPPER QUARTILE	110.00	99.60	131.00
INTERQUARTILE RANGE	33.60	23.60	25.00
SKEWNESS	3.680	0.285	1.540
KURTOSIS	19.214	-0.809	3.00

SILICA

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	8.858	9	8.304
VARIANCE	22.162	20.232	36.733
STANDARD ERROR	0.942	1.006	2.710
RANGE	15.40	15.40	13.70
LOWER QUARTILE	7.00	7.350	6.60
UPPER QUARTILE	8.60	8.80	6.80
INTERQUARTILE RANGE	1.60	1.45	0.20
SKEWNESS	1.588	1.613	2.234
KURTOSIS	0.934	1.131	4.993

SULFATE

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	N/A	N/A	119.409
VARIANCE	11,063	1304.69	42,398
STANDARD ERROR	12.227	4.663	55.031
RANGE	776.00	166.00	728.00
LOWER QUARTILE	33.00	25.00	76.00
UPPER QUARTILE	87.00	70.00	129.00
INTERQUARTILE RANGE	54.00	45.00	53.000
SKEWNESS	4.886	0.945	2.304
KURTOSIS	28.657	0.989	5.273

SI CALCITE

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	N/A	N/A	N/A
VARIANCE	0.293	0.262	0.455
STANDARD ERROR	0.065	0.068	0.195
RANGE	2.702	2.22	2.368
LOWER QUARTILE	-0.371	-0.371	-0.374
UPPER QUARTILE	0.314	0.311	0.478
INTERQUARTILE RANGE	0.685	0.68	0.852
SKEWNESS	0.660	0.485	0.921
KURTOSIS	0.112	-0.402	0.675

SI DOLOMITE

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	N/A	N/A	N/A
VARIANCE	1.196	1.064	1.867
STANDARD ERROR	0.132	0.137	0.394
RANGE	5.445	4.453	4.838
LOWER QUARTILE	−1.162	−1.172	−1.122
UPPER QUARTILE	0.295	0.255	0.671
INTERQUARTILE RANGE	1.457	1.427	1.793
SKEWNESS	0.677	0.512	0.90
KURTOSIS	0.092	−0.459	0.727

SI GYPSUM

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	N/A	N/A	N/A
VARIANCE	0.441	0.161	0.186
STANDARD ERROR	0.055	0.055	0.124
RANGE	2.594	1.790	1.633
LOWER QUARTILE	-1.826	-1.855	-1.516
UPPER QUARTILE	-1.358	-1.456	-1.254
INTERQUARTILE RANGE	0.468	0.399	0.262
SKEWNESS	-0.317	-1.040	1.29
KURTOSIS	1.915	0.967	2.136

CA:MG RATIO

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	1.900	1.903	1.885
VARIANCE	0.085	0.075	0.143
STANDARD ERROR	0.035	0.036	1.090
RANGE	1.674	1.674	1.237
LOWER QUARTILE	1.766	1.780	1.698
UPPER QUARTILE	2.058	2.051	2.105
INTERQUARTILE RANGE	0.292	0.271	0.407
SKEWNESS	0.159	0.192	0.105
KURTOSIS	1.383	2.277	-0.272

TDS

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	598.391	567.833	767.563
VARIANCE	30,703.10	6386.84	106,163.00
STANDARD ERROR	21.094	10.585	94.058
RANGE	1336.87	448.32	1216.38
LOWER QUARTILE	527.08	518.23	631.255
UPPER QUARTILE	645.23	615.37	863.805
INTERQUARTILE RANGE	118.15	97.140	232.55
SKEWNESS	4.087	0.348	2.240
KURTOSIS	23.472	1.106	5.787

DEPTH

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	70.216	71.888	62.740
VARIANCE	1202.11	1325.73	526.879
STANDARD ERROR	3.852	4.448	6.135
RANGE	203.00	203.00	82.00
LOWER QUARTILE	55.00	59.00	48.00
UPPER QUARTILE	91.00	93.00	88.00
INTERQUARTILE RANGE	36.00	34.00	40.00
SKEWNESS	1.579	1.530	0.410
KURTOSIS	4.016	3.578	−0.365

DPTHCAS

	CONTAMINATED AND UNCONTAMINATED WELLS	UNCONTAMINATED WELLS	CONTAMINATED WELLS
GEOMETRIC MEAN	0.00	0.00	0.00
VARIANCE	702.136	829.616	63.456
STANDARD ERROR	2.944	3.519	2.129
RANGE	193.00	193.00	26.00
LOWER QUARTILE	4.00	4.00	5.00
UPPER QUARTILE	18.00	19.00	18.00
INTERQUARTILE RANGE	14.00	13.00	13.00
SKEWNESS	4.591	4.232	0.774
KURTOSIS	26.311	22.030	−0.706

Appendix B

Regression Analyses

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = ALKALINITY

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
ALKALINITY	CC = 1.00 R = 100.00%	CC = 0.111 R = 1.22%	CC = 0.159 R = 2.53%	CC = 0.247 R = 6.08%	CC = −0.159 R = 2.53%	CC = −0.106 R = 1.11%	CC = 0.072% R = 0.51%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
ALKALINITY	CC = 0.425 R = 18.05%	CC = −0.341 R = 11.60%	CC = 0.194 R = 3.78%	CC = 0.366 R = 13.88%	CC = 0.047 R = 0.22%	CC = −0.176 R = 3.08%	CC = −0.185 R = 3.43%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
ALKALINITY	CC = −0.181 R = 3.26%	CC = −0.265 R = 7.01%	CC = −0.043 R = 0.19%	CC = 0.044 R = 0.20%	CC = 0.046 R = 0.21%	CC = 0.693 R = 47.97%	

REG1

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = CHLORIDE

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
CHLORIDE	CC = .111 R = 1.22%	CC = 1.00 R = 100.00%	CC = 0.453 R = 20.50%	CC = 0.251 R = 6.31%	CC = 0.124 R = 1.55%	CC = 0.568 R = 32.25%	CC = 0.160 R = 2.57%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
CHLORIDE	CC = 0.298 R = 8.90%	CC = −0.014 R = 0.02%	CC = 0.107 R = 1.15%	CC = 0.376 R = 14.14%	CC = 0.073 R = 0.53%	CC = 0.258 R = 6.66%	CC = 0.031 R = 0.09%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
CHLORIDE	CC = 0.021 R = 0.04%	CC = 0.274 R = 7.53%	CC = 0.162 R = 2.62%	CC = 0.012 R = 0.01%	CC = 0.118 R = 1.39%	CC = 0.293 R = 8.56%	

REG1

CC = CORRELATION COEFFICIENT
R = R – SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = CONDUCTIVITY

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
CONDUCTIVITY	CC = 0.159 R = 2.53%	CC = 0.453 R = 20.50%	CC = 1.00 R = 100.00%	CC = 0.715 R = 51.13%	CC = 0.289 R = 8.34%	CC = 0.439 R = 19.24%	CC = 0.085 R = 0.72%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
CONDUCTIVITY	CC = 0.677 R = 45.83%	CC = −0.271 R = 7.35%	CC = 0.148 R = 2.20%	CC = 0.743 R = 55.27%	CC = −0.184 R = 3.38%	CC = 0.553 R = 30.62%	CC = −0.193 R = 3.74%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
CONDUCTIVITY	CC = −0.204 R = 4.16%	CC = 0.444 R = 19.70%	C = 0.198 R = 3.91%	CC = −0.143 R = 2.06%	CC = −0.067 R = 0.45%	CC = 0.515 R = 26.49%	

REG3

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = HARDNESS

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
HARDNESS	CC = 0.247 R = 6.08%	CC = 0.251 R = 6.31%	CC = 0.715 R = 51.13%	CC = 1.00 R = 100.00%	CC = 0.158 R = 2.50%	CC = 0.252 R = 6.36%	CC = 0.020 R = 0.04%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
HARDNESS	CC = 0.813 R = 66.06%	CC = 0.144 R = 2.08%	CC = −0.002 R = 0.00%	CC = 0.766 R = 58.73%	CC = 0.258 R = 6.67%	CC = 0.503 R = 25.31%	CC = 0.243 R = 5.93%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
HARDNESS	CC = 0.239 R = 5.72%	CC = 0.430 R = 18.49%	CC = 0.033 R = 0.11%	CC = −0.118 R = 1.40%	CC = 0.050 R = 0.25%	CC = 0.515 R = 26.54%	

REG4

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = POTASSIUM

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
POTASSIUM	CC = −0.159 R = 2.53%	CC = 0.124 R = 1.55%	CC = 0.289 R = 8.34%	CC = 0.158 R = 2.50%	CC = 1.00 R = 100.00%	CC = 0.322 R = 10.36%	CC = 0.271 R = 7.36%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
POTASSIUM	CC = 0.080 R = 0.65%	CC = 0.165 R = 2.72%	CC = 0.346 R = 12.00%	CC = 0.166 R = 2.75%	CC = −0.480 R = 23.38%	CC = 0.235 R = 5.51%	CC = 0.156 R = 2.43%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
POTASSIUM	CC = 0.148 R = 2.18%	CC = 0.215 R = 4.62%	CC = 0.154 R = 2.37%	CC = −0.036 R = 0.13%	CC = 0.143 R = 2.04%	CC = 0.048 R = 0.23%	

REG 5

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = SODIUM

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
SODIUM	CC = −0.106 R = 1.11%	CC = 0.568 R = 32.25%	CC = 0.439 R = 19.24%	CC = 0.252 R = 6.36%	CC = 0.322 R = 10.36%	CC = 1.00 R = 100.00%	CC = 0.047 R = 0.22%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
SODIUM	CC = 0.405 R = 16.43%	CC = 0.111 R = 1.23%	CC = 0.421 R = 17.70%	CC = 0.289 R = 8.38%	CC = 0.346 R = 11.97%	CC = 0.356 R = 12.65%	CC = 0.143 R = 2.06%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
SODIUM	CC = 0.145 R = 2.11%	CC = 0.358 R = 12.81%	CC = −0.005 R = 0.00%	CC = −0.071 R = 0.51%	CC = −0.127 R = 1.60%	CC = 0.327 R = 10.72%	

REG6

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = IRON

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
IRON	CC = 0.072	CC = 0.160	CC = 0.085	CC = −0.020	CC = 0.271	CC = 0.047	CC = 1.00
	R = 0.51%	R = 2.57%	R = 0.72%	R = 0.04%	R = 7.36%	R = 0.22%	R = 100.00%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
IRON	CC = −0.068	CC = −0.087	CC = 0.011	CC = 0.251	CC = −0.445	CC = 0.196	CC = −0.066
	R = 0.47%	R = 0.75%	R = 0.01%	R = 6.28%	R = 19.77%	R = 3.83%	R = 0.44%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
IRON	CC = −0.090	CC = 0.216	CC = 0.463	CC = 0.060	CC = 0.022	CC = 0.137	
	R = 0.82%	R = 4.68%	R = 21.43%	R = 0.36%	R = 0.05%	R = 1.88%	

REG7

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = MAGNESIUM

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
MAGNESIUM	CC = 0.425 R = 18.05%	CC = 0.298 R = 8.90%	CC = 0.677 R = 45.83%	CC = 0.813 R = 16.06%	CC = 0.080 R = 0.65%	CC = 0.405 R = 16.45%	CC = −0.068 R = 0.47%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
MAGNESIUM	CC = 1.00 R = 100.00%	CC = 0.118 R = 1.40%	CC = 0.073 R = 0.54%	CC = 0.730 R = 53.36%	CC = 0.399 R = 15.92%	CC = 0.403 R = 16.24%	CC = 0.237 R = 5.61%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
MAGNESIUM	CC = 0.251 R = 6.30%	CC = 0.374 R = 13.98%	CC = −0.273 R = 7.45%	CC = −0.265 R = 7.02%	CC = −0.032 R = 0.10%	CC = 0.655 R = 42.87%	

REG8

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = pH

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
pH	CC = −0.341 R = 11.60%	CC = −0.014 R = 0.02%	CC = −0.271 R = 7.35%	CC = 0.114 R = 2.08%	CC = 0.165 R = 2.72%	CC = 0.111 R = 1.23%	CC = −0.087 R = 0.75%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
pH	CC = 0.118 R = 1.40%	CC = 1.00 R = 100.00%	CC = −0.210 R = 4.40%	CC = 0.035 R = 0.12%	CC = 0.812 R = 65.8%	CC = 0.201 R = 4.04%	CC = 0.981 R = 96.31%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
pH	CC = 0.983 R = 96.55%	CC = 0.177 R = 3.15%	CC = −0.131 R = 1.72%	CC = −0.370 R = 13.71%	CC = −0.119 R = 1.42%	CC = −0.156 R = 2.43%	

REG9

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = BARIUM

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
BARIUM	CC = 0.194 R = 3.78%	CC = 0.107 R = 1.15%	CC = 0.148 R = 2.20%	CC = −0.002 R = 0.0%	CC = 0.346 R = 12.00%	CC = 0.421 R = 17.70%	CC = 0.011 R = 0.01%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
BARIUM	CC = 0.073 R = 53.36%	CC = −0.210 R = 4.40%	CC = 1.00 R = 100.00%	CC = −0.061 R = 0.37%	CC = −0.172 R = 2.96%	CC = −0.010 R = 0.01%	CC = −0.214 R = 4.59%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
BARIUM	CC = −0.194 R = 3.78%	CC = 0.023 R = 0.05%	CC = −0.289 R = 8.35%	CC = 0.219 R = 4.79%	CC = 0.244 R = 5.95%	CC = 0.224 R = 5.01%	

REG10

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = CALCIUM

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
CALCIUM	CC = 0.366 R = 13.38%	CC = 0.376 R = 14.14%	CC = 0.743 R = 55.27%	CC = 0.766 R = 58.73%	CC = 0.166 R = 2.75%	CC = 0.289 R = 8.38%	CC = 0.251 R = 6.28%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
CALCIUM	CC = 0.730 R = 53.36%	CC = 0.035 R = 0.12%	CC = −0.061 R = 0.37%	CC = 1.00 R = 100.00%	CC = 0.018 R = 0.03%	CC = 0.676 R = 47.75%	CC = 0.175 R = 3.06%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
CALCIUM	CC = 0.145 R = 2.11%	CC = 0.636 R = 40.48%	CC = 0.492 R = 24.20%	CC = −0.192 R = 3.70%	CC = −0.045 R = 0.21%	CC = 0.731 R = 53.36%	

REG11

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = SILICA

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
SILICA	CC = 0.047 R = 0.22%	CC = 0.073 R = 0.53%	CC = −0.184 R = 3.38%	CC = 0.258 R = 6.67%	CC = −0.480 R = 23.38%	CC = 0.346 R = 11.97%	CC = −0.445 R = 19.77%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
SILICA	CC = 0.399 R = 15.92%	C = 0.812 R = 65.8%	CC = −0.172 R = 2.96%	CC = 0.018 R = 0.03%	CC = 1.00 R = 100.00%	CC = 0.068 R = 0.46%	CC = 0.735 R = 54.01%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
SILICA	CC = 0.776 R = 60.15%	CC = 0.125 R = 1.56%	CC = −0.384 R = 14.74%	CC = −0.175 R = 3.06%	CC = 0.058 R = 0.34%	CC = 0.186 R = 3.47%	

REG12

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = SULFATE

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
SULFATE	CC = −0.176 R = 3.08%	CC = 0.258 R = 6.66%	CC = 0.553 R = 30.62%	CC = 0.503 R = 25.31%	CC = 0.235 R = 5.51%	CC = 0.356 R = 12.65%	CC = 0.196 R = 3.83%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
SULFATE	CC = 0.403 R = 16.24%	CC = 0.201 R = 4.04%	CC = −0.010 R = 0.01%	CC = 0.676 R = 47.75%	CC = 0.68 R = 0.46%	CC = 1.00 R = 100.00%	CC = 0.242 R = 5.88%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
SULFATE	CC = 0.221 R = 4.86%	CC = 0.886 R = 78.52%	CC = 0.420 R = 17.61%	CC = −0.220 R = 4.85%	CC = −0.162 R = 2.63%	CC = 0.488 R = 23.80%	

REG13

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = TDS

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
TDS	CC = 0.693 R = 47.97%	CC = 0.293 R = 8.56%	CC = 0.515 R = 26.49%	CC = 0.515 R = 26.54%	CC = 0.048 R = 0.23%	CC = 0.327 R = 10.72%	CC = 0.137 R = 1.88%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
TDS	CC = 0.655 R = 42.87%	CC = −0.156 R = 2.43%	CC = 0.224 R = 5.01%	CC = 0.731 R = 53.36%	CC = 0.186 R = 3.47%	CC = 0.488 R = 23.80%	CC = 0.007 R = 1.88%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
TDS	CC = 0.001 R = 0.00%	CC = 0.371 R = 13.78%	CC = 0.143 R = 2.05%	CC = −0.124 R = 1.54%	CC = −0.124 R = 1.54%	CC = 1.00 R = 100.00%	

REG14

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = SI CALCITE

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
SI CALCITE	CC = −0.185 R = 4.43%	CC = 0.031 R = 0.09%	CC = −0.193 R = 3.74%	CC = 0.243 R = 5.93%	CC = 0.156 R = 2.43%	CC = 0.143 R = 2.06%	CC = −0.066 R = 0.44%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
SI CALCITE	CC = 0.237 R = 5.61%	CC = 0.981 R = 96.31%	CC = −0.214 R = 4.59%	CC = 0.175 R = 3.06%	CC = 0.735 R = 54.01%	CC = 0.242 R = 5.88%	CC = 1.00 R = 100.00%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
SI CALCITE	CC = 0.998 R = 99.63%	CC = 0.208 R = 4.32%	CC = −0.081 R = 0.66%	CC = −0.377 R = 14.25%	CC = −0.145 R = 2.09%	CC = 0.007 R = 1.88%	

REG15.WK3

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = SI DOLOMITE

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
SI DOLOMITE	CC = −0.181 R = 3.26%	CC = 0.021 R = 0.04%	CC = −0.204 R = 4.16%	CC = 0.239 R = 5.72%	CC = 0.148 R = 2.18%	CC = 0.145 R = 2.11%	CC = −0.090 R = 0.82%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
SI DOLOMITE	CC = 0.251 R = 6.30%	CC = 0.983 R = 96.55%	CC = −0.194 R = 3.78%	CC = 0.145 R = 2.11%	CC = 0.776 R = 60.15%	CC = 0.221 R = 4.86%	CC = 0.998 R = 99.63%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
SI DOLOMITE	CC = 1.00 R = 100.00%	CC = 0.187 R = 3.50%	CC = −0.140 R = 1.96%	CC = −0.383 R = 14.67%	CC = −0.145 R = 2.12%	CC = 0.001 R = 0.00%	

REG16

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = SI GYPSUM

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
SI GYPSUM	CC = −0.265 R = 7.01%	CC = 0.274 R = 7.53%	CC = 0.444 R = 19.70%	CC = 0.430 R = 18.49%	CC = 0.215 R = 4.62%	CC = 0.358 R = 12.81%	CC = 0.216 R = 4.68%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
SI GYPSUM	CC = 0.374 R = 13.98%	CC = 0.177 R = 3.15%	CC = 0.023 R = 0.05%	CC = 0.636 R = 40.48%	CC = 0.125 R = 1.56%	CC = 0.886 R = 78.52%	CC = 0.208 R = 4.32%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
SI GYPSUM	CC = 0.187 R = 3.50%	CC = 1.00 R = 100.00%	CC = 0.341 R = 11.61%	CC = −0.303 R = 9.20%	CC = −0.092 R = 0.84%	CC = 0.371 R = 13.78%	

REG17

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = DEPTH

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
DEPTH	CC = 0.044 R = 0.20%	CC = 0.012 R = 0.01%	CC = −0.087 R = 0.76%	CC = −0.118 R = 1.40%	CC = −0.036 R = 0.13%	CC = −0.071 R = 0.51%	CC = 0.060 R = 0.36%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
DEPTH	CC = −0.265 R = 7.02%	CC = −0.370 R = 13.71%	CC = 0.220 R = 4.79%	CC = −0.192 R =3.70%	CC = −0.175 R = 3.06%	CC = −0.220 R = 4.85%	CC = −0.377 R = 14.25%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
DEPTH	CC = −0.383 R = 14.67%	CC = −0.303 R = 9.20%	CC = 0.125 R = 1.56%	CC = 1.00 R = 100.00%	CC = 0.567 R = 32.10%	CC = −0.045 R = 0.21%	

REG19

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = CA:MG

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
CA:MG	CC = −0.043 R = 0.19%	CC = 0.162 R = 2.62%	CC = 0.198 R = 3.91%	CC = 0.033 R = 0.11%	CC =0.154 R = 2.37%	CC = −0.005 R = 0.00%	CC = 0.463 R = 21.43%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
CA:MG	CC = −0.273 R = 7.45%	CC = −0.131 R = 1.72%	CC = −0.289 R = 8.35%	CC = 0.492 R = 24.20%	CC = −0.384 R = 14.74%	CC = 0.420 R = 17.61%	CC = −0.081 R = 0.66%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
CA:MG	CC = −0.140 R = 1.96%	CC = 0.341 R = 11.61%	CC = 1.00 R = 100.00%	CC = 0.125 R = 1.56%	CC = −0.019 R = 0.03%	CC = −0.143 R = 2.05%	

CC = CORRELATION COEFFICIENT
R = R – SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

REGRESSION ANALYSIS
INDEPENDENT VARIABLE = DPTHCAS

	VS. ALKALINITY	VS. CHLORIDE	VS. CONDUCTIVITY	VS. HARDNESS	VS. POTASSIUM	VS. SODIUM	VS. IRON
DPTHCAS	CC = 0.046 R = 0.21%	CC = −0.118 R = 1.39%	CC = −0.067 R = 0.45%	CC = 0.050 R = 0.25%	CC = 0.143 R = 2.04%	CC = −0.127 R = 1.60%	CC = 0.022 R = 0.05%

	VS. MAGNESIUM	VS. pH	VS. BARIUM	VS. CALCIUM	VS. SILICA	VS. SULFATE	VS. SI CALCITE
DPTHCAS	CC = −0.032 R = 0.10%	CC = −0.119 R = 1.42%	CC = 0.244 R = 5.95%	CC = −0.045 R = 0.21%	CC = 0.058 R = 0.34%	CC = −0.162 R = 2.63%	CC = −0.145 R = 2.09%

	VS. SI DOLOMITE	VS. SI GYPSUM	VS. CA:MG	VS. DEPTH	VS. DPTHCAS	VS. TDS	
DPTHCAS	CC = −0.145 R = 2.12%	CC = −0.092 R = 0.84%	CC = −0.019 R = 0.03%	CC = 0.567 R = 32.10%	CC = 1.00 R = 100.00%	CC = −0.124 R = 1.54%	

REG20

CC = CORRELATION COEFFICIENT
R = R − SQUARED COEFFICIENT
SI = SATURATION INDEX
TDS = TOTAL DISSOLVED SOLIDS
CA:MG = CALCIUM TO MAGNESIUM RATIO

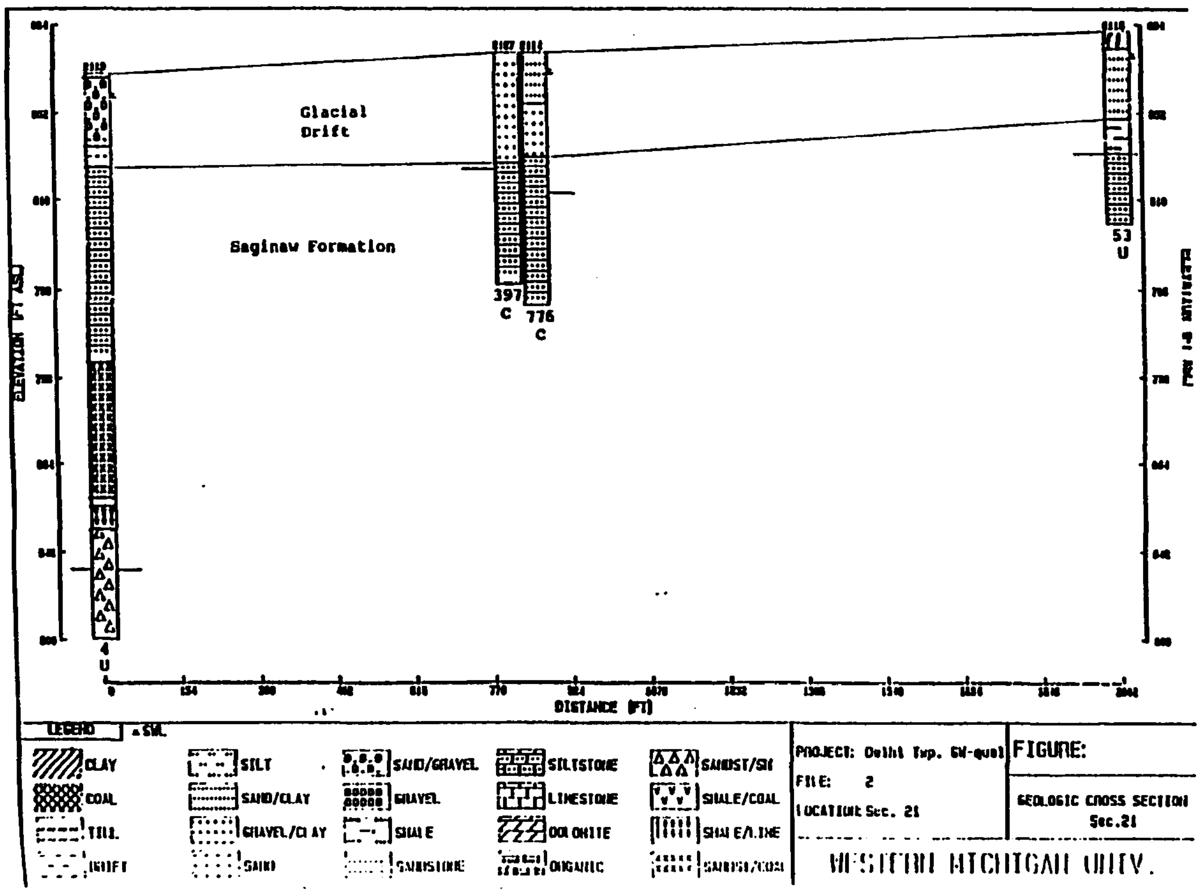
DPTHCAS = Depth of penetration of well casing into the Saginaw Formation
DEPTH = Depth of penetration of the borehole into the Saginaw Formation

Appendix C

Cross Sections

SULFATE
Sec. 21 west-east

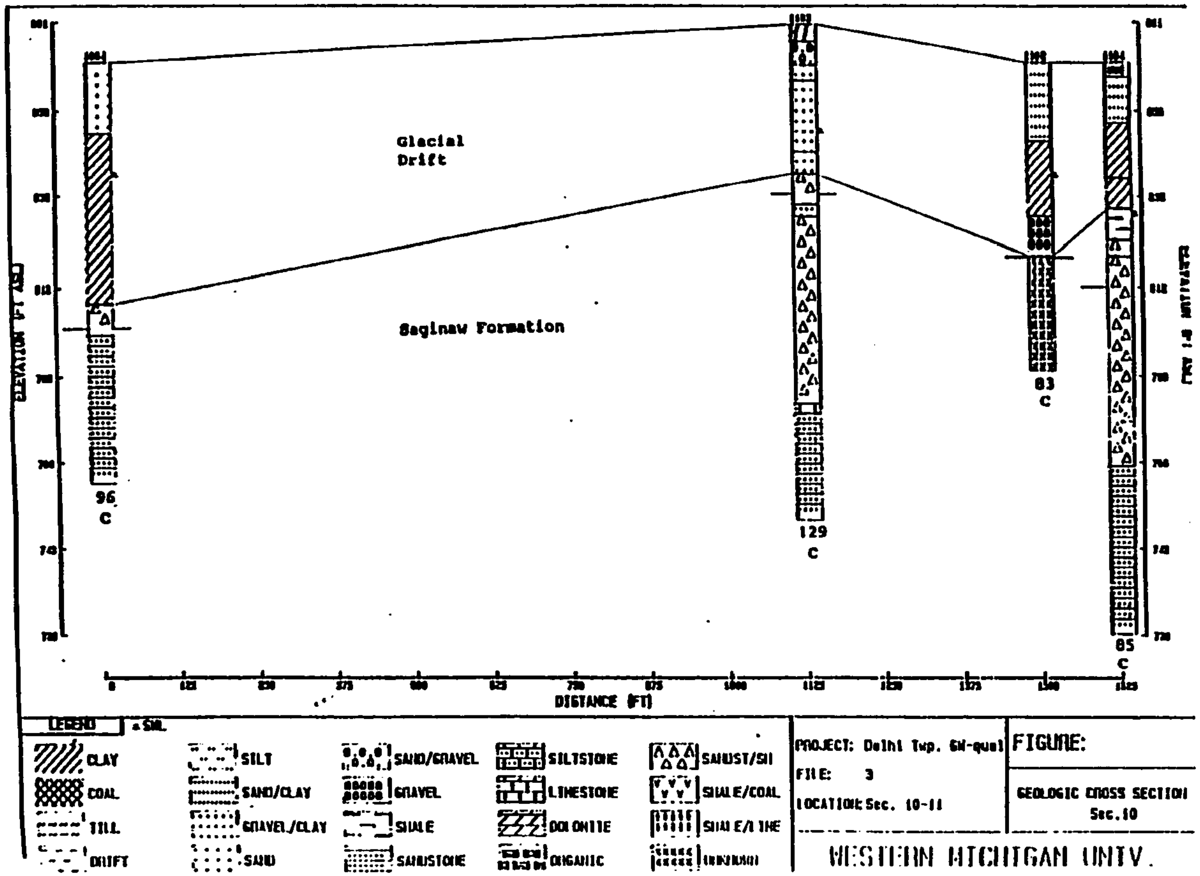
See Plate 1 (Cross Section D-D') for location.



