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FORMATION IN THE UPPER GRAND RIVER BASIN,  
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GEOCHEMISTRY OF GROUND WATER OF THE  
SAGINAW FORMATION IN THE UPPER  
GRAND RIVER BASIN, MICHIGAN

By

Warren W. Wood

A THESIS

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Michigan State University  
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## ABSTRACT

### GEOCHEMISTRY OF GROUND WATER OF THE SAGINAW FORMATION IN THE UPPER GRAND RIVER BASIN, MICHIGAN

By

Warren W. Wood

The Saginaw Formation of Pennsylvanian age serves as a potable water aquifer over 2,500 square miles in the Grand River basin, Michigan. This formation of sandstone, shale, limestone and coal is overlain in most of the basin by several hundred feet of glacial material of Pleistocene age. The ground water hydrology of the system is one of recharge by local precipitation through the overlying glacial drift.

Dissolved solids in the ground water of the Saginaw Formation are evaluated as to the most important source. Glacial drift and soils are found to contribute more dissolved solids to the ground water of the Saginaw Formation than atmospheric precipitation, migration of water from other formations, or solution of minerals from the Saginaw Formation.

Sodium is the only major chemical constituent that exhibited a coherent concentration distribution within the Saginaw Formation. Other constituents failed to yield

concentration trends. Dissolved solids within the Saginaw Formation were found to be lower than that of the recharging water of the glacial drift. Zones of high concentration of dissolved solids are found locally in the overlying glacial drift through which the recharge to the Saginaw Formation passes. Anion exchange, mineral precipitation, ultrafiltration, fossil water and selected recharge areas were considered in explaining the difference in dissolved solids between the Saginaw Formation and the overlying glacial drift. It is hypothesized, that by a process of reverse osmosis and ultrafiltration shale members of the Saginaw Formation filter out certain ions. This hypothesis explains many factors associated with the distribution of dissolved solids.

Equilibrium calculations were performed using the common carbonates, sulfate and iron minerals. Siderite was found to be the iron mineral most likely in equilibrium with the ground water. Carbonates of calcite and dolomite were, in general, in equilibrium with the ground water while the sulfates of gypsum and anhydrite were greatly undersaturated.

## ACKNOWLEDGMENTS

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I wish also to thank members of my thesis guidance committee, Drs. Robert Ehrlich, William Hinze, Harold Stonehouse and James Trow, who critically reviewed the manuscript. Thanks also go to Mr. Gary C. Huffman of the U. S. Geological Survey who wrote the computer program for the statistical analyses used in this study and the National Science Foundation who provided one-half hour of computer time.

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## INTRODUCTION

### Purpose and Scope

This thesis describes the distribution, source and mineral equilibria of the major chemical constituents in water of the Saginaw Formation in the Upper Grand River basin of Michigan. This study is an attempt to integrate the major dissolved constituents of ground water with the geology and flow system of a major aquifer system. The ultimate purpose of this thesis is to describe the manner in which the geochemical system functions within the aquifer system. Information of this type is essential to understanding the physical hydrology and utility of the aquifer.

The Saginaw Formation in the Upper Grand River basin was selected for this hydrogeochemical study because the geology and hydrology are relatively well known. Additionally, there are numerous wells tapping the aquifer which are suitable for water quality sampling, and at least one major outcrop area exists for the collection of rock samples.

The area of investigation is near the center of the Lower Peninsula of Michigan (Figure 1). It comprises all of Clinton and Ingham Counties and parts of Eaton, Livingston, Ionia, Gratiot, Montcalm, and Shiawassee Counties--

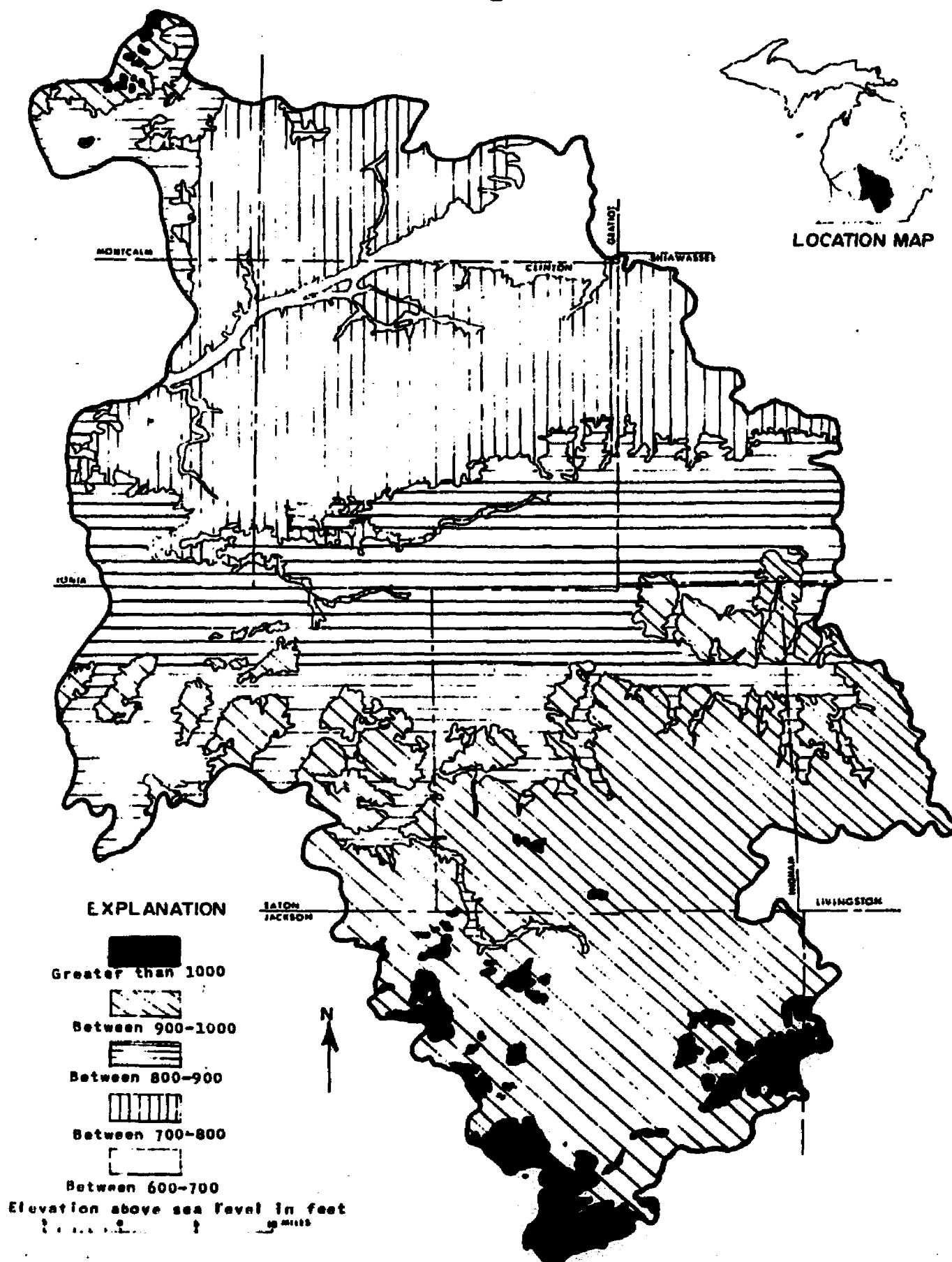


Figure 1.--Map showing generalized topography and location of the Grand River basin.

an area of about 3,000 square miles. The topography of the basin is given in Figure 1 and the stream network in Figure 6. The Saginaw Formation is utilized as an aquifer throughout its extent in the Upper Grand River basin. The aquifer is used most extensively in the Lansing Metropolitan area, where approximately 30 millions gallons per day (mgd) are presently being pumped (Giroux and Huffman, 1967). Total pumping from the aquifer in the study area, including industrial, agriculture, and domestic supplies is estimated at 45 mgd.

This thesis is concerned with only one aquifer of the many in the Michigan Basin. However, the aquifer system is typical of many in the glaciated north central United States and the relationships observed for this particular hydrologic system should have, with modification, application to other hydrologic systems.

#### Previous Studies

Geology and hydrology of the Saginaw Formation, in the Grand River basin, have been studied by many workers because of its importance as an aquifer in the Lansing Metropolitan area. Geology of the Saginaw Formation, including the area in the Upper Grand River basin has been described in detail by Kelly (1936). A study of the geology in the Lansing area was made by Mencenberg (1963). Hydrology of the Saginaw Formation in the Lansing area has been studied by Stuart (1945), Firouzian (1963), and

most recently by Wheeler (1967) and Vanlier and Wheeler (1968) by means of a resistive capacitive electric analog model. A report by Vanlier (1964) contains a general discussion of the geology, hydrology and water quality of the area of Clinton, Eaton, and Ingham Counties which are further treated in more detail by Vanlier, Wood and Brunett (1969). Hydrology, chemical quality of surface water, and water use of the Upper Grand River basin has been discussed by the Water Resources Commission of Michigan (1961). There have been no previous studies of the geochemistry of the ground water of the Saginaw Formation.

#### Methods of Investigation

Location and lithologic description of wells were obtained from the files of the Michigan Geologic Survey and the U. S. Geological Survey. Wells were selected for areal coverage, age of formation penetrated, topographic region and hydrology. As a result of a recent Michigan Drilling Act (Public Act 294 of 1965), which requires drillers to submit a record of all water wells drilled with their description, much of the data used herein are from wells less than 2 years old.

Samples collected for this study (Figure 2, Table A-1) were analyzed by the Water Analysis Laboratory, Department of Geology, Michigan State University. Concentrations of calcium, magnesium and iron were determined by atomic absorption spectrometry on samples acidified shortly

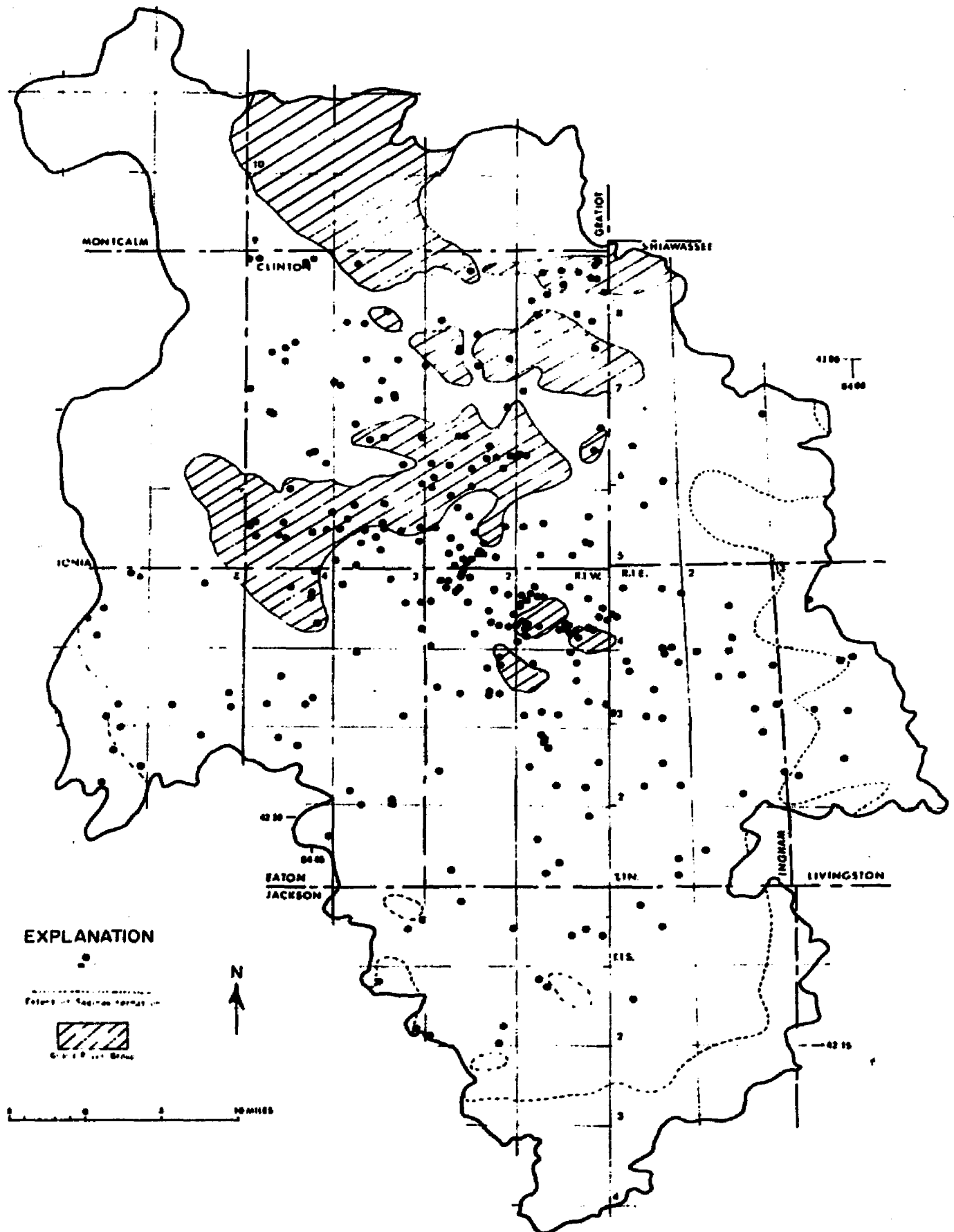


Figure 2.--Map showing location of wells sampled and extent of the Grand River Group and Saginaw Formation.

after collection. Acidification was necessary to maintain the carbonate and iron minerals in solution at atmospheric conditions. Sodium and potassium were determined by flame photometer from the same acidified samples. Chloride was determined by the mercuric nitrate method (American Public Health Association and others, 1965), and sulfate by the turbidimetric method using a Hach colorimeter (Hach Chemical Company, Ames, Iowa). Bicarbonate was determined at the time of collection, by colorimetric methods, during the early part of the study, and later a potentiometric method was used. The pH was also determined at the time of collection using a standard combination glass electrode and pH meter. Many samples were collected through pressure tanks and associated plumbing in domestic wells. To insure a fresh sample, the water was pumped for five minutes after the pump started or until the temperature of water reflected aquifer temperature or about 11°C. Previously, published chemical analyses were obtained from the Michigan Department of Health and the U. S. Geological Survey. Analyses from these sources were used only if a description of the geologic formation was available. Analyses performed by the U. S. Geological Survey were made at Columbus, Ohio, and follow analytical methods given in Rainwater and Thatcher (1960). Analyses performed by the Michigan Department of Health were made at Lansing and follow procedures given by the American Public Health Association and others (1965).

Analyses were considered to be complete if all the major constituents in the water were determined. Results of complete analyses expressed in this study balanced within 5 per cent, that is the total cations expressed as milliequivalents per liter (meq/l) are within 5 per cent of the total anions also expressed as meq/l. Because ionic solutions must be electrically neutral, the number of equivalents of cations must equal that of the anions. The unit meq/l is the valance of the ion divided by its molecular weight times its concentration in milligrams per liter. This balance insures that all major constituents have been determined and also provides a check on the analytical procedures used. The quality of partial analyses depends upon the reputation of the laboratory and the methods of analyses. Partial analyses used in this study are only from the sources listed above.

Results of analyses are reported in milligrams per liter (mg/l) for all parameters except pH and specific conductance. The pH is reported in standard pH units (negative logarithm of the hydrogen ion activity) and specific conductance in micromohs per centimeter at 25°C. The unit milligrams per liter can be considered numerically equal to parts per million (ppm) in the analyses used in this report because of the dilute nature of the waters studied.

## GEOLOGY OF THE SAGINAW FORMATION

### Introduction

Material comprising an aquifer system will have a significant influence on the chemistry of the intersitual water. Geochemical process of mineral solution, precipitation, ion exchange and ion filtration are functions of the type and distribution of the lithology of the aquifer system. Therefore, an examination of the geology is critical to the complete understanding of the hydrogeochemical system.

### Regional Setting

The Saginaw Formation occurs in the Michigan Basin sedimentary sequence. This sedimentary sequence contains Paleozoic age sediments approximately 14,000 feet in thickness and a thin and scattered sequence of Mesozoic age sediments (Michigan Department of Conservation, 1964). The Michigan Basin is bordered by the Precambrian Shield on the north and northeast; on the west by the Wisconsin Arch; on the southwest by the Kankakee Arch in northern Indiana and northeastern Illinois; and on the east and southeast by the Algonquin Arch in Ontario and the Findlay Arch in northern Ohio. The stratigraphic sequence of the basin contains sediments of all Paleozoic periods except the

Permian. These sediments are deposited in a basin which results in a series of saucer shaped beds with each formation being smaller in areal extent than the formation on which it is deposited (Eardley, 1962). The formations in general dip toward the center of the basin at about one degree. Paleozoic and Mesozoic formations are mantled by a layer of Pleistocene age glacial drift which ranges in thickness from a few feet to over 1,000 feet.

#### Occurrence and Type Locality

The Saginaw Formation is one of two Pennsylvanian age formations in the Michigan Basin. The other is the Grand River group which unconformably overlies the Saginaw (Figure 2). The name Saginaw Formation was originally proposed by Lane (1901) as a replacement for the terms "Jackson" and "Coal Measures." The name was elevated to group status by Kelly (1936). It has since been returned to formation rank by the Michigan Department of Conservation (1964). The Saginaw Formation as used in this report includes the Parma Foundation described by Winchell (1861). This is necessary because it is impossible to differentiate between the Parma and sandy facies of the Saginaw as shown in well cuttings or driller's descriptions.

The type locality of the Saginaw Formation is the Saginaw Valley outside the study area; however, because there are no outcrops in the type locality and because coal mining has been abandoned, the outcrop in Eaton County

near the town of Grand Ledge has become the type section (Kelly, 1936).

### Thickness and Limits

The extent of the Saginaw Formation (Figure 2) should be viewed as an approximation. The problem of defining the extent is complicated because the upper and lower surfaces are erosion surfaces. The thickness map (Figure 3) was made by subtracting the two surfaces and contouring the residual. Valleys in the pre-Saginaw surface can be readily delineated in areas where data are adequate. In the peripheral area of the Grand River Group, preservation is in low areas of the Saginaw Formation indicating erosion of the Saginaw Formation surface prior to the deposition of the Grand River Group. The combination of this erosion surface with the pre-glacial and glacial erosion results in a highly dissected surface on which to estimate thicknesses. The Howell Anticline further complicates estimates of thickness in the northeast part of the study area. The formation thins rapidly as the structure is approached and may have been involved in uplift and erosion, or the area may have been a topographic high during the deposition of the Saginaw Formation. In this part of the Michigan Basin it is extremely difficult to distinguish the sandstone-shale sequence of the Saginaw Formation from the Michigan, Marshall and Coldwater Formations on the basis of water

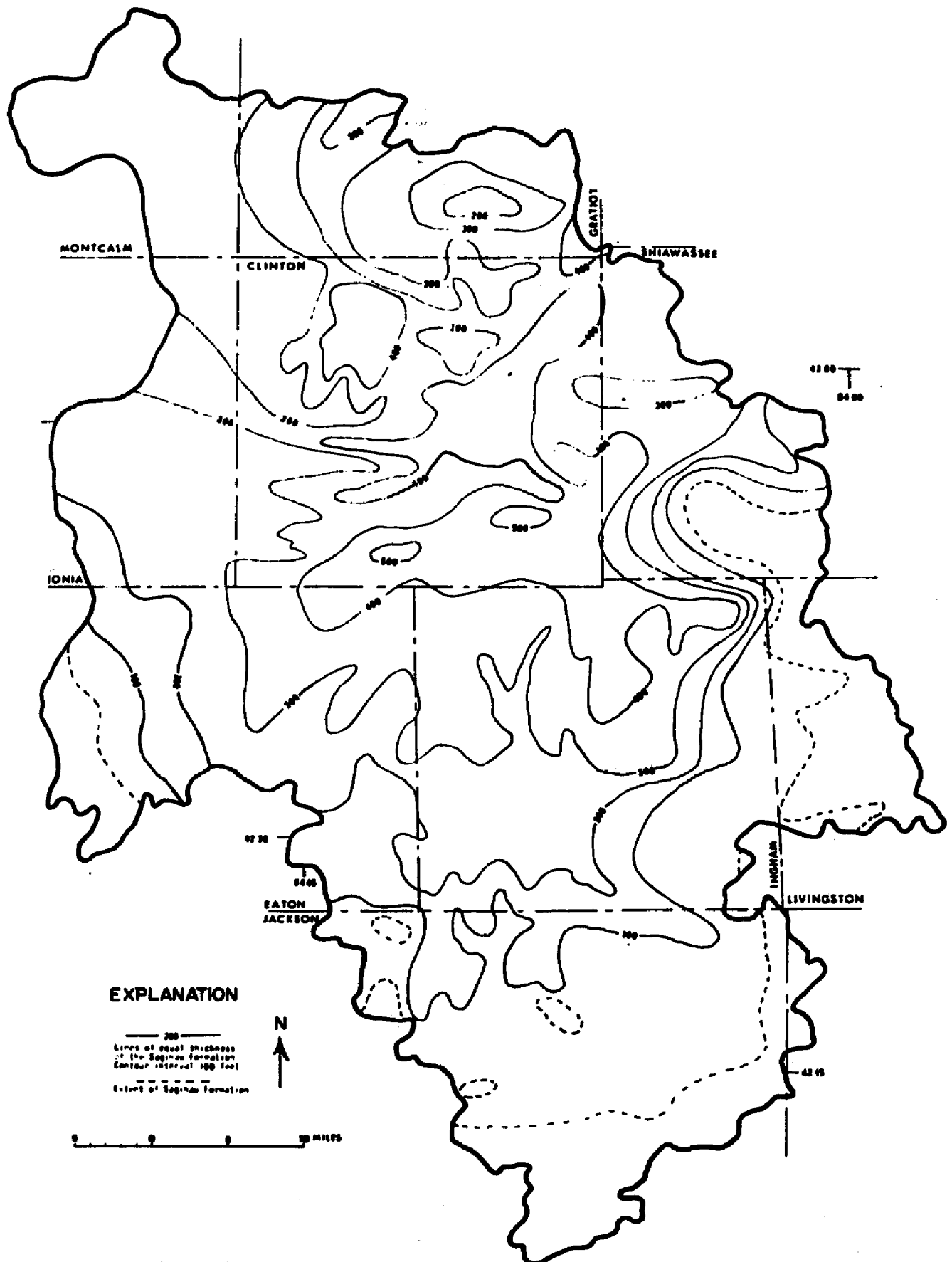


Figure 3.--Map showing thickness of the Saginaw Formation (modified after Vanlier, Wood and Brunett, 1969).

well drillers logs; consequently, the extent and thickness of the formation here is uncertain.

### Lithology

The Saginaw Formation is similar in composition to other Pennsylvanian age deposits of the Eastern Interior Basins in Illinois and Pennsylvania. It is composed of numerous beds of shale, sandstone, siltstone, coals and occasional limestone. Most of the lithologic types are non-persistent as individual members and cannot be traced over extensive distances. However, Kelly (1936) believes that at least one limestone member, which he calls the Vern Limestone, is recognizable over a large area.

The sandstones are lenticular, often ending abruptly against shale, and are usually less than 20 feet thick. However, in the Lansing Metropolitan area there are 300 feet of sandstone in a formation thickness of about 400 feet. The sandstones are composed of very fine quartz grains and contain abundant light colored mica as an accessory mineral. The dominant colors reported in drillers logs are light buff and dark grey. Kelly (1936) found tourmaline and zircon the most common heavy minerals. In addition to inorganic material there are fossil plant fragments in the sandstone outcrop at Grand Ledge and probably throughout the basin. The cementing agents from samples collected at the Grand Ledge outcrop are silica and

and calcium carbonate. The pore space is very small in the samples examined by the author.

The shales of the Saginaw Formation, like the sandstones, are not persistent over great distances and appear to have been truncated by channel sands in many instances. The term shale is used in a broad sense and includes every lithologic type the driller does not consider sandstone, coal or limestone. The latter three lithologic types are easily recognized in drilling. The shale designation includes shale, siltstone and underclay. The colors recorded are black, blue, brown, buff, gray and white. Black or dark gray is the most often recorded color.

Results of examination of the clay fraction (less than 2 microns) from two samples collected at a Grand Ledge quarry are given below. These analyses were performed by Mr. Bailey and Mr. Chazen of the Department of Geology, Michigan State University. The clay fraction was removed from the shale by mechanical disaggregation. Carbonates were removed using a sodium acetate buffer adjusted with acetic acid to a pH of 5. Organic matter was removed by using hydrogen peroxide and free iron oxides were removed by the sodium citrate sodium ditheonite method. The clay sized fraction was obtained by use of sedimentation cylinder.

The fraction obtained was then subjected to analyses indicated in Table 1. In addition, infrared, x-ray

TABLE 1.--Physical properties of clay from the Saginaw Formation at the Grand Ledge quarry.

| Sample Number                                         | A                                                                   |      |          | B                                                                         |      |          |
|-------------------------------------------------------|---------------------------------------------------------------------|------|----------|---------------------------------------------------------------------------|------|----------|
| Lithologic description and location                   | Black colored fissil shale collected near bottom of a new shale pit |      |          | Light brown colored silt-stone to shale collected near top of quarry wall |      |          |
| Specific surface area, in square meters glycol method | I                                                                   | 354  | Ave 326  | I                                                                         | 395  | Ave 365  |
|                                                       | II                                                                  | 295  |          | II                                                                        | 326  |          |
| Cation exchange capacity ca/mg meq/100 gr             | I                                                                   | 76.6 | Ave 67.7 | I                                                                         | 80.5 | Ave 65.5 |
|                                                       | II                                                                  | 60.8 |          | II                                                                        | 50.5 |          |
| Cation exchange capacity K/NH <sub>4</sub> meq/100 gr | I                                                                   | 64   | Ave 52   | I                                                                         | 54   | Ave 48   |
|                                                       | II                                                                  | 40   |          | II                                                                        | 42   |          |

diffraction and differential thermal analysis were performed on the sample. The results of these investigations combined with the physical properties (Table 1) indicate the following percentage and type of clay minerals present.

| A                               | B                                  |
|---------------------------------|------------------------------------|
| 59% Kaolinite                   | 42% Kaolinite                      |
| 30% Illite                      | 46% Illite                         |
| 11% Vermiculite                 | 12% Vermiculite                    |
| trace of quartz and<br>chlorite | trace of plagioclase<br>and quartz |

The underclays are very light in color at the outcrop and according to Kelly (1936) contain irregular nodules of iron carbonate. Because underclays are seldom recorded in drillers logs as distinct units it is difficult to determine the extent of the facies. Presumably they would be found beneath coal zones.

Coal provided the early impetus to study the Saginaw Formation, however, this is not a common lithologic type in the study area. Because of its color and physical properties it is easily recognized in drilling. Its absence in drillers records is thought to be an indication that coal beds are not abundant in the study area.

Limestone is commonly recorded in drillers logs. However, its thickness is small, usually less than 2 feet, and several different beds are often recorded in a single well. Because limestones are extremely resistant to

drilling even though they are thin, they are recorded by most drillers and probably gives a positive bias to the amount of limestone recorded in the logs. As mentioned previously, Kelly (1936) believed that at least one of these limestones is extensively distributed.

## GEOHYDROLOGY

### Introduction

Source, distribution and movement of water within the aquifer system affect the water chemistry. To evaluate the type, amount, and spatial distribution of the chemical constituents it is necessary to identify the source and quantity of the water and the potentiometric distribution of the hydraulic head in the formation.

### Regional Setting

The source of water in the Saginaw Formation in the Grand River basin is precipitation within the topographic basin. In certain instances small amounts of water are lost to or received from adjacent basins, but in general the ground-water basin corresponds very closely to the topographic divide. Precipitation on the Grand River basin above Ionia averages annually 31.12 inches (Water Resources Commission of Michigan, 1961). This value was determined by using the Thiessen method of mathematically weighing precipitation from stations in and adjacent to the basin. Stream runoff for the same area, based on sixteen years of record averages 7.63 inches annually (U. S. Geological Survey, 1968). The difference, 23.49

inches, is the average annual lost to evapotranspiration. The precipitation and runoff data are based on a slightly smaller area than that used in this study. However, they do represent the hydrologic conditions of the study area accurately.

The Grand River at Ionia had 7.05 inches of runoff for the water year 1966 (U. S. Geological Survey, 1967). Because this value closely approximates the long term average of 7.63 inches, it was separated into its components of overland and ground-water runoff by graphical methods (Wisler and Brater, 1949). This was done in order to delineate the relative contribution of ground water to the total annual flow. For this particular year it was found that 58 per cent of the total flow, or 4.09 inches was derived from ground water sources. The area of the drainage basin at Ionia is 2,840 square miles, thus, a total of 0.30 cfs (cubic feet per second per square mile) is ground-water runoff. This value is considered to be representative of the average ground water contribution to streamflow in the area. However, because of the size of the basin, precipitation may have occurred during periods which were assumed to be at base flow, consequently this figure of 0.30 cfs may be higher than the true value.

Many pumping tests indicate that the sandstone in the Saginaw Formation has a relatively constant permeability of approximately 100 gpd per sq. ft. (gallons per day per square foot). The permeability of the shale is much lower

and more variable, ranging from 0.01 to 1.0 gpd per sq. ft. Pumping tests also indicate that the Saginaw Formation acts as a leaky artesian system over most of the study area. An average value of the leakage between the glacial drift and the Saginaw Formation was found by Wheeler (1967) to be approximately 0.0012 gpd per sq. ft. under existing head conditions. This value represented the leakage in the Lansing Metropolitan area prior to the extensive pumping development and is used here as an average value of the system throughout the study area.

Assuming steady-state ground-water conditions over most of the basin, with the exception of Lansing Metropolitan area, recharge to the formation will equal the discharge from the formation of 0.0012 gpd per sq. ft., or 0.051 cfs. This amount would be the contribution from the Saginaw Formation to streams from each square mile in the basin. However, only about 90 per cent of the area is underlain by the Saginaw Formation, which, when accounted for, reduces the contribution from the formation to approximately .046 cfs. Comparing this to the total ground-water runoff of 0.30 cfs, the ratio is about 7 to 1. That is about 1/7 of the water in a stream under base flow conditions is from the Saginaw Formation. Most of the remaining water is from the overlying glacial drift.

The potentiometric surface of the Saginaw Formation (Figure 4) is a smoothed reflection of the surface

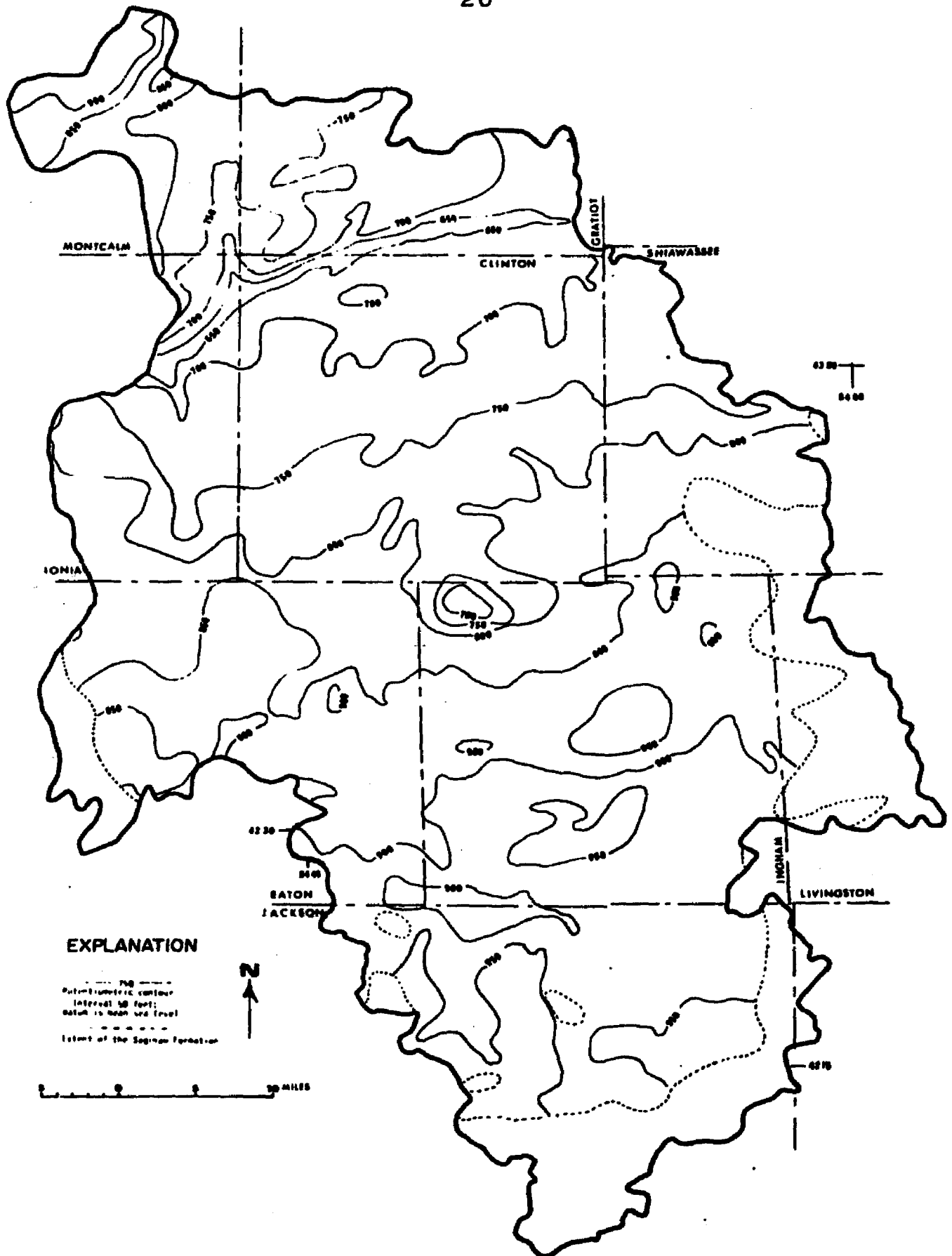


Figure 4.--Map showing potentiometric surface of the Saginaw Formation (modified after Vanlier, Wood and Brunett, 1969).

topography. This further substantiates that there is a hydrologic connection between the overlying glacial material and the Saginaw Formation. In the Lansing Metropolitan area, however, the potentiometric surface of the Saginaw Formation is greatly depressed as the result of large amounts of ground water having been withdrawn and no longer reflects natural conditions.

The Bayport Formation, which directly underlies the Saginaw Formation in most of the study area, is a dense limestone approximately 40 feet thick. This formation effectively acts as a base to the flow system and prevents the passage of large quantities of water from moving either into the Saginaw Formation from below or from the Saginaw into the lower formations. This contention is supported by the shape of the potentiometric surface of the Saginaw, which is controlled by the local surface topography and not by movement of water into or out of the underlying formations. The Bayport Formation usually transmits only small quantities of water where it is used as an aquifer. However, its quality as an aquifer is dependent on its geologic position. It has a greater permeability where it subcrops directly beneath the glacial drift than where it is capped by the Saginaw Formation. This condition is probably due to preglacial solution channels and fracturing due to load reduction as the Saginaw Formation was eroded. The presence of major faults or fractures in the Bayport Formation would certainly affect its ability

to transmit water. It is therefore possible that in certain areas water moves in relatively large quantities through this formation.

In summary, precipitation falling upon the basin recharges to and discharges from the Saginaw Formation through the glacial drift in a series of small flow systems (Figure 5). The patterns of flow of ground water result from the topography, formation thickness, contrasts in permeability, and basin size (Toth, 1963; Freeze and Witherspoon, 1966, 1967, and 1968). The Bayport Formation acts as a base to the system, minimizing flow into the system from below and retarding flow from the Saginaw Formation into the lower formations.

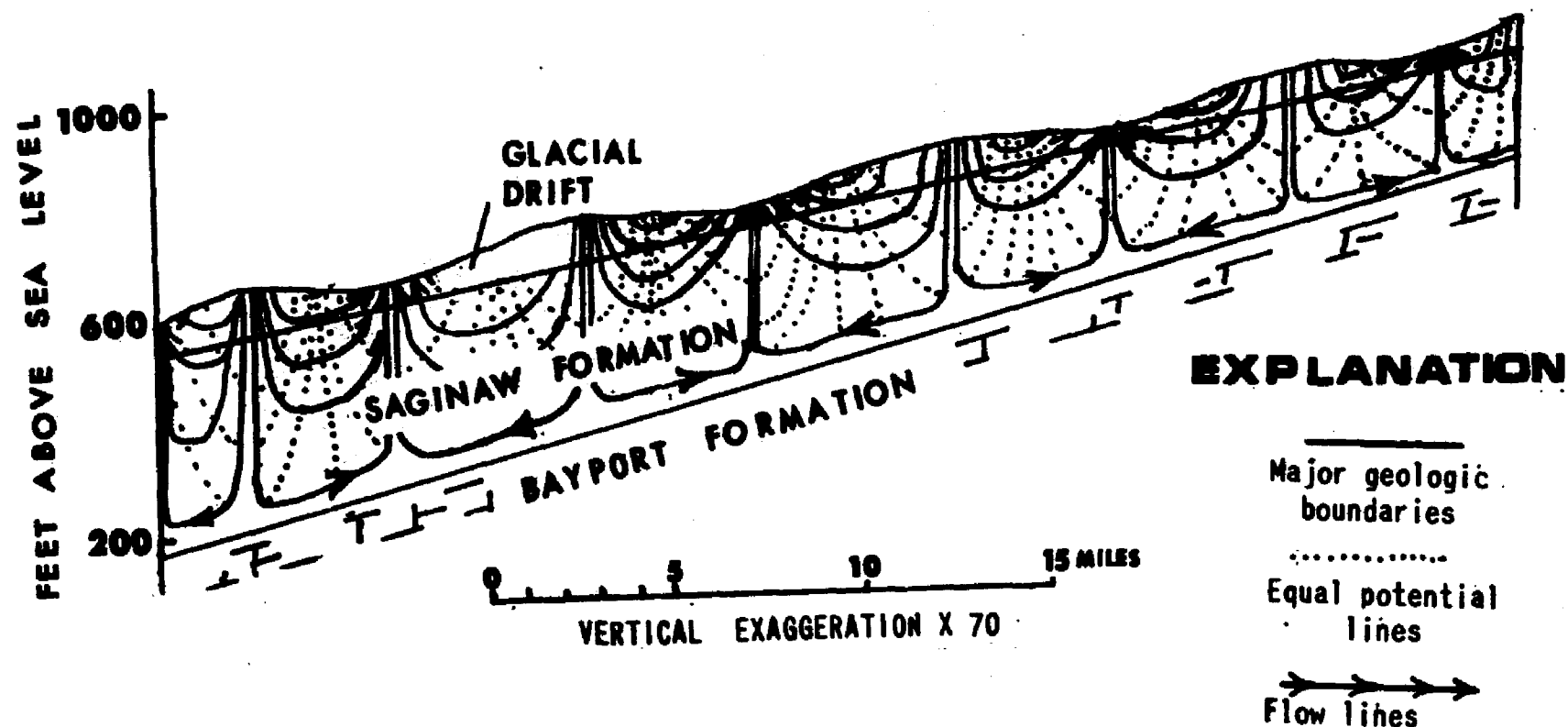


Figure 5.--Hypothetical section of the Grand River basin showing potential distribution and two dimensional patterns of major ground water flow.

## GEOCHEMISTRY OF GROUND WATER IN THE SAGINAW FORMATION

### Type and Concentration of Major Ions

Water in the Saginaw Formation is a calcium-magnesium-bicarbonate type; that is, calcium and magnesium ions constitute more than 50 per cent of the cations, and bicarbonate constitutes more than 50 per cent of the anions expressed as milliequivalents. Sodium, silica, chloride, and sulfate are four other major ions found in the water. These seven substances constitute over 98 per cent of the dissolved solids in all the samples examined. Iron and potassium are ubiquitous in the ground water of the Saginaw Formation but never exceed 1 per cent of the total dissolved solids. Nitrate concentrations greater than 2 mg/l are seldom found in the Saginaw Formation. Nitrate in glacial drift wells is usually associated with sewage or agricultural pollution and is not a result of nitrate minerals in the aquifer.

### Source of Dissolved Solids in Ground Water

#### Atmospheric Precipitation

Determining the source of dissolved solids in ground water is essential in demonstrating the relationship

between chemical character of the water, hydrology and geology. Because local precipitation is the source of water in the aquifer, several samples of rain water were collected by the author and analyzed for common ions (Table 2). Results of these analyses and others collected in North Carolina and southeastern Virginia (Fisher, 1968), Kentucky (Hendrickson and Krieger, 1964), and northern Sierra Nevada (Feth, Rogers and Roberson, 1964) indicate, that in relation to the total dissolved solids in the Saginaw Formation, very small amounts are contributed by precipitation to the ground water. As a result of evaporation and transpiration, which removes about 85 per cent of the precipitation that does not run directly off the ground, the concentration of dissolved solids contributed to the ground water is about seven times greater than the analyses indicate. Even with this increase in concentration due to evapotranspiration, precipitation cannot account for the magnitude of concentration observed for most of the major ions. Chloride is the only major ion for which precipitation may be a significant source. Continuous analyses of stream and precipitation data would be necessary to establish this relationship.

#### Soil and Glacial Material

The next source of dissolved solids, when viewed within the hydrologic framework, is the soil and glacial debris on which the precipitation falls. To evaluate

TABLE 2.--Sources of dissolved solids in ground water.

| Local<br>Number | Sample Description                                         | HCO <sub>3</sub> | SO <sub>4</sub> | Cl  | Specific<br>conduct-<br>ance | Hardness |                    | pH  |
|-----------------|------------------------------------------------------------|------------------|-----------------|-----|------------------------------|----------|--------------------|-----|
|                 |                                                            |                  |                 |     |                              | Ca,Mg    | Non-car-<br>bonate |     |
| 1.              | Rain water June 23, 1968<br>East Lansing, Mich.            | 7                | 3.5             | .8  | <50                          | 10       | 0                  | 5.8 |
| 2.              | Rain water June 27, 1968<br>East Lansing, Mich.            | 5                | 2.0             | .9  | <50                          | 10       | 0                  | 5.3 |
| 3.              | Soil and glacial material<br>SW 1/4 sec. 19, T.4N.,R.1W.   | 154              | 10              | 10  | 265                          | 124      | 0                  | 8.1 |
| 4.              | Glacial drift<br>NW 1/4 sec. 12, T.3N.,R.1E.               | 114              | 11              | 4.0 | 225                          | 98       | 4                  | 7.6 |
| 5.              | Soil<br>NW 1/4 sec. 12, T.3N.,R.1E.                        | 181              | 14              | 5.0 | 320                          | 160      | 12                 | 7.5 |
| 6.              | Fine sand and silt<br>SW 1/4 sec. 18, T.4N.,R.2E.          | 86               | 19              | 22  | 225                          | 94       | 24                 | 8.1 |
| 7.              | Soil<br>SW 1/4 sec. 25, T.4N.,R.1W.                        | 482              | 14              | 6.0 | 750                          | 390      | 0                  | 8.0 |
| 8.              | Light brown shale from Grand<br>Ledge quarry 115 mesh 3/8" | 9.3              | 24              | 4.0 | 105                          | 30       | 22                 | 6.8 |
| 9.              | Black shale from Grand Ledge<br>quarry 115 mesh            | 30               | 1020            | 68  | 1400                         | 1100     | 1076               | 7.7 |
| 10.             | Sandstone from Grand Ledge<br>quarry 115 mesh 3/8"         | 5.4              | 21              | 8.0 | 110                          | 33       | 29                 | 6.7 |

these materials as a source of dissolved solids, a laboratory experiment was designed in which the change in dissolved solids in water were measured after it had been in contact with the soil-glacial material. Five hundred grams of representative soil-glacial material from five localities were dried at room temperature (23°C) and placed in plastic cylinders. The material was not sorted by size, nor was any attempt made to preserve original packing or structure. Five hundred ml (milliliters) of distilled deionized water in equilibrium with the atmosphere were shaken with the sample, stoppered, except for a small air vent, and allowed to stand 5 to 7 days. The water was then filtered through a filter paper and funnel attached to the cylinder. The water slurry acted as a natural filter, giving a clear, usually colorless, filtrate. The filtrate was analyzed by the same methods used for well water.