SULFATE

Sec. 10-11 west-east

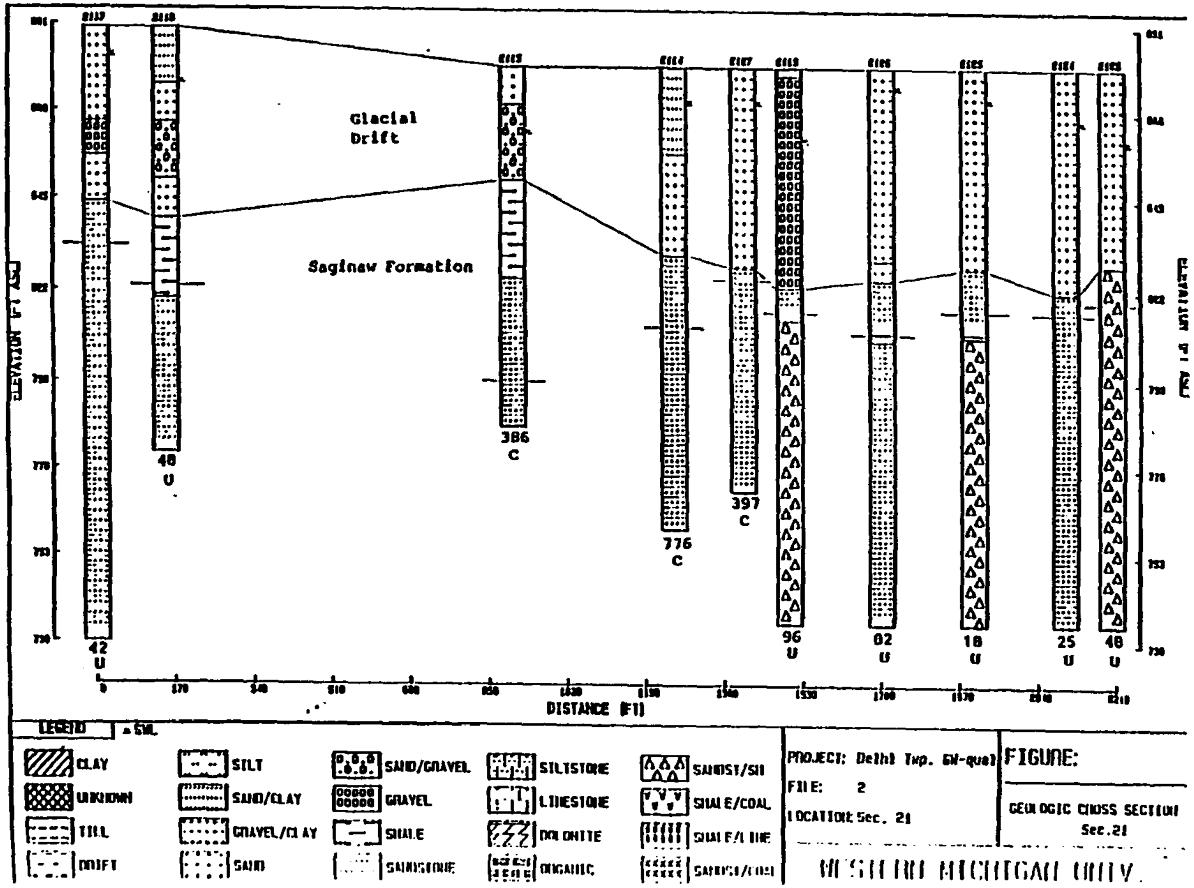
See Plate 1 (Cross Section E-E') for location.



SULFATE

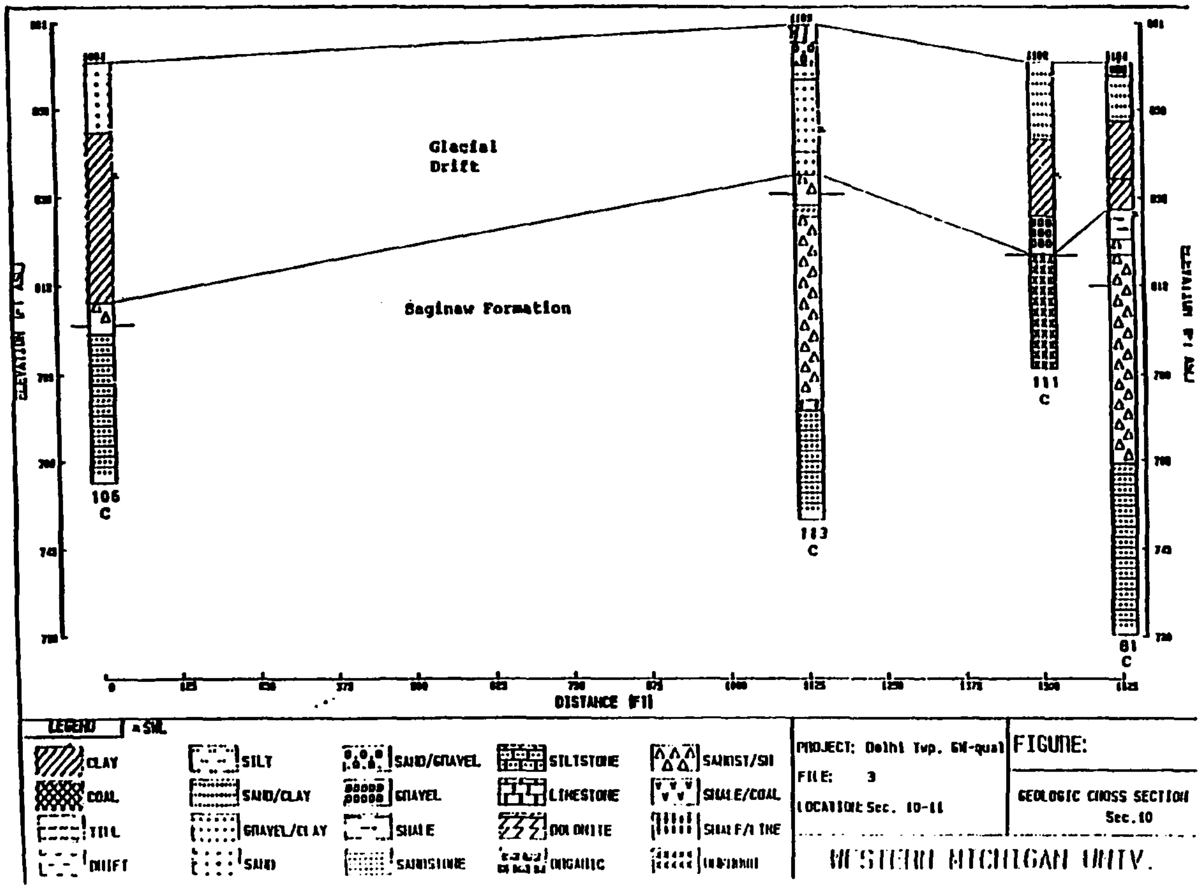
Sec. 21 north-south

See Plate 1 (Cross Section C-C') for location.



CALCIUM
Sec. 10-11 west-east

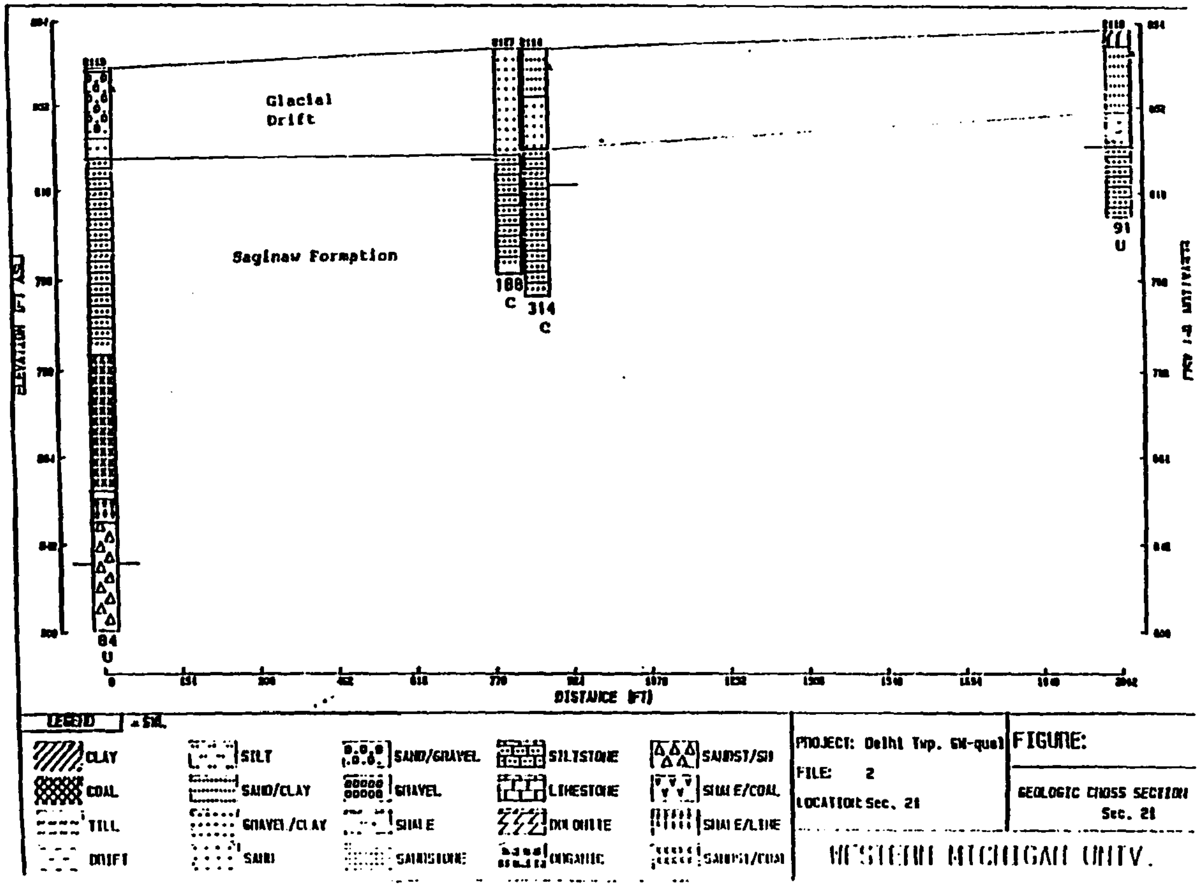
See Plate 1 (Cross Section E-E') for location.



CALCIUM

Sec. 21 west-east

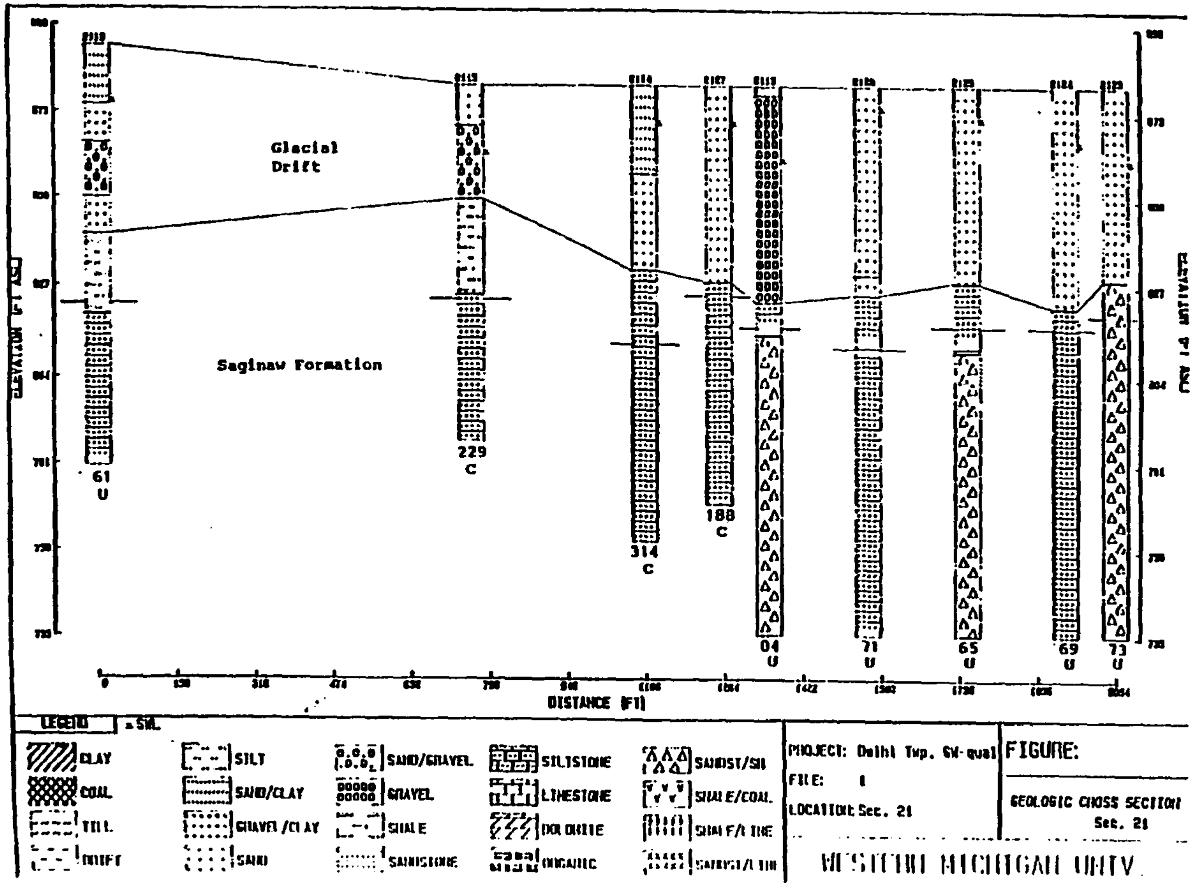
See Plate 1 (Cross Section D-D') for location.



CALCIUM

Sec. 21 north-south

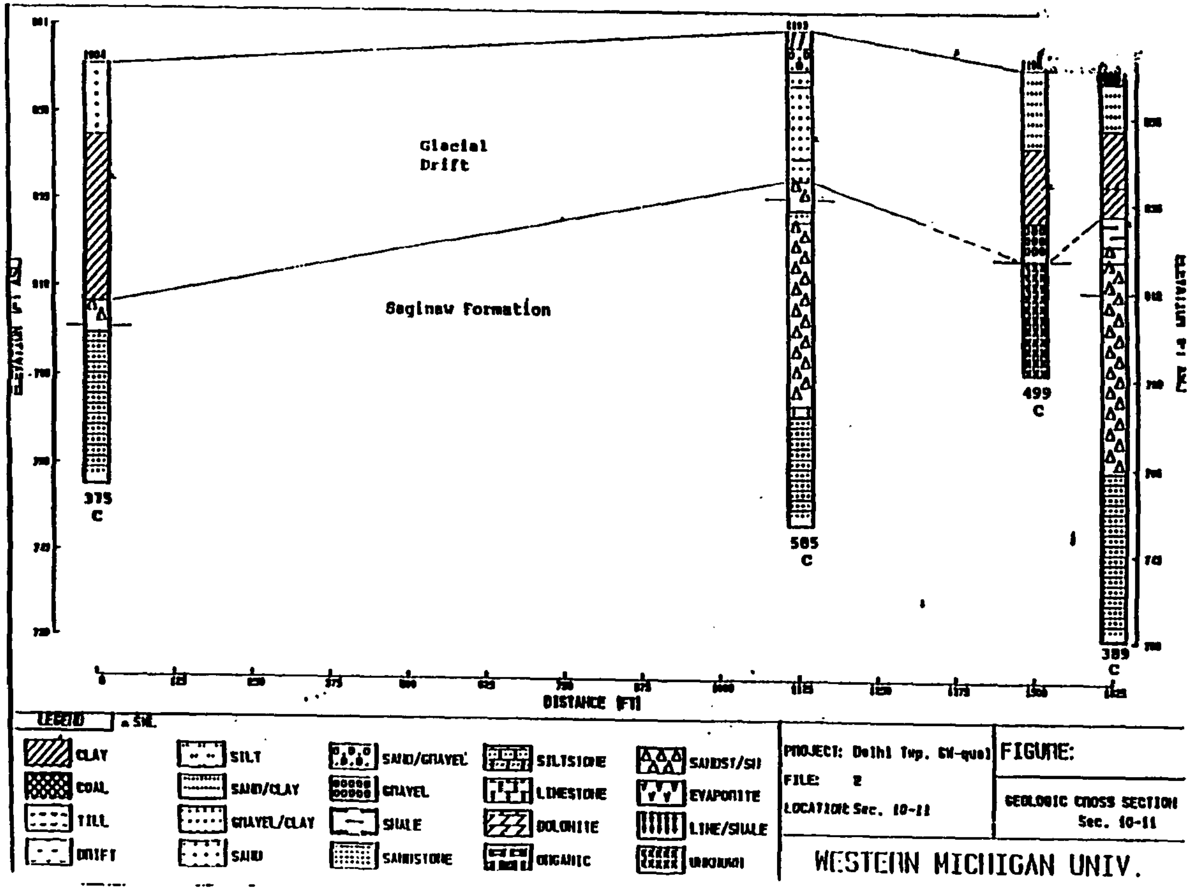
See Plate 1 (Cross-Section C-C') for location.



HARDNESS

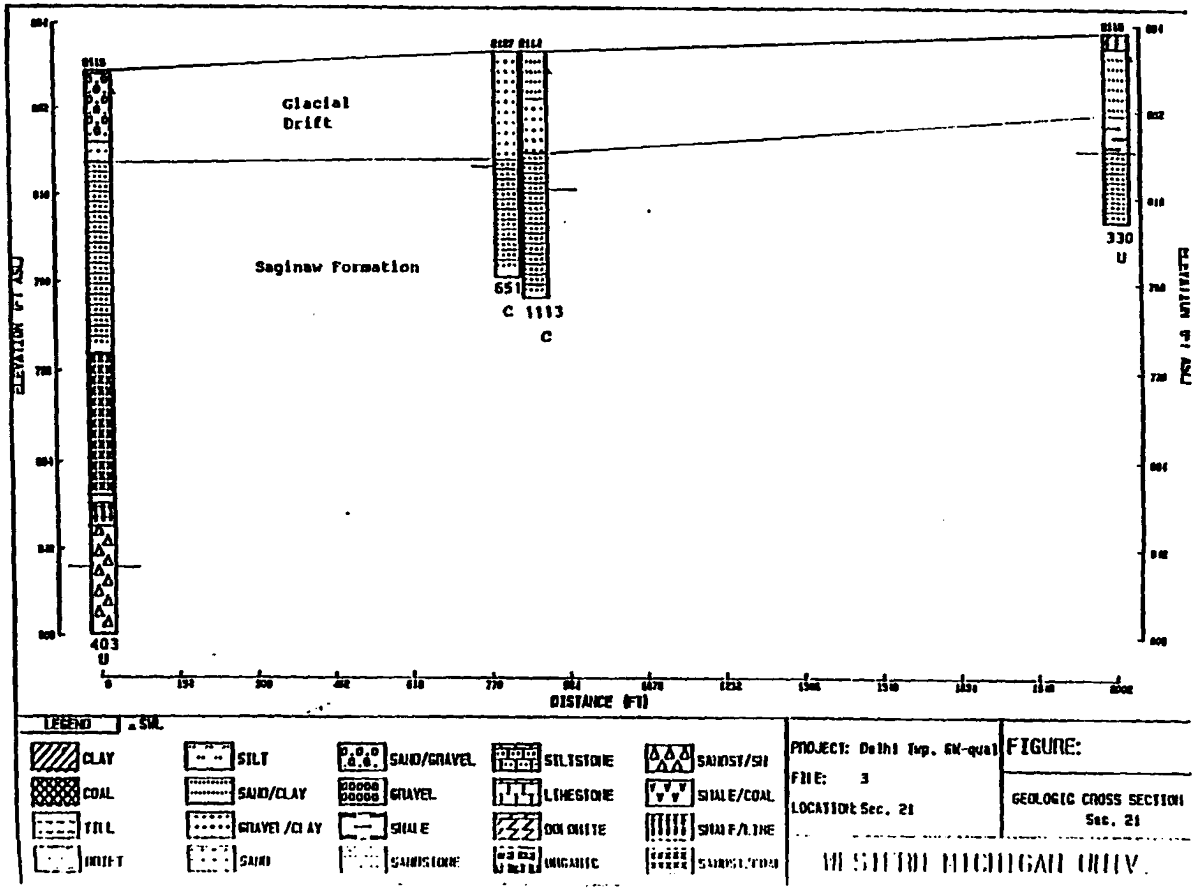
Sec. 10-11 west-east

See Plate 1 (Cross Section E-E') for location.



HARDNESS
Sec. 21 west-east

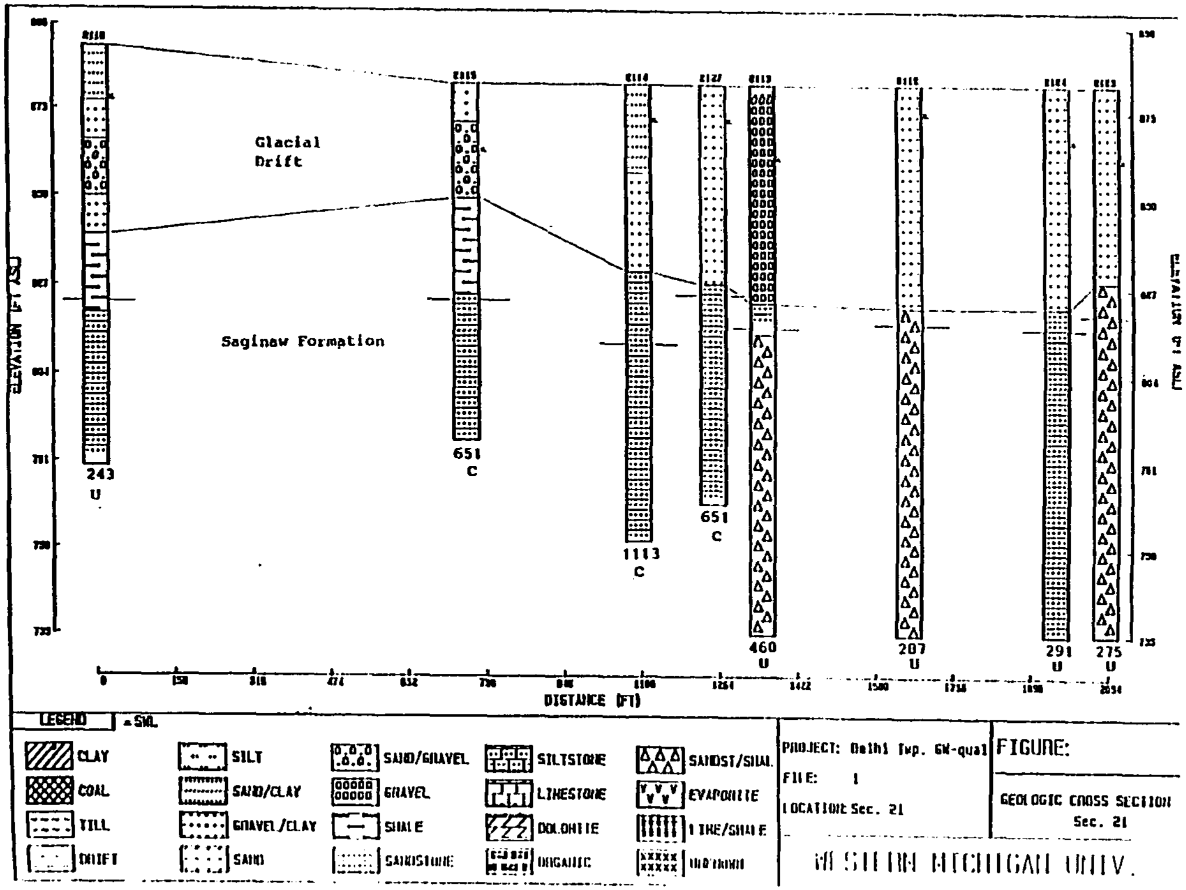
See Plate 1 (Cross Section D-D') for location.



HARDNESS

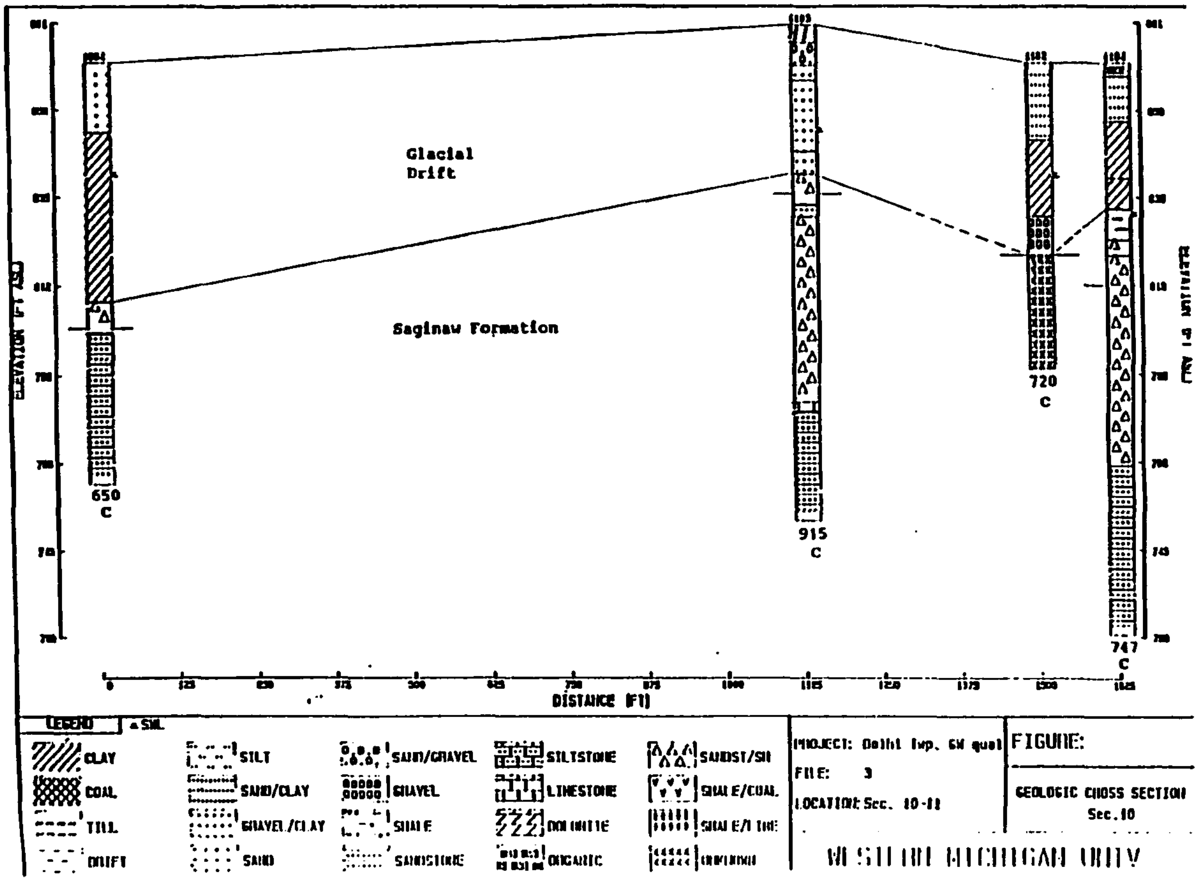
Sec. 21 north-south

See Plate 1 (Cross Section C-C') for location.



CONDUCTIVITY
Sec. 10-11 west-east

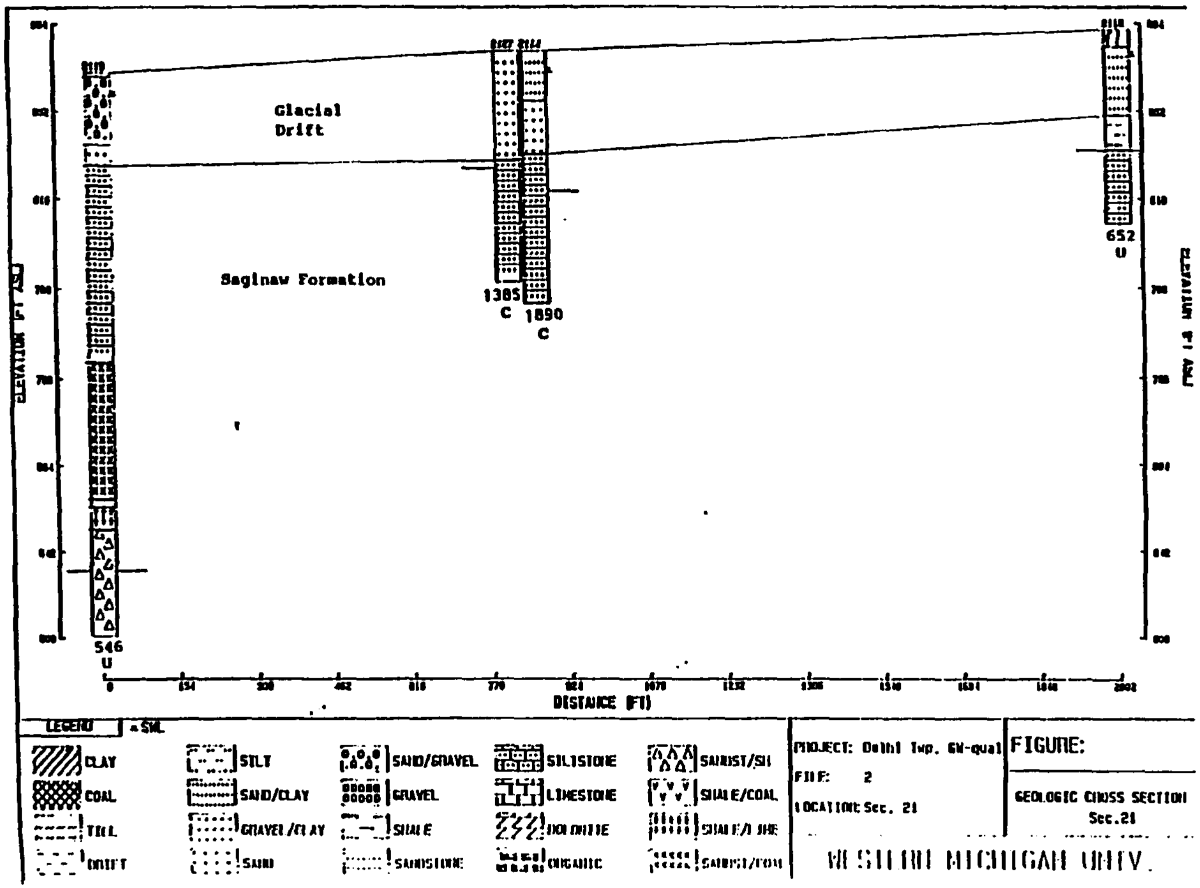
See Plate 1 (Cross Section E-E') for location.