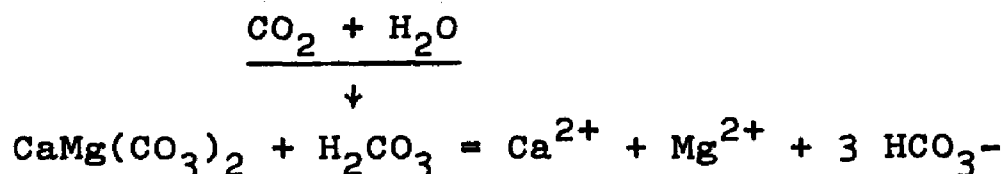
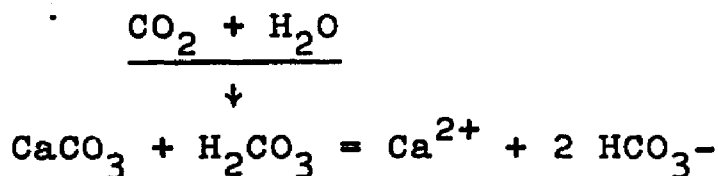
Water obtained from these leaching experiments (Table 2) was, in general, similar to that observed in the Saginaw Formation and glacial drift wells (Table A-1). Much of the calcium and sulfate in the glacial debris and derived soil material results from the solution of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and/or anhydrite ( $\text{CaSO}_4$ ). These minerals were probably derived from the Michigan Formation and are irregularly distributed in the glacial deposits. The Michigan Formation, which is a commercial source of gypsum in the Michigan basin (Martin, 1936) subcrops in the

northeastern part of the basin and lies in the path of the last glacial advance in the area (Leverett and Taylor, 1915).

That the sulfate ions are derived from sulfate minerals rather than by oxidation of sulfide minerals can be ascertained by comparison of values of non-carbonate hardness with the sulfate values shown in Table A-1 and Table 2. Most analyses show an approximate one-to-one relationship between sulfate and non-carbonate hardness. This indicates that the sulfate was originally associated with  $\text{CaSO}_4$  or  $\text{MgSO}_4$  because, non-carbonate hardness, as the name implies, results from calcium and magnesium from sources other than carbonates. Possible minor sources of non-carbonate hardness are nitrates which contain calcium or magnesium and chlorides as  $\text{CaCl}_2$  or  $\text{MgCl}_2$  which may be present in very small quantities. However, the chloride ion concentration is generally related to the sodium ion concentration in this water and consequently does not contribute to the non-carbonate hardness. If sulfides were oxidized and brought into solution the resulting water would contain no calcium or magnesium from this source and consequently no non-carbonate hardness.

The major source of calcium, magnesium and bicarbonate is from the reaction of carbonic acid, which is the result of the solution of carbon dioxide ( $\text{CO}_2$ ) in water ( $\text{H}_2\text{O}$ ), with limestone ( $\text{CaCO}_3$ ) and dolomite  $\text{CaMg}(\text{CO}_3)_2$

or magnesium rich limestone. The reactions are summarized by the equations:



Carbon dioxide may be ten to twenty times atmospheric value in the soil due to plant respiration and decaying organic material (Boynton and Reuther, 1938). Soil carbon dioxide concentration and mineral equilibria are probably the controlling factors in the amount of carbonate dissolved in this environment as there is an abundance of carbonaceous material in the glacial drift in the study area (Johnsgard et al., 1942; Veatch et al., 1941).

Chloride and sodium ions are derived from solution of halite (NaCl) which, like the sulfate minerals, was probably incorporated in the surficial deposits by the glacier. As mentioned earlier, some of the chloride and sodium may come from precipitation. The relatively small amounts of chloride compared to sulfate ions may reflect greater solubility of the chloride and its removal shortly after deposition, or a lower initial concentration in the

drift. Sodium is also obtained by ion exchange with calcium from certain clay minerals present in the glacial drift.

In addition to leaching studies, evidence for a soil-glacial debris origin for the dissolved solids can be obtained from evaluation of high water runoff in the streams. During periods of high stream-flow, water is derived primarily from surface runoff and only a small percentage is derived from ground-water discharge. Over-land runoff has been in contact only with the upper soil horizons and usually for a short period of time, seldom exceeding a week. Therefore, chemical analysis of stream water under these conditions compared to that of base flow conditions, which is entirely ground water, indicates the relative effects of soil horizons on water quality.

In order to compare the stream water in the two types of flow conditions, statistical analyses, of previously published chemical data from streams (Table A-2), were performed using the "t" test of mean comparison. Location of the sampling sites is given in Figure 6. These sites were selected to avoid known sources of industrial and municipal waste disposal and to give a wide geographic distribution within the basin. The major chemical parameters were found, by single classification analysis of variance technique, not to vary significantly between major sub-basins of the Grand River basin (Table A-2). Chemical data for each parameter were separated into class intervals, arrayed and plotted on normal probability paper

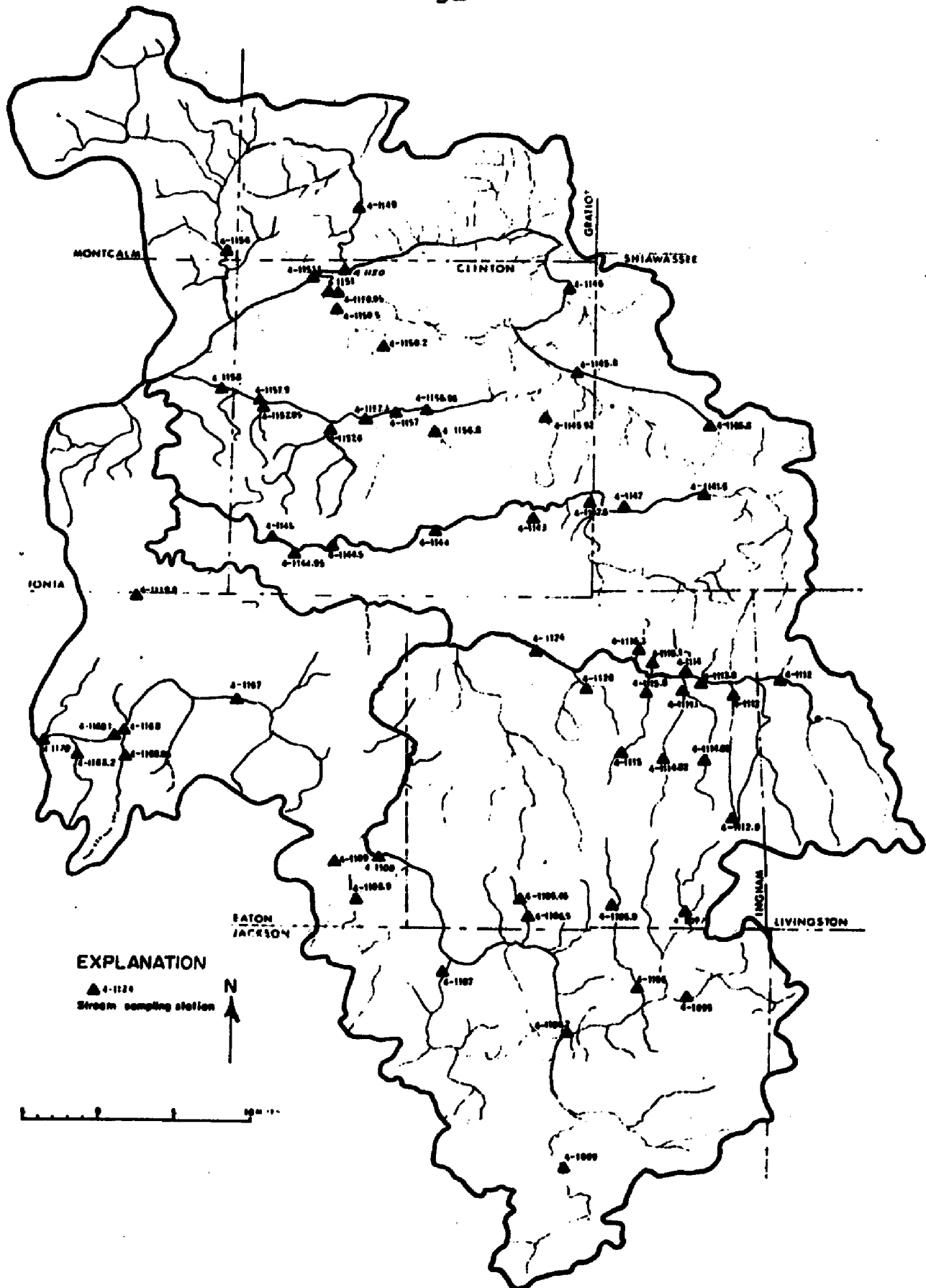


Figure 6.--Map showing location of stream sampling sites.

to check for normal distribution. The data were then subjected to an "F" test at the 5 per cent level of significance to determine if the ratio of the standard deviations were acceptable for use in comparison of the means. If the "F" test indicated suitable ratios, the average of each parameter under high-flow was compared to the average of the corresponding parameter under low-flow by means of the "t" test. A 5 per cent level of significance was chosen and a "t" was calculated using the following formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{[SP]^2[(1/N_1) + (1/N_2)]}}$$

where

$\bar{X}$  = average value of samples from populations 1, 2

t = statistic

N = number of samples from populations 1, 2

$SP^2$  = pooled mean square.

The calculated value of "t" was compared to standard tables (Dixon and Massey, 1957) at the indicated level of significance to determine the acceptance or rejection of the hypothesis. The data are summarized in Table 3.

These statistical analyses indicate that bicarbonate and sodium ions have higher concentrations in streams during base flow than during periods of overland runoff. The remainder of the major chemical parameters, including

TABLE 3.--Statistical comparison of chemical parameters of water at high stream flow with low stream flow.

| Chemical parameter  | Low flow |             |       | High flow |             |       | $S_1/S_2$ | Accept hypothesis of equal variance of "F" test at 5% level of signif. | Hypothesis of means "t" test | Calculated t | Accept hypothesis at 5% level of significance |
|---------------------|----------|-------------|-------|-----------|-------------|-------|-----------|------------------------------------------------------------------------|------------------------------|--------------|-----------------------------------------------|
|                     | $N_1$    | $\bar{X}_1$ | $S_1$ | $N_2$     | $\bar{X}_2$ | $S_2$ |           |                                                                        |                              |              |                                               |
| Ca                  | 34       | 82.2        | 13.03 | 46        | 85.9        | 12.12 | 1.07      | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | -1.31        | yes                                           |
| Mg                  | 34       | 26.0        | 5.77  | 46        | 24.5        | 4.16  | 1.39      | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | 1.36         | yes                                           |
| Na                  | 35       | 10.6        | 6.98  | 46        | 7.6         | 5.26  | 1.33      | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | 2.22         | no                                            |
| K                   | 32       | 2.23        | 1.51  | 46        | 2.09        | 0.812 | 1.86      | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | 0.4          | yes                                           |
| HCO <sub>3</sub>    | 63       | 321         | 40.2  | 69        | 256         | 54.1  | 0.743     | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | 7.78         | no                                            |
| SO <sub>4</sub>     | 63       | 74.1        | 27.1  | 69        | 74.0        | 28.6  | 0.946     | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | 0.021        | yes                                           |
| Cl                  | 63       | 12.6        | 9.03  | 69        | 11.1        | 11.4  | 0.800     | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | 0.828        | yes                                           |
| SO <sub>4</sub> /Cl | 61       | 7.75        | 4.45  | 69        | 8.61        | 6.76  | 0.658     | yes                                                                    | $\bar{X}_1 = \bar{X}_2$      | -0.835       | yes                                           |

Where: N = Number of samples  
 $\bar{X}$  = Average value of the samples  
S = Standard deviation of the samples  
t = Calculated statistic

the sulfate/chloride ratio, were the same under both flow conditions. In base flow a greater percentage of the total stream flow is derived from the Saginaw Formation than in overland runoff and the greater bicarbonate and sodium concentrations are probably the result of water from this source. Much of the sodium in water of the Saginaw Formation is derived from the clay minerals by ion exchange for calcium and magnesium (Numbers A and B, Table 1). Greater bicarbonate concentration probably result from the combination of greater solubility of sodium bicarbonate compared to calcium bicarbonate, and the greater penetration of ground water into deeper soil zones with a greater carbon dioxide content. The Saginaw Formation itself may contribute some carbon dioxide and subsequently bicarbonate, by the decay of coal in the formation (Foster, 1950).

#### Saginaw Formation

The next source of dissolved solids to be investigated is the Saginaw Formation. Sandstone and shale collected from the outcrop at Grand Ledge were used in a series of leaching experiments. The samples were from the same location as those used for the clay-fraction analysis. The leaching experiments were performed by the same methods as those used with the soil-glacial material except that the material was crushed and divided into two sizes: less than 115 mesh and between 115 mesh and 3/8-inch.

Results of the leaching experiment indicate that the sandstones yield very small concentrations of dissolved solids (Analysis Number 10, Table 2). The light brown colored shale (Analysis 8, Table 2) also contributed very small concentrations of dissolved solids. The black shale (Analysis 9, Table 2) yielded a calcium sulfate type water relatively high in chloride and is not typical of the water obtained from the Saginaw Formation. This shale is shown later in the report probably to be a calcium and sulfate ion sink for recharging water and not a source of these ions.

Sodium is not readily released from the Saginaw Formation when it is treated with distilled water but is exchanged for calcium and magnesium when these ions are present in the recharging water. This ion-exchange capacity was measured in the dispersed clay sample (A and B, Table 1) and shown to have approximately 66 meq per 100 grams. However, this is a very small sample and may not accurately represent the clays of the basin.

The stratigraphically higher Grand River Group yields water that is the same as the Saginaw Formation and therefore it was not considered as a separate source. Additionally, the Grand River Group overlies only a small part of the Saginaw Formation and could not significantly affect the dissolved solids of the formation.

### Stratigraphically Lower Formations

It has been shown previously that over most of the study area it is hydrologically unlikely for water to migrate from a stratigraphically lower formation into the Saginaw Formation. Upward migration of water in the study area is only possible in topographically low areas, usually associated with river valleys. Lack of migration of dissolved solids from lower formations into the Saginaw Formation is demonstrated by a significant chemical difference between the various waters (Table 4). These formations, remote from their subcrop area, contain larger amounts of dissolved solids and in different ratios than the Saginaw Formation. The difference in ratios between the Paleozoic age formation is illustrated in Figure 7. This diagram shows that water from the Saginaw Formation plots in a different section than that of the Michigan and Marshall formations. Water from the latter formations is a calcium-sodium chloride type while water from the Saginaw Formation is a calcium-magnesium bicarbonate type.

The Lansing area affords an example of what water quality in the Saginaw Formation would be like if the dissolved solids were derived from stratigraphically lower formations. In 1870, a well was drilled into the Michigan Formation in search of salt (Cook, 1914) near what is now the center of Lansing. The search for salt was a commercial failure and the well was abandoned. Analyses of the water

TABLE 4.--Chemical analyses of water from the Michigan and Marshall Formation. Analyses in milligrams per liter.

| Local No.          | 1                   | 2                    | 3                     | 4                     | 5                     | 6                   |
|--------------------|---------------------|----------------------|-----------------------|-----------------------|-----------------------|---------------------|
| Location           | sec. 35, T4N., R5W. | sec. 36, T11N., R3W. | sec. 30, T.20N., R6W. | sec. 5, T11N., R.13W. | sec. 18, T12N., R.2W. | sec. 21, T4N., R4W. |
| Depth              | 550                 | 853                  | 1346                  | 741                   | 1260                  | 600                 |
| Formation          | Michigan            | Michigan             | Michigan              | Marshall              | Marshall              | Michigan            |
| Ca                 | --                  | 30,300               | 29,700                | 14,900                | 26,700                | 384                 |
| Mg                 | --                  | 8,240                | 7,590                 | 3,880                 | 6,200                 | 56                  |
| Na                 | --                  | 72,500               | 71,600                | 38,600                | 34,700                | 2,529               |
| K                  | --                  | 340                  | 672                   | 595                   | 399                   | 62                  |
| HCO <sub>3</sub>   | 240                 | --                   | --                    | 15                    | 0                     | 2,438               |
| SO <sub>4</sub>    | 620                 | 231                  | 232                   | 1,010                 | .7                    | 443                 |
| Cl                 | 1,800               | 202,000              | 196,000               | 103,000               | 124,000               | 2,791               |
| Total hardness     | 600                 | 109,500              | 105,400               | 43,200                | 92,900                | 1,190               |
| Total solids       | 5,900               | 314,000              | 306,000               | 162,000               | 192,000               | 7,460               |
| Source of analysis | Unpublished MDH     | Graf et al. 1966     | Graf et al. 1966      | Graf et al. 1966      | Unpublished USGS      | Lane, 1899          |

Numbers refer to analyses given in Table 4

- Saginaw Formation
- Michigan-Marshall Formations
- ▲ Salt seep

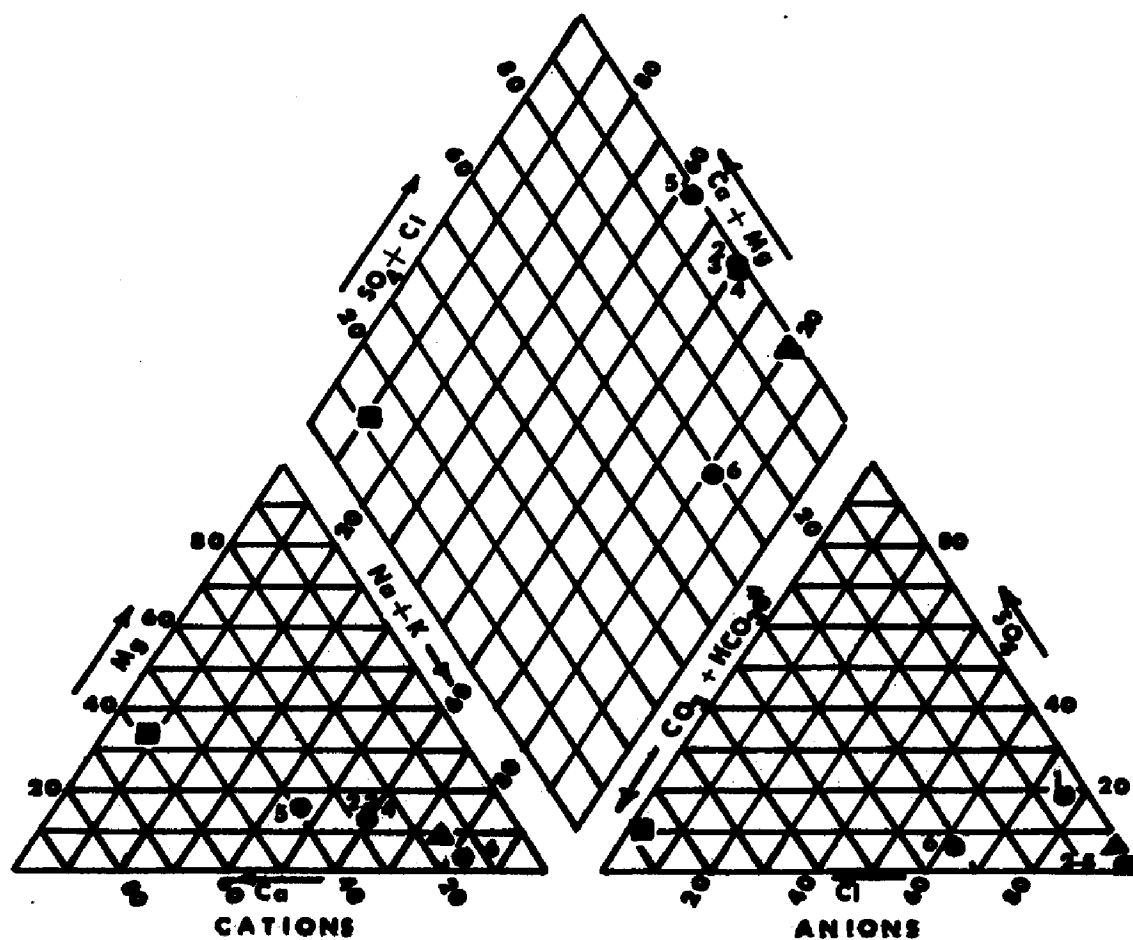


Figure 7.--Water analysis diagram for selected Paleozoic formations in Michigan.

originally produced from this well (Local No. 6) are given in Table 4. In 1954 a well (City of Lansing RS-2) was drilled into the Saginaw Formation near the site of the old brine well and produced water with chloride concentration in excess of 1000 mg/l.

Distribution of chloride in the aquifer adjacent to the brine well is given in Figure 8. The highest chloride values in this figure are not close to the old brine well due to the shape of the potentiometric surface and varying pumping rates of the adjacent wells but there is little doubt that the brine well is the source of the dissolved solids. The fact that the remainder of the cone of depression in the Lansing area is not mineralized like the area near the brine well indicates the effectiveness of the Bayport Formation in preventing dissolved solids from entering the Saginaw Formation from below.