CONNECTIVITY

Sec. 21 west-east

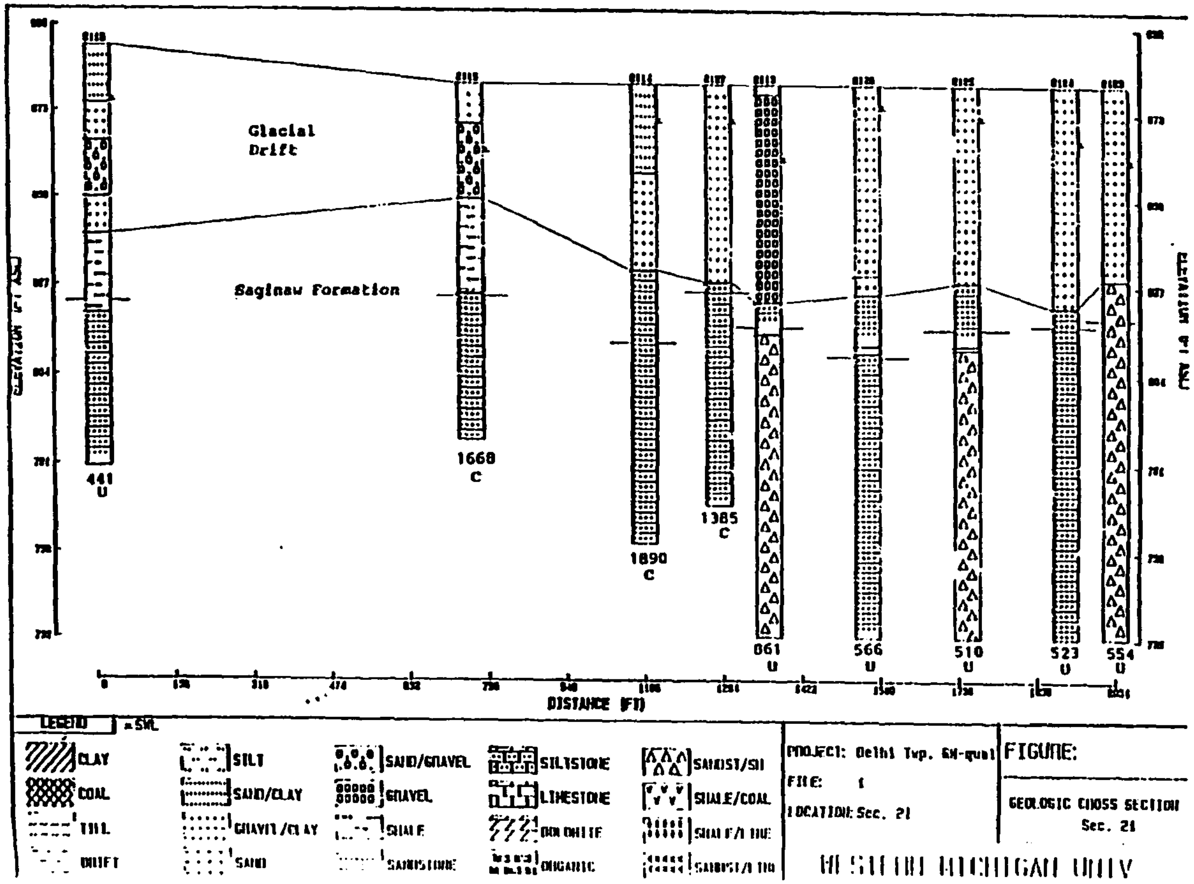
See Plate 1 (Cross Section D-D') for location.



CONDUCTIVITY

Sec. 21 north-south

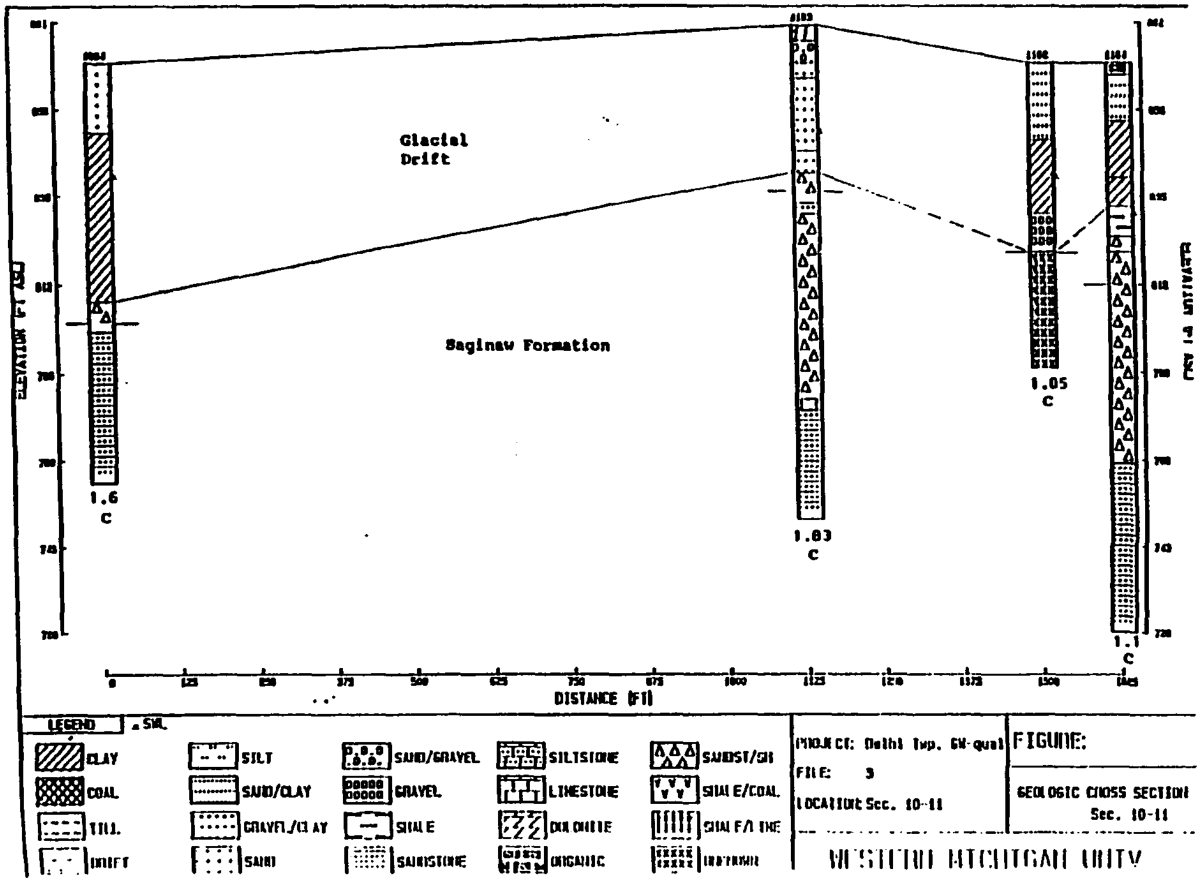
See Plate 1 (Cross Section C-C') for location.



IRON

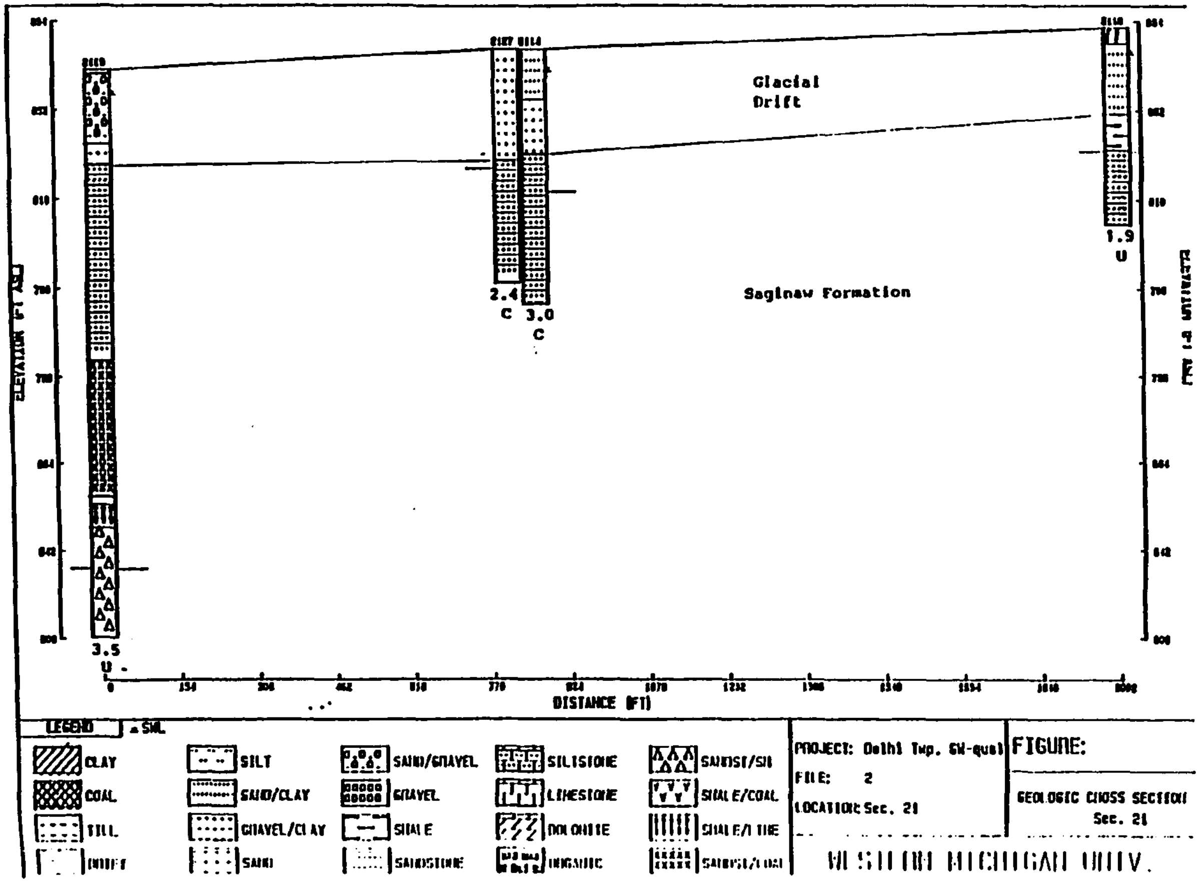
Sec. 10-11 west-east

See Plate 1 (Cross Section E-E') for location.



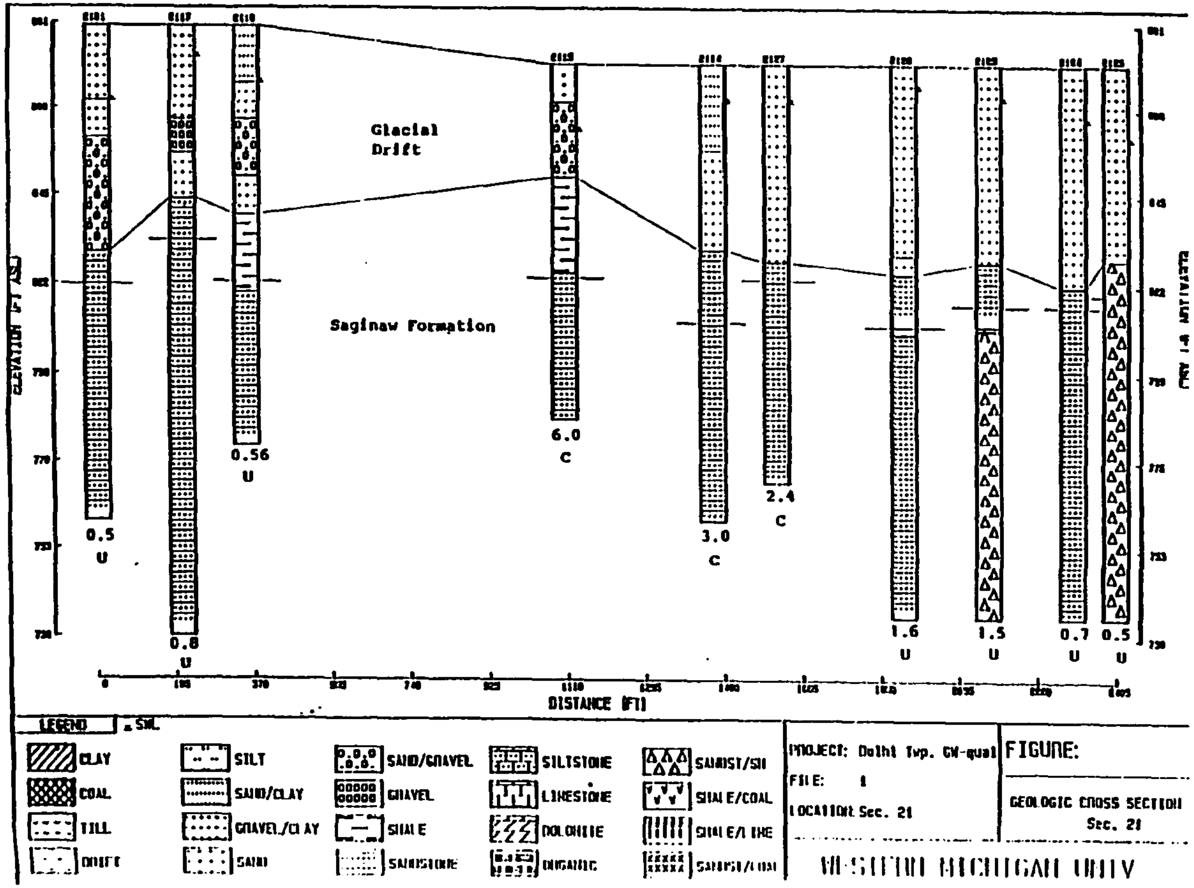
IRON
Sec. 21 west-east

See Plate 1 (Cross Section D-D') for location.



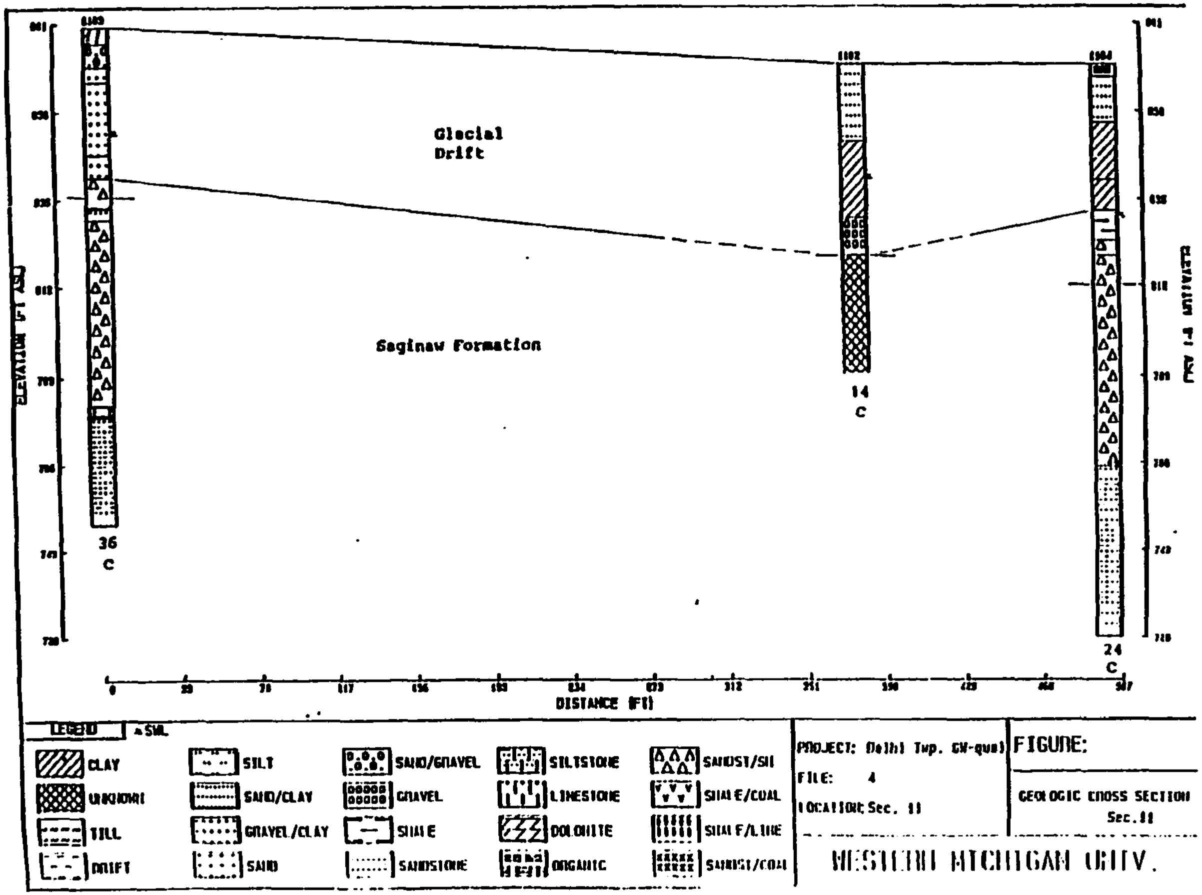
IRON
Sec. 21 north-south

See Plate 1 (Cross Section C-C') for location.



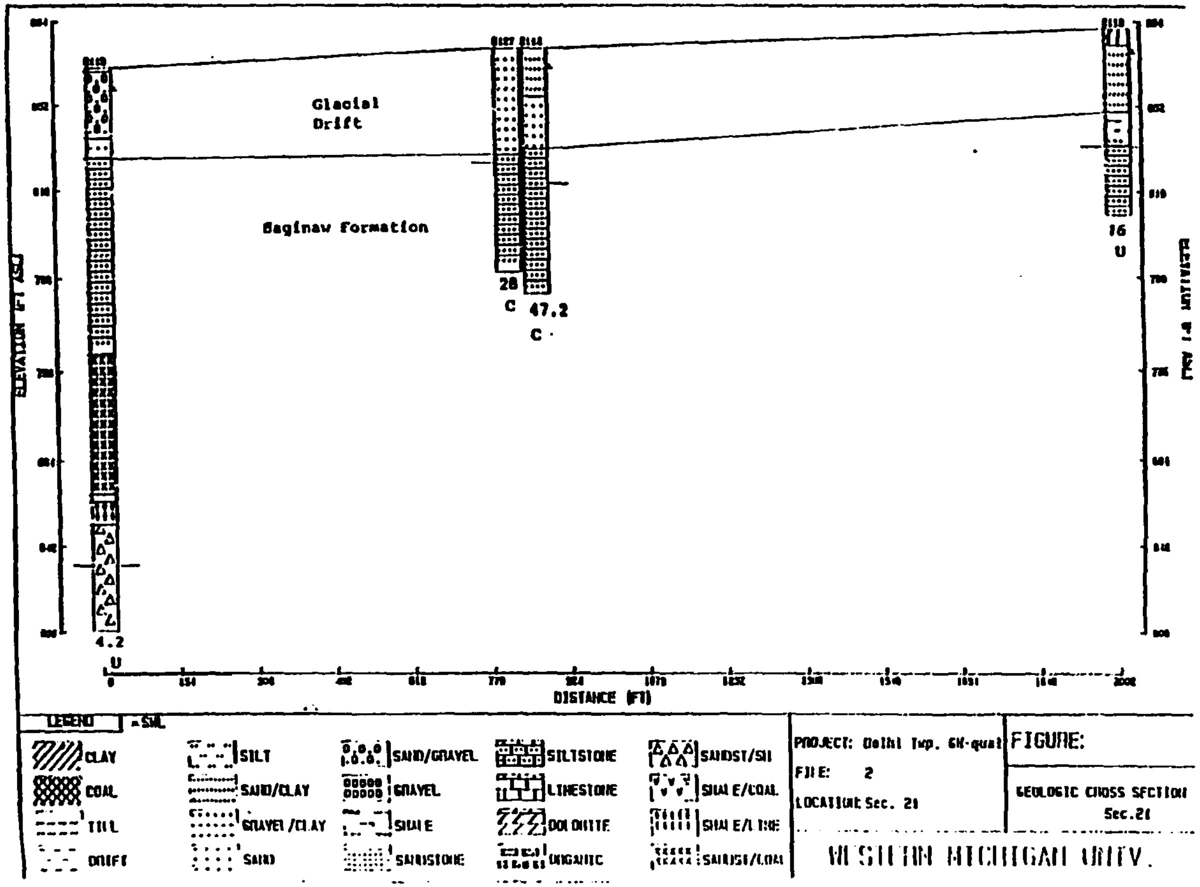
SODIUM
Sec. 11 west-east

See Plate 1 (Cross Section E-E') for location.



SODIUM
Sec. 21 west-east

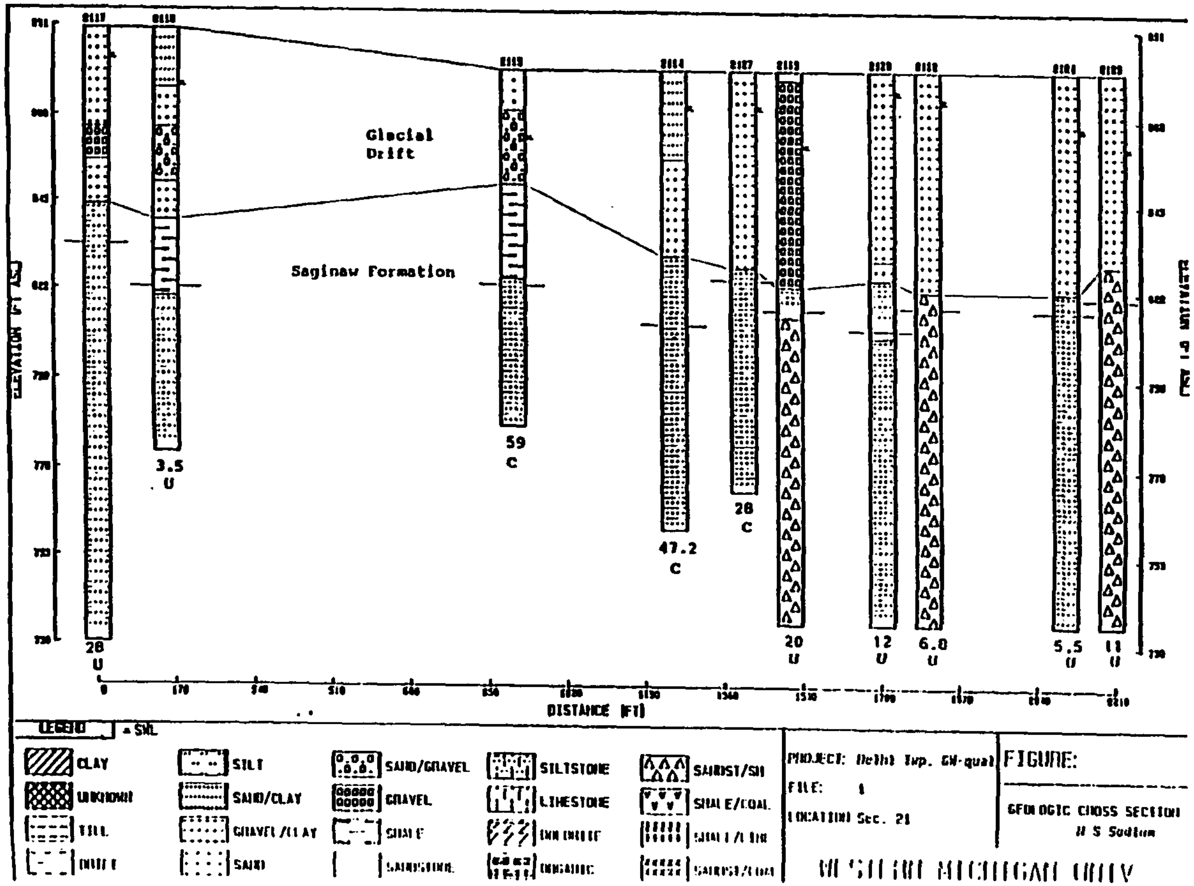
See Plate 1 (Cross Section D-D') for location.



SODIUM

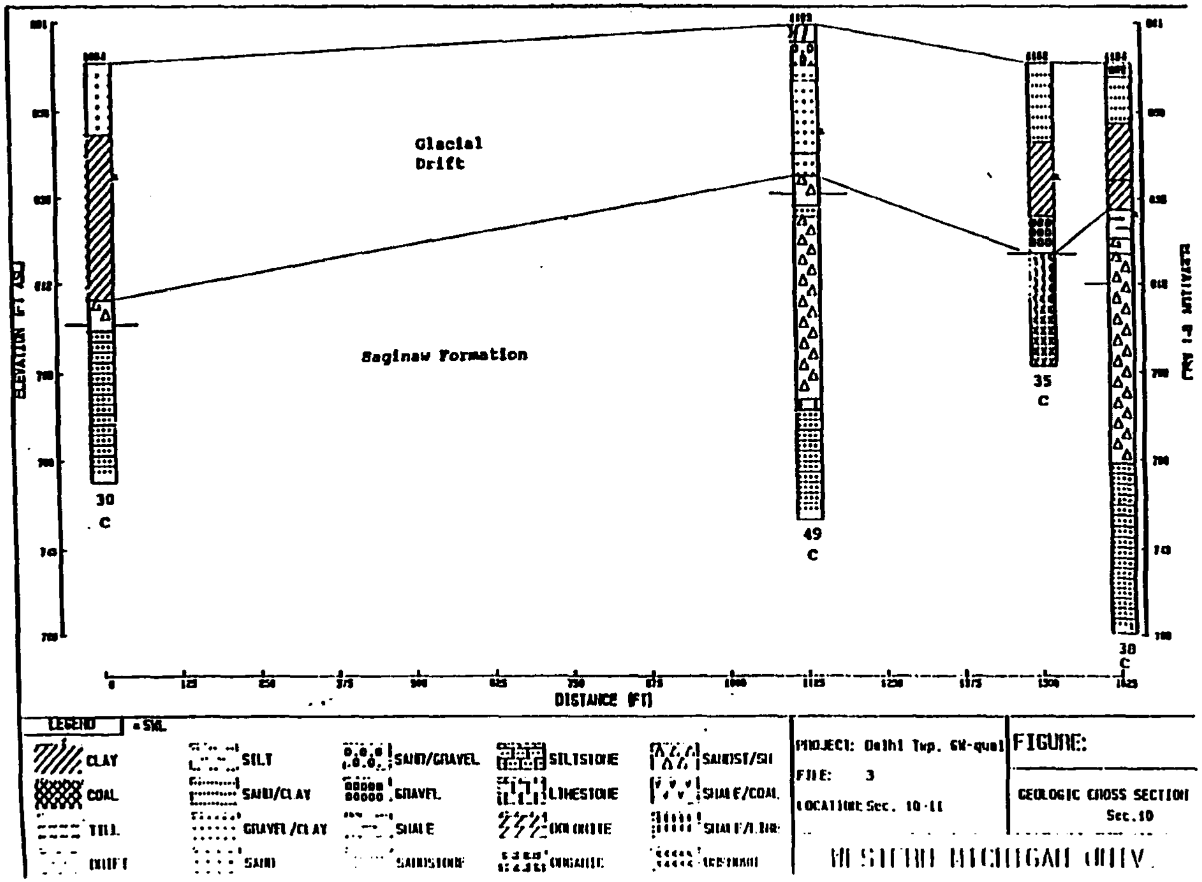
Sec. 21 north-south

See Plate 1 (Cross Section C-C') for location.