In areas where the dissolved solids are greater than average and the sulfate/chloride ratio is less than about four, it is suspected that flow is coming from the stratigraphically lower formations. For example analyses 05N04W19DADD1, and 07N03W35CCCB1 (Table A-1) are from wells that were drilled through the Saginaw Formation and then plugged. Analyses 07N03W27DDDD1, 07N03W22CCD1 and 08N04W02DCC (Table A-1) are from wells close to oil well test drillings and probably represent contamination from poorly plugged holes. Water at stream base flow does not show the effects of high chloride in the area of

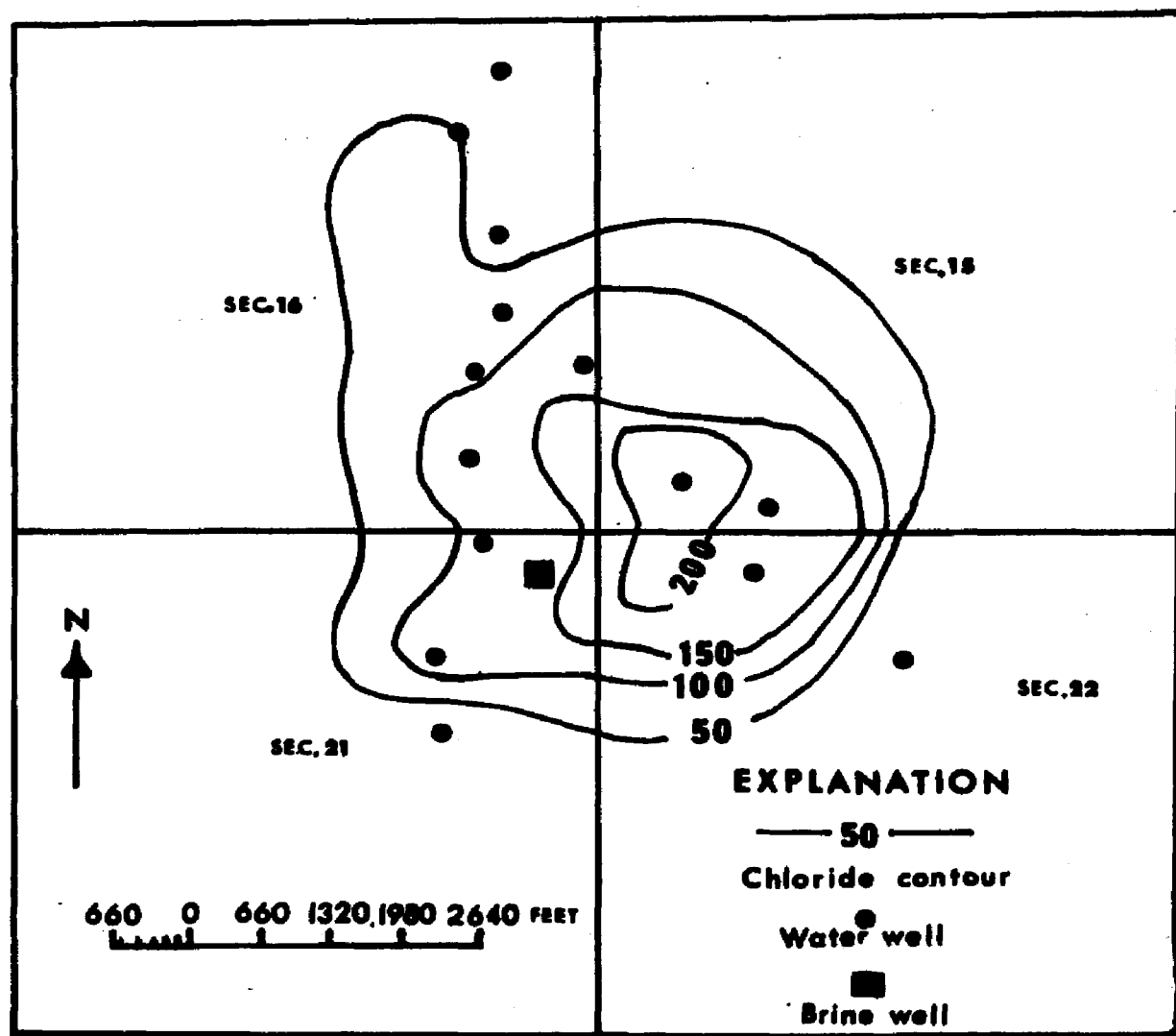


Figure 8.--Map showing distribution of chloride in the Saginaw Formation near an abandoned brine well in the city of Lansing T.4 N., R.2 W.

these wells indicating that the mineralization is recent and is probably limited to areas where improperly plugged oil wells exist.

Two natural salt seeps were recorded by Houghton (1838) in section 15 township 8 north and range 4 west along the Maple River. The analysis of water, in mg/l, from one of these seeps as reported by Houghton is given below and is plotted on Figure 7.

|           |      |             |      |
|-----------|------|-------------|------|
| Iron      | 1.1  | Bicarbonate | 299  |
| Calcium   | 316  | Sulfate     | 375  |
| Magnesium | 129  | Chloride    | 4033 |
| Sodium    | 2235 |             |      |

The analysis plots in the same location as the Michigan and Marshall Formation on Figure 7 and is probably from this source.

A detailed search by earlier workers indicated that these are the only two points of natural discharge of brine in the study area. It is difficult to explain why the brine seeps are limited to a small area of the river along which the hydraulic gradient is probably favorable for discharge from lower formations. It would appear that the geologic formations are either disrupted by faulting or the covering impermeable formations are missing through erosion or non-deposition in this very narrow area.

### Dissolved Solids Budget

Defining the dissolved solids budget for the basin aids in evaluating the relative magnitude of the various dissolved solids sources. Total dissolved solids input to the basin from atmospheric precipitation is given below.

|           | <u>mg/l</u> | <u>tons/year</u> |             | <u>mg/l</u> | <u>tons/year</u> |
|-----------|-------------|------------------|-------------|-------------|------------------|
| Calcium   | 1.32        | 8,500            | Bicarbonate | 4.60        | 29,500           |
| Magnesium | .26         | 1,600            | Sulfate     | 1.59        | 10,200           |
| Sodium    | .53         | 3,400            | Chloride    | .74         | 4,800            |
| Potassium | .39         | 2,500            |             |             |                  |

Because of limited data on the composition of atmospheric precipitation from the study area, values from Feth, Rodgers and Roberson (1964) and Hendrickson and Krieger (1964) were averaged and used to calculate the dissolved solid input. The average values used to calculate loads compare very favorably with the values collected for this thesis (Table 2) and are believed to represent accurately the chemical composition of atmospheric precipitation for this area. The average annual precipitation of 31.12 inch was used in calculating the loads.

Lacking continuous chemical analyses of natural unpolluted stream flow from the basin, total dissolved solid output was evaluated by separating total stream flow into base flow and overland runoff and then using the average value of the chemical parameter for each flow condition (Table 3). The base flow separation used

previously (58 per cent of the average annual flow) was used in calculating the loads. The loads calculated are believed to be a reasonable approximation of the natural unpolluted dissolved solids output of the basin.

#### Base Flow

|           | <u>tons/year</u> |             | <u>tons/year</u> |
|-----------|------------------|-------------|------------------|
| Calcium   | 74,900           | Bicarbonate | 292,500          |
| Magnesium | 23,700           | Sulfate     | 67,500           |
| Sodium    | 9,700            | Chloride    | 11,500           |
| Potassium | 2,000            |             |                  |

#### Overland Flow

|           | <u>tons/year</u> |             | <u>tons/year</u> |
|-----------|------------------|-------------|------------------|
| Calcium   | 56,700           | Bicarbonate | 169,000          |
| Magnesium | 16,200           | Sulfate     | 48,900           |
| Sodium    | 5,200            | Chloride    | 7,300            |
| Potassium | 1,400            |             |                  |

Difference in dissolved solids between the atmospheric precipitation and total of base flow and overland flow is the amount dissolved from the materials in the basin. The amount of sodium the basin yields annually by ion exchange can be estimated from these figures if it is assumed that halite (NaCl) is the only significant soluble sodium mineral present and that all the chloride is associated with sodium and not calcium or magnesium. This last assumption is not completely valid and probably leads to

a slightly lower estimate of the amount of sodium removed from the basin by ion exchange. Taking into consideration the difference in combining weights between sodium and chloride and assuming an average annual output of 18,800 tons of chloride, it can be shown that 12,200 tons of sodium should be associated with the chloride. The difference in sodium value between 12,200 tons and the observed output of 14,900 tons is the amount contributed to stream flow by ion exchange. It can be further shown that most of this amount is contributed, as expected, under base flow conditions.

To determine if the value of 2,700 tons of sodium is a reasonable yield from a basin of this size, calculations were made indicating approximately 2.5 million cubic feet of shale would be necessary to produce 2,700 tons of exchanged sodium. This calculation is based on an exchange value of 66 meq/100 grams. A shale bed one foot thick over one square mile yields 27.8 million cubic feet, therefore, even if the exchange rate were 1/10 or 1/100 of that observed there is an adequate supply of exchangeable shale in a basin of this size.

### Dissolved Solids Distribution

#### Areal Trends

Knowledge of the three dimensional distribution of dissolved solids in the Saginaw Formation is essential to the understanding of the nature of the chemical processes that affect water chemistry. Additionally, if trends of

certain objectionable ions can be delineated or if drilling techniques affect the distribution of dissolved solids, this information can be utilized in water management decisions. It is known from the previous section that the source of most of the dissolved solids is the glacial drift. It has been previously stated that there is no apparent difference in chemical quality between the sub-basin streams throughout the basin. Therefore, the distribution within the Saginaw Formation must be a function of the water flow patterns and the lithology of the formation.

Concentration of most major chemical parameters in water of the Saginaw Formation is observed to vary over several orders of magnitude (Table A-1). This large range in concentration persists although polluted wells are removed from consideration. To determine if areal distribution trends exist, the major chemical parameters were plotted on a map and contoured. This method of presenting the data was generally unsuccessful in defining trends of ion concentration. Sodium was the only parameter which exhibited a mappable distribution (Figure 9). It is not unexpected that sodium is the only constituent showing a coherent distribution when it is recalled that this is the only major chemical constituent contributed by the Saginaw Formation. Figure 9 was constructed using wells finished in the Saginaw Formation that give no indication of contamination by poorly cased or plugged oil test wells. The areas delineated in Figure 9 are generalized, that is,

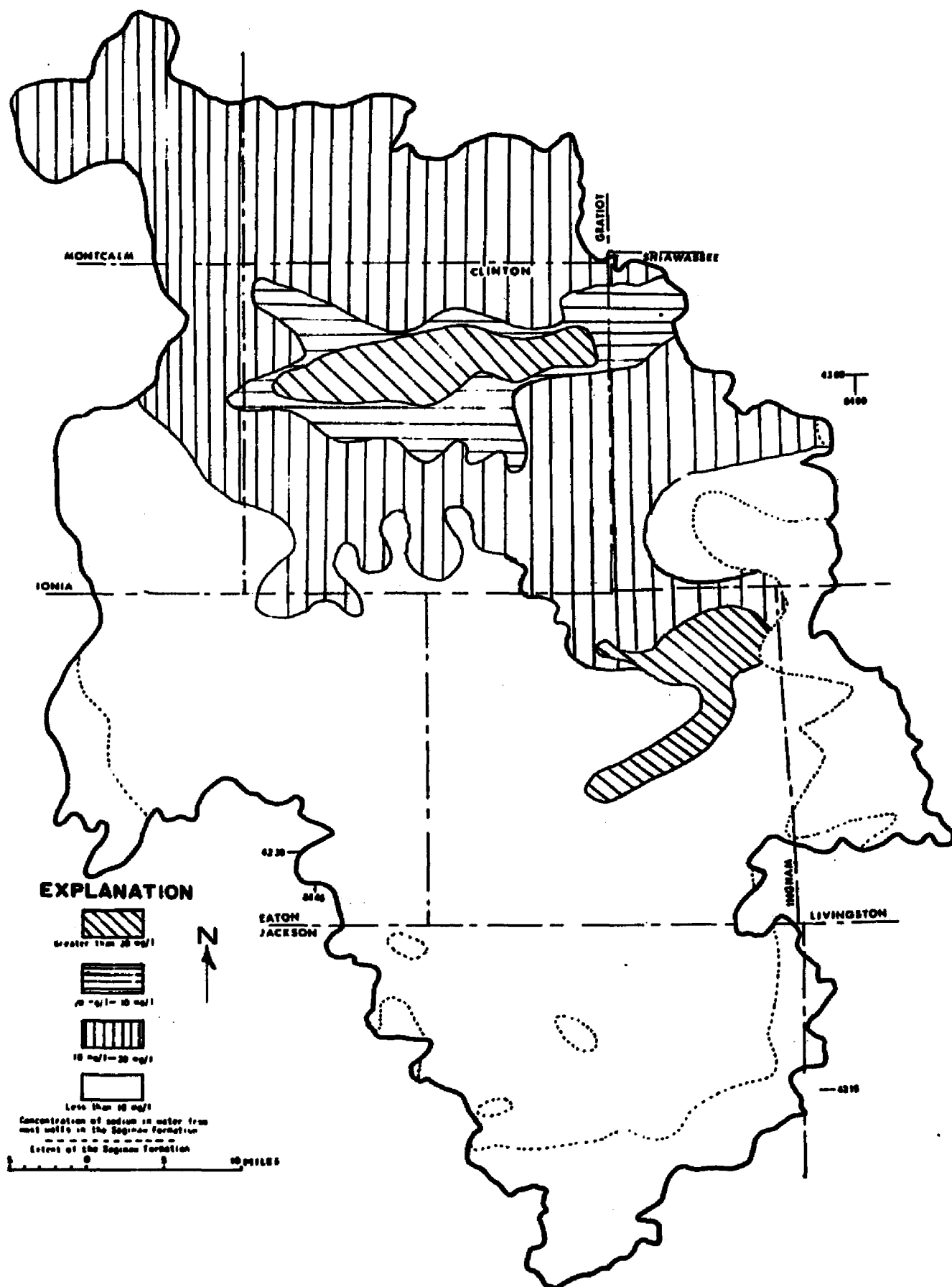


Figure 9.--Map showing distribution of sodium in the water of the Saginaw Formation.

occasionally a well will produce water with a higher or lower value than the indicated pattern. The distribution trend exhibited in Figure 9 is probably not affected by sodium from the glacial drift. It was shown previously that sodium ions are associated with chloride ions in glacial drift water, while the sodium concentration in the water of the Saginaw Formation results primarily from ion exchange for calcium and is consequently associated with the bicarbonate ion. Further support for a Saginaw Formation origin of the sodium is obtained from examination of lithologic logs. Logs of wells which yield high concentrations of sodium exhibit a large proportion of shale.

To verify the apparent lack of an areal distribution, statistical analyses of the major chemical constituents were made by comparing the mean values in Ingham, Clinton, Jackson and Eaton Counties by means of a single classification analysis of variance technique (Dixon and Massey, 1957). Results of these analyses failed to show a significant difference between these regions at the 5 per cent level of significance.

Major chemical parameters were plotted on maps in known areas of recharge to and discharge from the Saginaw Formation and compared to determine if mappable differences exist. This procedure failed to define significant differences between the two different flow regions.

Chemical analyses taken from wells drilled by one drilling company were plotted on a map to determine if

regional trends could be established when the personal factor in drilling and casing was held constant. However, because most drillers operate in a limited regional area it was impossible to obtain a sufficient distribution of data to test this factor.

### Vertical Distribution

Statistical analyses were made to determine if the large range in concentration of the major chemical parameters were a function of the depth of the well. Depths of Saginaw Formation penetration of 0-100, 101-200, 201-300 and greater than 300 feet were selected and the means of each chemical parameter was compared at each depth by the use of a single classification analysis of variance technique (Dixon and Massey, 1957). No statistically significant differences were observed at the 5 per cent level of significance. In contrast, changes of one or two orders of magnitude in some parameters often occurred between wells of the same depth within several hundred feet distance of each other. Additionally, water from glacial drift wells and base flow of streams appeared to be greater in chloride and sulfate concentration than did water from wells in the Saginaw Formation. This observation is in agreement with comments made by many well drillers that the "better" water is in the "rock." It was also observed that when wells yielded water higher in one parameter, they were generally higher in all other parameters; that is, if the sulfate

was about twice the average value the chloride would also be about twice the average value.

To determine if these differences in chemical concentrations were apparent or real, analyses of chloride and sulfate from base flow of streams (Table A-2) were combined with analyses from glacial drift wells (Table A-1) and compared by means of a "t" test with analyses from the Saginaw Formation (Table A-1). Combining base flow chemical data with data from glacial drift wells to obtain a larger sample size is permissible for these parameters because they are from the same statistical population. Wells affected by pollution were not included in the statistical analyses. Where multiple chemical analyses exist only the most representative was used. The results, tabulated in Table 5, indicate that sulfate and chloride concentrations are greater in water from the glacial material than in water from the Saginaw Formation, but the sulfate/chloride ratios are the same. Base flow analyses of iron, which is precipitated on exposure to the atmosphere, calcium, magnesium, and bicarbonate, which are removed by mineral precipitation, and potassium, which is utilized by aquatic vegetation, are not representative of well water from the glacial drift and cannot be combined in a statistical analysis. Analyses of water from drift only wells were compared at the 10 per cent level of significance with analyses of well water from the Saginaw Formation. Results, presented in Table 6, indicate sodium, magnesium and

TABLE 5.--Statistical comparison of chemical parameters of water from glacial drift and low stream flow with the Saginaw Formation.

| Chemical<br>parameters | Wells in<br>glacial drift and<br>low flow stream |             |       | Wells in<br>Saginaw Formation |             |       | $S_1/S_2$ | Accept hypothesis<br>of equal variance<br>("F" test) at 5%<br>level of signif. | Hypothesis of<br>means<br>("t" test) | Calculated "t" | Accept hypothesis<br>at 5% level of<br>significance |
|------------------------|--------------------------------------------------|-------------|-------|-------------------------------|-------------|-------|-----------|--------------------------------------------------------------------------------|--------------------------------------|----------------|-----------------------------------------------------|
|                        | $N_1$                                            | $\bar{X}_1$ | $S_1$ | $N_2$                         | $\bar{X}_2$ | $S_2$ |           |                                                                                |                                      |                |                                                     |
| SO <sub>4</sub>        | 112                                              | 59.9        | 33.70 | 241                           | 34.2        | 40.30 | .836      | yes                                                                            | $\bar{X}_1 > \bar{X}_2$              | 6.37           | yes                                                 |
| Cl                     | 110                                              | 10.9        | 12.21 | 245                           | 6.10        | 11.10 | 1.10      | yes                                                                            | $\bar{X}_1 > \bar{X}_2$              | 3.72           | yes                                                 |
| SO <sub>4</sub> /Cl    | 109                                              | 8.80        | 8.33  | 221                           | 8.67        | 10.75 | .775      | yes                                                                            | $\bar{X}_1 = \bar{X}_2$              | .116           | yes                                                 |

Where: N = Number of samples  
 $\bar{X}$  = Average value of the samples  
S = Standard deviation of the samples  
t = Calculated statistic

TABLE 6.--Statistical comparison of chemical parameter of water from glacial drift with the Saginaw Formation.

| Chemical<br>parameter | Wells in<br>glacial drift |             |       | Wells in<br>Saginaw Formation |             |       | $S_1/S_2$ | Accept hypothesis<br>of equal variance<br>"F" test at 5%<br>level of signif. | Hypothesis of<br>means<br>"t" test | Calculated "t" | Accept hypothesis<br>at 10% level of<br>significance |
|-----------------------|---------------------------|-------------|-------|-------------------------------|-------------|-------|-----------|------------------------------------------------------------------------------|------------------------------------|----------------|------------------------------------------------------|
|                       | $N_1$                     | $\bar{X}_1$ | $S_1$ | $N_2$                         | $\bar{X}_2$ | $S_2$ |           |                                                                              |                                    |                |                                                      |
| Fe                    | 46                        | 2.09        | 2.23  | 235                           | 1.39        | 1.67  | 1.34      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 2.45           | yes                                                  |
| Ca                    | 42                        | 85.1        | 18.74 | 223                           | 79.8        | 21.87 | .857      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 1.48           | yes                                                  |
| Mg                    | 42                        | 29.1        | 8.10  | 229                           | 27.6        | 11.13 | .728      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | .866           | no                                                   |
| Na                    | 42                        | 12.7        | 14.02 | 218                           | 14.3        | 17.4  | .805      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | -.747          | no                                                   |
| K                     | 42                        | 1.68        | .91   | 206                           | 2.69        | 2.29  | .397      | no                                                                           | --                                 | --             | --                                                   |
| HCO <sub>3</sub>      | 50                        | 360         | 70.2  | 252                           | 376         | 66.1  | 1.06      | yes                                                                          | $\bar{X}_1 < \bar{X}_2$            | -1.49          | yes                                                  |
| SO <sub>4</sub>       | 49                        | 41.7        | 32.05 | 241                           | 34.2        | 40.30 | .795      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 1.32           | yes                                                  |
| Cl                    | 47                        | 8.6         | 15.3  | 245                           | 6.1         | 11.10 | 1.37      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 1.37           | yes                                                  |
| SO <sub>4</sub> /Cl   | 47                        | 10.2        | 11.48 | 221                           | 8.7         | 10.75 | 1.06      | yes                                                                          | $\bar{X}_1 = \bar{X}_2$            | .857           | yes                                                  |

Where: N = Number of samples  
 $\bar{X}$  = Average value of the samples  
S = Standard deviation of the samples  
t = Calculated statistic

sulfate-chloride ratio are the same in both formations. The variance of the potassium concentration was too large for comparison. Iron, calcium, sulfate and chloride concentrations are greater in the glacial drift while bicarbonate is less.