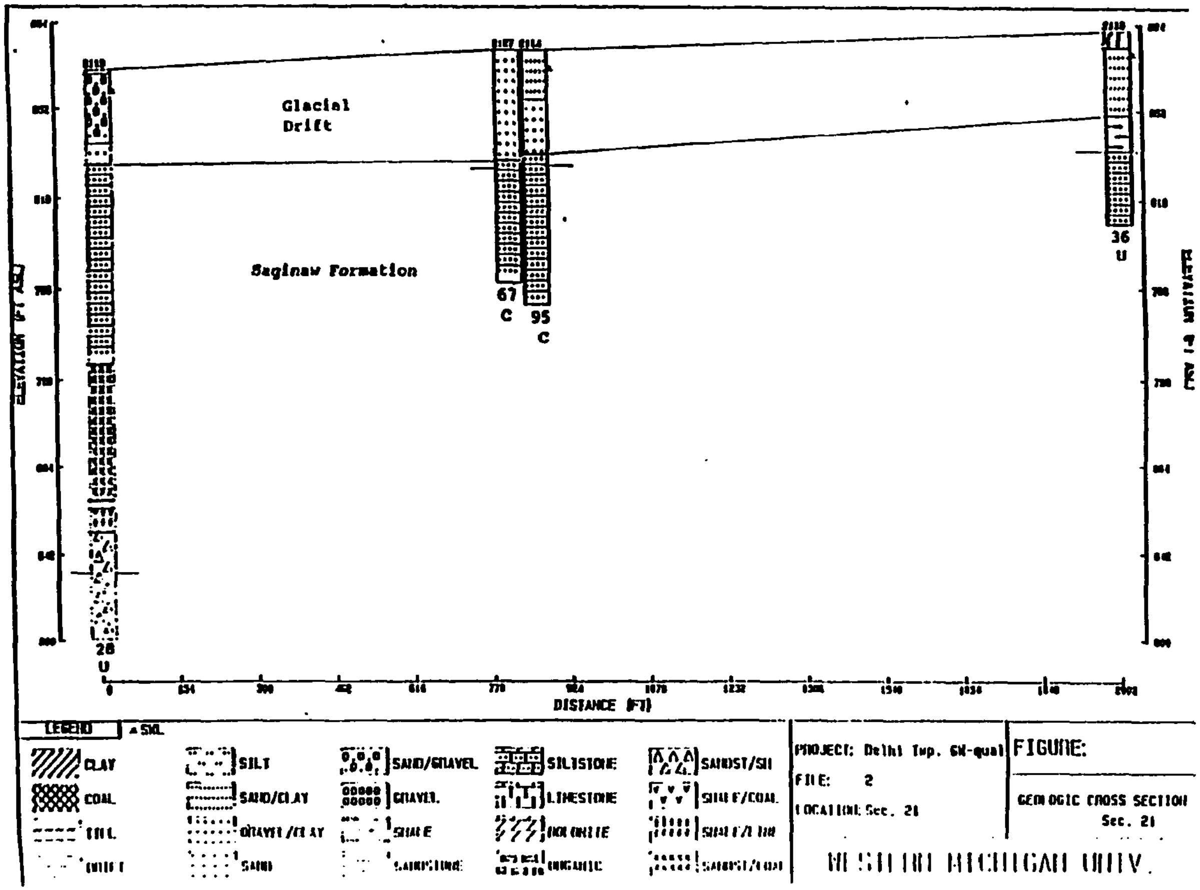
MAGNESIUM
sec. 10-11 west-east

See Plate 1 (Cross Section E-E') for location.



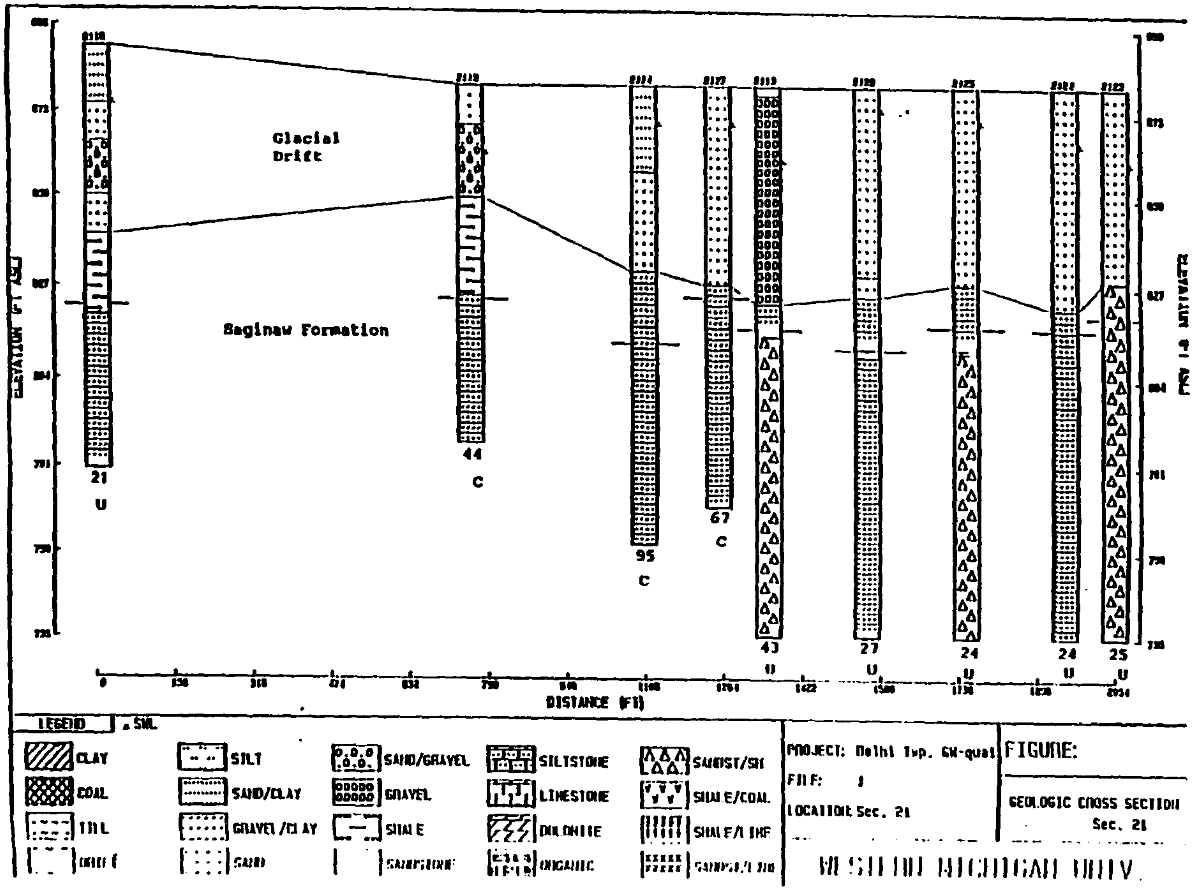
sec. 21 west-east

See Plate 1 (Cross Section D-D') for location.



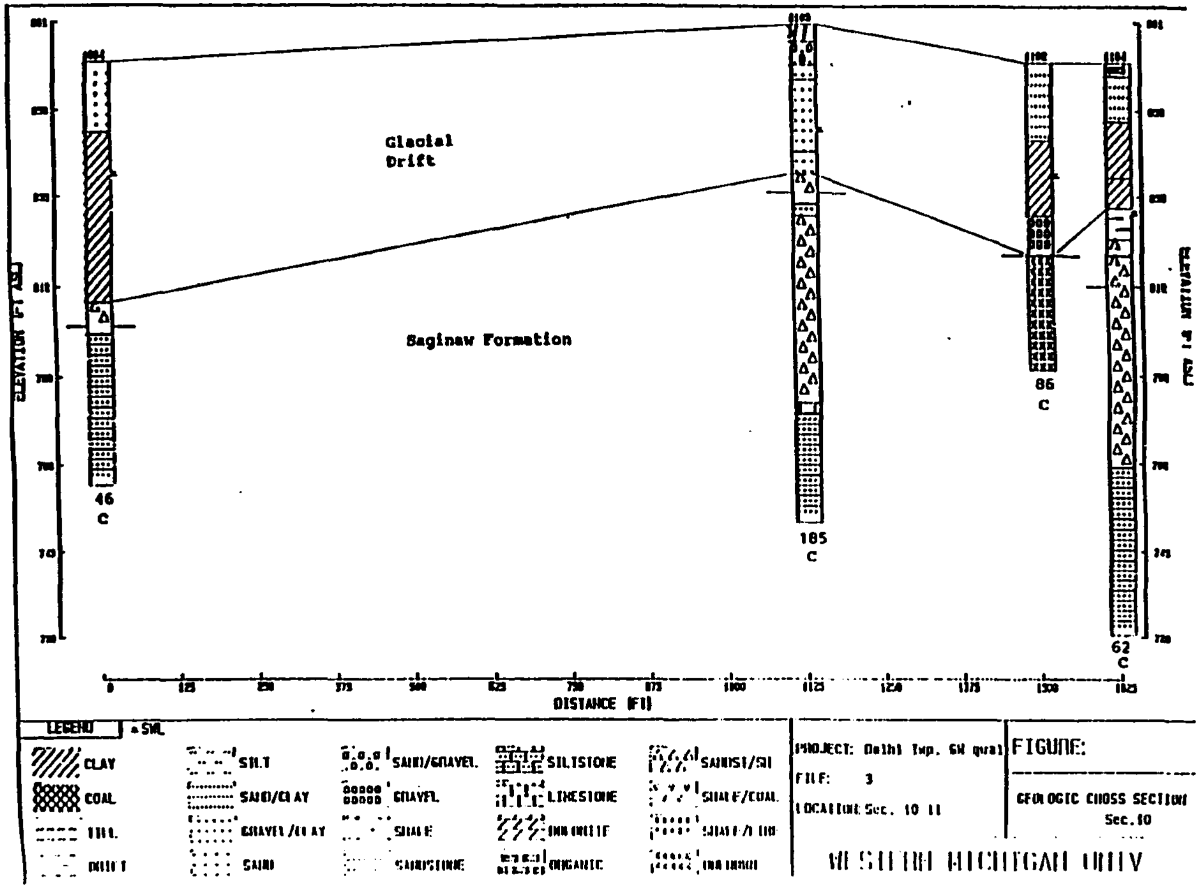
MAGNESIUM
Sec. 21 north-south

See Plate 1 (Cross Section C-C') for location.

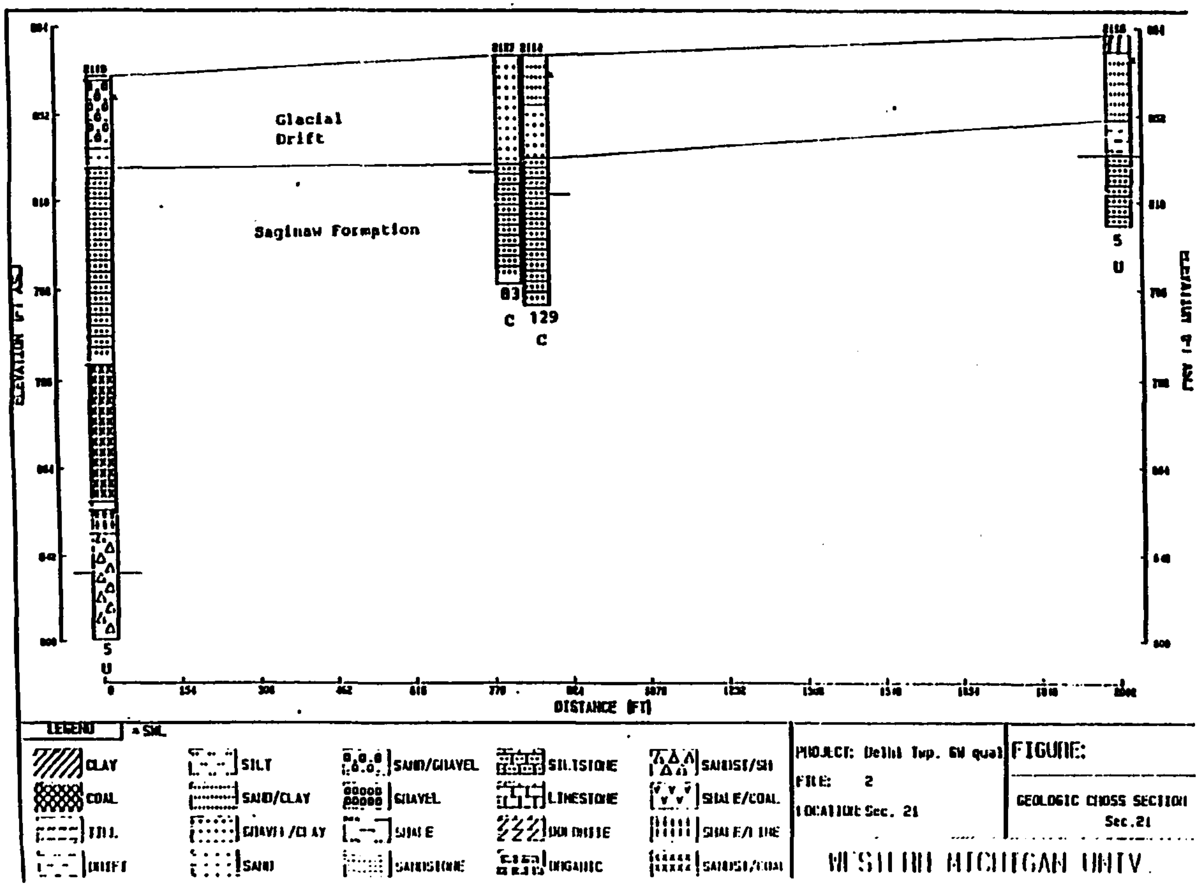


CHLORIDE
Sec. 10-11 west-east

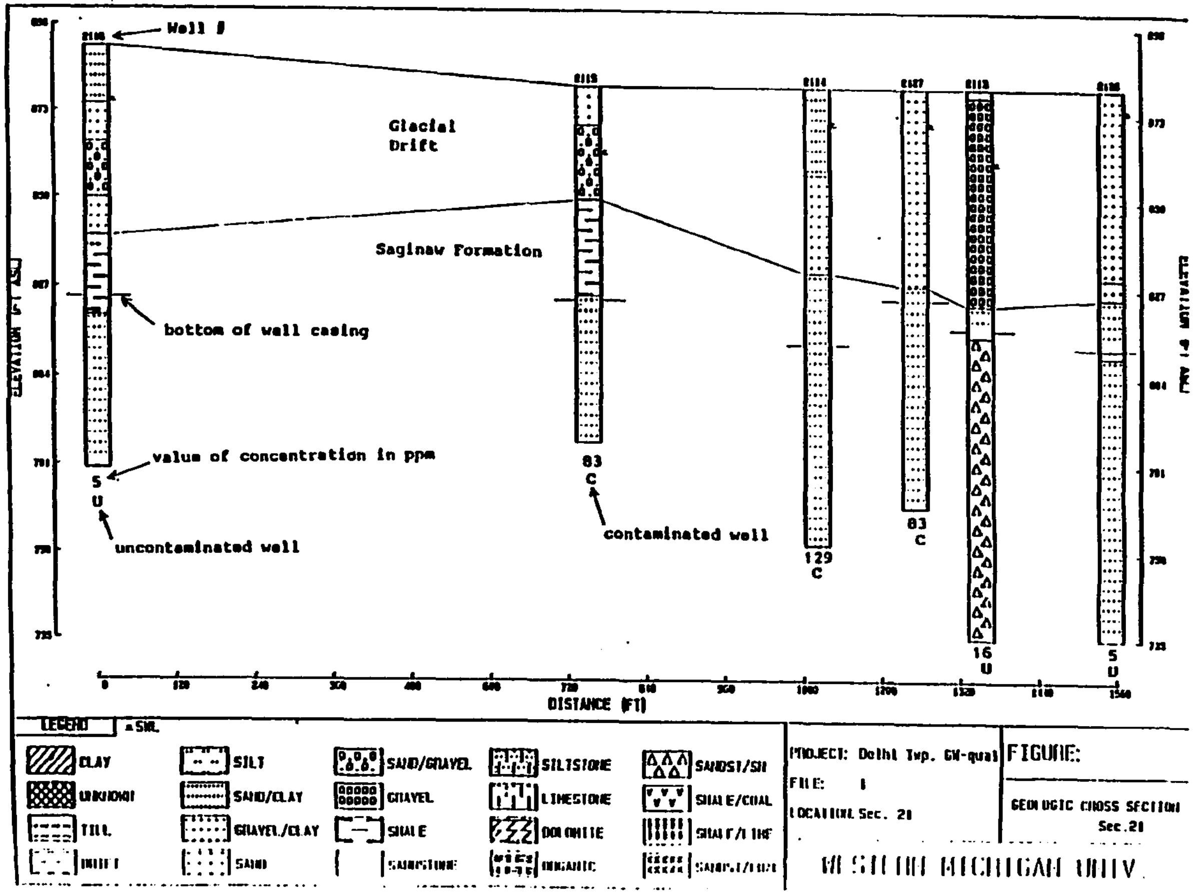
See Plate 1 (Cross Section E-E') for location.



CHLORIDE
Sec. 21 west-east See Plate 1 (Cross Section D-D') for location.



Sec. 21 north-south   See Plate 1 (Cross Section C-C') for location.



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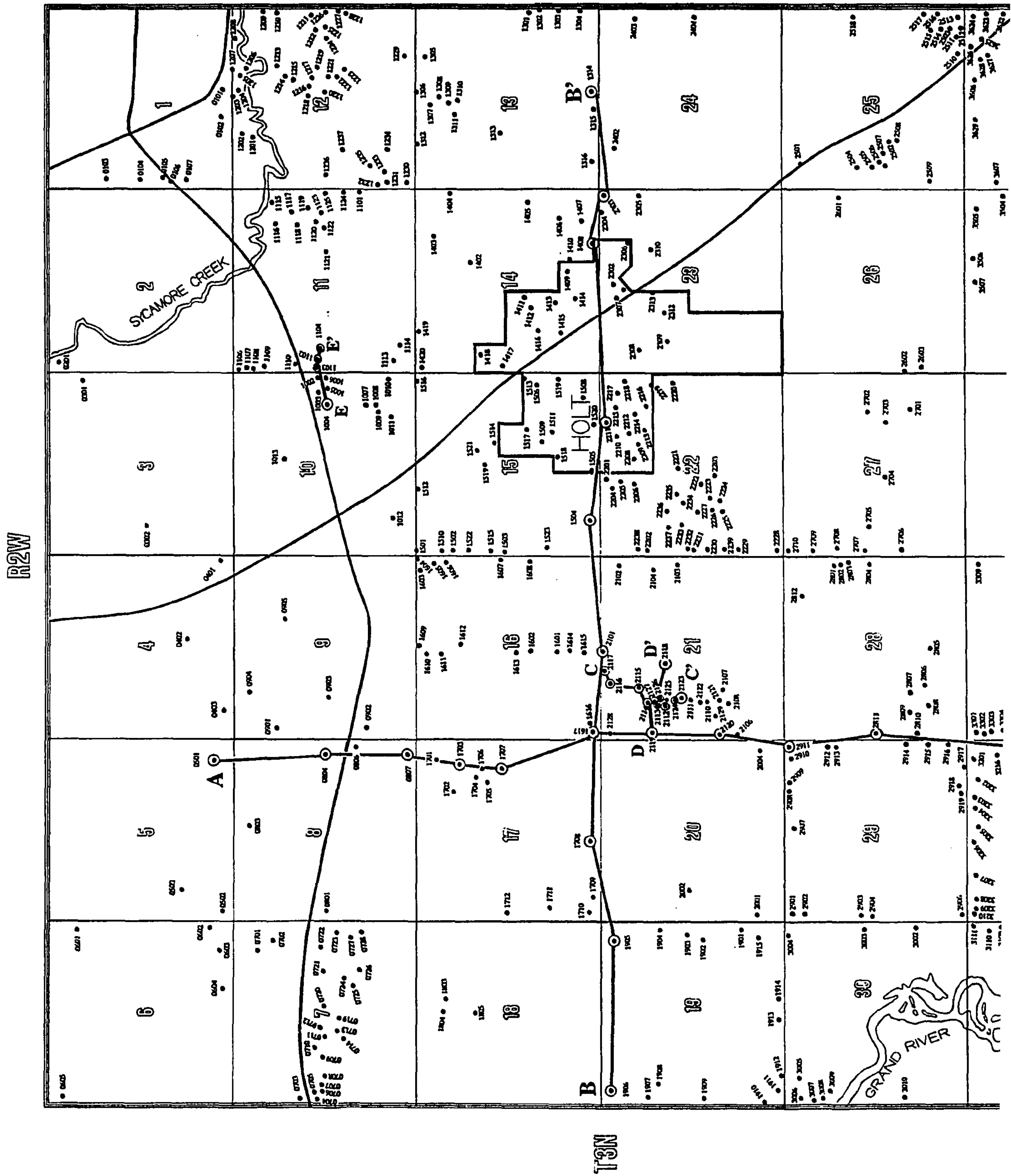
R2W
T3N
SYCAMORE CREEK
GRAND RIVER
HOLT
A
B
B'
C
C'
D
D'
E
E'
1
2
3
4
5
6
7
8
9
10
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25
26
27
28
29
30

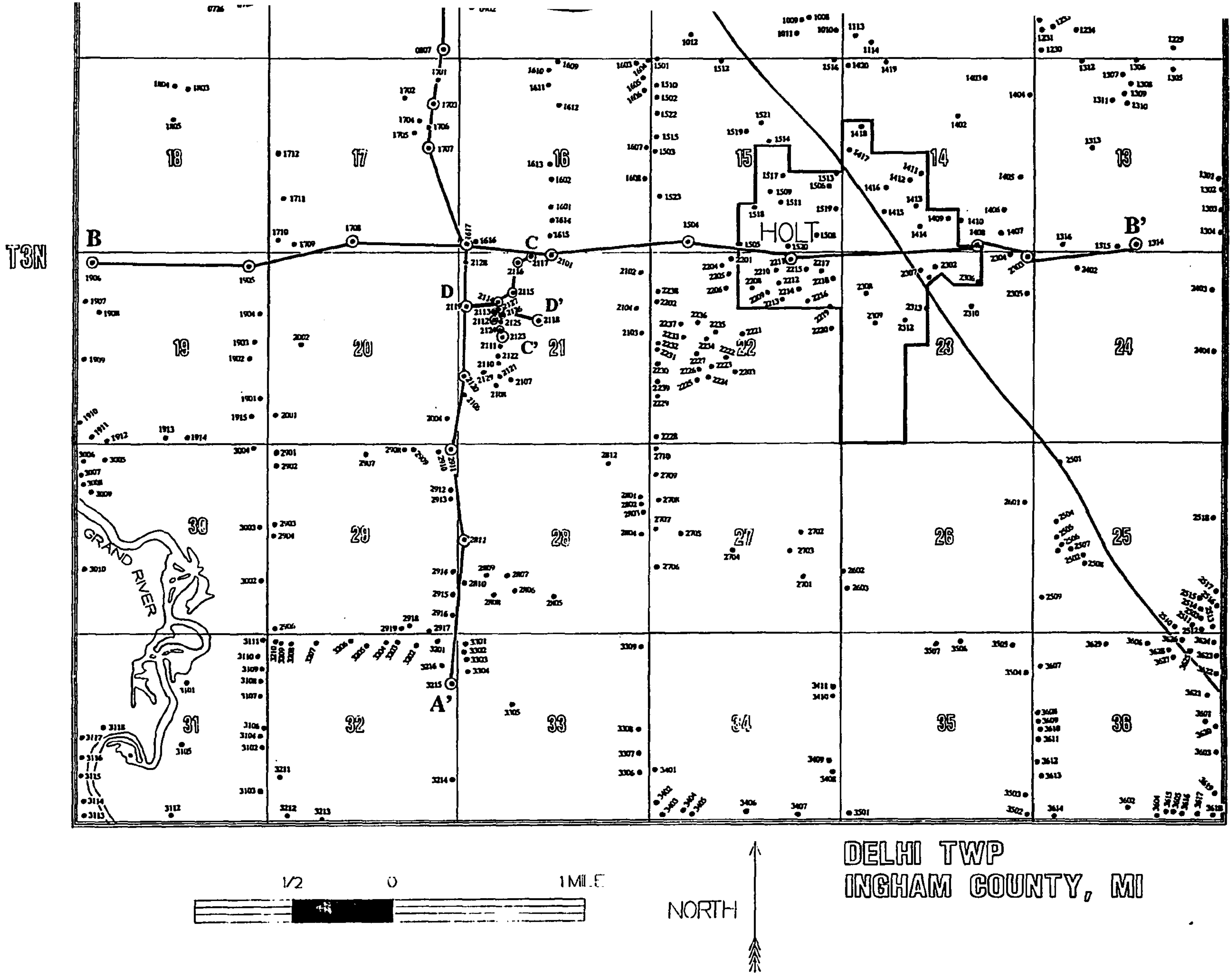
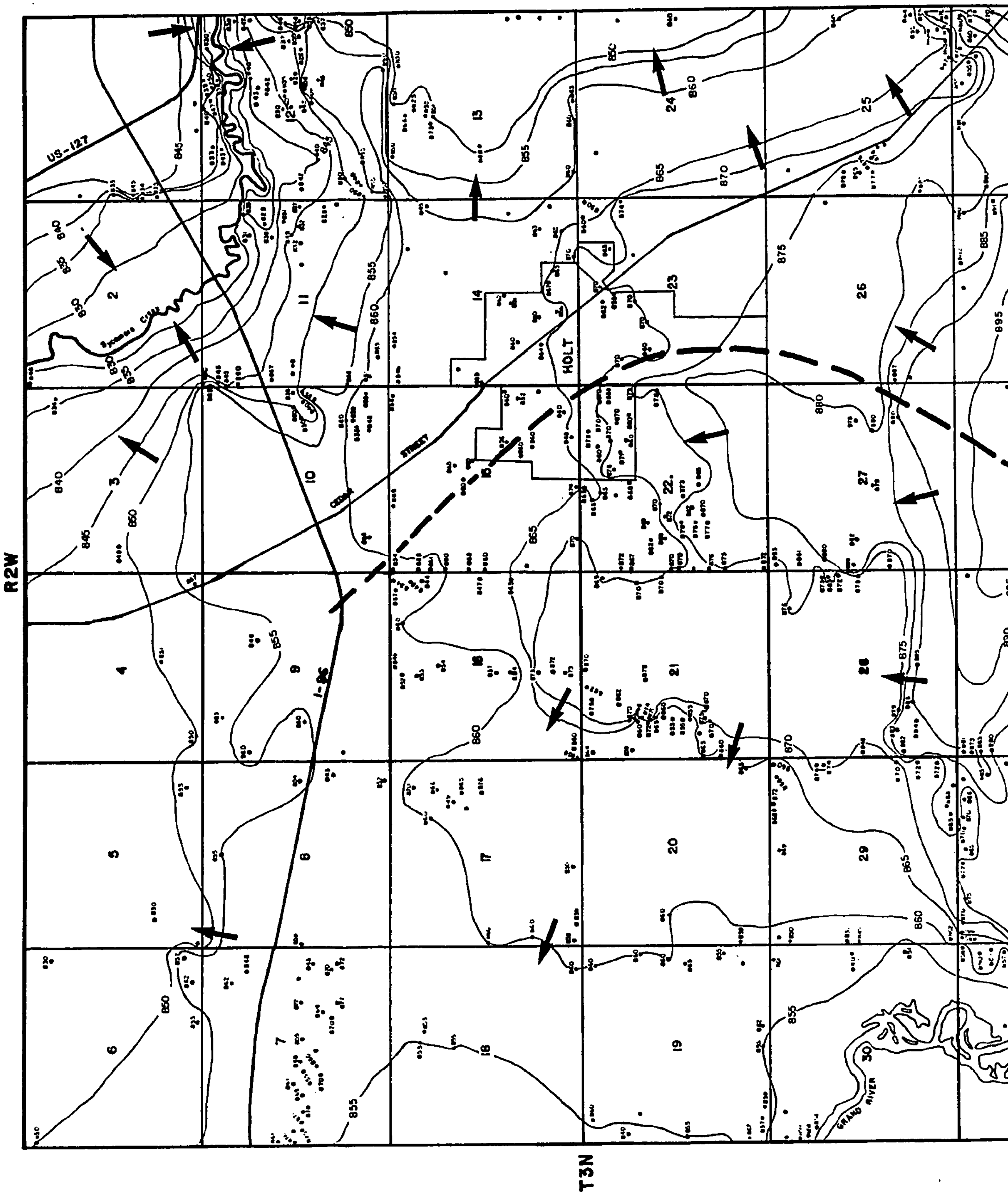


PLATE 1 Well numbers and cross section locations


R2W
T3N
US-127
I-96
CEDAR STREET
HOLT
Sycamore Creek
GRAND RIVER
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
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865
870
875
880
885
895