Differences in concentrations of major ions between glacial drift wells and wells in the Saginaw Formation can be observed in individual analyses by comparing wells 02N03E14CBA and 02N03E14CBAB1, 05N02W27CCAB1 and 05N02W27CCAD1, 06N02W29BAAA1 and 06N02W29BAAA2, and 07N02W15CBAA1 and 07N02W15CBAB1 (Table A-1). These are pairs of wells drilled adjacent to each other; one well of each pair is in glacial drift, the other is in a rock formation. In every case, the water obtained from the glacial drift well contains greater concentration of major ions than does the well finished in rock. The hydraulic head, based upon topographic relief, in all of these paired wells indicate the water is moving from the glacial drift into the consolidated rock formation.

Difference in concentration of certain chemical parameters between the glacial drift and the Saginaw Formation is perplexing. It was demonstrated that the soil and glacial material were the source of most of the major ions in the water and that hydrologically the Saginaw Formation is recharged by water from the glacial drift. It might be assumed that the water in the Saginaw Formation would be equally mineralized. It might be of a different

chemical type of water through ion exchange or solution of soluble salts, but it would not be expected to be lower in most dissolved species than the recharging water. Most of the differences in water chemistry between the formations, that cannot be explained, exist in the sulfate and chloride concentrations and the apparent concentration of some ions in water from many wells in the glacial drift. Differences in iron, calcium, sodium and bicarbonate concentrations could be explained by cation exchange in varying degrees, but the fact that sulfate and chloride concentrations are lower in water from the Saginaw Formation yet remain in the same ratio as in water from the glacial drift is unusual.

#### Explanation of Observed Distribution

Pre-Pleistocene age water.--Several possibilities exist that may explain the differences between the water chemistry in the two formations. Water from the Saginaw Formation may not be of Pleistocene age; but rather it may be water remaining in the formation from a period before the glacial cover. The hydrology does not support this hypothesis, but the water has not been dated by radiometric techniques. The potentiometric surface of the Saginaw Formation follows the present land surface, indicating that recharge and discharge are presently taking place. Additionally, Wheeler (1967) demonstrated that the Saginaw

system in the Lansing area before extensive pumping was in dynamic equilibrium, with recharge equalling discharge. From these considerations it seems very unlikely that the water is of pre-Pleistocene age.

Selected areas of recharge.--Another possibility is, that water is recharged to the Saginaw Formation at the outcrops and in zones where the glacial drift is composed of coarse sand and gravels which contain few chloride or sulfate minerals. Again this hypothesis is not compatible with the hydrology of the system. The potentiometric surface conforms to the topographic surface, showing recharge is taking place over the entire area and not in selected areas. Also, the amount of outcrop area, or area covered by permeable "clean" sand and gravel, is very small (Johnsgard et al., 1942; Veatch et al., 1941) and totally insufficient for supplying the observed discharge.

Anion exchange.--A hypothesis of anion exchange could explain the lower concentrations but there is little experimental evidence to support it. This mechanism would remove sulfate and chloride and replace it with some other anion, presumably bicarbonate. From analogy with cation exchange it would be expected that there would be a greater exchange of either sulfate or chloride, yet the ratio remains the same in both formations. The clay minerals have negative surfaces, as suggested by cation exchange which would seem to preclude anion exchange in this system. Also this

process does not account for the concentrating effects of ions observed in water from many glacial drift wells.

Mineral reduction.--Sulfate could be removed from water by reduction to a sulfide mineral, if the redox potential were sufficiently low. Reduction probably occurs in small areas in the aquifer as hydrogen sulfide gas is detected in the wells occasionally and pyrite is observed in the coal beds in the Grand Ledge outcrop. However, redox potential is higher (more positive) in most of the aquifer than that required for pyrite formation. This is suggested in the section on mineral equilibrium. The most convincing evidence that sulfate reduction is not a major cause of lower sulfate concentration in the Saginaw Formation is that the sulfate-chloride ratio remains the same in both formations and no mechanism for the parallel decrease in chloride is available under these conditions. Also this hypothesis does not explain the ion-concentrating effects observed in water from many glacial wells.

Reverse osmosis and ultrafiltration.--The best explanation for the differences in water quality between the two formations and the apparent concentration effect in water from wells in glacial material involves a hypothesis that parts of the Saginaw Formation filter out certain ions as the water passes through them. It has been demonstrated that shales act as semipermeable membranes; that is, they allow the water to move through them but retard some of the dissolved solids in the water. An early mention of

membrane properties of natural geologic material was given by Wyllie (1948). Kemper (1961) demonstrated that osmotic pressure will occur on the high salt side of a clay membrane. McKelvey and Milne (1962) demonstrated reverse osmosis could occur in a natural clay sample as did Kemper and Maasland (1964). That is, the application of pressure to one side of a salt solution-clay membrane system results in salt removal and an increase in concentration on the high pressure side of the membrane. The process of reverse osmosis, using synthetic membranes, is one of several methods under investigation for desalination of water (Howe, 1966).

Breedehoeft et al. (1963) used the concept of ultrafiltration to explain the origin of brines in the Illinois basin. Graf et al. (1966) applied essentially the same concept, with some biological functions added, to explain the origin of the brines in the Michigan and Illinois basins. Jones (1968) explains the abnormal fluid pressure and relatively fresh water in some Neogene deposits in the Gulf of Mexico by a modification of this process.

There are several types of forces that can operate on a solution of dissolved solids separated by a semipermeable membrane. Chemical or normal osmosis, which depends upon different activities on either side of a semipermeable membrane, resulting in a mass transfer of water from the side of higher activity to the side of lower activity. Movement will continue until sufficient pressure (osmotic

pressure) is built up to prevent further transfer of water. Electroosmosis is a system in which the charged ionic species are driven by electrical potential through a semi-permeable membrane which retards some species while letting others pass through. The transfer of certain species will continue until the potential build up by the ions equals the potential applied across the membrane plus the chemical osmotic pressure that will develop as soon as a concentration gradient exists. Thermoosmotic systems operate when dissolved solids are separated by a semipermeable membrane with a temperature gradient across the membrane. The side with the greatest temperature will lose water to the lower temperature side but not certain ionic species. This process will continue until a chemical gradient of sufficient force is established that will cause the reaction to stop. The fourth process is one of gravity or reverse osmosis, that is, water is transmitted through a membrane by gravitational forces and the membrane retards the passage of certain ions. The transfer of water through the membrane will continue until the concentration of ions on the high potential side increases to the point where chemical osmosis would counter the driving force and all flow would stop. Reverse osmosis could occur in a natural or in an artificial recharge environment.

To determine if the hydraulic gradient observed between the glacial drift and the Saginaw Formation was larger than the osmotic pressure generated by the activity

difference between the formations, calculations of osmotic pressure were made using an approximation to the van't Hoff law

$$\pi = \frac{n_2 R T}{V}$$

where

$\pi$  = osmotic pressure

R = gas constant

T = absolute temperature

$n_2$  = number of moles difference across the membrane

V = volume of solution.

This approximation is probably valid because of the dilute solutions involved in this study. With an assumed difference in activity of 0.0001 moles which is typical for this system, the osmotic pressure is 0.08 feet, that is where the hydraulic head in the glacial drift is 0.08 feet higher than the Saginaw Formation, flow and ion filtering can occur. This small osmotic pressure is exceeded over most of the recharge area. Assuming 0.01 moles difference, which may exist at an interface where the dissolved solids have increased, the head necessary to overcome the osmotic pressure is one hundred times greater or 8 feet. This head difference is exceeded in many areas of the basin, however, in each area of investigation it is necessary to obtain detailed chemical analyses and hydraulic head data in order to determine if reverse osmosis is occurring.

The operation of reverse osmosis in the Saginaw Formation is illustrated in Figure 10. Many observations on ion distribution in the Saginaw ground-water system are included in this illustration. The soluble salts are leached from the glacial drift and filter out on shale lense. The water above the lense becomes concentrated in the ions removed by filtration. Wells in this zone yield water high in dissolved solids.

Comments by local drillers, that water quality is superior when wells are drilled using the hydraulic rotary methods of drilling instead of the cable tool method, are explained by assuming that the casing is cemented in the formation deeper and more securely with the rotary method. This difference in casing techniques could explain why wells 200 feet apart which have overlapping cones of depression and obtain water from the same depth yield water of different quality. Wells from the Saginaw Formation yielding the higher mineralized water have either poor casing cementing or are cased in a fractured rock that lets drift water directly into the well bore without benefit of ion filtering. This situation is emphasized in a recharge area where concentration of dissolved solids have built up over years of recharge. Highly mineralized water may then seep into the well drilled in this environment. The sudden deterioration in water quality reported by some owners is explained in assuming that the casing has rusted, letting water from the glacial drift into the well.

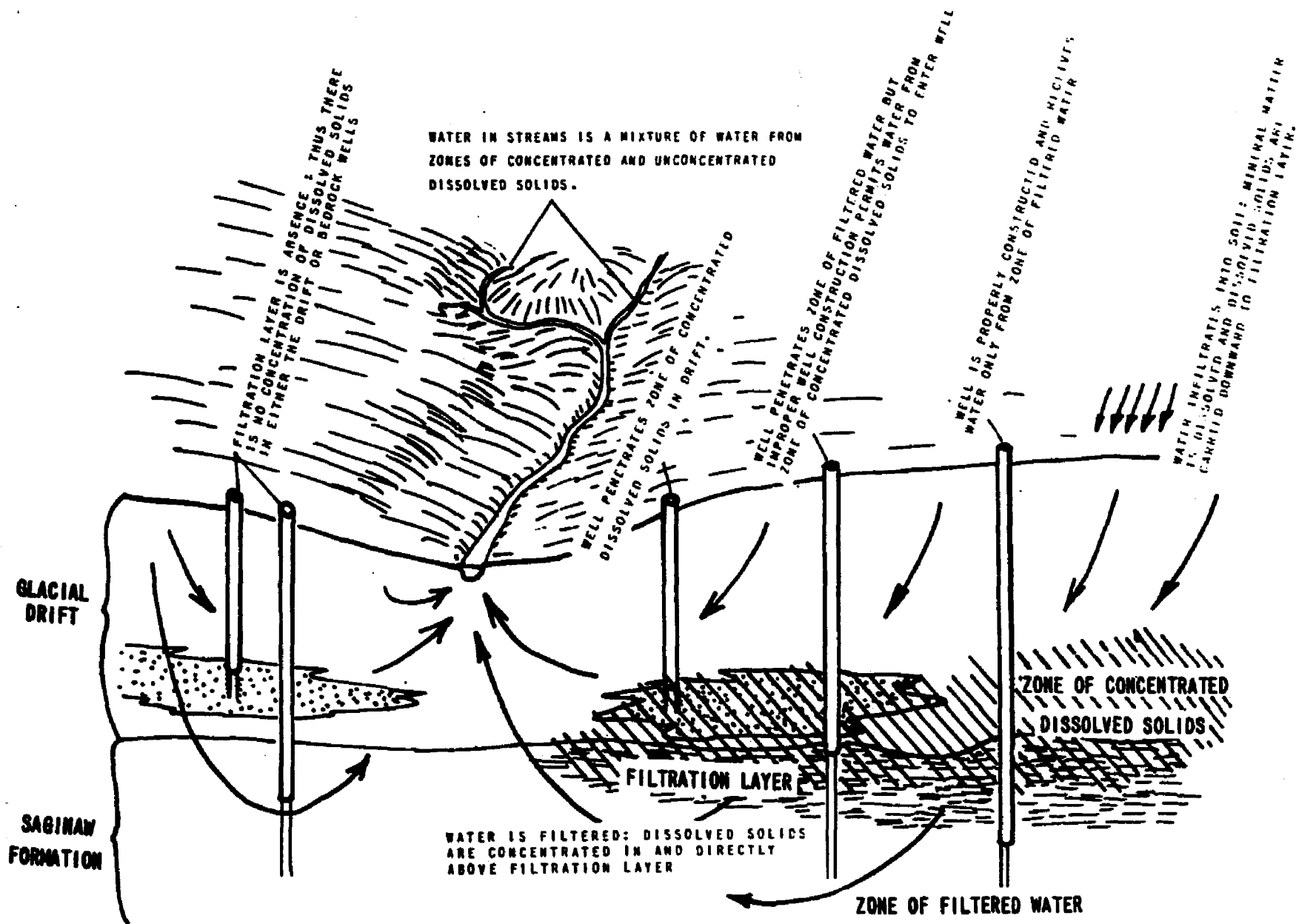


Figure 10.--Diagram showing process by which dissolved solids are concentrated by hydrology and geology.

The effects on chemical quality of water by different drilling methods was compared by the "t" test. No statistically significant difference between drilling methods was observed. It is probable, however, that casing techniques vary with individual drillers and obscures the true effect of drilling methods and consequently casing techniques. The effect of recharge and discharge as illustrated in Figure 10 also affects the chemical quality. However, it was assumed that each drilling method was affected equally.

Using the "t" test, wells cased the first 20 feet in sandstone were compared to wells cased the first 20 feet in shale. It was observed (Table 7) that sulfate, chloride and magnesium concentrations were greater in wells cased in sandstone than in shale and that calcium, sodium and bicarbonate were the same in both lithologic types. Iron, potassium, and the sulfate/chloride ratio varies too much to obtain a valid comparison of means. Results of this statistical analysis further suggests that the shale in the formation act as the ion filter.

The concept of reverse osmosis explains why the analysis of stream water is different from that of the Saginaw Formation yet the sulfate/chloride ratio remains the same. It also explains why the black shale in the leaching experiment yielded the high value of sulfate and chloride. In this environment near the bottom of a freshly dug pit from which the samples were taken for the leaching experiments, the hydraulic gradient is and has been for a

TABLE 7.--Statistical comparison of chemical parameter of water from wells cased in sandstone with those cased in shale of the Saginaw Formation.

| Chemical<br>parameter | Saginaw Formation           |       |       |                         |       |       | $S_1/S_2$ | Accept hypothesis<br>of equal variance<br>"F" test at 5%<br>level of signif. | Hypothesis of<br>means<br>"t" test | Calculated "t" | Accept hypothesis<br>at 10% level of<br>significance |
|-----------------------|-----------------------------|-------|-------|-------------------------|-------|-------|-----------|------------------------------------------------------------------------------|------------------------------------|----------------|------------------------------------------------------|
|                       | Wells cased<br>in sandstone |       |       | Wells cased<br>in shale |       |       |           |                                                                              |                                    |                |                                                      |
|                       | $N_1$                       | $X_1$ | $S_1$ | $N_2$                   | $X_2$ | $S_2$ |           |                                                                              |                                    |                |                                                      |
|                       |                             |       |       |                         |       |       |           |                                                                              |                                    |                |                                                      |
| Fe                    | 70                          | 1.53  | 2.11  | 69                      | 1.09  | 1.02  | 2.07      | no                                                                           | --                                 | --             | --                                                   |
| Ca                    | 68                          | 79.3  | 19.44 | 66                      | 75.2  | 22.51 | .864      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 1.15           | no                                                   |
| Mg                    | 69                          | 28.3  | 8.24  | 68                      | 25.1  | 8.40  | .981      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 2.26           | yes                                                  |
| Na                    | 67                          | 12.1  | 15.24 | 62                      | 15.4  | 17.51 | .870      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | -1.16          | no                                                   |
| K                     | 66                          | 2.00  | 1.32  | 64                      | 3.27  | 2.31  | .571      | no                                                                           | --                                 | --             | --                                                   |
| HCO <sub>3</sub>      | 73                          | 380   | 64.10 | 71                      | 384   | 60.70 | 1.06      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | - .432         | no                                                   |
| SO <sub>4</sub>       | 73                          | 35.2  | 39.09 | 72                      | 25.8  | 36.27 | 1.08      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 1.48           | yes                                                  |
| Cl                    | 73                          | 4.30  | 4.84  | 71                      | 3.03  | 3.81  | 1.27      | yes                                                                          | $\bar{X}_1 > \bar{X}_2$            | 1.74           | yes                                                  |
| SO <sub>4</sub> /Cl   | 65                          | 9.32  | 6.08  | 62                      | 8.65  | 11.81 | .515      | no                                                                           | --                                 | --             | --                                                   |

Where: N = Number of samples  
 $\bar{X}$  = Average value of the samples  
S = Standard deviation of the samples  
t = calculated statistic

long time down through the shale. The shale in this situation is acting as a semi-permeable membrane and trapping the sulfate and chloride ions along with associated cations. X-ray study of the shale from the pit gave no indication of the minerals gypsum, anhydrite or halite being present in this sample which suggests the substances are present in ionic or amorphous state and not in crystalline mineral form.

### Mineral Equilibria

#### Theory

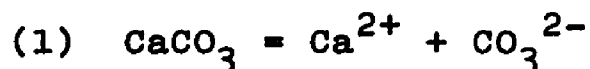
A study of equilibria between dissolved species in ground water and minerals in the aquifer aids in assessing the potential for precipitation or solution of minerals to occur in the aquifer. The hydrologic consequence of mineral precipitation in the skeletal framework of the aquifer is the reduction of storage and transmissivity of the aquifer. Conversely, solution of minerals from the aquifer will increase the transmissivity and the storage. Equilibrium concepts have been used as a tool for locating areas of recharge to an aquifer (Hanshaw, Back and Rubin, 1965). It is also apparent that mineral solution and precipitation will affect the water chemistry.

Attainment of equilibrium between minerals and ground water is generally slow, and metastable conditions may exist for long periods of time. However, the common carbonates, sulfates and iron hydroxides can, in general,

be evaluated by means of equilibrium concepts. The minerals evaluated in this study are the slightly soluble carbonates calcite, aragonite, dolomite and siderite ( $\text{FeCO}_3$ ) and the sulfates gypsum and anhydrite. The common chloride and nitrate minerals are extremely soluble and present in such small quantities that they would not be expected to control water chemistry by equilibrium process. In addition to siderite, other common iron minerals are evaluated for equilibrium by means of an Eh-pH diagram.

The thermodynamic model for this study was given by Back (1961, 1963), Hanshaw, Back and Rubin (1965), and Hem (1960a, 1960b) and is, essentially a method by which values calculated from analytical data are compared to known equilibrium values to determine if the water is in equilibrium with minerals in the aquifer. The following chemical equations describe the reaction of the mineral species where (a) is the activity. The activity of solid phases and water in dilute solution is assumed to be one. The equilibrium constants are given for 25°C and one atmosphere of pressure.

For calcite:



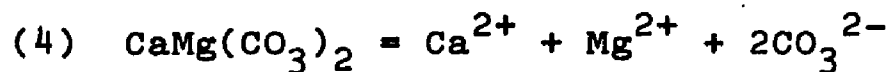
For which:

$$(2) \quad K_{sp} = (a \text{ Ca}^{2+})(a \text{ CO}_3^{2-}) = 10^{-8.35}$$

For aragonite:

$$(3) K_{sp} = 10^{-8.22}$$

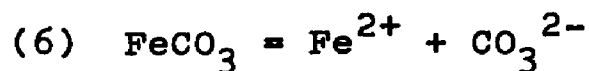
For dolomite:



For which:

$$(5) K_{sp} = (a \text{Ca}^{2+})(a \text{Mg}^{2+})(a \text{CO}_3^{2-})^2 = 10^{-16.7}$$

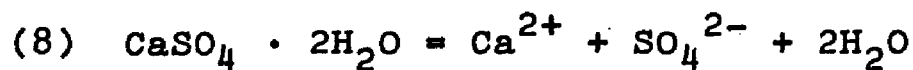
For siderite:



For which:

$$(7) K_{sp} = (a \text{Fe}^{2+})(a \text{CO}_3^{2-}) = 10^{-10.5}$$

For gypsum:



For which:

$$(9) (a \text{Ca}^{2+})(a \text{SO}_4^{2-}) = 10^{-4.6}$$

For anhydrite:

$$(10) K_{sp} = 10^{-4.5}$$

For the second ionization of carbonic acid:



The equilibrium constants of all species except dolomite were obtained from tables published in Krauskopf (1967). The equilibrium value of  $10^{-16.7}$  for dolomite was obtained from Hsu (1963).

To determine the activities of the various species of solution it is necessary to determine the total ionic strength of each solution by means of the following expression:

$$\mu = \frac{m_1 z_1^2}{2} + \frac{m_2 z_2^2}{2} \dots + \frac{m_i z_i^2}{2}$$

where

$\mu$  = ionic strength

$m$  = molar concentration of species 1, 2, ..., i

$z$  = charge on ion

Computation has been simplified by Hem (1961) who developed a nomograph that was used in this study. Values of ionic strength were utilized in the Debye-Huckel equation (given below) for the determination of activity coefficients ( $\gamma$ ) for each ion:

$$\log \gamma_i = \frac{-Az_i^2 \sqrt{\mu}}{1 + Ba_i \sqrt{\mu}}$$

where

A, B and a are temperature dependent constants tabulated by Klotz (1950)

$\mu$  = ionic strength

$z$  = charge on ion of species  $i$

$a_i$  = activity coefficient of species  $i$

Hem (1961) has also developed a graphical procedure for the solution of this equation which was used in this study. The ion activity product,  $K_{iap}$ , was calculated from the concentration of the ions, in moles/1000 gms  $H_2O$  (which in the dilute solutions considered here can be assumed equal to moles/liter) and from the activity coefficients derived from Hem (1961) using the equation

$$K_{iap} = (\gamma_i)(m_i)(\gamma_j)(m_j)$$

where  $i$  and  $j$  are the dissolved species considered. The results are found in Table A-3. Before these values could be compared with the theoretical values, the latter values were adjusted to the temperature of the aquifer ( $11^\circ C$ ) by means of the van't Hoff equation

$$\frac{d \ln K}{dt} = \frac{\Delta H}{RT^2}$$

where

$K$  = equilibrium constant

$T$  = absolute temperature

$R$  = gas constant

$\Delta H$  = heat of solution

The integrated form of this equation assumes that  $\Delta H$  remains constant through the range in temperature under consideration. This assumption is probably valid for this study as the temperature changes are only  $14^{\circ}\text{C}$  from the reference temperatures.