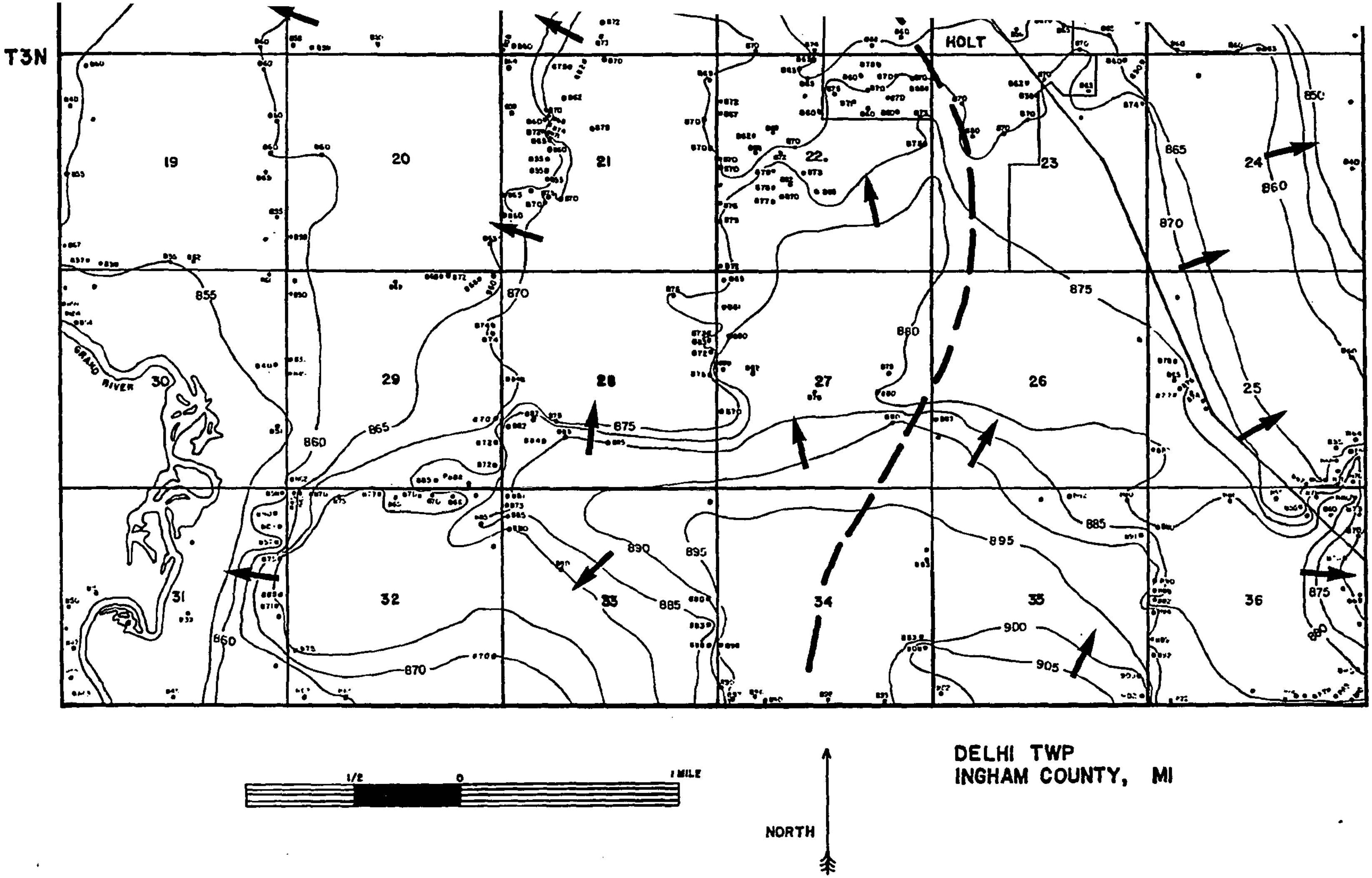
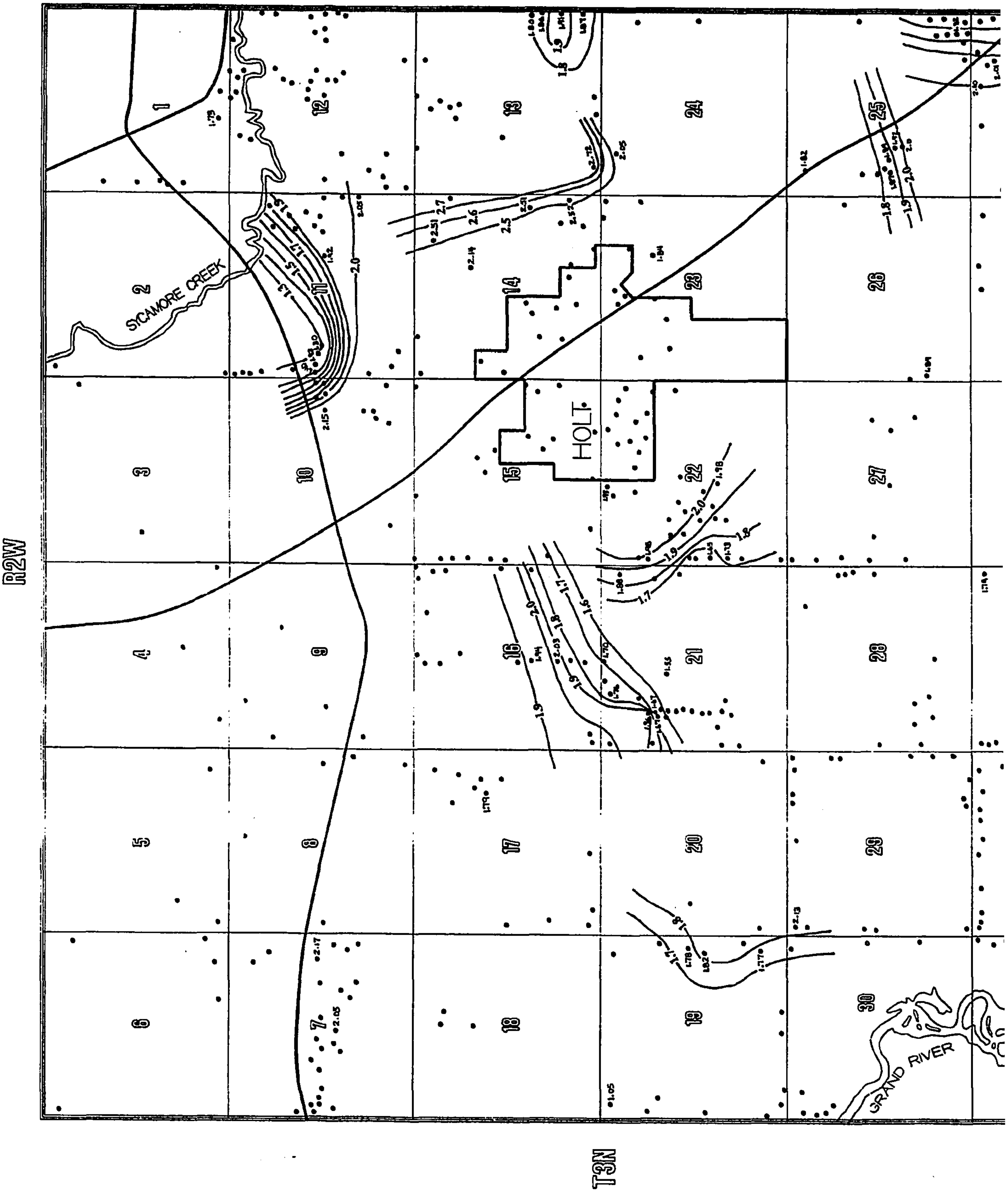


PLATE 2 Potentiometric surface of the Saginaw Aquifer in feet above sea level

Contour Interval: 5 feet

→ Direction of groundwater flow

— — Groundwater Divide


R2W
T3N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
SYCAMORE CREEK
HOLT
GRAND RIVER
2.0
1.9
1.8
1.7
1.6
1.5
1.3
1.1
2.7
2.6
2.5

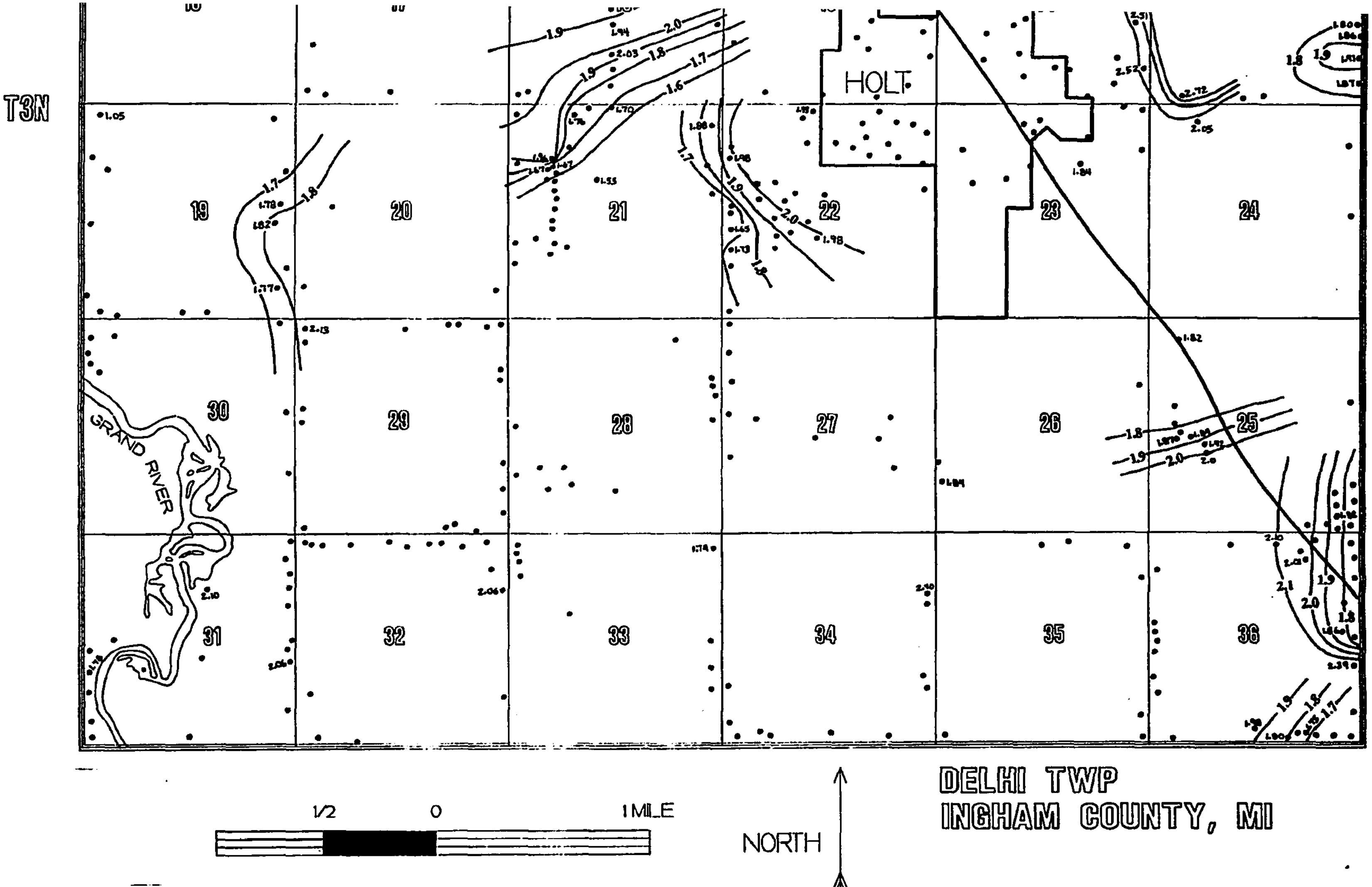
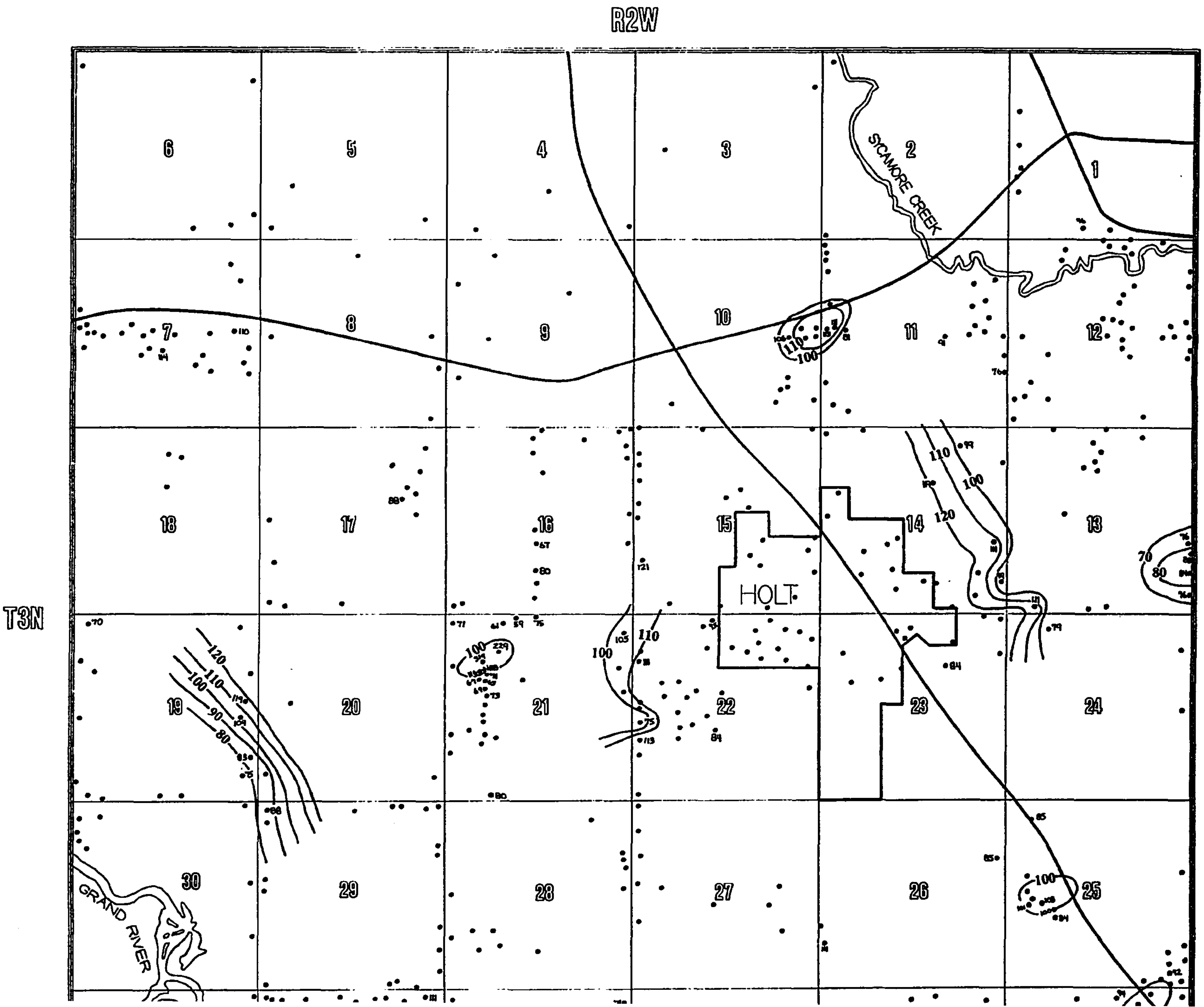


PLATE 3 $Ca^{2+}:Mg^{2+}$ Ratio Distribution Map

Contour Interval: 0.10


R2W
T3N
6
5
4
3
2
1
SYCAMORE CREEK
7
8
9
10
11
12
18
17
16
15
14
13
HOLT
19
20
21
22
23
24
30
29
28
27
26
25
GRAND RIVER
120
110
100
90
80
70

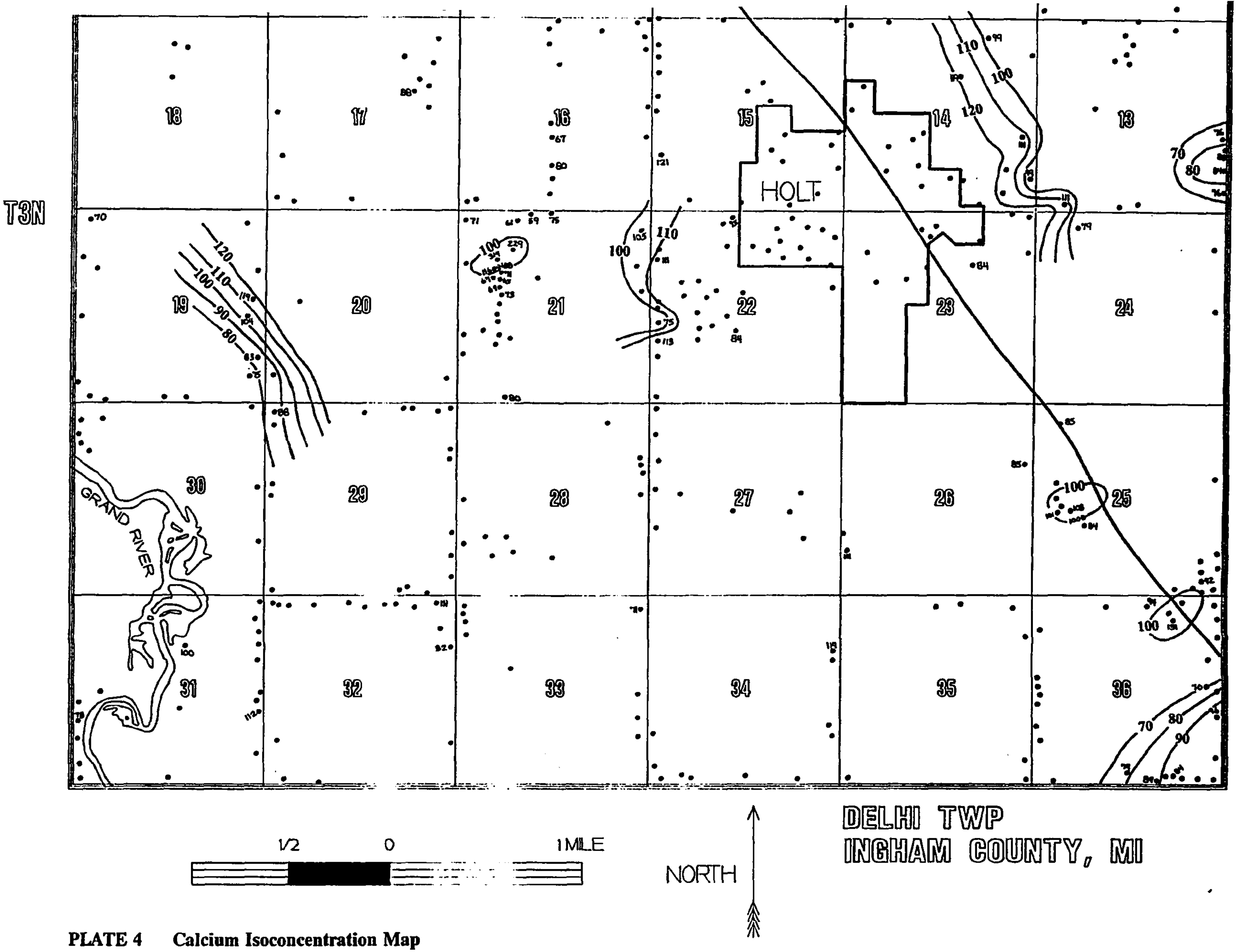
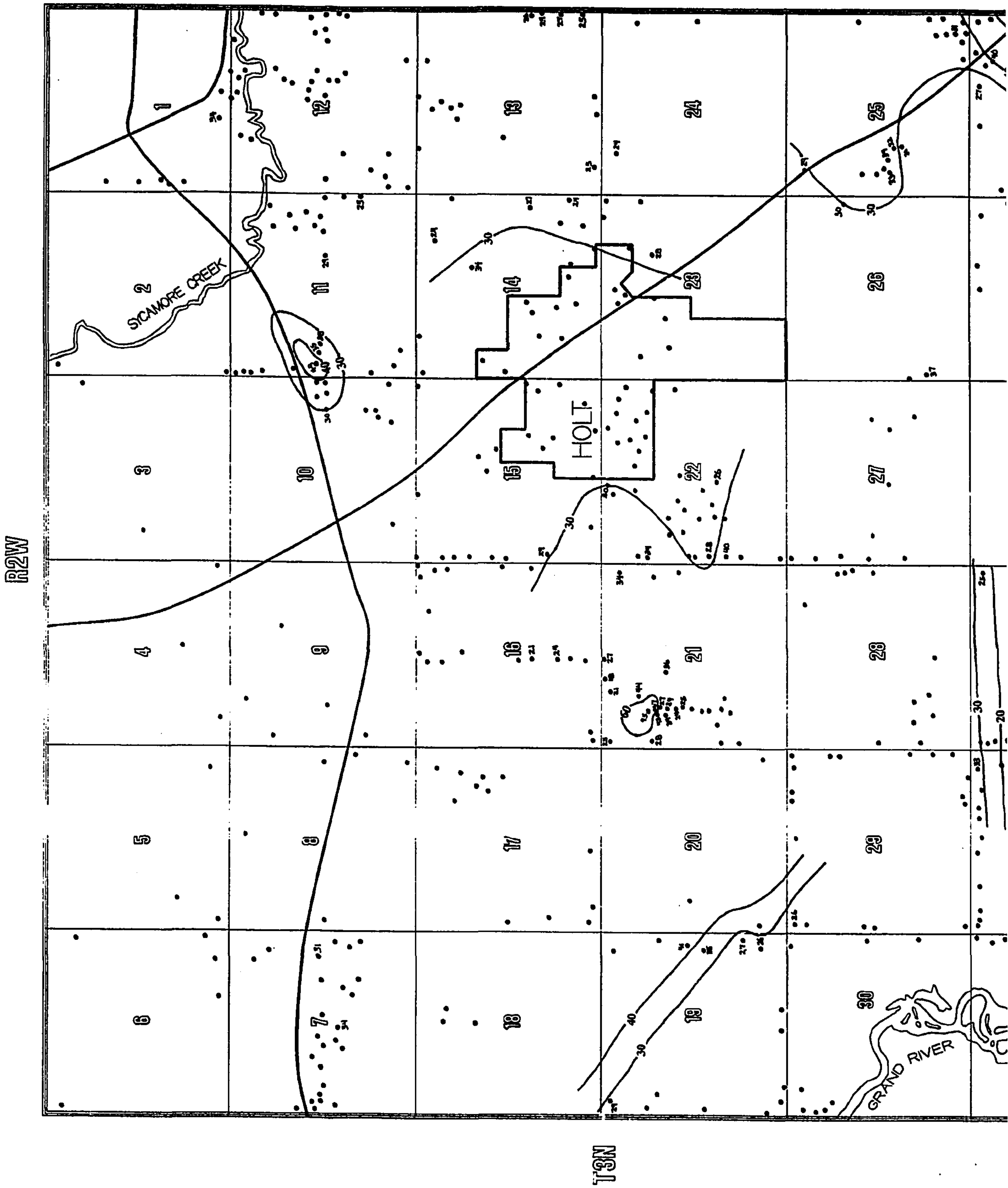


PLATE 4 Calcium Isoconcentration Map

Contour Interval: 10ppm


R2W
T3N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
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18
19
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SYCAMORE CREEK
HOLT
GRAND RIVER
30
40
20
60

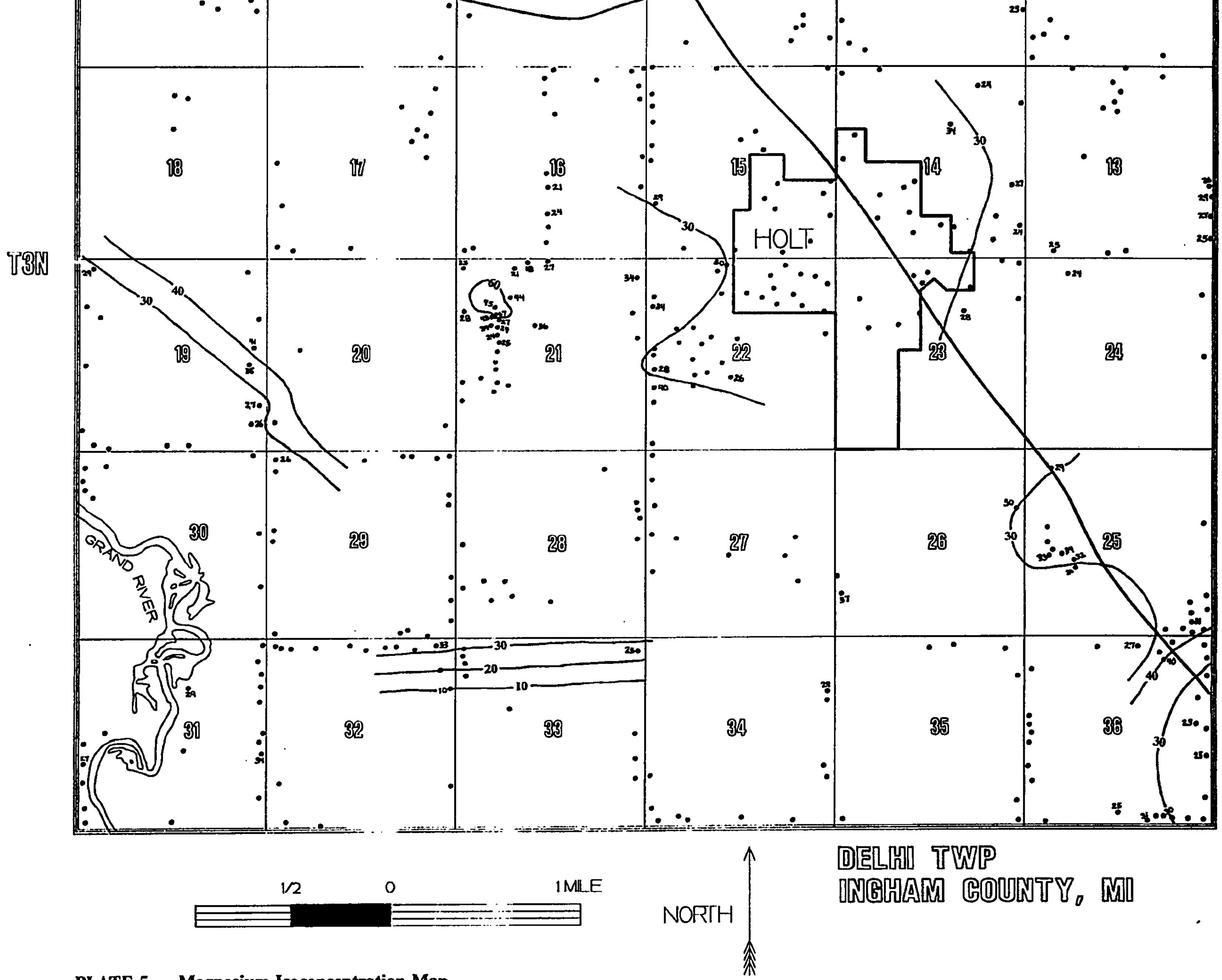
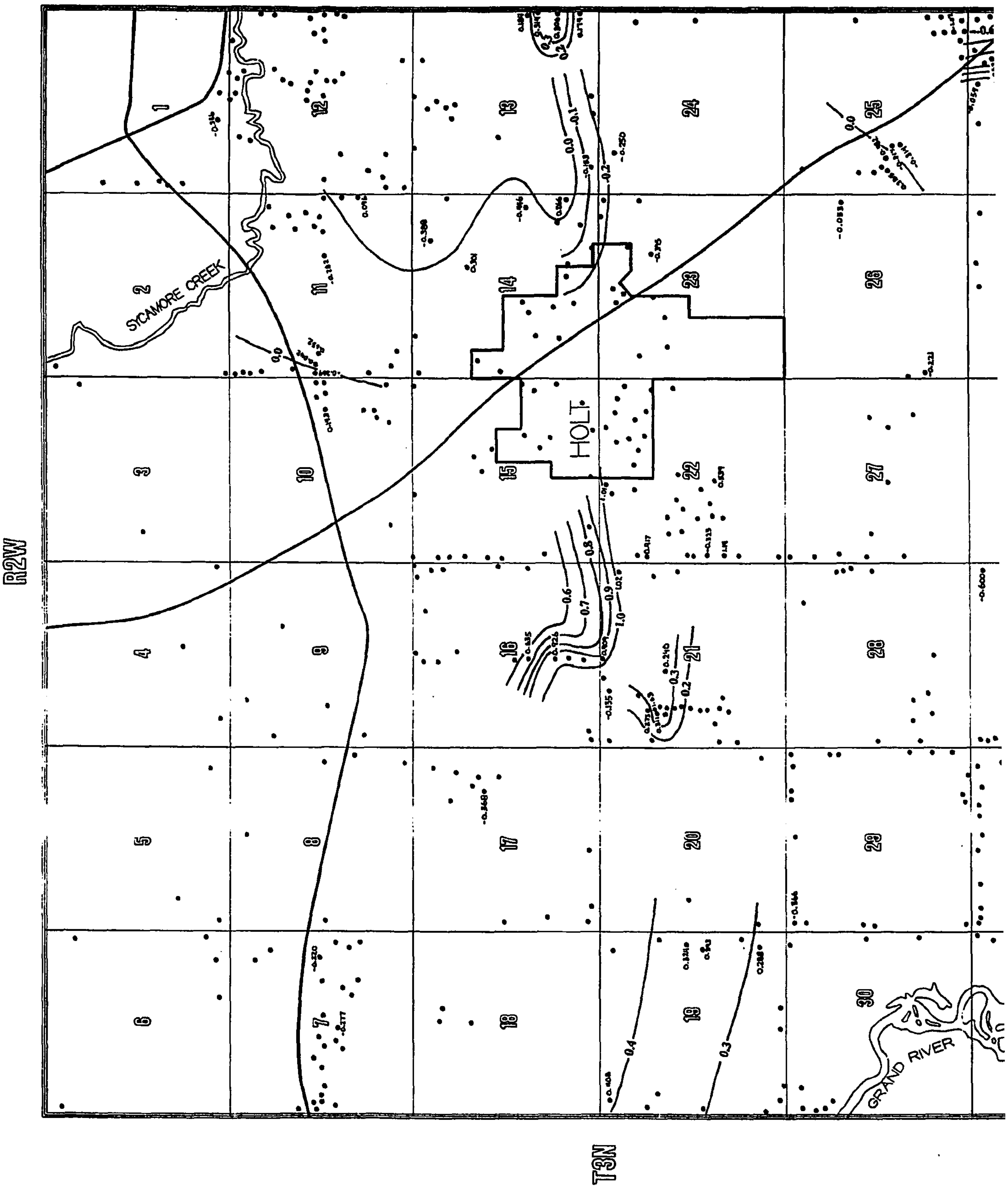