### Data Analysis

The ratio of the  $K_{\text{lap}}$  to  $K_{\text{sp}}$  for each of the species is given in Table A-3. A ratio is greater than 1 suggests the water is supersaturated with respect to that mineral, and precipitation may occur. If the ratio is less than 1, the water is undersaturated with respect to the mineral and solution of that mineral in the aquifer is possible. Because of some uncertainty in chemical analyses and in pH determinations, ratios of 0.8 to 1.2 are considered to be in the range of equilibrium. pH was determined in the field at the time of collection but sampling through plumbing could change pH by as much as 0.1 pH unit. This could in turn change the degree of saturation by as much as 0.5.

Most wells sampled in this investigation show saturation or supersaturation with respect to calcite and dolomite and generally undersaturated with respect to aragonite (Table A-3). There appears to be no relationship between degree of saturation and whether the well is located in a recharge or discharge area as was observed by Hanshaw, Back, and Rubin (1965). Nor is there any

apparent difference in saturation between wells in the glacial formation and wells in the Saginaw Formation. This is expected, because it was demonstrated earlier that the water obtains its dominant chemical characteristic within the soil glacial material. It would appear that solution of calcite in the Saginaw Formation is unlikely while precipitation of calcite is possible, particularly, on the filter layers where concentration of calcium and bicarbonate should be the highest.

The apparent greater degree of supersaturation of the dolomite compared to the calcite may result from a poor choice of the equilibrium constant. Perhaps the value should be closer to  $2.5$  or  $3.0 \times 10^{-17}$  instead of  $10^{-16.7}$ . Dolomite has not been observed to precipitate in an environment similar to the one under study; however, it may form by replacement of magnesium for calcium in freshly precipitated calcite or aragonite. It can only be stated that the water in the aquifer is probably saturated with respect to dolomite and solution of dolomite is therefore unlikely. Gypsum and anhydrite are understaturated and the water would be expected to dissolve these minerals if they exist in the aquifer.

The factors controlling the solubility of iron are more complex than the solution-precipitation equilibrium of the common carbonates and sulfates because of the existence of two oxidation states trivalent (ferric) and divalent (ferrous). Diagrams of stability fields for

aqueous systems containing iron, bicarbonate and sulfate have been constructed by Hem (1960a, b). These diagrams utilize Eh (redox potential), pH and various concentrations of the dissolved species to illustrate the equilibrium position of the common iron minerals. Figure 11 was constructed using the techniques suggested by Hem (1959) and Garrels and Christ (1965) and covers the range in parameters found in this study. Figure 11 was constructed for conditions of 11°C, one atmosphere pressure, sulfur  $10^{-3}$  m and bicarbonate species  $10^{-2.5}$ .

If three control parameters, species concentration, pH and Eh are known it would be possible to read directly from the graph to determine if the water was in equilibrium with the mineral present. However, Eh values were not determined in this study because the method of sampling was unsuitable for accurate Eh determinations. Through indirect methods it is possible to estimate the Eh, and therefore use the diagram for determining the degree of equilibrium of the water to the mineral species. From Hem and Cropper (1959) it is known that iron rapidly attains equilibrium with its environment and, therefore, the iron determined must be in the ferrous state because the solubility of ferric iron at the pH of the samples is below the limit of detection by analytical procedures used in this study. Iron is also observed to precipitate as ferric hydroxide on exposure to the atmosphere which further supports the assumption of a ferrous oxidation

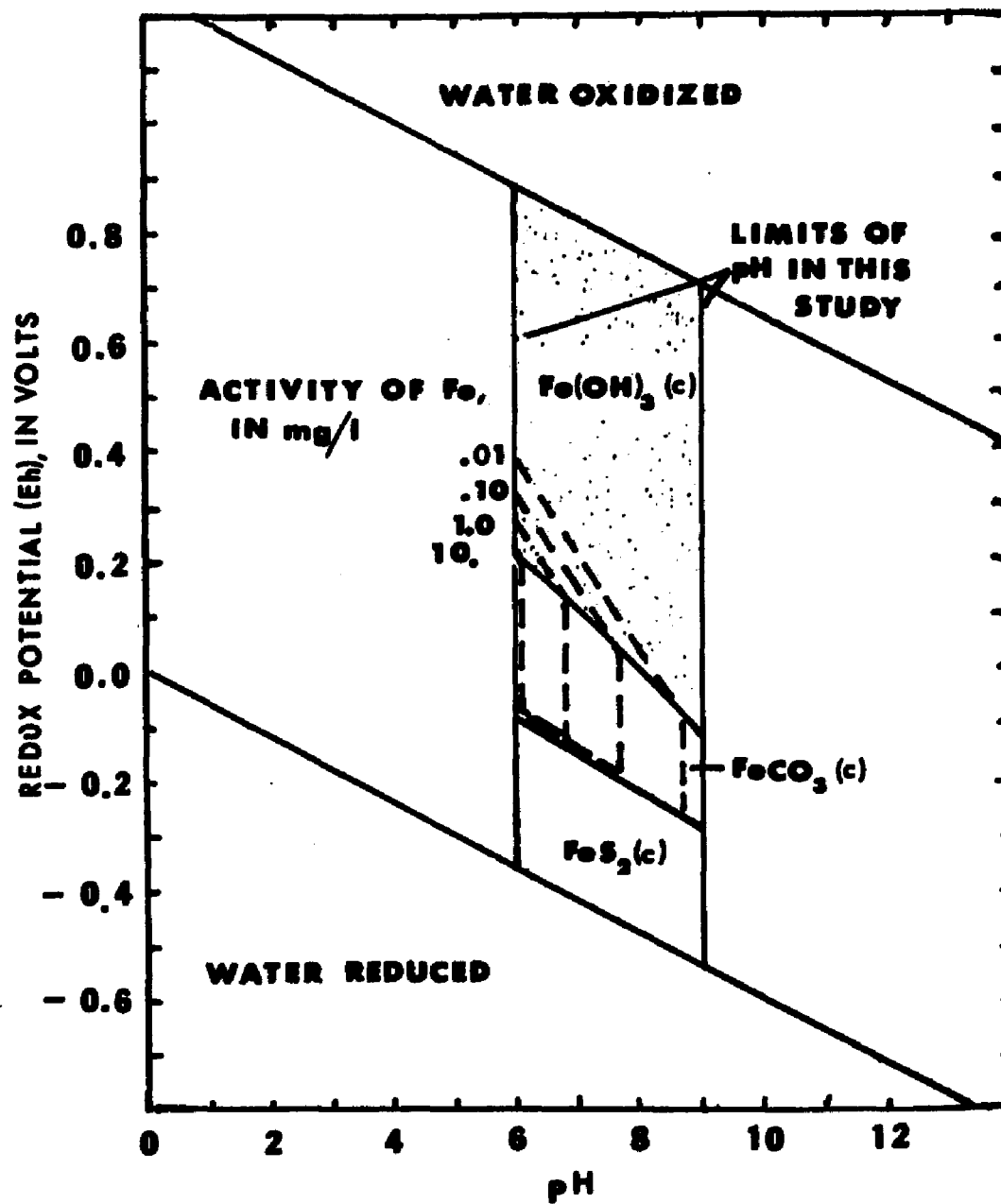


Figure 11.--Graph showing solubility of iron in relation to pH and Eh at 11°C and one atmosphere pressure. Total dissolved sulfur  $10^{-3}$  m, bicarbonate species  $10^{-2.5}$  m (modified after Hem, 1960a).

state. From Figure 11 it is shown at the observed pH and iron concentration that the ferrous ion must be in equilibrium with pyrite ( $\text{FeS}_2$ ) siderite ( $\text{FeCO}_3$ ) or ferric hydroxide  $\text{Fe}(\text{OH})_3$ . The problem then is which mineral controls the water chemistry. Further indirect inference from the water analyses shows that  $\text{SO}_4^{2-}$  ion is the dominant sulfur ion and its stability field corresponds with that of siderite and ferric hydroxide and not pyrite. It could be argued that the sulfate resulted from the oxidation of  $\text{HS}^-$  ion, which is in equilibrium with pyrite, after collection but before analysis. However, this process would release  $\text{H}^+$  and lower the pH of the solution. The well water is observed to increase and not decrease in pH on exposure to air so it would not appear  $\text{HS}^-$  is the dominant sulfur ion. It was also noticed that hydrogen sulfide gas ( $\text{H}_2\text{S}$ ) was present in several wells in amounts too small to detect analytically. This is the sulfur species in equilibrium with pyrite at pH below 7. This does not indicate that the system was out of equilibrium because some hydrogen sulfide gas can exist at higher pH and Eh but it is not the dominant species. The presence of  $\text{H}_2\text{S}$  gas does indicate that the redox potential is close to the pyrite boundary in these wells. It would be expected that wells which show the trace amounts of  $\text{H}_2\text{S}$  may have  $\text{HS}^-$  present and may consequently oxidize to  $\text{SO}_4^{2-}$ .

Calculations were made to determine the degree of saturation with the three mineral species. It was found

that iron was oversaturated with respect to pyrite and ferric hydroxide in all cases. It was in general in equilibrium with siderite and it appears that siderite controls the iron chemistry in the aquifer. Equilibrium calculation for siderite are given in Table A-3. Supporting the contention that siderite is the mineral controlling the iron chemistry is the observation by Kelly (1936) of iron carbonate nodules in the Saginaw Formation. Ferric hydroxide and pyrite may be important locally in controlling the iron chemistry of the aquifer. The Eh is probably very close to the boundary between siderite and pyrite on Figure 11. This condition is illustrated by a sample of Bayport Formation collected at the Bellvue quarry adjacent to the study area. The sample shows signs of fresh siderite and pyrite deposited beside each other. The Eh may change annually due to temperature changes effecting the carbonate system or due to recharging water not containing as much soil carbon dioxide during the growing season. Perhaps the changes are not annual but are a function of the geochemical changes that occurred since Pleistocene time. The addition of organic material and fresh unweathered soluble material are changing continuously in this geologically immature environment. The entire geochemical system may be out of equilibrium because of the rapid changes of type and amount of material in the geological cover.

An example of the equilibrium changes that occur in well water when it is discharged to atmospheric conditions is given in Figure 12. Here water obtained from four typical wells was allowed to stand in beaker covered with watch glasses and the specific conductance was measured each day until no further changes were observed. Immediately after collection, when the sample warmed to room temperature ( $23^{\circ}\text{C}$ ), the pH changed to about 8.4. At the end of the second day precipitation of calcite crystals (determined by X-ray) and amorphous ferris hydroxide were visible. It can be seen that the dissolved solids, as a function of specific conductance, decreased by almost 40 per cent in these samples as the precipitation continued. This change is explained by carbon dioxide escaping from the water. The loss of carbon dioxide caused a reduction in hydrogen ion concentration and consequent precipitation of calcite. Iron was oxidized from soluble ferrous ions to insoluble ferric hydroxide on exposure to oxygen in the atmosphere.

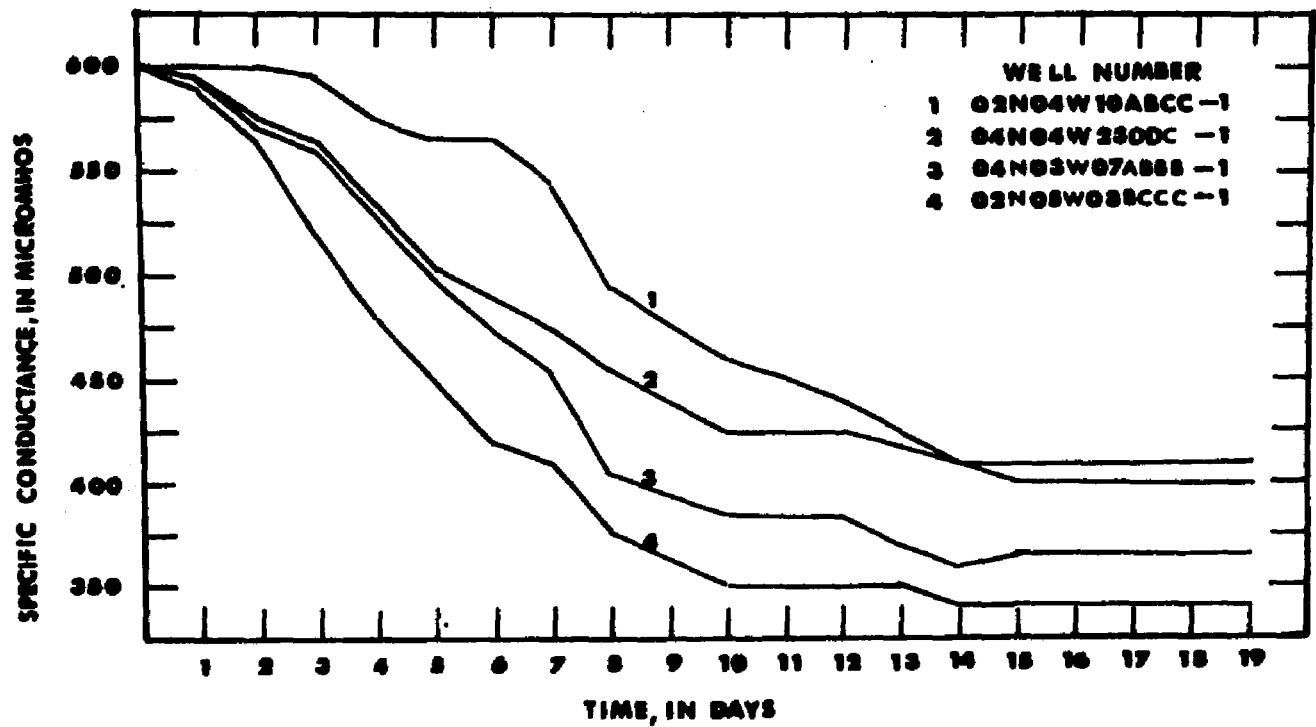


Figure 12.--Graph showing change in specific conductance of well water with time, on exposure to the atmosphere.

## SUMMARY AND CONCLUSIONS

Several processes which affect the chemical quality of the ground water have been observed to operate in the Saginaw aquifer system. Atmospheric precipitation containing relatively small amounts of dissolved solids fall upon soil and glacial material. Approximately 76 per cent of this total water input is lost by evapotranspiration which has the effect of concentrating the dissolved solids in the remaining water. Evapotranspiration concentration processes, however, cannot account for the observed concentration of dissolved solids. Most of the dissolved solids in the ground water are obtained from the reaction of atmospheric precipitation with minerals in the glacial material and chemically active soil zone. Approximately 42 per cent of the water not lost to evapotranspiration discharges to the streams as surface runoff and the remainder seeps into the soil and eventually becomes ground water. The dissolved solids from ground-water discharge in the Upper Grand River basin annually averages approximately 481,000 tons while that from surface-water runoff averages 305,000 tons.

Approximately 6/7 of the water entering the glacial drift is discharged as base flow before it reaches the

Saginaw Formation. The remaining ground water enters the Saginaw Formation and is ion filtered as it passes through shale zones in the formation. As a result of this filtration the water produced from the Saginaw Formation often contains fewer dissolved solids than the water recharging to the formation. Concentrations of dissolved solids increase within and adjacent to the filter zone and consequently the mineral equilibrium is shifted and calcium and iron carbonates are probably precipitated. Calcium and magnesium ions that pass into the shale zone are subject to ion exchange for sodium by the clay minerals in the shale zone which further changes the chemical composition of the water.

The geochemical process of ion filtering is presently in a steady state condition over the natural undeveloped areas of the basin. That is, the amount of dissolved solids concentrated annually by water filtering through shale lenses is removed by local flow cells and lateral movement of the ground water at the filtration interface. This dynamic equilibrium condition can be shown to exist by comparing the concentration of chloride and sulfate at high and low stream flow. If these species were being removed from the recharging water and concentrated on the filtration layers, low stream flow would have smaller concentrations of these species than high stream flow. However, it was shown in Table 3 that the concentrations of these species are the same, hence the system must be in

dynamic equilibrium. In areas of the aquifer where pumping is extensive the flow lines through the overlying glacial material are vertical, concentrations of dissolved solids may be increasing with time. The Lansing Metropolitan area is an example of this hydrologic situation in which the concentration of dissolved solids may reach a point in which osmotic pressure reduces recharge to the Saginaw Formation through the glacial drift.

Ion exchange process operating in this aquifer system are not in a steady state condition. The annual amount of sodium exchanged is almost certainly decreasing with time, as there are a finite amount of exchange sites available in the clay minerals. The present annual yield of exchanged sodium is approximately 2,700 tons. If the yield were known at some other point in the distant past, then a prediction could be made as to when in the future the process should have negligible influence on the chemical composition of the ground water. However, the historical data necessary for this analysis are not available. The process can, however, be considered in a steady state condition for purposes of water management.

The steady state condition of the ion filtration process effects the mineral solution and precipitation process. The lateral movement and local flow cells which prevent the increase of dissolved solids in the filtration zones also prevent the concentration of many ions from reaching supersaturation and consequent precipitation.

Calcium and iron carbonates are probably, however, being deposited in some ion filter zones with probable reduction of the permeability. The precipitation process may be the factor which will ultimately reduce recharge to the Saginaw Formation through the glacial drift. However, when viewed from the time scale utilized by man for water management purposes it is of little concern. In areas where dissolved solids in the filter zone continue to increase with time as is probably occurring in the Lansing Metropolitan area, mineral precipitation may reduce the recharge to the Saginaw Formation through the glacial drift.

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## APPENDIX

TABLE 1. Chemical analyses of ground water

Results in milligrams per liter except as indicated. Agency making analyses: (1) U.S. Geological Survey, (3) Michigan Department of Public Health, (7) Department of Geology Michigan State University. Aquifer: NISA-Saginaw Formation Q800-glacial drift, N10R-Grand River group, N10M-Marshall Formation, N10N=Michigan Formation, N30M-Bayport Formation.

| LOCAL WELL NUMBER | DEPTH, FEET | ANALYST | DATE OF COLLECTION | TEMPERATURE (°F) | SILICA (SiO <sub>2</sub> ) | IRON (PPM) | CALCIUM (CA) | MAGNESIUM (MG) | SODIUM (NA) | POTASSIUM (K) | STRONTIUM (SR) | SULFATE (SO <sub>4</sub> ) | CHLORIDE (CL) | FLUORIDE (F) | NITRATE (NO <sub>3</sub> ) | DISCLOSED SPECIES |                | HARDNESS AS CaCO <sub>3</sub> |                | TDS (PPM)   |                     | PH | ANALYST |
|-------------------|-------------|---------|--------------------|------------------|----------------------------|------------|--------------|----------------|-------------|---------------|----------------|----------------------------|---------------|--------------|----------------------------|-------------------|----------------|-------------------------------|----------------|-------------|---------------------|----|---------|
|                   |             |         |                    |                  |                            |            |              |                |             |               |                |                            |               |              |                            | CALCIUM (CA)      | MAGNESIUM (MG) | CALCIUM (CA)                  | MAGNESIUM (MG) | TOTAL (TDS) | NON-CALC (NON-CALC) |    |         |
| CLINTON COUNTY    |             |         |                    |                  |                            |            |              |                |             |               |                |                            |               |              |                            |                   |                |                               |                |             |                     |    |         |
| 05N01W14AAA 1     | 505         | NISA    | 03 11 65           | 45               | .....                      | 1.0        | .....        | .....          | .....       | .....         | .....          | 310                        | 45            | 12           | .....                      | .....             | .....          | 260                           | 6              | 421         | 7.6                 | 1  |         |
| 05N01W17000 2     | 378         | OGUO    | 03 11 65           | .....            | .....                      | .....      | .....        | .....          | .....       | .....         | .....          | 308                        | 27            | 2.0          | .....                      | .....             | .....          | 264                           | 11             | 418         | 7.5                 | 1  |         |
| 05N01W18000 1     | 220         | NISA    | 11 30 67           | .....            | .....                      | .....      | 67           | 14             | 18          | 4.9           | .....          | 306                        | 4.0           | 3.2          | .....                      | .....             | 274            | 225                           | 0              | .....       | 7.62                | 7  |         |
| 05N01W23000 1     | 300         | NISA    | 03 11 65           | 42               | .....                      | 2.2        | .....        | .....          | .....       | .....         | .....          | 284                        | 35            | 4.0          | .....                      | .....             | .....          | 242                           | 0              | 415         | 7.6                 | 1  |         |
| 05N01W24000 1     | 76          | OGUO    | 03 11 65           | .....            | .....                      | .....      | 3.0          | .....          | .....       | .....         | .....          | 276                        | 12            | 6.0          | .....                      | .....             | .....          | 242                           | 0              | 421         | 7.5                 | 1  |         |
| 05N01W2700 1      | 175         | NISA    | 03 06 45           | .....            | 4.0                        | 2.0        | 121          | 17             | 22          | .....         | .....          | 256                        | 150           | 9.0          | .....                      | .....             | 487            | 372                           | 161            | .....       | .....               | 1  |         |
| 05N01W2900 1      | 161         | NISA    | 03 09 45           | .....            | 8.6                        | 4.0        | 64           | 23             | 12          | .....         | .....          | 332                        | 5.3           | 4.0          | .....                      | .....             | 281            | 257                           | 0              | .....       | .....               | 1  |         |
| 05N02W0500 1      | 200         | NISA    | 01 17 45           | .....            | 17                         | 3.0        | 73           | 24             | 5.0         | .....         | .....          | 345                        | 4.4           | 4.0          | .....                      | .....             | 317            | 302                           | 2              | .....       | .....               | 1  |         |
| 05N02W0900 1      | 44          | OGUO    | 04 26 67           | .....            | .....                      | 4.4        | 45           | 24             | 6.5         | 1.4           | .....          | 344                        | 27            | 2.5          | .....                      | .....             | 344            | 427                           | 3              | .....       | 7.62                | 7  |         |
| 05N02W1300 1      | 160         | NISA    | 01 22 45           | .....            | 6.0                        | 3.0        | 61           | 14             | 13          | .....         | .....          | 346                        | 2.6           | 4.0          | .....                      | .....             | 244            | 231                           | 0              | .....       | .....               | 1  |         |
| 05N02W16AAA 1     | 260         | NISA    | 04 22 67           | .....            | .....                      | 4.0        | 55           | 14             | 20          | 4.2           | .....          | 410                        | 3.2           | 2.0          | .....                      | .....             | 244            | 294                           | 40             | .....       | 7.75                | 7  |         |
| 05N02W1800 1      | 215         | NISA    | 06 22 67           | .....            | .....                      | 6.0        | 58           | 19             | 18          | 3.1           | .....          | 318                        | 2.4           | 1.5          | .....                      | .....             | 240            | 273                           | 0              | .....       | 7.54                | 7  |         |
| 05N02W2000 1      | 217         | NISA    | 01 17 45           | .....            | 4.6                        | 2.0        | 42           | 16             | 17          | .....         | .....          | 301                        | 2.0           | 4.0          | .....                      | .....             | 254            | 214                           | 0              | .....       | .....               | 1  |         |
| 05N02W2200 1      | 192         | NISA    | 01 18 45           | .....            | 17                         | 4.0        | 71           | 29             | 8.3         | .....         | .....          | 474                        | 2.5           | 4.0          | .....                      | .....             | 411            | 247                           | 0              | .....       | .....               | 1  |         |
| 05N02W2200A 1     | 225         | NISA    | 04 04 68           | .....            | .....                      | 4.0        | 68           | 20             | 9.0         | 3.2           | .....          | 312                        | 8.0           | 1.3          | .....                      | .....             | 244            | 252                           | 0              | .....       | 7.70                | 7  |         |
| 05N02W2200C 1     | 230         | NISA    | 03 28 68           | .....            | .....                      | 1.0        | 62           | 22             | 20          | 3.6           | .....          | 308                        | 19            | 5.4          | .....                      | .....             | 244            | 244                           | 0              | .....       | 7.14                | 7  |         |
| 05N02W27CAA 1     | 85          | OGUO    | 03 28 68           | .....            | .....                      | 3.0        | 106          | 34             | 25          | 1.4           | .....          | 354                        | 81            | 4.8          | .....                      | .....             | 474            | 405                           | 115            | .....       | 7.15                | 7  |         |
| 05N02W27C00 1     | 240         | NISA    | 03 28 68           | .....            | .....                      | 2.4        | 57           | 13             | 21          | 4.4           | .....          | 290                        | 11            | 1.5          | .....                      | .....             | 244            | 194                           | 0              | .....       | 7.19                | 7  |         |
| 05N02W27CCAB 1    | 105         | OGUO    | 04 04 68           | .....            | .....                      | 7.2        | 76           | 18             | 12          | 4.2           | .....          | 307                        | 37            | 2.0          | .....                      | .....             | 304            | 264                           | 12             | .....       | 7.62                | 7  |         |
| 05N02W27CCAD 1    | 240         | NISA    | 03 28 68           | .....            | .....                      | 8.0        | 83           | 25             | 9.0         | 3.0           | .....          | 345                        | 8.0           | 1.2          | .....                      | .....             | 320            | 310                           | 0              | .....       | 7.10                | 7  |         |
| 05N02W27CDBA 1    | 92          | OGUO    | 03 28 68           | .....            | .....                      | 1.3        | 80           | 21             | 12          | 3.7           | .....          | 341                        | 17            | 1.5          | .....                      | .....             | 310            | 284                           | 0              | .....       | 7.25                | 7  |         |
| 05N02W28000A 1    | 190         | NISA    | 04 04 68           | .....            | .....                      | 2.0        | 93           | 24             | 9.0         | 2.0           | .....          | 370                        | 44            | 4.3          | .....                      | .....             | 380            | 331                           | 61             | .....       | 7.56                | 7  |         |
| 05N02W2800C 1     | 200         | NISA    | 03 28 68           | .....            | .....                      | 3.0        | 129          | 38             | 7.5         | 1.4           | .....          | 417                        | 140           | 6.7          | .....                      | .....             | 542            | 474                           | 134            | .....       | 7.12                | 7  |         |
| 05N02W2900 1      | 135         | NISA    | 03 06 45           | .....            | 7.8                        | 6.0        | 77           | 20             | 10          | .....         | .....          | 307                        | 24            | 9.0          | .....                      | .....             | 403            | 273                           | 21             | .....       | .....               | 1  |         |
| 05N02W33AAA 1     | 120         | NISA    | 04 04 68           | .....            | .....                      | 1.1        | 74           | 18             | 12          | 3.4           | .....          | 292                        | 44            | 2.2          | .....                      | .....             | 307            | 269                           | 0              | .....       | 7.40                | 7  |         |
| 05N02W33ABAB 1    | 245         | NISA    | 03 28 68           | .....            | .....                      | 7.0        | 127          | 34             | 8.0         | 4.4           | .....          | 344                        | 170           | 1.9          | .....                      | .....             | 512            | 444                           | 174            | .....       | 7.23                | 7  |         |
| 05N02W33ACR 1     | 200         | NISA    | 03 28 68           | .....            | .....                      | 4.5        | 74           | 20             | 8.0         | 2.3           | .....          | 317                        | 72            | 1.4          | .....                      | .....             | 264            | 247                           | 7              | .....       | 7.20                | 7  |         |
| 05N02W33BAAA 1    | 235         | NISA    | 03 28 68           | .....            | .....                      | 1.2        | 184          | 42             | 14          | 7.2           | .....          | 341                        | 342           | 7.5          | .....                      | .....             | 774            | 632                           | 334            | .....       | 7.14                | 7  |         |
| 05N02W33C00 1     | 231         | NISA    | 04 04 68           | .....            | .....                      | 4.5        | 178          | 51             | 10          | 2.5           | .....          | 510                        | 244           | 25           | .....                      | .....             | 767            | 654                           | 228            | .....       | 7.21                | 7  |         |
| 05N02W35AA 1      | 180         | NISA    | 03 01 45           | .....            | 7.2                        | 1.5        | 60           | 24             | 24          | .....         | .....          | 312                        | 7.1           | 4.0          | .....                      | .....             | 400            | 290                           | 0              | .....       | .....               | 1  |         |
| 05N03W05CC00 1    | 180         | N1GR    | 06 13 68           | .....            | .....                      | 7.3        | 60           | 24             | 14          | 1.4           | .....          | 451                        | 11            | 1.2          | .....                      | .....             | 284            | 257                           | 1              | .....       | 7.30                | 7  |         |
| 05N03W100A 1      | 279         | NISA    | 01 18 45           | .....            | 16                         | 6.0        | 97           | 38             | 1.9         | .....         | .....          | 424                        | 27            | 4.0          | .....                      | .....             | 407            | 401                           | 24             | .....       | .....               | 1  |         |
| 05N03W130C 1      | 178         | NISA    | 01 18 45           | .....            | 7.4                        | 3.0        | 64           | 23             | 12          | .....         | .....          | 333                        | 2.5           | 5.0          | .....                      | .....             | 470            | 254                           | 0              | .....       | .....               | 1  |         |
| 05N03W15ARCC 1    | 160         | NISA    | 04 13 68           | .....            | .....                      | 6.0        | 100          | 33             | 4.0         | 1.5           | .....          | 441                        | 8.0           | 1.3          | .....                      | .....             | 376            | 356                           | 4              | .....       | 7.28                | 7  |         |
| 05N03W15C0 1      | 144         | NISA    | 03 07 45           | .....            | 13                         | 3.0        | 76           | 26             | 4.4         | .....         | .....          | 404                        | 5.1           | 4.0          | .....                      | .....             | 344            | 295                           | 1              | .....       | .....               | 1  |         |
| 05N03W18AAA 1     | 154         | NISA    | 06 13 68           | .....            | .....                      | 1.4        | 90           | 32             | 9.5         | 2.2           | .....          | 454                        | 8.0           | 1.1          | .....                      | .....             | 410            | 347                           | 1              | .....       | 7.40                | 7  |         |
| 05N03W18CCAA 1    | 140         | NISA    | 06 13 68           | .....            | .....                      | 4.7        | 82           | 27             | 5.5         | 2.1           | .....          | 404                        | 9.1           | 1.0          | .....                      | .....             | 410            | 310                           | 1              | .....       | 7.22                | 7  |         |
| 05N03W21000 1     | 220         | NISA    | 06 22 67           | .....            | .....                      | 6.0        | 70           | 26             | 14          | 4.3           | .....          | 400                        | 4.4           | 2.0          | .....                      | .....             | 341            | 294                           | 1              | .....       | 7.72                | 7  |         |
| 05N03W23000A 1    | 180         | NISA    | 06 13 68           | .....            | .....                      | 4.3        | 77           | 25             | 15          | 4.8           | .....          | 386                        | 4.0           | 1.4          | .....                      | .....             | 323            | 225                           | 0              | .....       | 7.40                | 7  |         |
| 05N03W240C 1      | 187         | NISA    | 03 01 45           | .....            | 10                         | 6.0        | 62           | 25             | 18          | .....         | .....          | 354                        | 1.4           | 5.0          | .....                      | .....             | 297            | 260                           | 0              | .....       | .....               | 1  |         |
| 05N03W2700 1      | 142         | NISA    | 06 13 68           | .....            | .....                      | 1.5        | 93           | 22             | 4.0         | 1.4           | .....          | 318                        | 42            | 1.9          | .....                      | .....             | 324            | 323                           | 61             | .....       | 7.52                | 7  |         |
| 05N03W29AA 1      | 164         | NISA    | 03 07 45           | .....            | 15                         | 6.0        | 109          | 24             | 5.2         | .....         | .....          | 474                        | 4.4           | 4.0          | .....                      | .....             | 410            | 323                           | 1              | .....       | .....               | 1  |         |
| 05N03W31C00 1     | 140         | NISA    | 08 08 67           | .....            | .....                      | .....      | .....        | .....          | .....       | .....         | .....          | 344                        | 3.4           | 4.0          | .....                      | .....             | 321            | 290                           | 0              | .....       | 7.7                 | 1  |         |
| 05N03W320C 1      | 264         | NISA    | 01 16 45           | .....            | 14                         | 5.0        | 40           | 34             | 2.5         | .....         | .....          | 444                        | 4.4           | 2.0          | .....                      | .....             | 356            | 356                           | 0              | .....       | .....               | 1  |         |
| 05N04W120000 1    | 140         | NISA    | 06 22 67           | .....            | .....                      | 2.5        | 115          | 43             | 12          | 2.2           | .....          | 434                        | 44            | 3.0          | .....                      | .....             | 547            | 506                           | 0              | .....       | 7.50                | 7  |         |
| 05N04W14AC0A 1    | 140         | NISA    | 06 06 68           | .....            | .....                      | 1.2        | 62           | 32             | 7.5         | 1.4           | .....          | 434                        | 12            | 1.1          | .....                      | .....             | 354            | 331                           | 0              | .....       | 7.22                | 7  |         |
| 05N04W14C00A 1    | 165         | NISA    | 06 06 68           | .....            | .....                      | 4.5        | 76           | 28             | 6.0         | 1.2           | .....          | 380                        | 11            | 1.7          | .....                      | .....             | 314            | 310                           | 0              | .....       | 7.19                | 7  |         |
| 05N04W19000A 1    | 120         | N1GR    | 02 16 65           | .....            | .....                      | 2.4        | .....        | .....          | .....       | .....         | .....          | 410                        | 14            | 1.5          | .....                      | .....             | 444            | 444                           | 0              | .....       | 7.40                | 1  |         |
| 05N04W190000 1    | 323         | NISA    | 02 16 65           | 42               | .....                      | .....      | .....        | .....          | .....       | .....         | .....          | 370                        | 434           | 120          | .....                      | .....             | .....          | 466                           | 0              | 18.0        | 7.4                 | 1  |         |
| 05N04W210000 1    | 304         | NISA    | 04 13 68           | .....            | .....                      | 2.4        | 78           | 24             | 9.5         | 1.4           | .....          | 412                        | 11            | 1.2          | .....                      | .....             | 334            | 310                           | 0              | .....       | 7.35                | 7  |         |
| 05N04W21000C 1    | 144         | NISA    | 04 13 68           | .....            | .....                      | 1.2        | 64           | 40             | 12          | 1.4           | .....          | 444                        | 49            | 14           | .....                      | .....             | 44             | 406                           | 26             | .....       | 7.40                | 7  |         |
| 05N04W240000 1    | 170         | NISA    | 04 13 68           | .....            | .....                      | 2.0        | 84           | 30             | 7.2         | 1.2           | .....          | 410                        | 44            | 2.8          | .....                      | .....             | 374            | 338                           | 6              | .....       | 7.62                | 7  |         |
| 05N04W24000C 1    | 140         | NISA    | 04 23 67           | .....            | .....                      | .....      | .....        | .....          | .....       | .....         | .....          | 444                        | 44            | 5.0          | .....                      | .....             | 342            | 315                           | 0              | .....       | 7.52                | 7  |         |



| LOCAL WELL NUMBER | DEPTH, FEET | AQUIFER | DATE OF COLLECTION | TEMPERATURE (°F) | SILICA (SIOP) | IRON (PPM) | CALCIUM (CGA) | MAGNESIUM (MG) | SODIUM (NB) | POTASSIUM (K) | NITRATE-NITRATES (MG/L) | CHLORIDE (CL) | TOTAL SOLIDS (TSS) |        | TDS (TSS) | TSS (TSS) | TSS (TSS) |
|-------------------|-------------|---------|--------------------|------------------|---------------|------------|---------------|----------------|-------------|---------------|-------------------------|---------------|--------------------|--------|-----------|-----------|-----------|
|                   |             |         |                    |                  |               |            |               |                |             |               |                         |               | ANION              | CATION |           |           |           |
| 070004100000      | 105         | 0600    | 02 01 65           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 070004100000      | 346         | MISA    | 01 03 57           | .....            | 7.0           | 1.0        | 1.0           | 5.4            | 210         | 2.0           | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 070004100000      | 307         | MISA    | 02 16 65           | .....            | .....         | 1.8        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 070004100000      | 185         | MISA    | 02 08 68           | .....            | .....         | 1.8        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 070004100000      | 75          | 0600    | 06 06 68           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 223         | MISA    | 05 02 61           | .....            | .....         | 3.4        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 200         | MISA    | 06 13 61           | .....            | .....         | 1.0        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 280         | MISA    | 02 01 68           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 299         | MISA    | 05 02 61           | .....            | .....         | 2.9        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 71          | MISA    | 05 02 61           | .....            | .....         | 3.8        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 325         | MISA    | 12 30 59           | .....            | 12            | 1.7        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 535         | MISA    | 03 15 43           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 61          | 0600    | 11 27 51           | .....            | 12            | 2.5        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 61          | 0600    | 11 28 52           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 61          | 0600    | 02 10 54           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 61          | 0600    | 10 12 54           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 61          | 0600    | 12 30 59           | .....            | 15            | 2.0        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 57          | 0600    | 05 24 49           | .....            | 12            | 3.2        | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 57          | 0600    | 02 10 54           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 57          | 0600    | 10 12 54           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 57          | 0600    | 06 07 55           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 57          | 0600    | 12 12 54           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 57          | 0600    | 12 30 59           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 341         | MISA    | 03 15 43           | .....            | .....         | .....      | .....         | .....          | .....       | .....         | .....                   | .....         | .....              | .....  | .....     | .....     | .....     |
| 080001010000      | 341         | MISA    | 06 10 53           | .....            | .....         | .....      |               |                |             |               |                         |               |                    |        |           |           |           |