PLATE 5 **Magnesium Isoconcentration Map**

Contour Interval: 10ppm


R2W
T3N
SYCAMORE CREEK
HOLT
GRAND RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
0.0
-0.1
-0.2
0.2
0.3
0.4
0.6
0.7
0.8
0.9
1.0

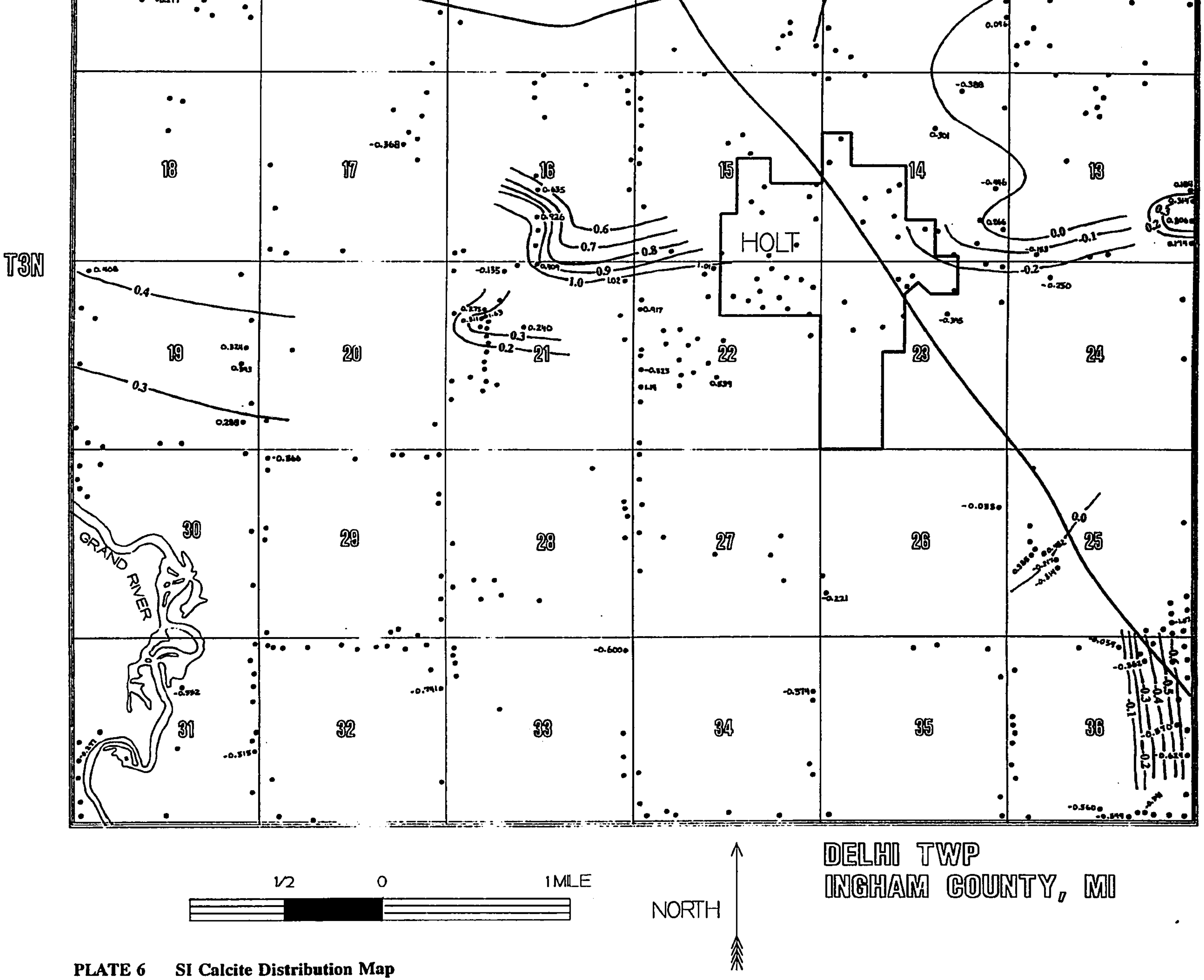
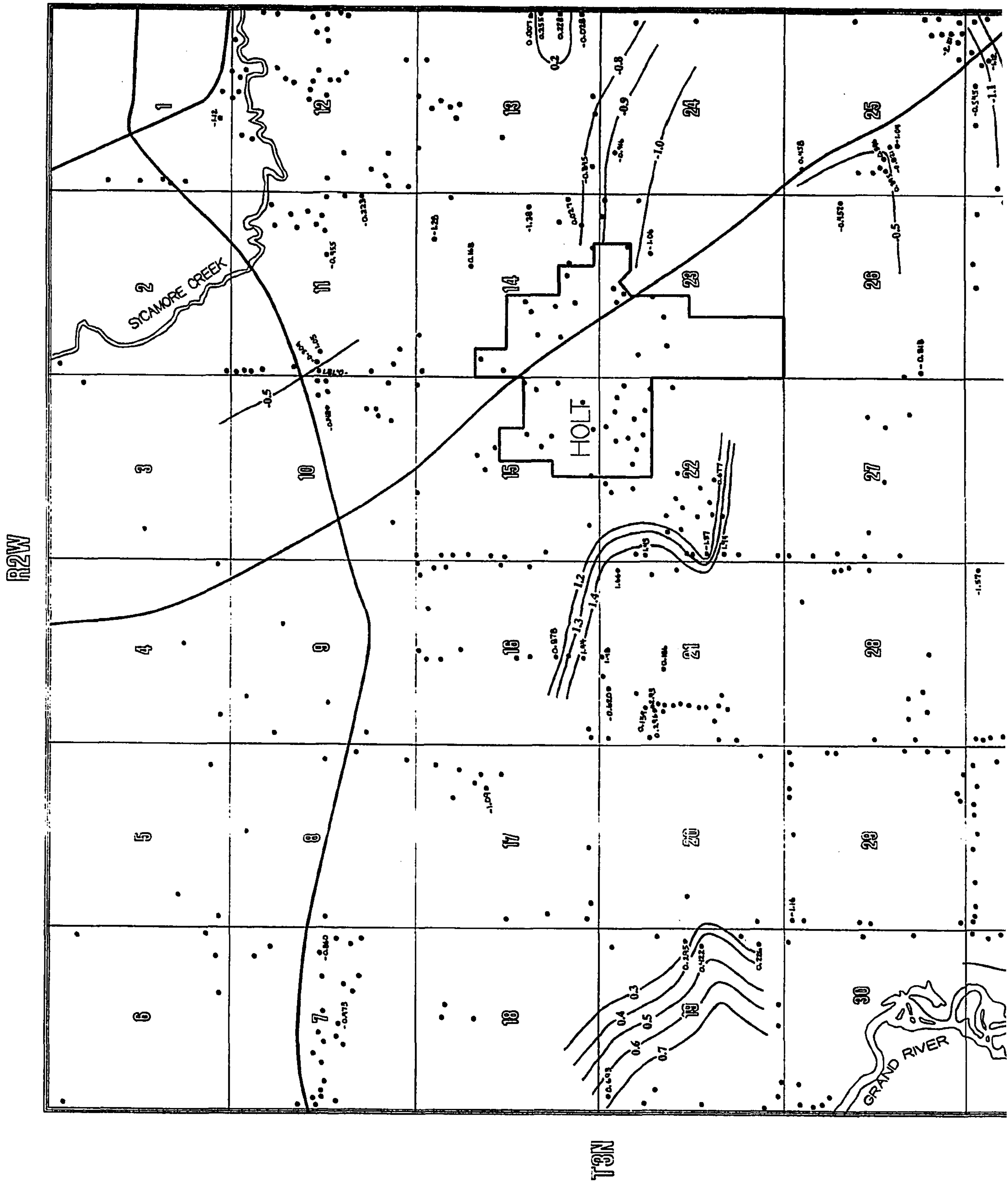


PLATE 6 SI Calcite Distribution Map

Contour Interval: 0.10


R2W
T3N
SYCAMORE CREEK
GRAND RIVER
HOLT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
-0.5
-0.8
-0.9
-1.0
-1.1
1.2
1.3
1.4
0.3
0.4
0.5
0.6
0.7
0.2

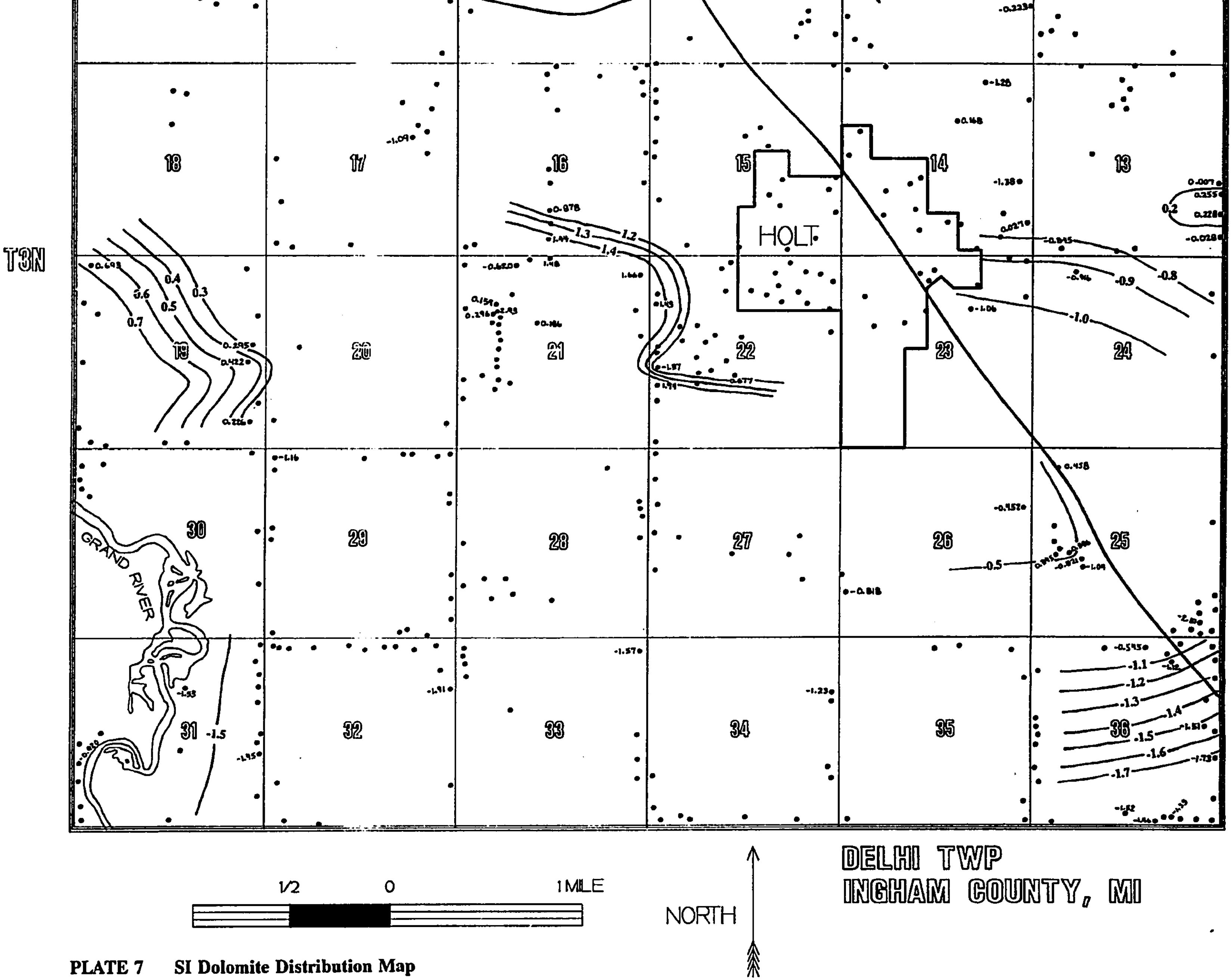
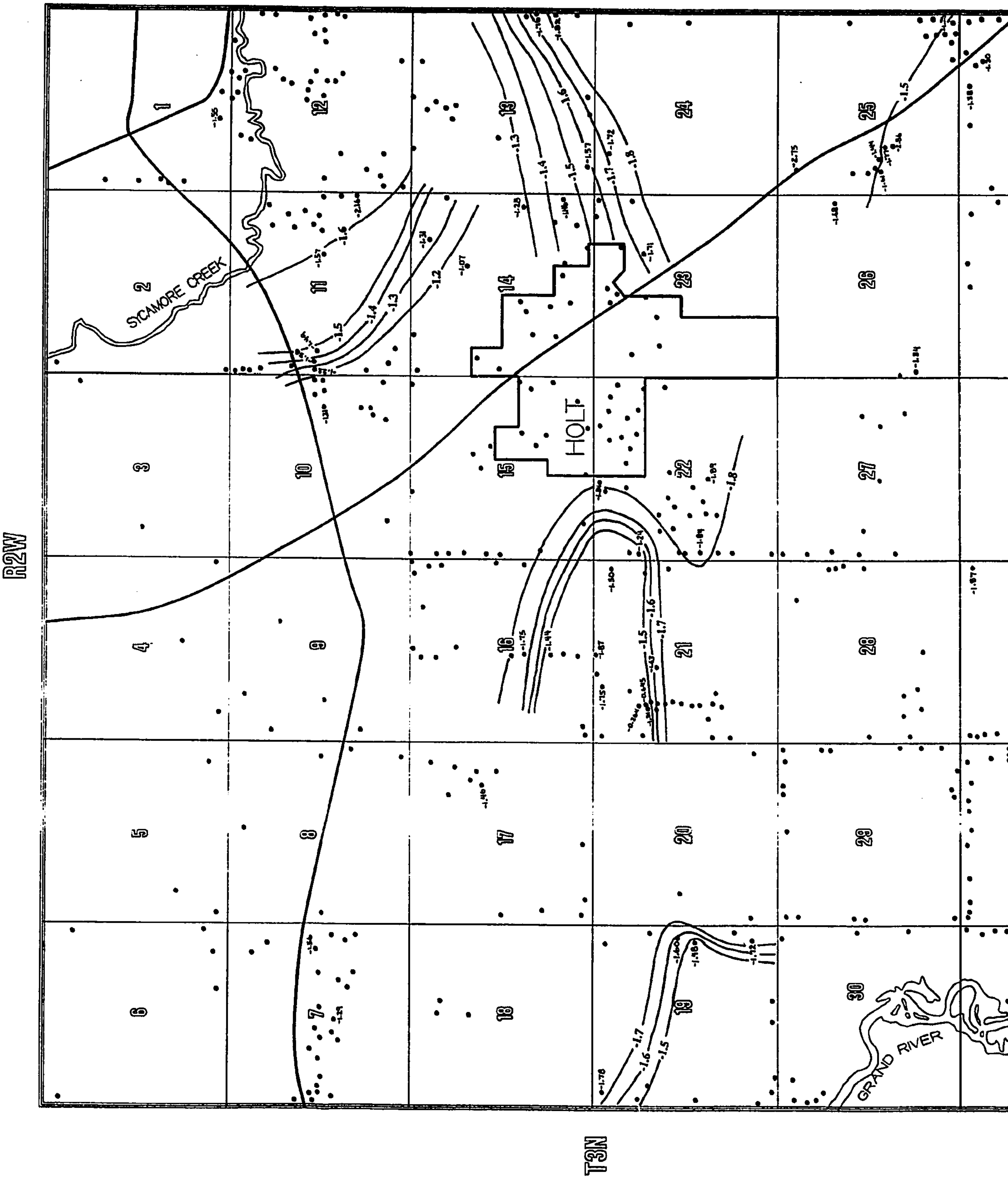


PLATE 7 **SI Dolomite Distribution Map**

Contour Interval: 0.10


R2W
T3N
SYCAMORE CREEK
HOLT
GRAND RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
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29
30
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8

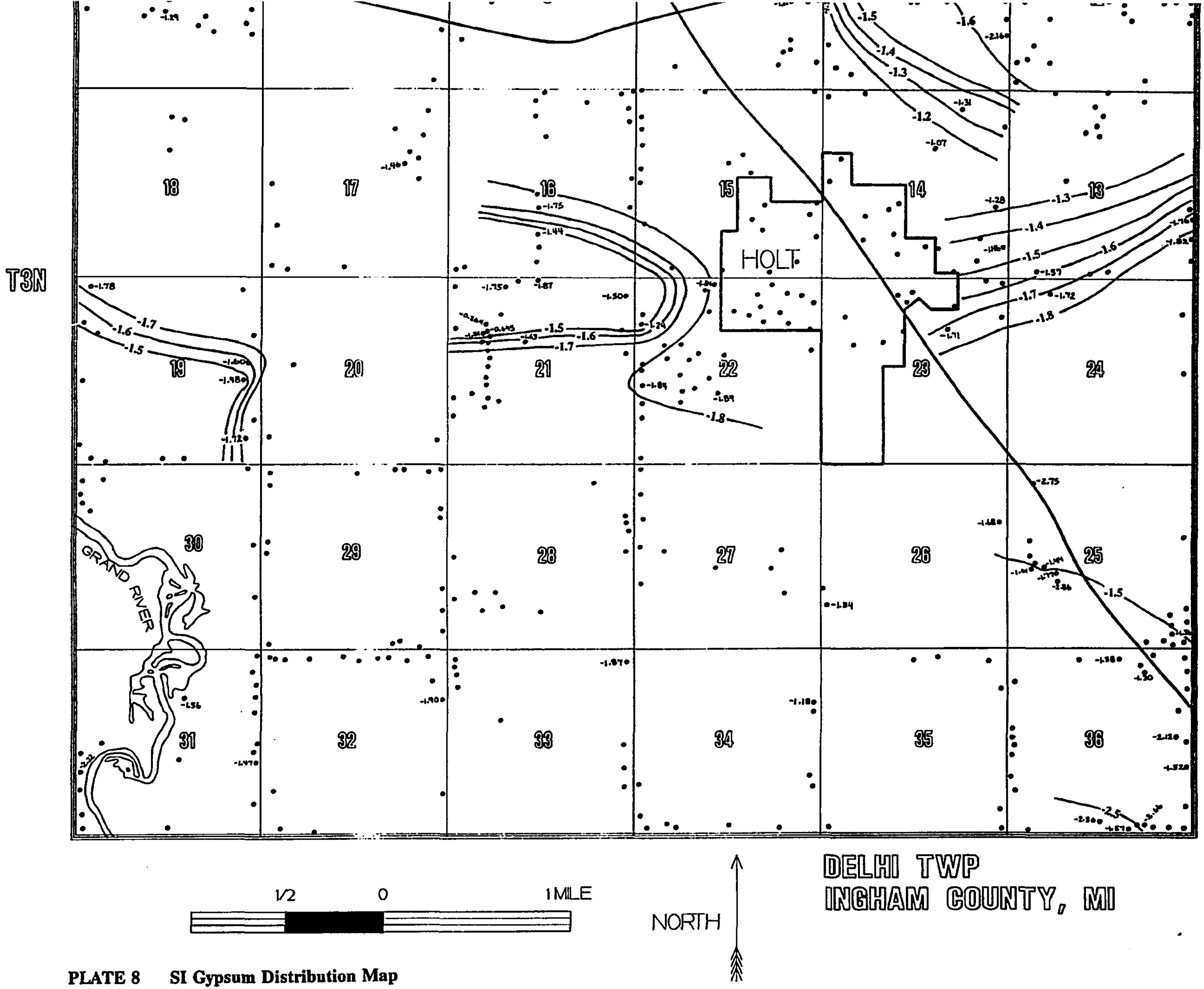
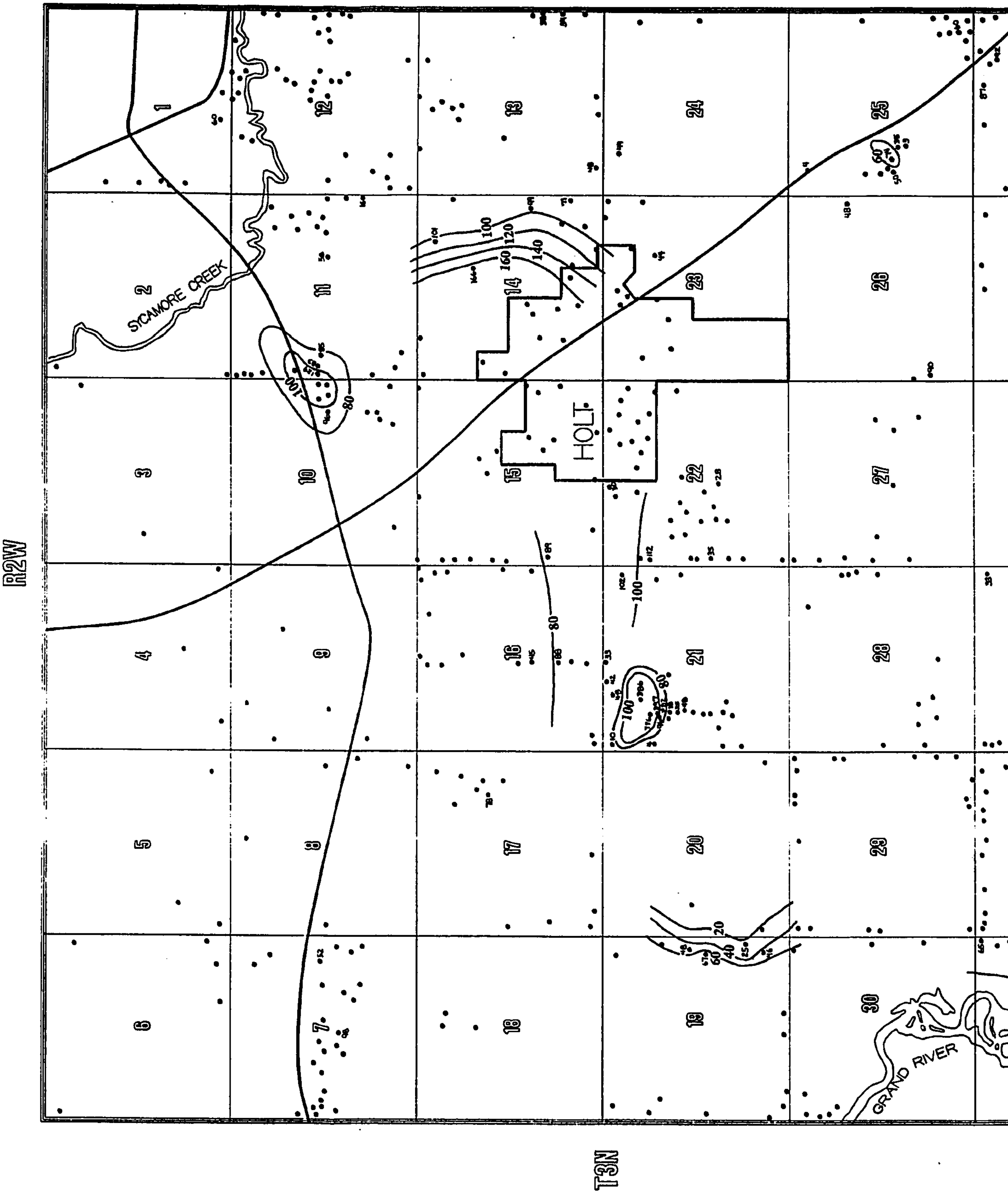


PLATE 8 SI Gypsum Distribution Map

Contour Interval: 0.10


R2W
T3N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
SYCAMORE CREEK
HOLT
GRAND RIVER
100
120
140
160
80
100
80
100
80
100
60
20
40
60

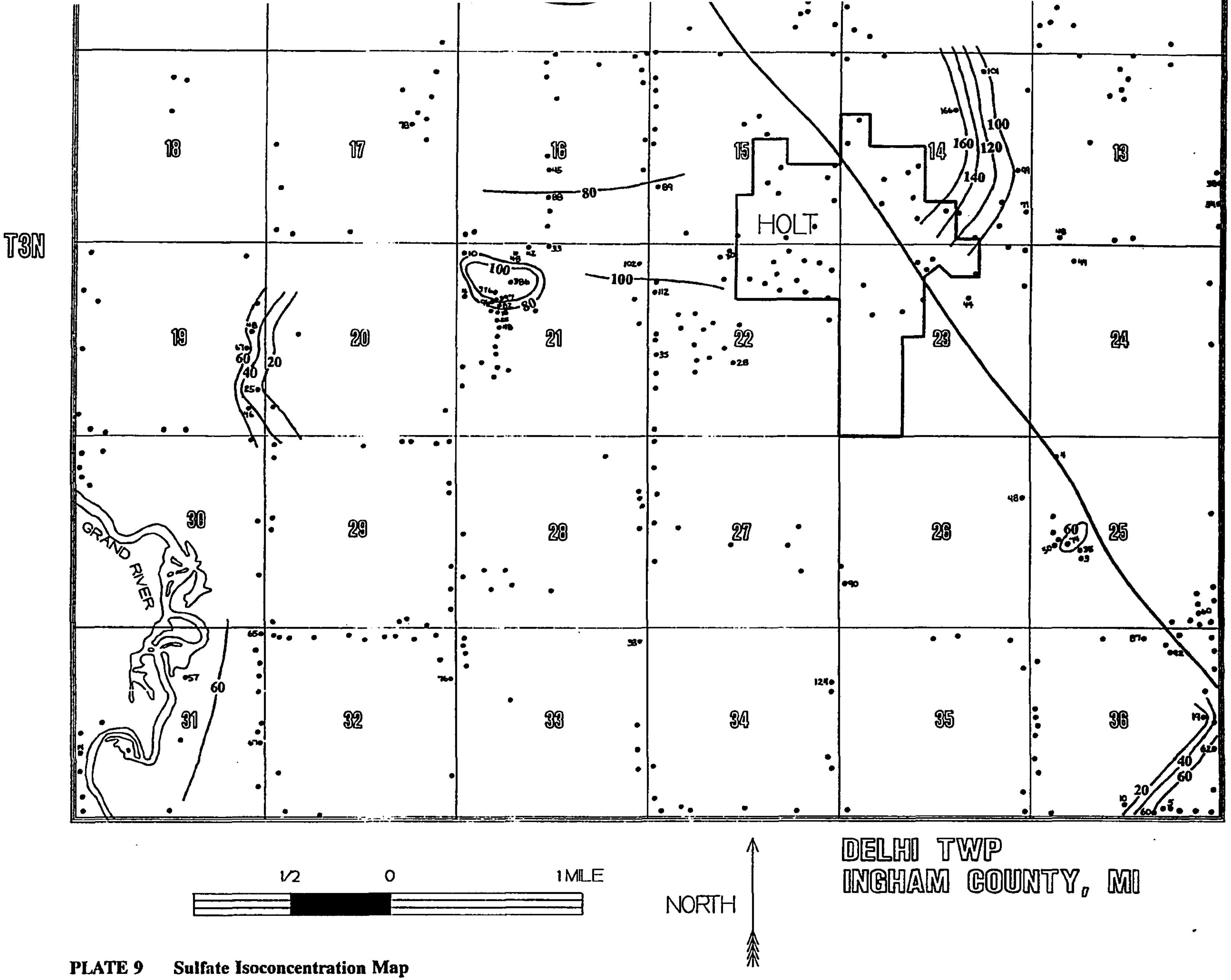
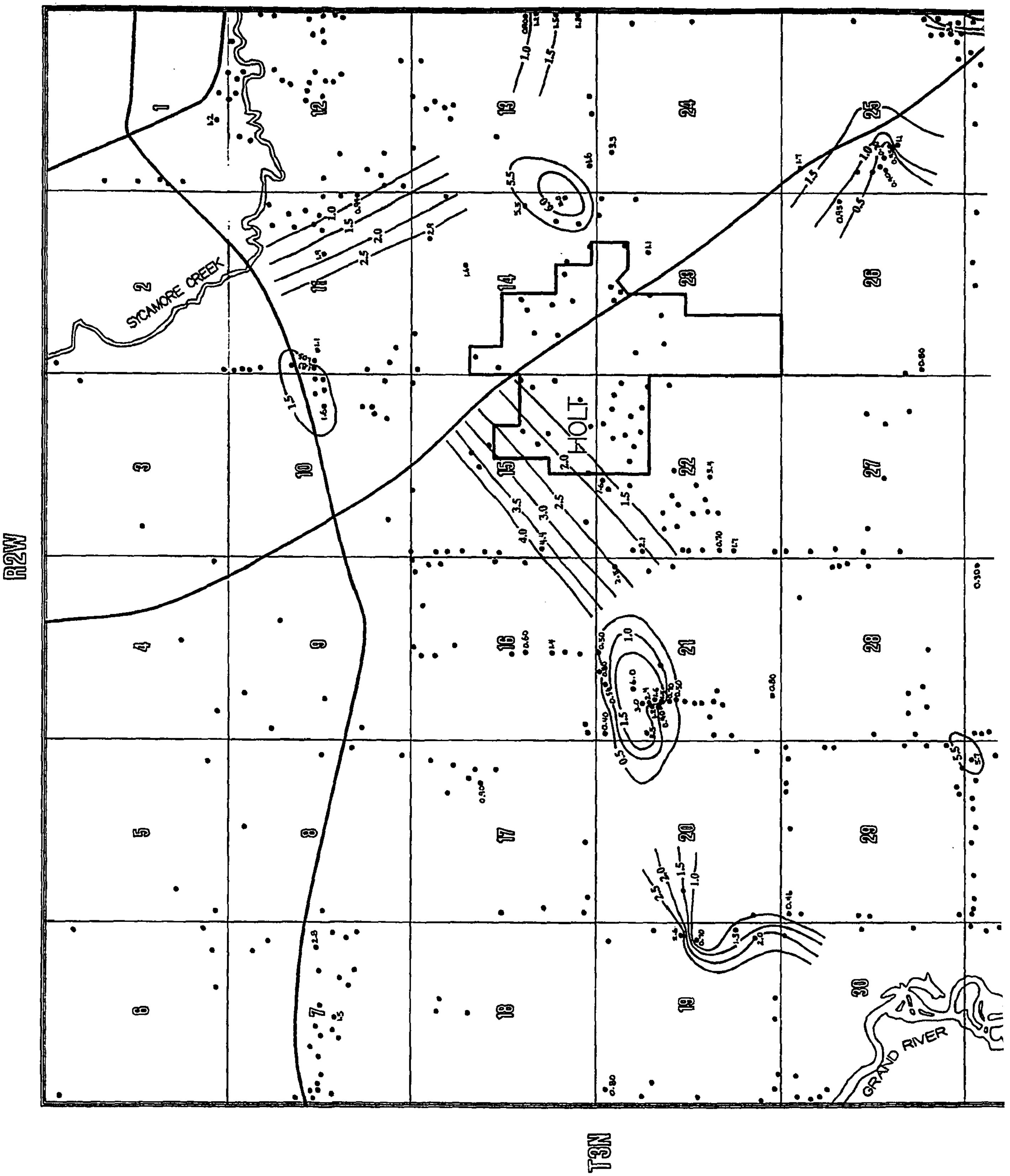


PLATE 9 Sulfate Isoconcentration Map

Contour Interval: 20 ppm


R2W
T3N
SYCAMORE CREEK
GRAND RIVER
HOLT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
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28
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1.0
1.5
2.0
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3.0
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4.0
5.5
6.0

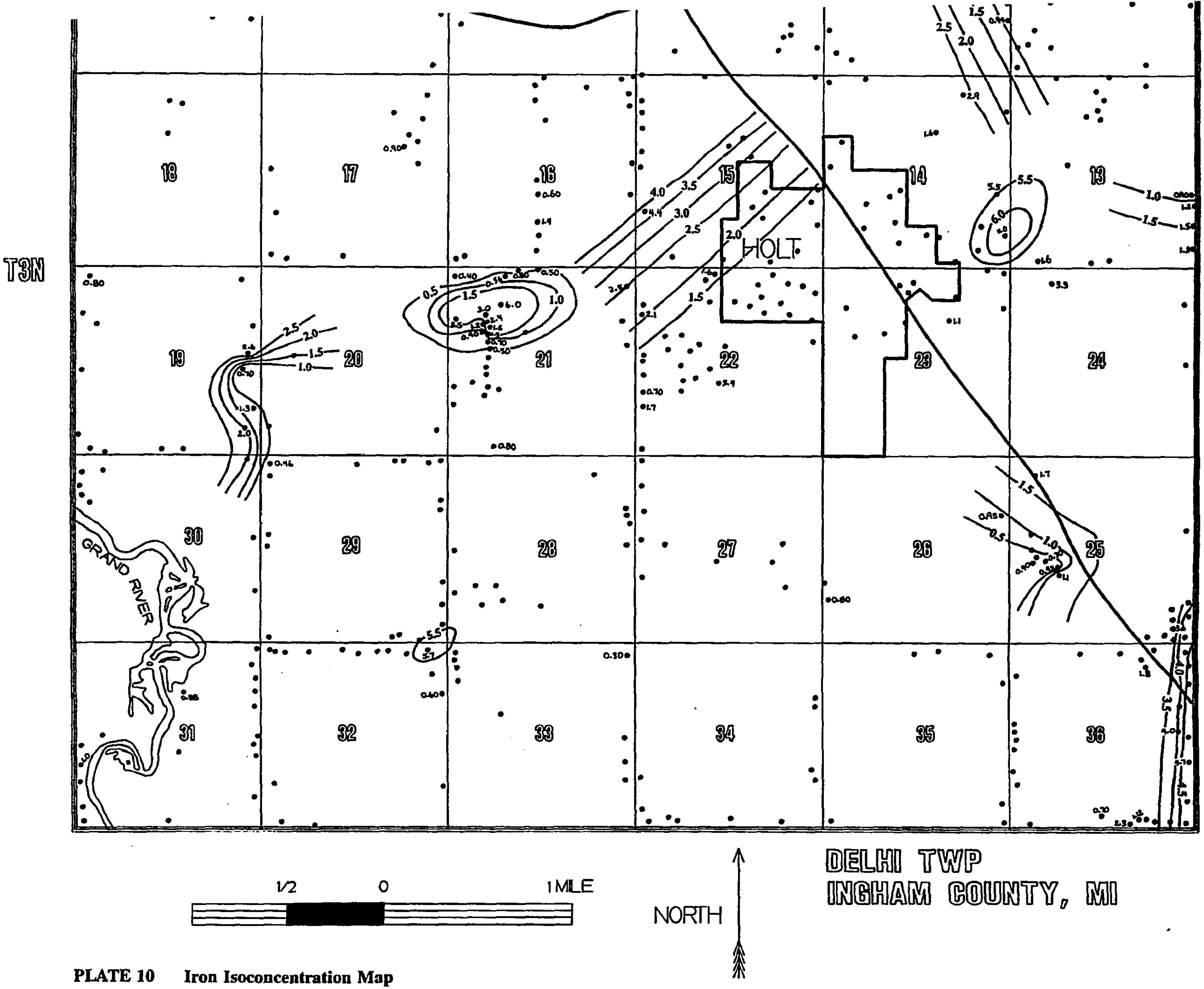
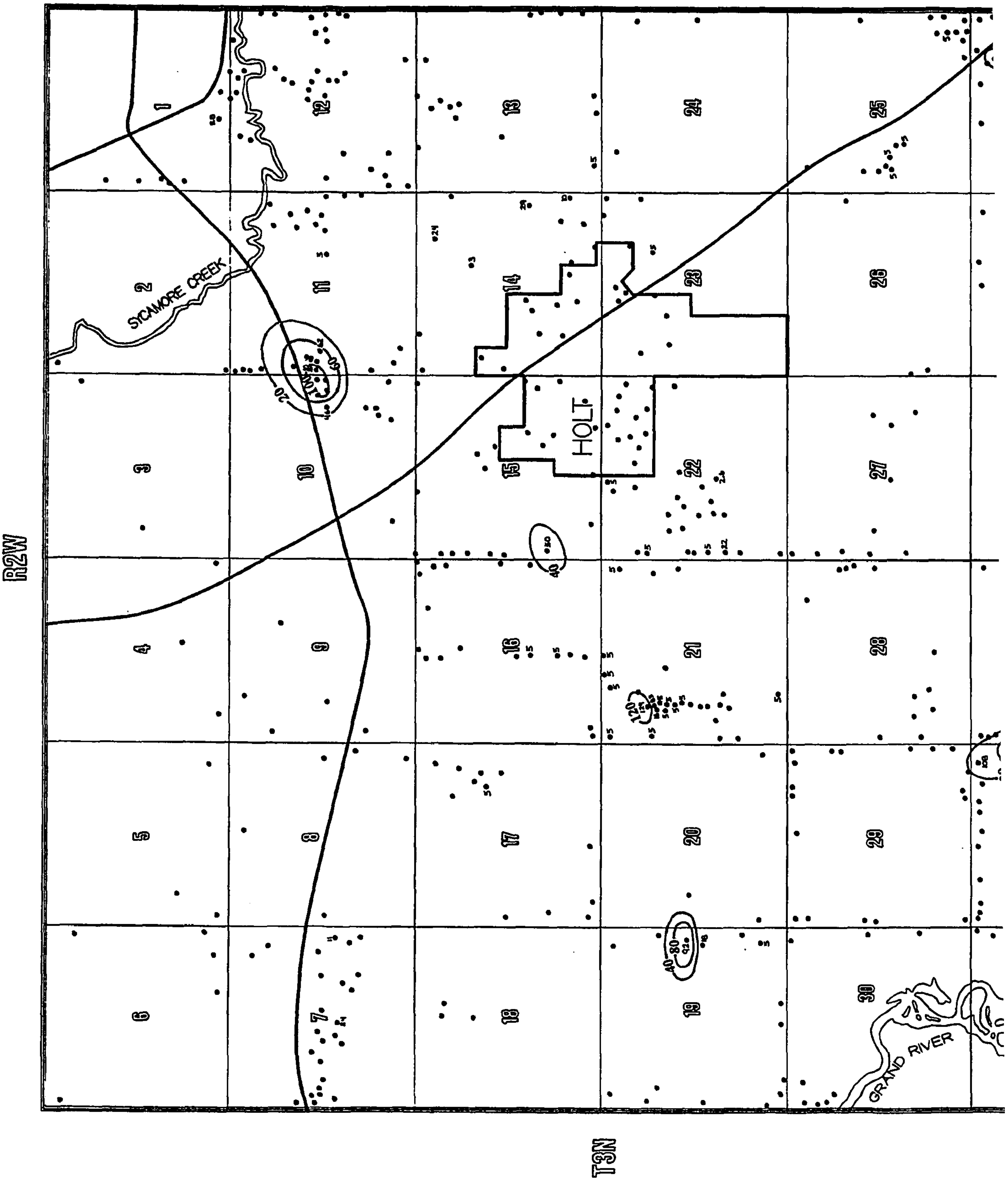


PLATE 10 **Iron Isoconcentration Map**

Contour Interval: 0.5 ppm


R2W
T3N
SYCAMORE CREEK
HOLT
GRAND RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
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29
30
20
40
80
120

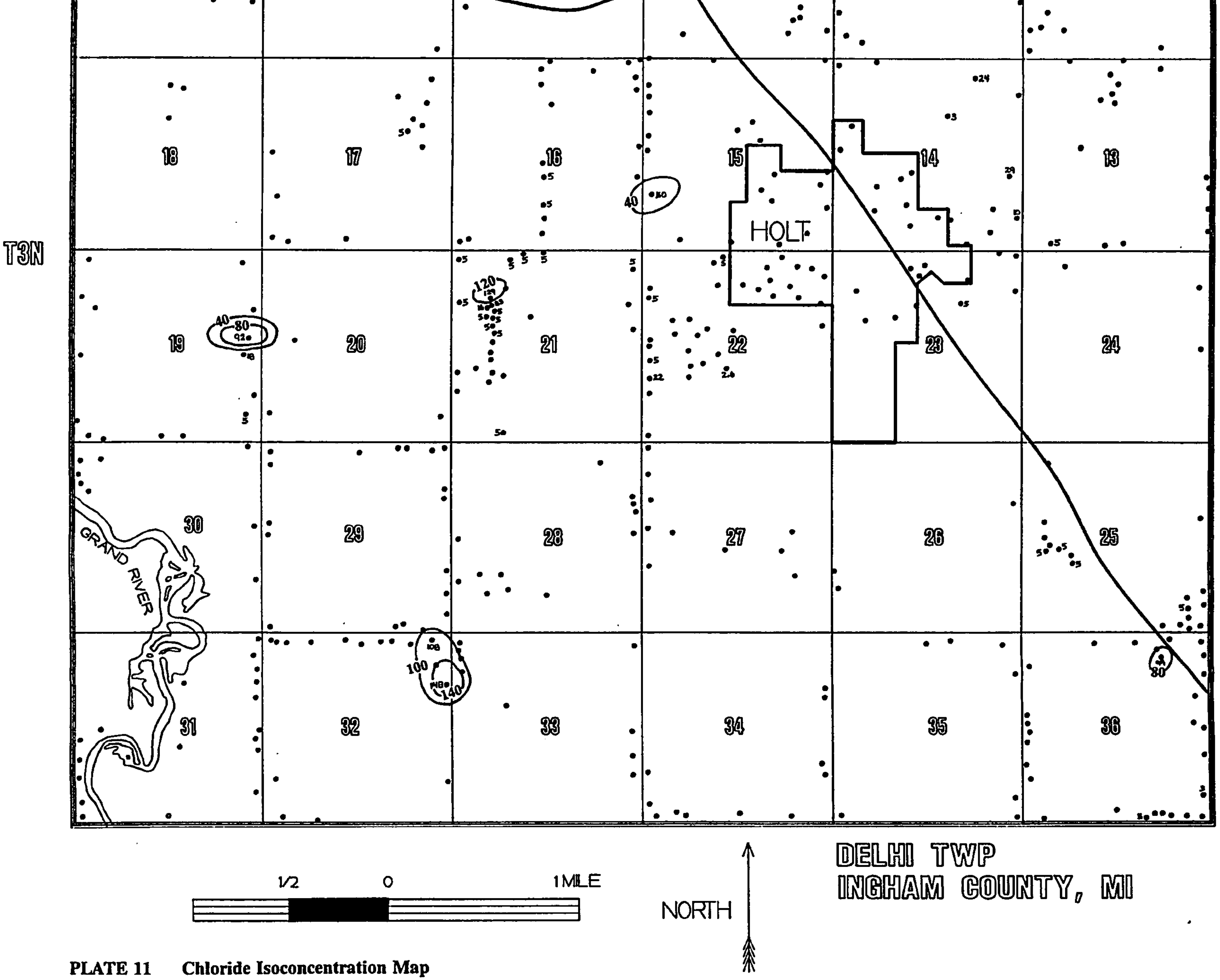
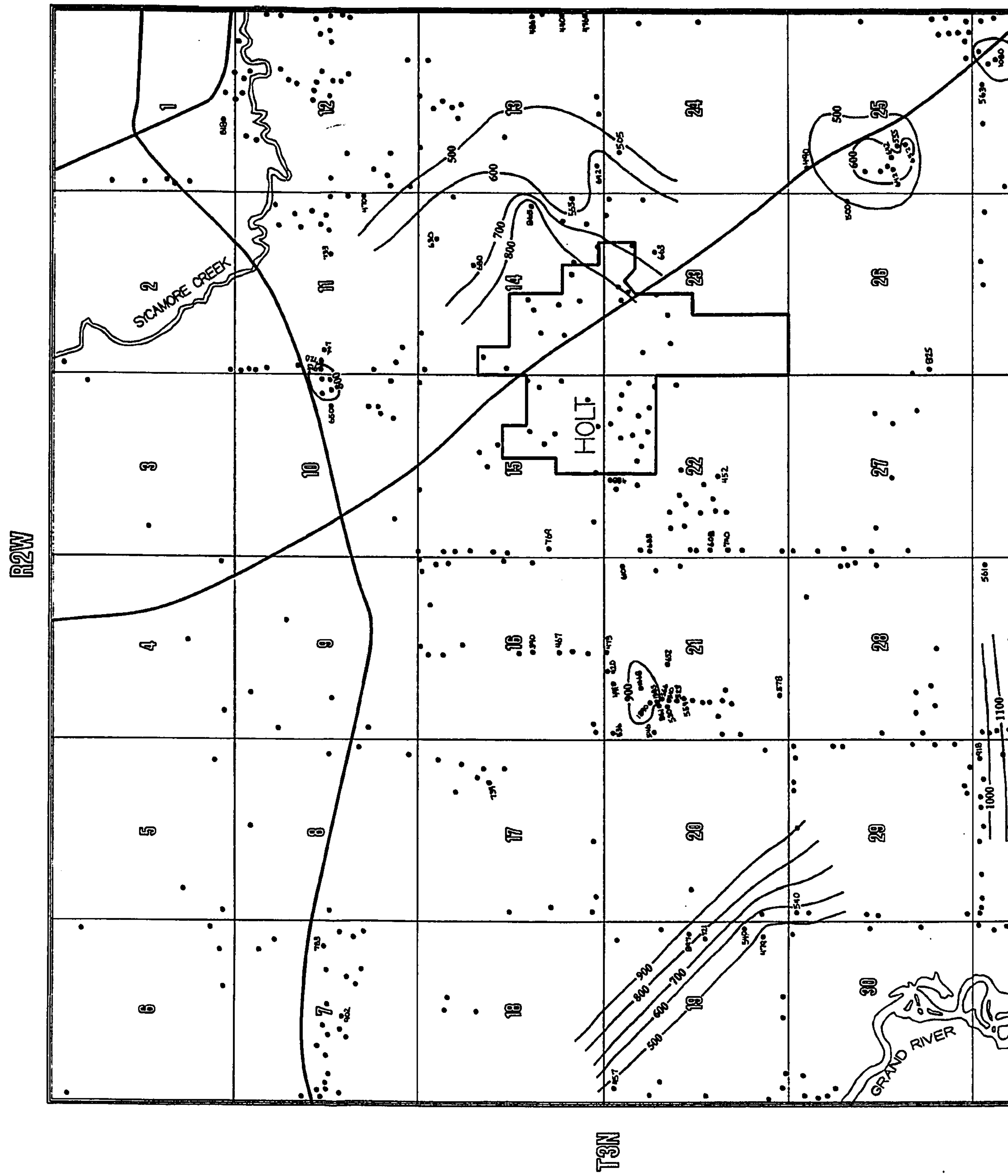


PLATE 11 Chloride Isoconcentration Map

Contour Interval: 40 ppm


R2W
T3N
1
2
3
4
5
6
7
8
9
10
11
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13
14
15
16
17
18
19
20
21
22
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HOLT
GRAND RIVER
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600
700
800
900
1000
1100

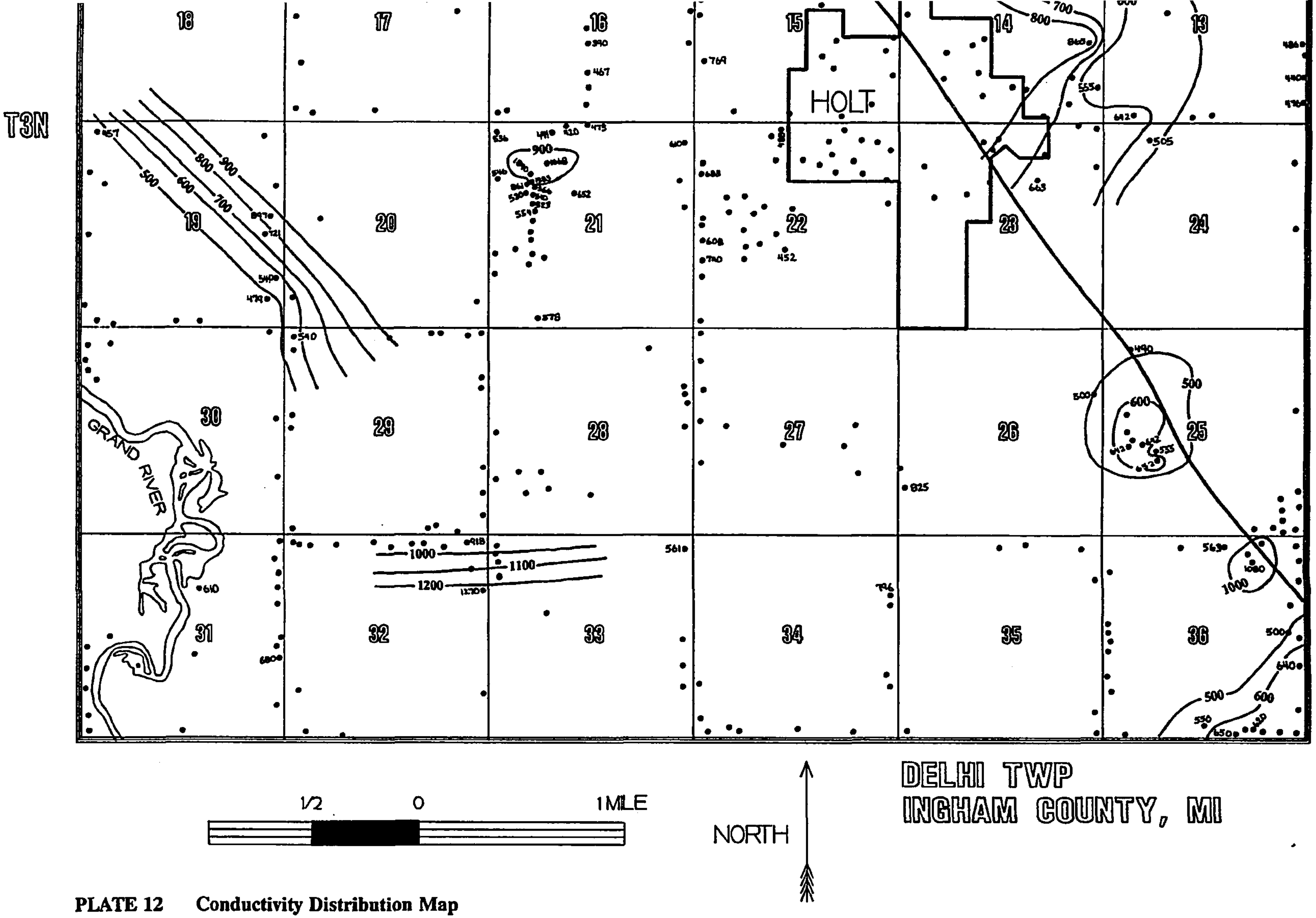
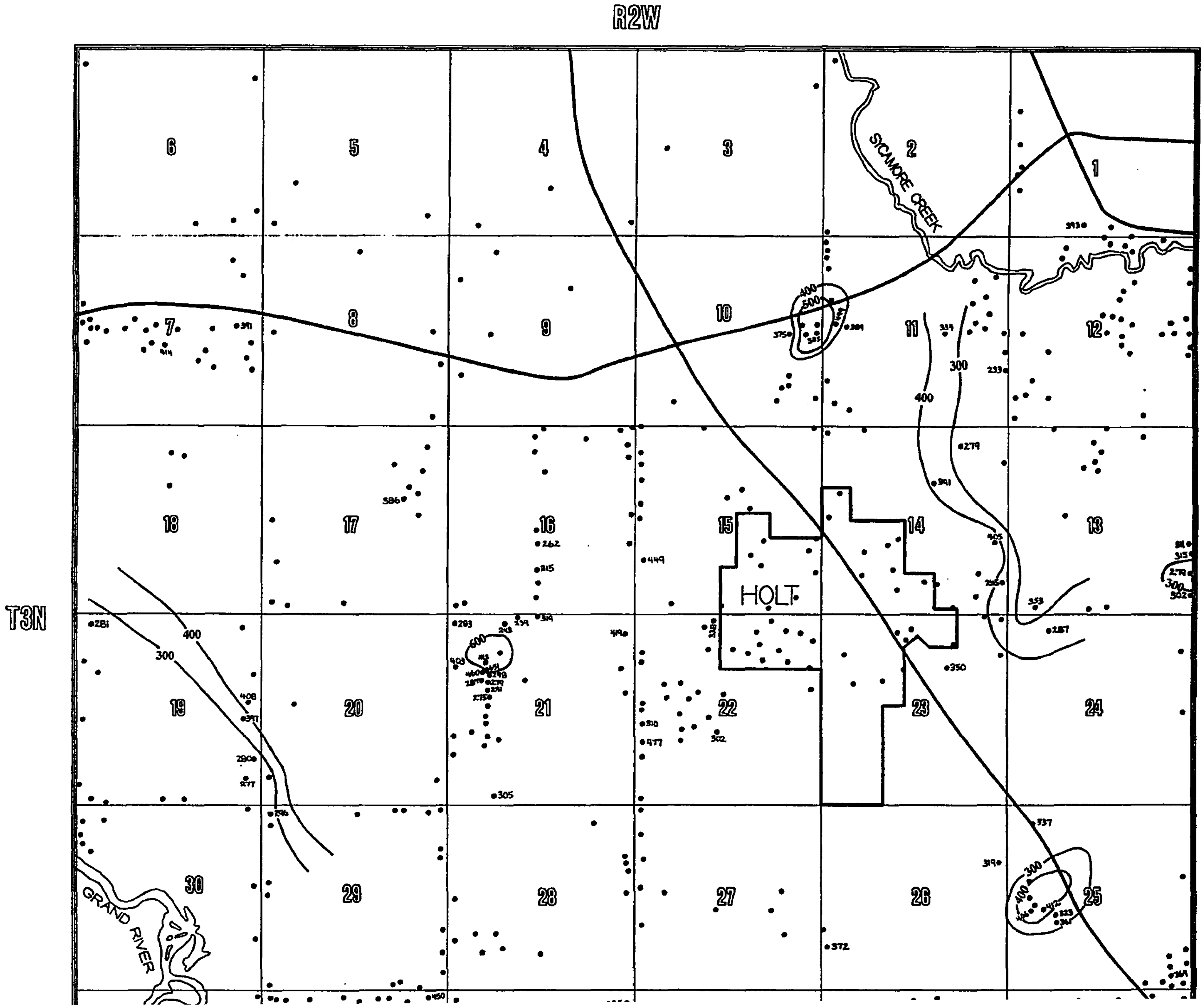


PLATE 12 **Conductivity Distribution Map**

Contour Interval: 100 mmhos


R2W
T3N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
SYCAMORE CREEK
GRAND RIVER
HOLT
300
400
500
600

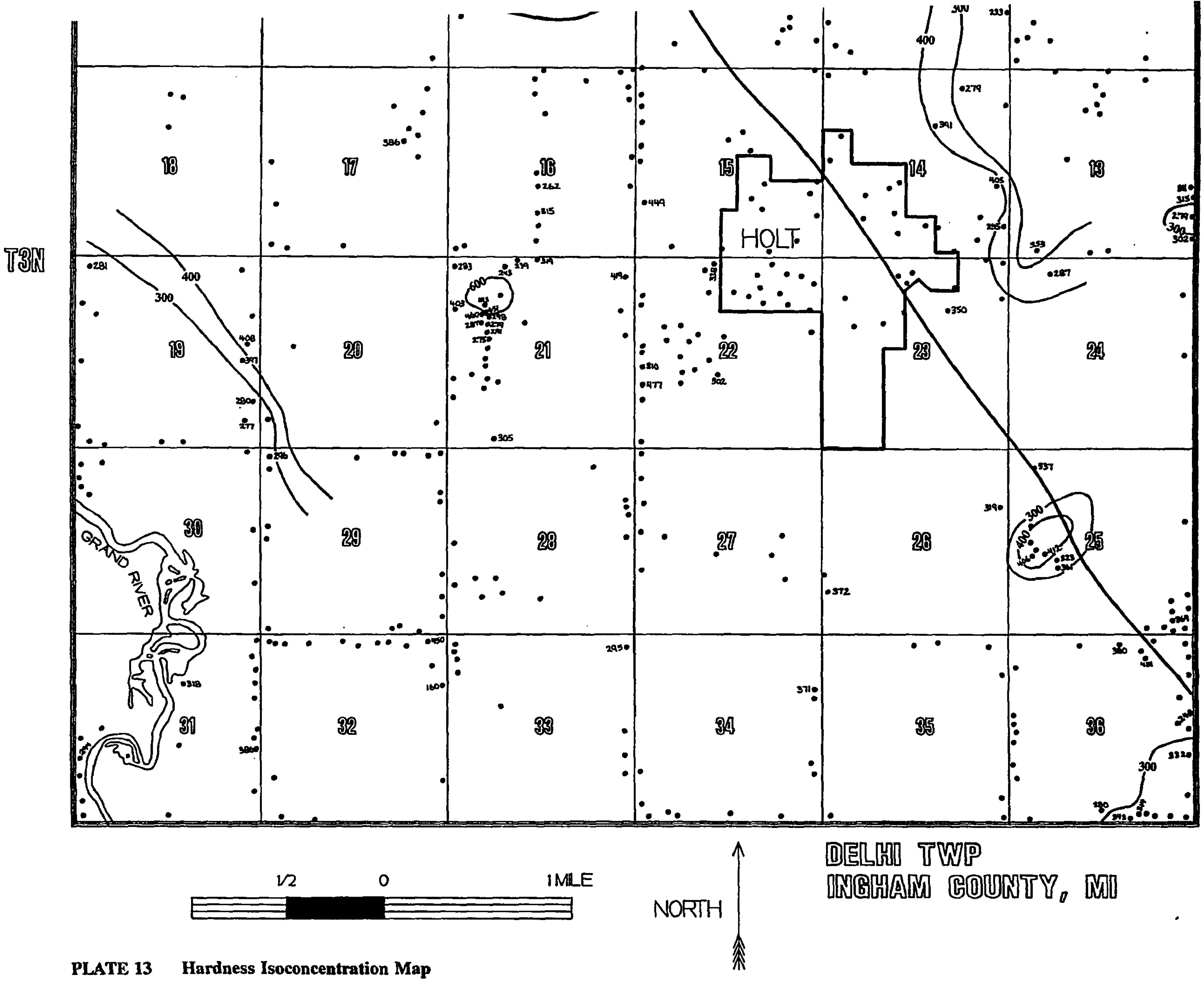
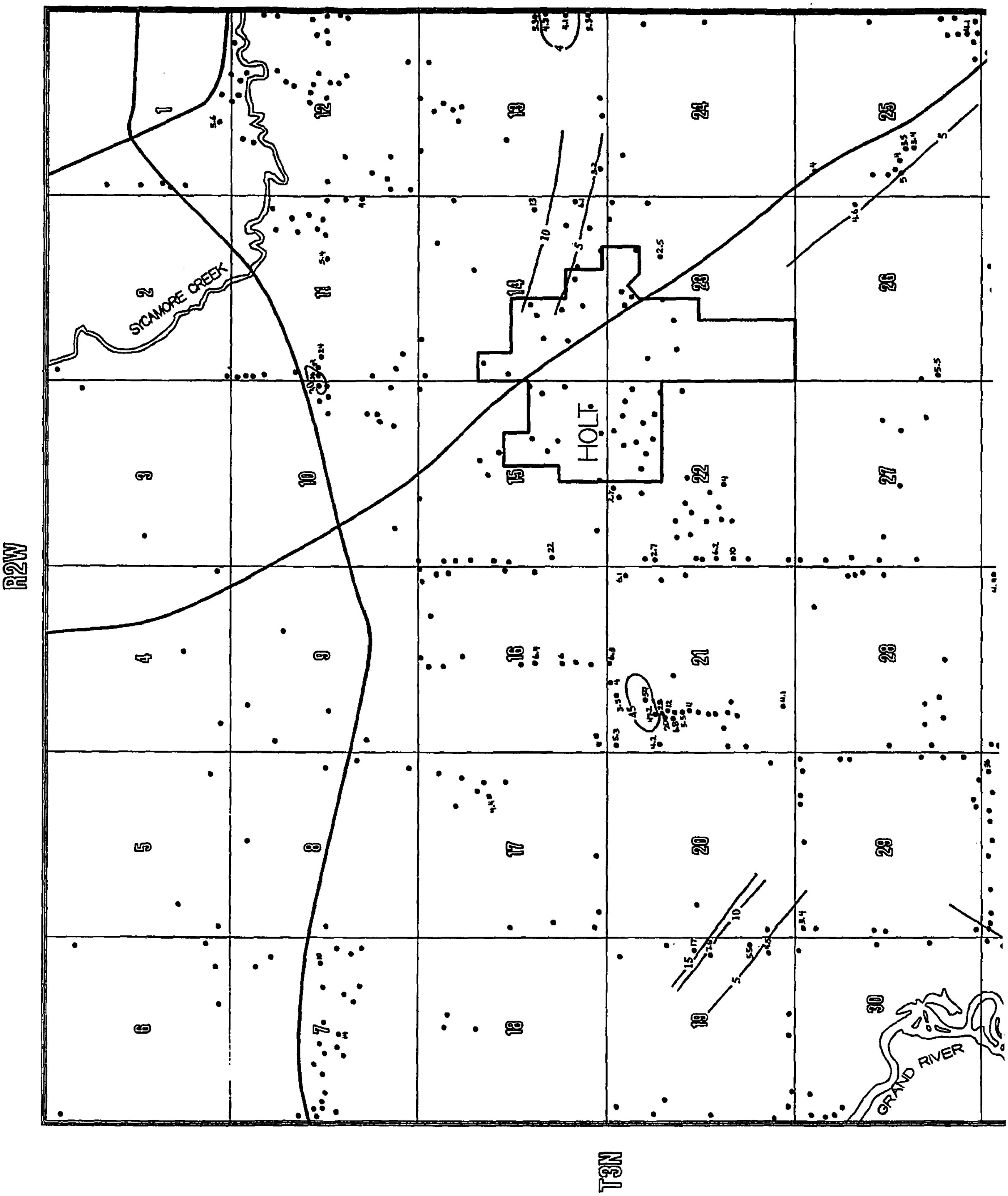


PLATE 13 Hardness Isoconcentration Map

Contour Interval: 100 ppm


R2W
T3N
SYCAMORE CREEK
HOLT
GRAND RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
10
5
15

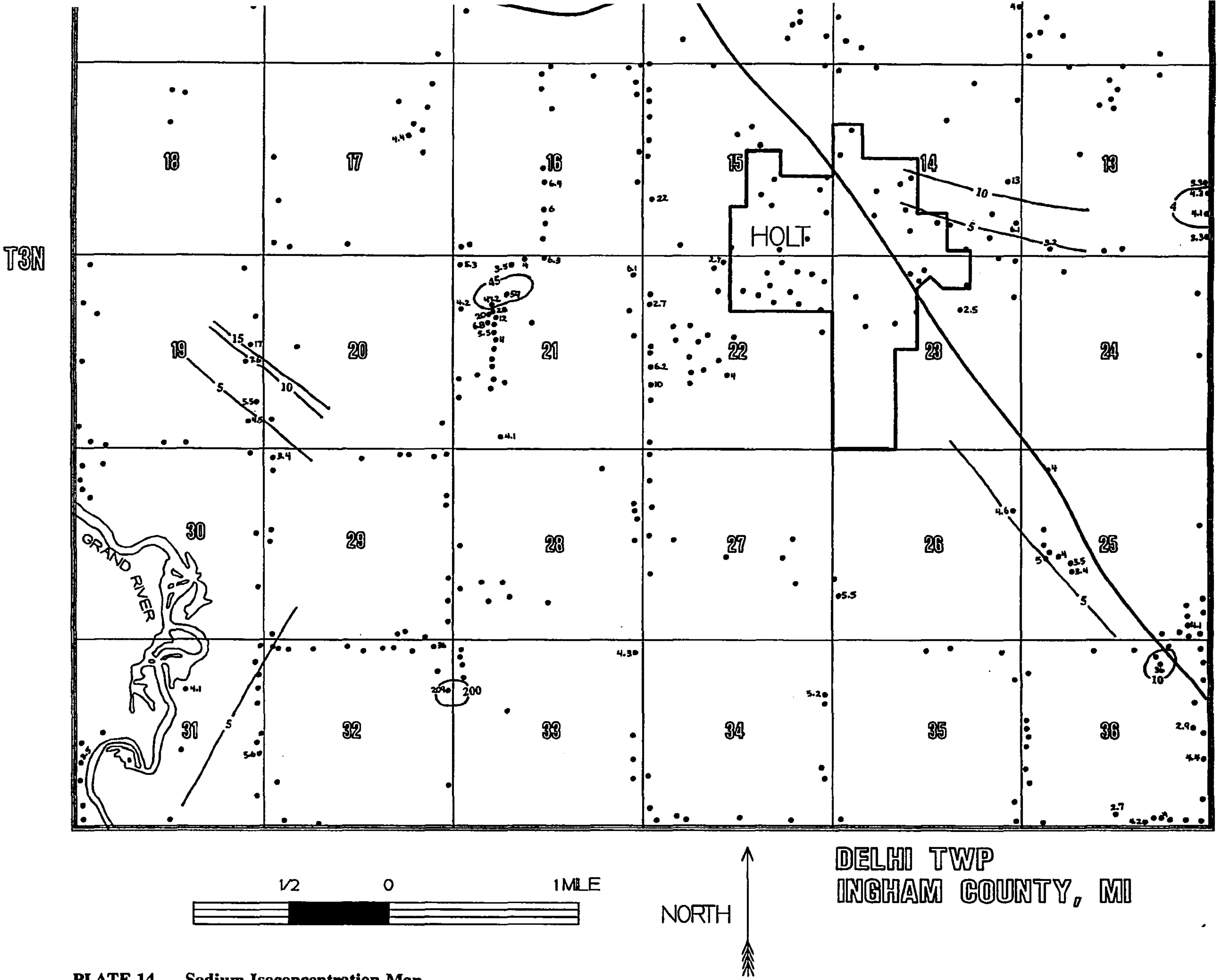
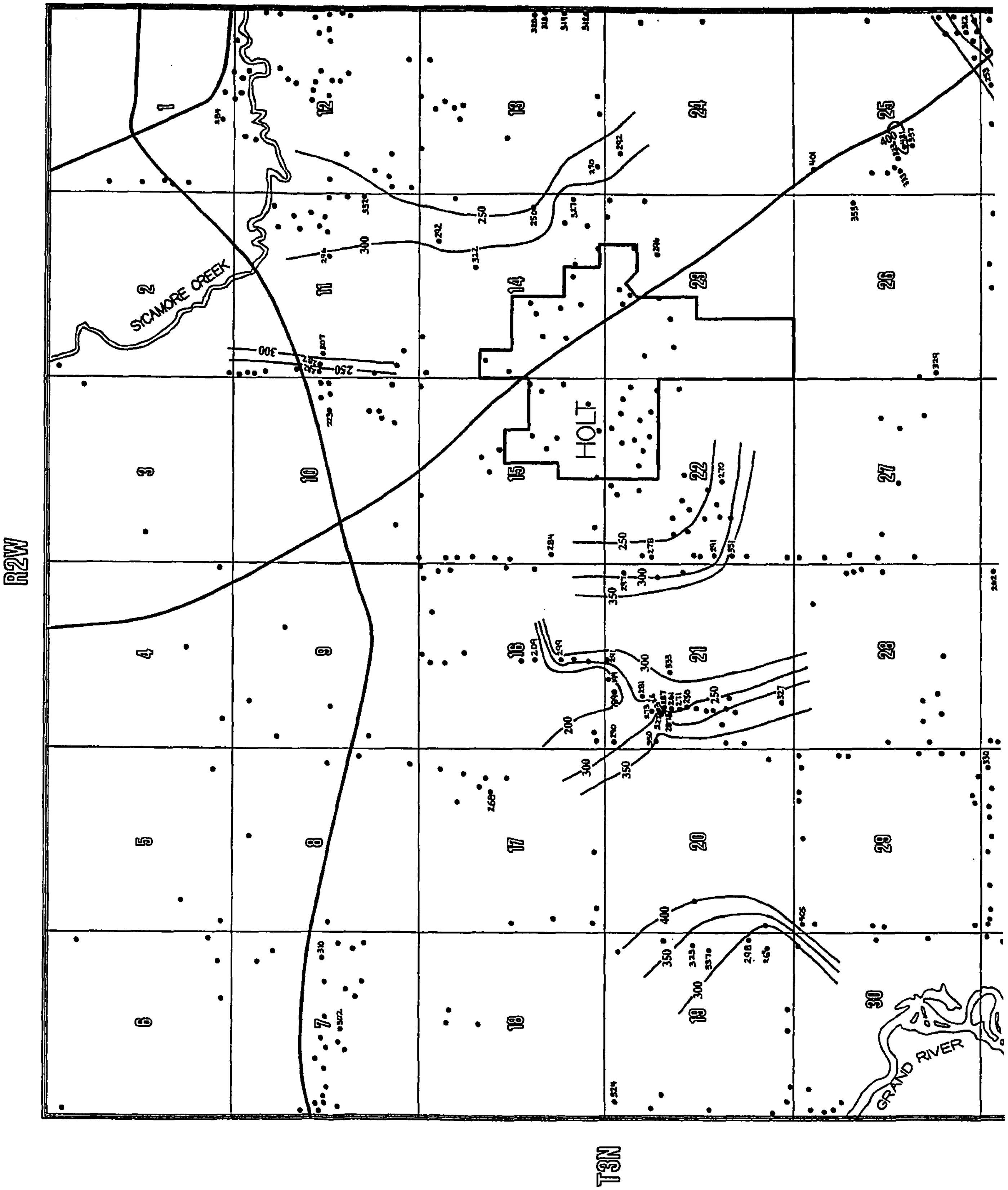


PLATE 14 Sodium Isoconcentration Map

Contour Interval: 5.0 ppm

R2W
T3N
SYCAMORE CREEK
HOLT
GRAND RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
200
250
300
350
400

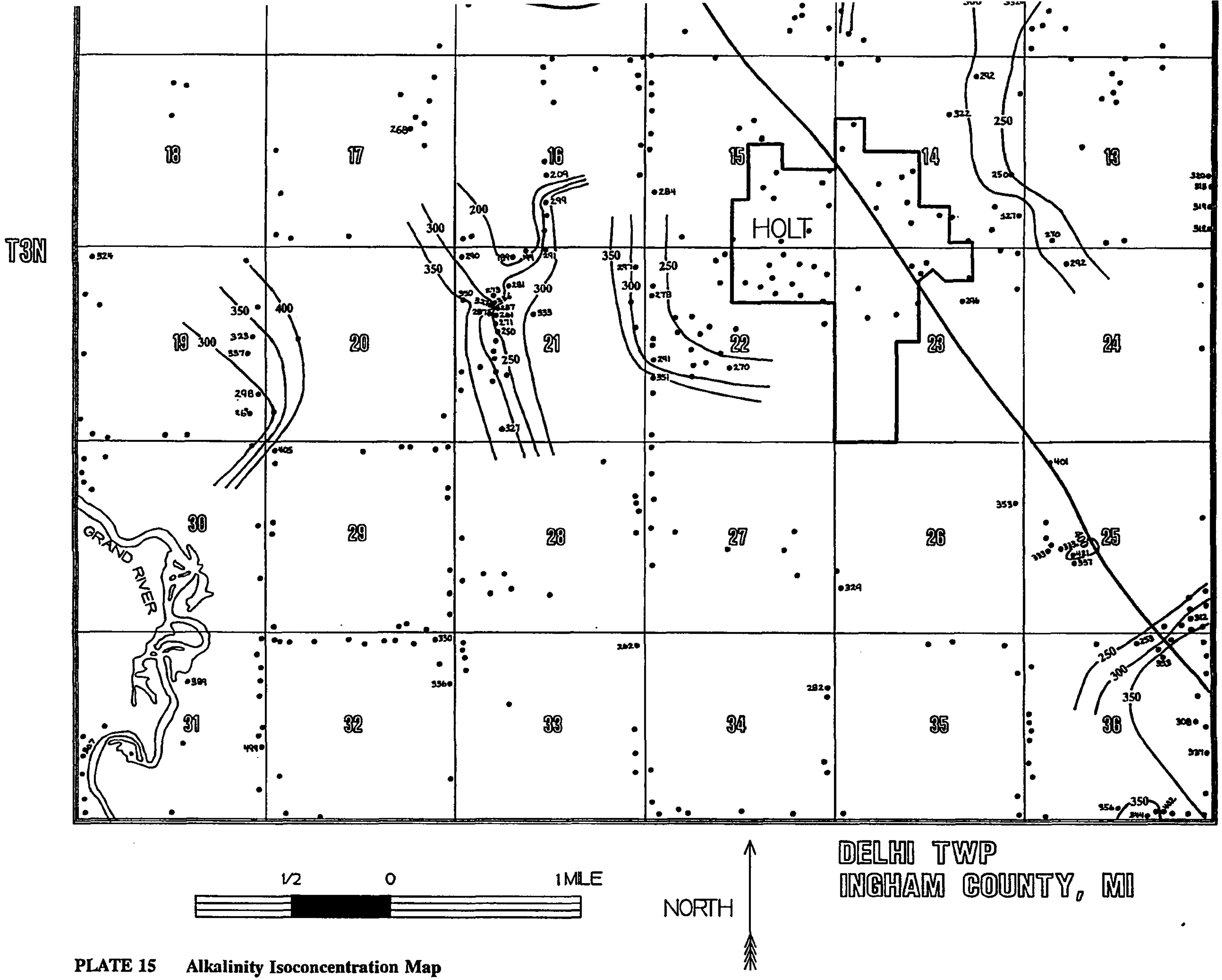
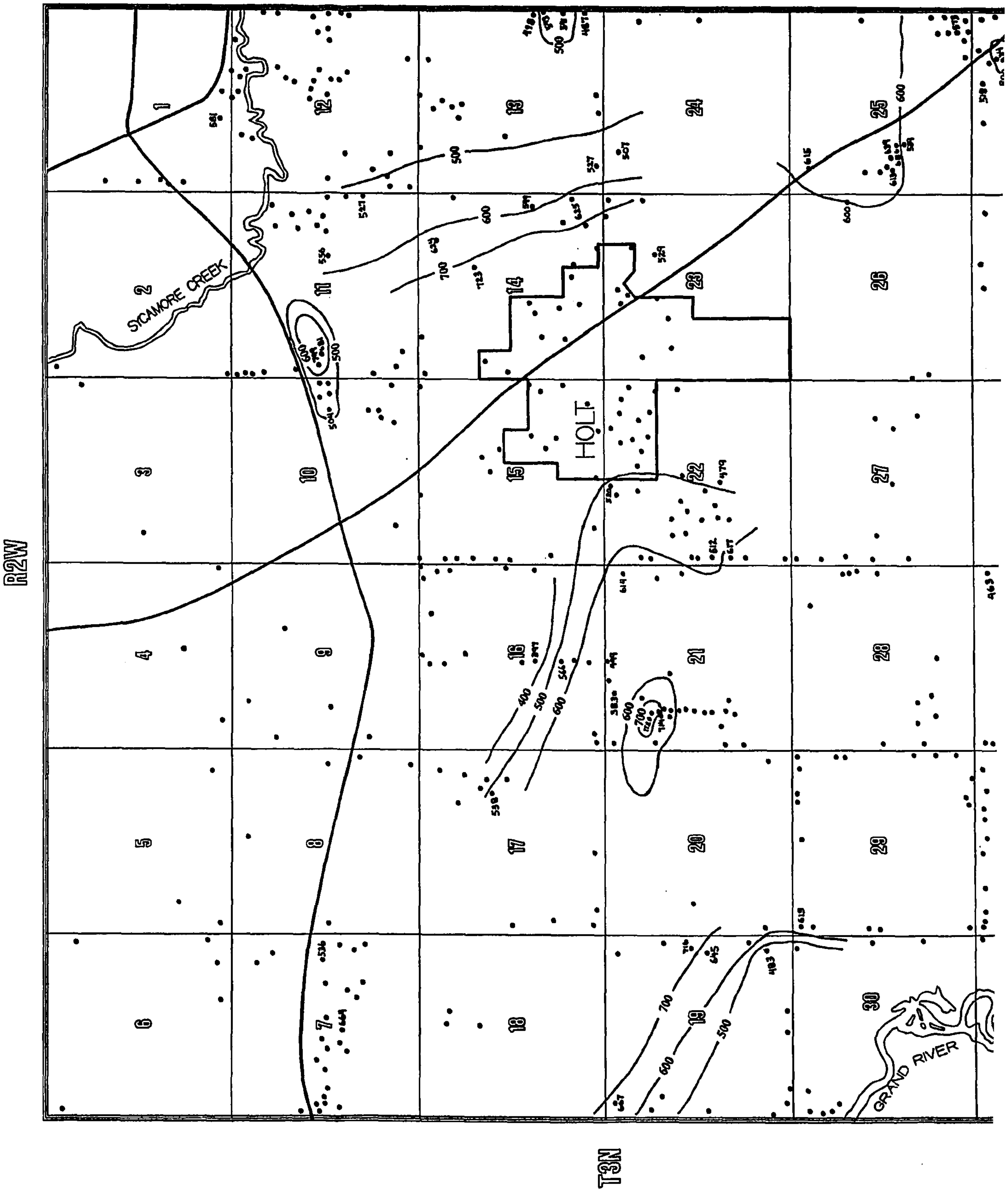


PLATE 15 **Alkalinity Isoconcentration Map**

Contour Interval: 50 ppm


R2W
T3N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
SYCAMORE CREEK
HOLT
GRAND RIVER
400
500
600
700

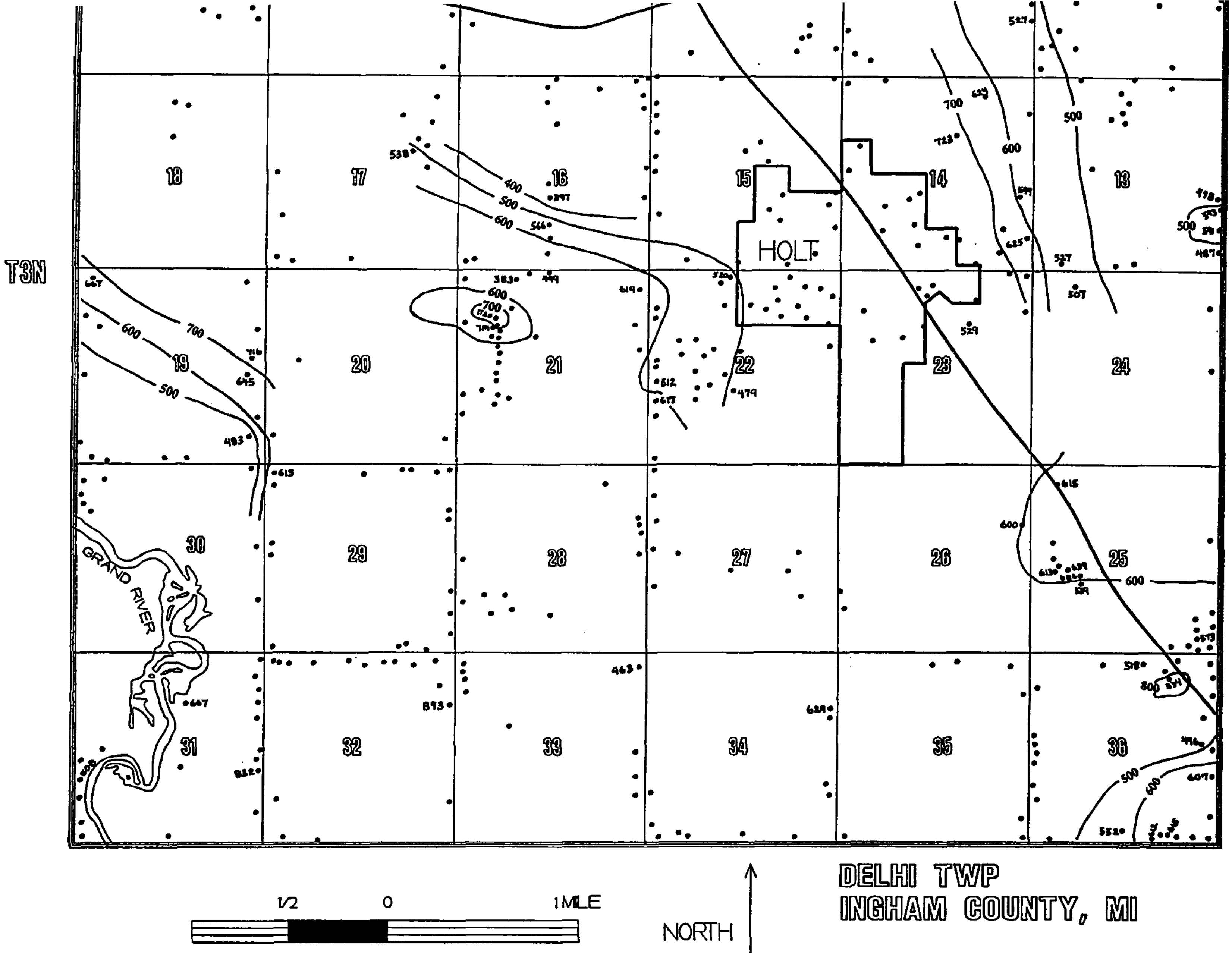
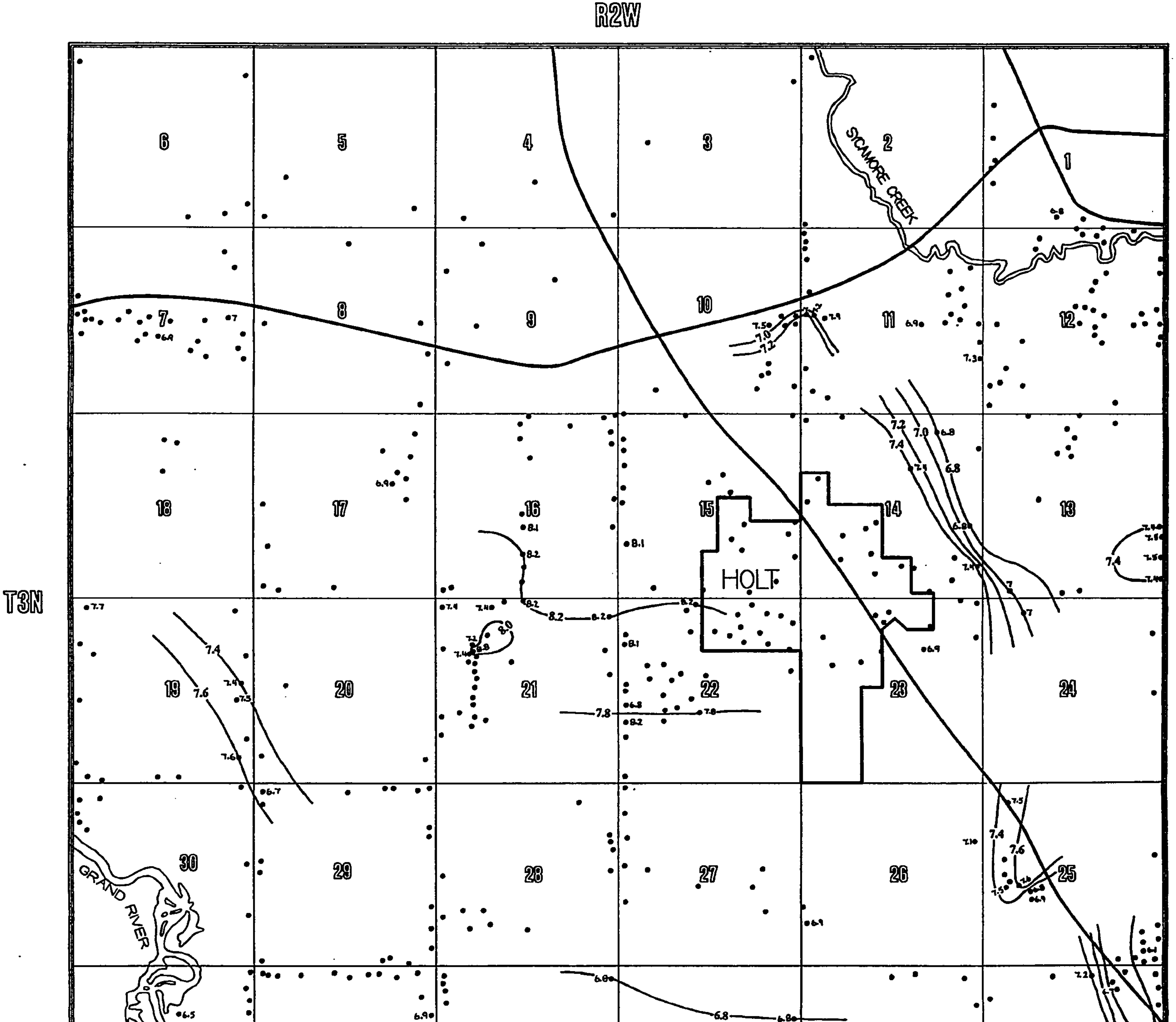


PLATE 16 Total Dissolved Solids (TDS)

Contour Interval: 100 ppm


R2W
T3N
HOLT
SYCAMORE CREEK
GRAND RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
7.0
7.2
7.4
7.6
6.8
7.8
8.0
8.2
8.1
6.9
7.5
7.3
7.7
6.7
6.5

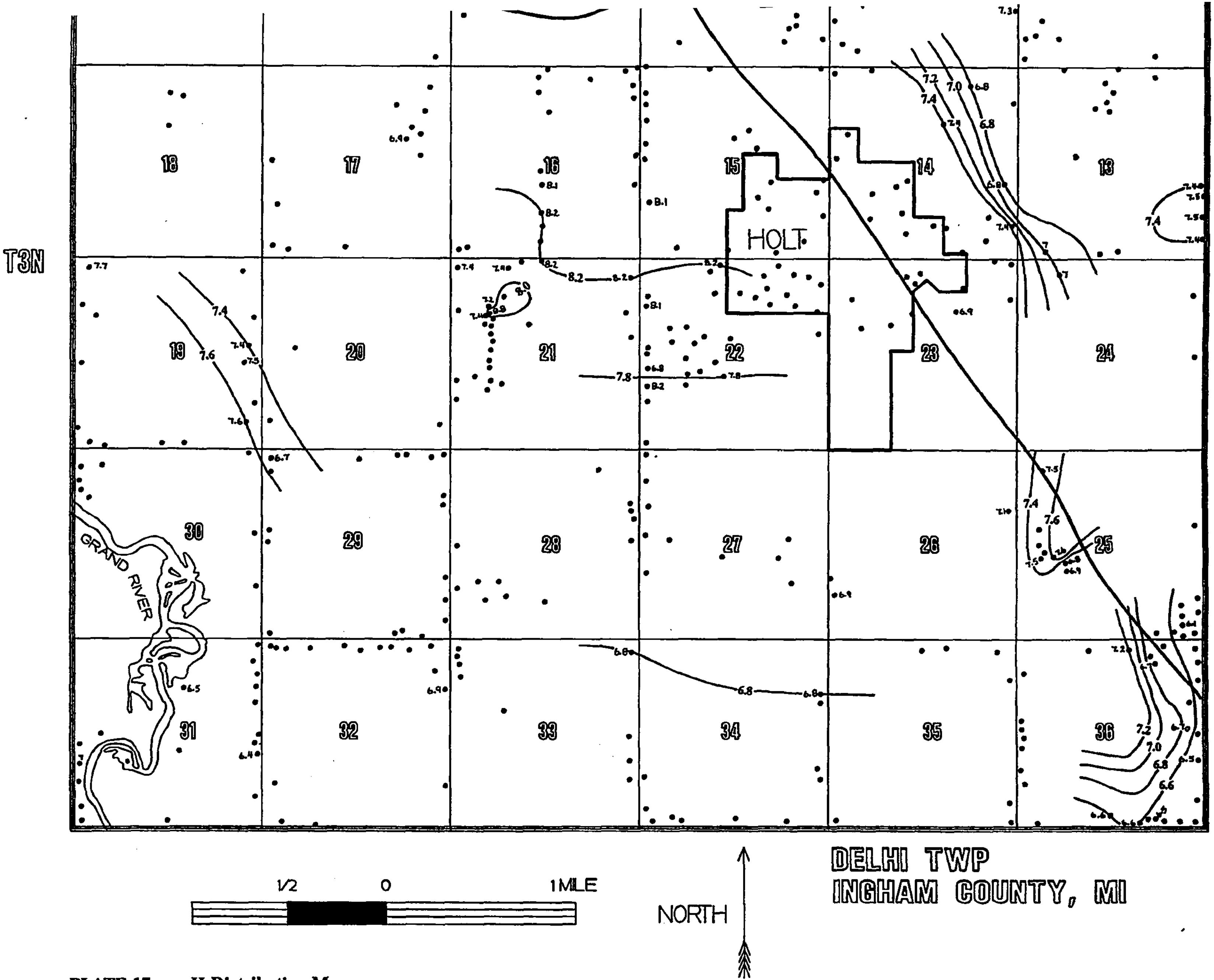


PLATE 17 pH Distribution Map

Contour Interval: 0.2 pH units