TABLE A-1.--continued

| LOCAL WELL NUMBER | DEPTH FEET | AQUIFER | DATE OF COLLECTION | TEMPERATURE (°F) | SILICA (SI02) | IRON (FE) | CALCIUM (CA) | MAGNESIUM (MG) | SODIUM (NA) | POTASSIUM (K) | NITRATE (NO3) | SULFATE (SO4) | CHLORIDE (CL) | FLUORIDE (F) | NITRATE (NO3) | DISSOLVED SOLIDS |              | HARDNESS AS CaCO3 |                          | SPECIFIC CONDUCTANCE (MICRO-MHOS AT 25°C) | PH    | ANALYST |   |
|-------------------|------------|---------|--------------------|------------------|---------------|-----------|--------------|----------------|-------------|---------------|---------------|---------------|---------------|--------------|---------------|------------------|--------------|-------------------|--------------------------|-------------------------------------------|-------|---------|---|
|                   |            |         |                    |                  |               |           |              |                |             |               |               |               |               |              |               | CALCIUM (CA)     | FLUORIDE (F) | CARBONATE (CARB)  | NON-CARBONATE (NON-CARB) |                                           |       |         |   |
| EATON COUNTY      |            |         |                    |                  |               |           |              |                |             |               |               |               |               |              |               |                  |              |                   |                          |                                           |       |         |   |
| 01M04W13ABA       | 1          | 150     | NISA               | 03 14 68         | .....         | 2.5       | 56           | 20             | 80          | 13            | 434           | 1.0           | 1.4           | .....        | .....         | 370              | .....        | 222               | 0                        | .....                                     | 7.65  | 7       |   |
| 02M03W300AB       | 1          | 250     | NISA               | 03 14 68         | .....         | 2.7       | 85           | 20             | 6.0         | 2.4           | 322           | 40            | 1.9           | .....        | .....         | 318              | .....        | 294               | 30                       | .....                                     | 7.65  | 7       |   |
| 02M03W32000       | 1          | 95      | OGUO               | 03 14 68         | .....         | 3.5       | 86           | 30             | 3.0         | 1.0           | 384           | 19            | 3.6           | .....        | .....         | 332              | .....        | 337               | 21                       | .....                                     | 7.71  | 7       |   |
| 02M03W34CAB       | 1          | 294     | NISA               | 01 17 61         | .....         | 10        | 30           | 21             | 3.5         | .8            | 315           | 35            | 2.0           | .0           | .0            | .....            | 308          | 285               | 27                       | 525                                       | 7.5   | 3       |   |
| 02M03W34000C      | 1          | 185     | NISA               | 10 19 67         | .....         | 45        | 116          | 29             | 11          | 2.6           | 384           | 41            | 1.6           | .....        | .....         | 446              | .....        | 412               | 97                       | .....                                     | 7.67  | 7       |   |
| 02M04W04C00C      | 1          | 110     | NISA               | 03 14 68         | .....         | 2.6       | 76           | 23             | 2.0         | .9            | 298           | 32            | 2.9           | .....        | .....         | 286              | .....        | 285               | 41                       | .....                                     | 7.62  | 7       |   |
| 02M04W10ABCC      | 1          | 70      | NISA               | 10 19 67         | .....         | .87       | 98           | 27             | 3.0         | 1.0           | 346           | 53            | 4.2           | .....        | .....         | 358              | .....        | 356               | 72                       | .....                                     | 7.30  | 7       |   |
| 02M05W030CCC      | 1          | 140     | NISA               | 05 02 68         | .....         | 4.8       | 83           | 23             | 12          | 6.4           | 424           | 11            | 1.6           | .....        | .....         | 352              | .....        | 302               | 0                        | .....                                     | 7.60  | 7       |   |
| 02M06W0200AA      | 1          | 186     | NISA               | 09 15 64         | .....         | .59       | 87           | 42             | 9.7         | 1.5           | 422           | 37            | 2.0           | .....        | .....         | .....            | 412          | 390               | 26                       | 725                                       | 7.4   | 1       |   |
| 02M06W1000CC      | 1          | 300     | NISA               | 09 15 64         | .....         | 1.5       | 540          | 141            | 273         | 20            | 180           | 1120          | 810           | .....        | .....         | .....            | 3180         | 1930              | 1780                     | 4330                                      | 7.2   | 1       |   |
| 02M06W24AB8       | 1          | 230     | NISA               | 01 11 65         | .....         | 2.4       | .....        | .....          | .....       | .....         | 372           | 8.8           | 4.0           | .....        | 1.3           | .....            | .....        | 282               | 0                        | 570                                       | 7.6   | 1       |   |
| 02M06W28AB0       | 1          | 180     | NISA               | 04 18 68         | .....         | 4.5       | 94           | 24             | 13          | 6.0           | 410           | 9.0           | 1.4           | .....        | .....         | 351              | .....        | 334               | 0                        | .....                                     | 7.35  | 7       |   |
| 03M03W090AB       | 1          | 111     | NISA               | 03 14 68         | .....         | 2.6       | 75           | 30             | 8.0         | 2.8           | 354           | 24            | 4.4           | .....        | .....         | 323              | .....        | 310               | 20                       | .....                                     | 7.67  | 7       |   |
| 03M03W350AB       | 1          | 120     | NISA               | 03 14 68         | .....         | 1.5       | 84           | 28             | 3.5         | 1.2           | 402           | 7.0           | 1.2           | .....        | .....         | 321              | .....        | 325               | 0                        | .....                                     | 7.73  | 7       |   |
| 03M04W090CC0      | 1          | 166     | NISA               | 10 26 67         | .....         | 1.6       | 74           | 26             | 3.7         | 2.4           | 337           | 23            | 2.0           | .....        | .....         | 300              | .....        | 293               | 17                       | .....                                     | 7.55  | 7       |   |
| 03M04W23000       | 1          | 300     | NISA               | 12 14 60         | .....         | 15        | 2.3          | 116            | 39          | 12            | 1.2           | 440           | 85            | 25           | .0            | .0               | .....        | 496               | 450                      | 89                                        | 800   | 7.3     | 3 |
| 03M04W23000       | 2          | 200     | NISA               | 12 14 60         | .....         | 15        | .70          | 92             | 32          | 4.6           | .8            | 400           | 34            | 7.0          | .0            | .0               | .....        | 394               | 360                      | 32                                        | 650   | 7.5     | 3 |
| 03M04W260000      | 1          | 100     | NISA               | 10 26 67         | .....         | 7.0       | 114          | 36             | 6.7         | 1.4           | 450           | 82            | 12            | .....        | .....         | 440              | .....        | 432               | 67                       | .....                                     | 7.58  | 7       |   |
| 03M04W2900AA      | 1          | 108     | NISA               | 04 18 68         | .....         | 1.6       | 102          | 35             | 5.5         | 1.3           | 448           | 33            | 6.6           | .....        | .....         | 408              | .....        | 399               | 31                       | .....                                     | 7.48  | 7       |   |
| 03M05W234AA       | 1          | 269     | NISA               | 04 18 68         | .....         | .51       | 46           | 16             | 47          | 7.8           | 442           | 7.0           | 2.0           | .....        | .....         | 386              | .....        | 181               | 0                        | .....                                     | 7.62  | 7       |   |
| 03M05W234AA       | 2          | 268     | NISA               | 04 18 68         | .....         | 3.0       | 80           | 30             | 9.5         | 2.5           | 407           | 10            | 1.2           | .....        | .....         | 342              | .....        | 323               | 0                        | .....                                     | 7.54  | 7       |   |
| 03M05W25CBB       | 1          | 141     | NISA               | 04 18 68         | .....         | 1.1       | 86           | 33             | 7.5         | 1.7           | 425           | 13            | 2.2           | .....        | .....         | 354              | .....        | 351               | 3                        | .....                                     | 7.55  | 7       |   |
| 03M05W290AB       | 1          | 89      | OGUO               | 10 26 67         | .....         | 2.3       | 112          | 38             | 7.1         | 1.2           | 490           | 56            | 8.5           | .....        | .....         | 461              | .....        | 437               | 33                       | .....                                     | 7.69  | 7       |   |
| 03M06W270AB       | 1          | 410     | NISA               | 05 02 68         | .....         | 1.4       | 130          | 32             | 14          | 7.2           | 363           | 165           | 4.6           | .....        | .....         | 536              | .....        | 447               | 151                      | .....                                     | 7.39  | 7       |   |
| 03M06W280AB       | 2          | 167     | OGUO               | 05 28 59         | .....         | 15        | .90          | 88             | 34          | 5.8           | .8            | 425           | 21            | 3.0          | .0            | .0               | .....        | 400               | 340                      | .....                                     | 650   | 7.5     | 3 |
| 03M06W340C        | 1          | 94      | OGUO               | 09 16 64         | .....         | .38       | 103          | 42             | 4.2         | 1.0           | 444           | 66            | 2.0           | .....        | .....         | .....            | 448          | 430               | 66                       | 758                                       | 7.6   | 1       |   |
| 04M03W0300B       | 1          | 160     | NISA               | 07 08 65         | .....         | .84       | .....        | .....          | 4.4         | .....         | 418           | 49            | 3.0           | .....        | .0            | .....            | .....        | 400               | 57                       | 689                                       | 7.6   | 1       |   |
| 04M03W07AB8A      | 1          | 110     | NISA               | 05 02 68         | .....         | .55       | 75           | 32             | 11          | 7.1           | 421           | 9.0           | 1.3           | .....        | .....         | 314              | .....        | 319               | 0                        | .....                                     | 7.50  | 7       |   |
| 04M03W13000       | 1          | 425     | NISA               | 06 19 64         | .....         | 10        | .60          | 80             | 24          | 13            | 2.8           | 400           | 4.0           | .0           | .2            | .0               | .....        | 334               | 300                      | 0                                         | 560   | 7.4     | 3 |
| 04M03W140AB       | 1          | 450     | NISA               | 01 07 64         | .....         | 9.0       | .40          | 62             | 26          | 31            | 3.0           | 390           | 8.0           | 5.0          | .3            | .0               | .....        | 326               | 260                      | 0                                         | 580   | 7.4     | 3 |
| 04M03W25AD        | 1          | 110     | NISA               | 01 10 45         | 56            | .....     | .90          | 73             | 27          | 6.4           | .....         | 367           | 3.4           | 3.0          | .....         | .....            | .....        | 307               | 295                      | 0                                         | ..... | .....   | 1 |
| 04M04W0200C0      | 1          | 404     | NISA               | 12 14 60         | .....         | 13        | .50          | 80             | 29          | 11            | 1.5           | 385           | 18            | 5.0          | .2            | .0               | .....        | 354               | 320                      | 4                                         | 600   | 7.5     | 3 |
| 04M04W1088BA      | 1          | 90      | NISA               | 10 26 67         | .....         | .....     | .80          | 72             | 32          | 12            | 1.9           | 400           | 23            | 2.0          | .....         | 361              | .....        | 313               | 0                        | .....                                     | 7.68  | 7       |   |
| 04M04W110CAD      | 1          | 190     | NISA               | 12 14 60         | .....         | 17        | 2.0          | 80             | 30          | 6.0           | .8            | 344           | 43            | 3.0          | .3            | .7               | .....        | 370               | 325                      | 27                                        | 600   | 7.5     | 3 |
| 04M04W1400AA      | 1          | 225     | NISA               | 06 17 54         | 50            | 16        | .83          | 93             | 31          | 6.9           | 1.0           | 406           | 31            | 3.5          | .1            | .1               | .....        | 353               | 360                      | 27                                        | 651   | 7.3     | 1 |
| 04M04W1400AA      | 1          | 225     | NISA               | 12 14 60         | .....         | 15        | .50          | 92             | 34          | 6.0           | .8            | 405           | 50            | 4.0          | .0            | .0               | .....        | 400               | 370                      | 38                                        | 650   | 7.4     | 3 |
| 04M04W2300C       | 1          | 200     | NISA               | 10 26 67         | .....         | .....     | .95          | 74             | 32          | 6.6           | 1.8           | 373           | 24            | 1.5          | .....         | 329              | .....        | 320               | 15                       | .....                                     | 7.67  | 7       |   |
| 04M05W030C0C      | 1          | 260     | NISA               | 10 26 67         | .....         | .....     | .80          | 38             | 24          | 49            | 3.4           | 378           | 10            | 1.2          | .....         | 312              | .....        | 142               | 0                        | .....                                     | 7.60  | 7       |   |
| 04M06W0200C0      | 1          | 174     | OGUO               | 10 28 59         | .....         | 17        | 1.0          | 84             | 32          | 8.3           | 1.0           | 410           | 17            | 5.0          | .0            | .0               | .....        | 380               | 340                      | .....                                     | 600   | 7.7     | 3 |
| 04M06W200CC       | 1          | 340     | NISA               | 06 14 65         | .....         | .....     | .....        | .....          | .....       | .....         | 362           | 9.6           | 1.0           | .....        | .2            | .....            | .....        | 320               | 10                       | 566                                       | 5.4   | 1       |   |
| 04M06W2100AA      | 1          | 245     | NISA               | 01 11 65         | .....         | .....     | 1.7          | 80             | 26          | 3.5           | 1.2           | 385           | 4.0           | 1.0          | .....         | .8               | .....        | 338               | 0                        | 618                                       | 7.5   | 1       |   |
| 04M06W240C0C      | 1          | 245     | NISA               | 10 26 67         | .....         | .....     | 2.9          | .....          | .....       | .....         | .....         | .....         | .....         | .....        | .....         | 311              | .....        | 309               | 0                        | .....                                     | 7.65  | 7       |   |

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TABLE A-1.--continued.

| LOCAL WELL NUMBER | DEPTH, FEET | AQUIFER | DATE OF COLLECTION | TEMPERATURE (°F) | SILICA (SiO <sub>2</sub> ) | IRON (FE) | CALCIUM (CA) | MAGNESIUM (MG) | SODIUM (NA) | POTASSIUM (K) | NITRATE (NO <sub>3</sub> ) | SULFATE (SO <sub>4</sub> ) | CHLORIDE (CL) | FLUORIDE (F) | NITRATE (NO <sub>3</sub> ) | DISSOLVED SOLIDS |                  | HARDNESS AS CaCO <sub>3</sub> |                 | SPECIFIC CONDUCTANCE (µMHO/CM AT 25°C) | PH    | ANALYST |   |
|-------------------|-------------|---------|--------------------|------------------|----------------------------|-----------|--------------|----------------|-------------|---------------|----------------------------|----------------------------|---------------|--------------|----------------------------|------------------|------------------|-------------------------------|-----------------|----------------------------------------|-------|---------|---|
|                   |             |         |                    |                  |                            |           |              |                |             |               |                            |                            |               |              |                            | CALCIUM (LATON)  | FLUORIDE (LATON) | CARBONATE (LATON)             | NITRATE (LATON) |                                        |       |         |   |
| INGHAM COUNTY     |             |         |                    |                  |                            |           |              |                |             |               |                            |                            |               |              |                            |                  |                  |                               |                 |                                        |       |         |   |
| 01N01E230000      | 1           | 77      | NISA               | 10 05 67         | .....                      | 1.3       | 106          | 35             | 5.3         | 1.8           | 410                        | 38                         | 21            | .....        | .....                      | 409              | .....            | 406                           | NA              | .....                                  | 7.70  | 7       |   |
| 01N01E3600CC      | 1           | 98      | NISA               | 09 29 64         | .....                      | .....     | 98           | 34             | 5.8         | 1.7           | 406                        | 49                         | 8.0           | .....        | .....                      | .....            | .....            | 385                           | 52              | .....                                  | 7.4   | 1       |   |
| 01N01W02CAAA      | 1           | 140     | NISA               | 10 05 67         | .....                      | 7.7       | 59           | 14             | 6.6         | 4.6           | 272                        | 3.0                        | 1.5           | .....        | .....                      | 273              | .....            | 207                           | 0               | .....                                  | 8.05  | 7       |   |
| 01N01W1700BB      | 1           | 100     | NISA               | 10 05 67         | .....                      | 2.0       | 85           | 26             | 3.3         | 1.7           | 330                        | 51                         | 3.0           | .....        | .....                      | 345              | .....            | 317                           | 47              | .....                                  | 7.80  | 7       |   |
| 01N01W20AADD      | 1           | 185     | NISA               | 04 11 61         | .....                      | 1.1       | 136          | 25             | 5.1         | 1.6           | 370                        | 155                        | 1.0           | .....        | .....                      | .....            | .....            | 465                           | .....           | 800                                    | 7.1   | 3       |   |
| 01N01W24AADD      | 1           | 223     | NISA               | 02 08 62         | .....                      | 1.1       | 130          | 23             | 5.7         | 1.2           | 360                        | 125                        | 2.0           | .....        | .....                      | .....            | .....            | 420                           | .....           | 750                                    | 7.4   | 3       |   |
| 01N01W2900AD      | 1           | 118     | NISA               | 10 05 67         | .....                      | 1.9       | 90           | 24             | 3.0         | 1.9           | 366                        | 32                         | 2.4           | .....        | .....                      | 334              | .....            | 337                           | 37              | .....                                  | 7.85  | 7       |   |
| 02N01E19ADC       | 1           | 70      | NISA               | 09 29 64         | .....                      | .....     | 85           | 22             | 6.1         | 1.1           | 224                        | 108                        | 6.0           | .....        | .....                      | .....            | .....            | 442                           | 303             | 116                                    | 583   | 7.4     | 1 |
| 02N01W09CACC      | 1           | 178     | NISA               | 11 09 67         | .....                      | 1.65      | 74           | 21             | 3.3         | 2.1           | 329                        | 16                         | 1.0           | .....        | .....                      | 240              | .....            | 271                           | 1               | .....                                  | 7.60  | 7       |   |
| 02N01E1500BB      | 1           | 164     | NISA               | 10 05 68         | .....                      | 1.80      | 87           | 25             | 20          | 6.8           | 434                        | 11                         | 3.2           | .....        | .....                      | 368              | .....            | 320                           | 0               | .....                                  | 7.80  | 7       |   |
| 02N01E2500AA      | 1           | 134     | NISA               | 11 05 68         | .....                      | 1.84      | 60           | 23             | 6.0         | 1.1           | 324                        | 3.0                        | 1.9           | .....        | .....                      | 253              | .....            | 245                           | 0               | .....                                  | 7.80  | 7       |   |
| 02N01E2800CC      | 1           | 120     | NISA               | 11 05 68         | .....                      | 1.53      | 57           | 18             | 7.5         | 1.8           | 295                        | 2.0                        | 1.9           | .....        | .....                      | 231              | .....            | 276                           | 0               | .....                                  | 7.51  | 7       |   |
| 02N01W05ACCC      | 1           | 218     | NISA               | 05 12 61         | .....                      | 1.38      | 80           | 27             | 4.6         | 1.0           | 374                        | 6.0                        | 4.0           | .....        | .....                      | 344              | .....            | 310                           | .....           | 580                                    | 7.4   | 3       |   |
| 02N01W0500AD      | 1           | 169     | NISA               | 10 26 59         | .....                      | .....     | 130          | 33             | 25          | 8.4           | 392                        | 172                        | 14            | .....        | .....                      | .....            | .....            | 416                           | 440             | 139                                    | 840   | 6.8     | 1 |
| 02N01W08AACB      | 1           | 48      | OGOO               | 01 23 53         | 54                         | .....     | 108          | 32             | .....       | .....         | 356                        | 80                         | 4.4           | .....        | 1.0                        | .....            | .....            | 420                           | 400             | .....                                  | 820   | 7.3     | 3 |
| 02N01W08AACB      | 1           | 48      | OGOO               | 05 12 41         | .....                      | 1.0       | 120          | 35             | 4.2         | 2.5           | 350                        | 91                         | 10.8          | .....        | 4.5                        | .....            | .....            | 420                           | 442             | .....                                  | 1000  | 7.4     | 3 |
| 02N01W09CACC      | 1           | 43      | OGOO               | 01 23 53         | 50                         | 1.0       | 108          | 30             | 11          | .....         | 361                        | 93                         | 1.8           | .....        | .....                      | .....            | .....            | 404                           | .....           | 800                                    | 7.3   | 3       |   |
| 02N01W09CACC      | 1           | 43      | OGOO               | 04 08 62         | .....                      | 1.0       | 84           | 30             | 14          | 2.5           | 308                        | 73                         | 2.3           | .....        | .....                      | .....            | .....            | 400                           | .....           | 670                                    | 7.3   | 3       |   |
| 02N01W130CBB      | 1           | 135     | NISA               | 10 17 68         | .....                      | 1.37      | 54           | 22             | 32          | 7.4           | 376                        | .....                      | 1.1           | .....        | .....                      | 299              | .....            | 276                           | 0               | .....                                  | 7.50  | 7       |   |
| 02N01W180CCC      | 1           | 125     | NISA               | 10 05 67         | .....                      | 1.8       | 100          | 28             | 5.6         | 1.5           | 370                        | 42                         | 14            | .....        | .....                      | 274              | .....            | 363                           | 59              | .....                                  | 7.75  | 7       |   |
| 02N01W2600BB      | 1           | 130     | NISA               | 10 17 68         | .....                      | 1.96      | 95           | 36             | 5.5         | 1.2           | 414                        | 58                         | 1.7           | .....        | .....                      | 400              | .....            | 385                           | 45              | .....                                  | 7.30  | 7       |   |
| 02N01W2600BB      | 1           | 119     | NISA               | 10 17 68         | .....                      | 1.2       | 90           | 28             | 4.0         | 1.2           | 396                        | 19                         | 2.4           | .....        | .....                      | 338              | .....            | 340                           | 15              | .....                                  | 7.32  | 7       |   |
| 02N02E02ACDD      | 1           | 110     | NISA               | 10 05 67         | .....                      | 1.6       | 94           | 30             | 5.7         | 1.0           | 380                        | 41                         | 12            | .....        | .....                      | 373              | .....            | 359                           | 47              | .....                                  | 7.93  | 7       |   |
| 02N02E240AAA      | 1           | 101     | NISA               | 10 05 67         | .....                      | 1.9       | 114          | 36             | 4.0         | 1.3           | 435                        | 74                         | 2.2           | .....        | .....                      | 452              | .....            | 433                           | 75              | .....                                  | 7.73  | 7       |   |
| 02N02E34CAA       | 2           | 340     | NISA               | 10 05 67         | .....                      | 1.80      | 116          | 36             | 10          | 2.8           | 435                        | 98                         | 1.5           | .....        | .....                      | 479              | .....            | 436                           | 80              | .....                                  | 7.63  | 7       |   |
| 02N02E34CAA       | 2           | 124     | NISA               | 10 05 68         | .....                      | 5.9       | 120          | 42             | 33          | 1.6           | 500                        | 97                         | 3.3           | .....        | .....                      | 579              | .....            | 472                           | 64              | .....                                  | 7.55  | 7       |   |
| 02N02W19AABA      | 1           | 160     | NISA               | 05 02 68         | .....                      | 1.38      | 80           | 30             | 7.0         | 2.2           | 398                        | 14                         | 1.5           | .....        | .....                      | 331              | .....            | 323                           | 0               | .....                                  | 7.45  | 7       |   |
| 03N01E02AAAA      | 3           | 167     | NISA               | 03 15 67         | .....                      | .....     | .....        | .....          | 104         | .....         | 396                        | 16                         | 6.0           | .....        | .....                      | .....            | .....            | 368                           | 98              | 0                                      | 633   | 7.8     | 1 |
| 03N01E02AAAA      | 3           | 167     | NISA               | 06 24 54         | 51                         | 7.7       | 33           | 11             | 116         | 5.6           | 431                        | 18                         | 8.5           | .....        | .....                      | 413              | .....            | 125                           | 0               | .....                                  | 684   | 7.7     | 1 |
| 03N01E02AAAA      | 3           | 167     | NISA               | 10 29 58         | .....                      | 7.0       | 34           | 10             | 117         | 6.2           | 427                        | 17                         | 7.0           | .....        | .....                      | .....            | .....            | 410                           | 125             | .....                                  | 700   | 7.6     | 3 |
| 03N01E02AAAA      | 3           | 165     | NISA               | 03 24 67         | .....                      | .....     | .....        | .....          | 100         | .....         | 400                        | 21                         | 8.0           | .....        | .....                      | .....            | .....            | 396                           | 110             | 0                                      | 654   | 7.7     | 1 |
| 03N01E02BBA       | 1           | 40      | OGOO               | 02 08 52         | .....                      | 7.3       | 60           | 18             | 3.5         | .....         | 214                        | 49                         | 2.0           | .....        | .....                      | .....            | .....            | 254                           | .....           | 374                                    | 7.8   | 3       |   |
| 03N01E02BBA       | 1           | 38      | OGOO               | 10 29 58         | .....                      | 9.0       | 86           | 22             | 6.6         | 1.2           | 254                        | 93                         | 9.0           | .....        | .....                      | .....            | .....            | 474                           | 307             | .....                                  | 810   | 7.3     | 3 |
| 03N01E02CAD       | 1           | 200     | NISA               | 11 09 68         | .....                      | 1.50      | 28           | 10             | .....       | .....         | 383                        | 19                         | 2.0           | .....        | .....                      | .....            | .....            | 358                           | 110             | 0                                      | ..... | 8.1     | 8 |
| 03N01E08AAB       | 1           | 185     | NISA               | 10 12 67         | .....                      | 1.35      | 47           | 12             | 90          | 7.8           | 444                        | 5.0                        | 1.8           | .....        | .....                      | 384              | .....            | 168                           | 0               | .....                                  | 7.73  | 7       |   |
| 03N01E0800CC      | 1           | 81      | NISA               | 10 12 67         | .....                      | 1.2       | 80           | 30             | 7.9         | 1.6           | 405                        | 6.0                        | 1.8           | .....        | .....                      | .....            | .....            | 327                           | .....           | .....                                  | 7.65  | 7       |   |
| 03N01E120CC       | 1           | 184     | NISA               | 03 15 67         | .....                      | .....     | .....        | .....          | 8.6         | .....         | 246                        | 9.2                        | 4.0           | .....        | .....                      | .....            | .....            | 272                           | 194             | 0                                      | 392   | 7.9     | 1 |
| 03N01E120CC       | 1           | 184     | NISA               | 10 17 68         | .....                      | 1.1       | 90           | 30             | 7.5         | 4.0           | 445                        | 2.0                        | 1.6           | .....        | .....                      | 354              | .....            | 348                           | 0               | .....                                  | 7.45  | 7       |   |
| 03N01E220AAB      | 1           | 110     | NISA               | 10 24 68         | .....                      | 1.70      | 65           | 25             | 9.5         | 1.5           | 344                        | 3.0                        | 1.3           | .....        | .....                      | 277              | .....            | 265                           | 0               | .....                                  | 7.75  | 7       |   |
| 03N01E3200CC      | 1           | 180     | NISA               | 10 17 68         | .....                      | 1.57      | 72           | 28             | 10          | 1.6           | 378                        | 5.0                        | 1.0           | .....        | .....                      | 307              | .....            | 294                           | 0               | .....                                  | 7.51  | 7       |   |
| 03N01E3400DD      | 1           | 165     | NISA               | 10 12 67         | .....                      | 1.35      | 44           | 15             | 65          | 7.4           | 376                        | 6.0                        | 1.1           | .....        | .....                      | 324              | .....            | 171                           | 0               | .....                                  | 8.03  | 7       |   |
| 03N01E340CB       | 1           | 32      | OGOO               | 12 12 68         | 50                         | .....     | .....        | .....          | .....       | .....         | 348                        | 58                         | 5.5           | .....        | .....                      | 424              | .....            | 324                           | 34              | .....                                  | 440   | 7.5     | 1 |
| 03N01W1700BB      | 1           | 172     | NISA               | 10 17 68         | .....                      | 2.4       | 94           | 27             | 3.0         | 1.8           | 473                        | 61                         | 2.4           | .....        | .....                      | 373              | .....            | 344                           | 40              | .....                                  | 7.32  | 7       |   |
| 03N01W03AABB      | 1           | 280     | NISA               | 10 17 68         | .....                      | 1.77      | 91           | 30             | 4.0         | 2.8           | 423                        | 23                         | 1.2           | .....        | .....                      | 354              | .....            | 350                           | 3               | .....                                  | 7.29  | 7       |   |
| 03N01W07AAAA      | 1           | 150     | NISA               | 10 17 68         | .....                      | 1.44      | 82           | 28             | 5.0         | 2.0           | 390                        | 15                         | 2.0           | .....        | .....                      | 334              | .....            | 320                           | 0               | .....                                  | 7.45  | 7       |   |
| 03N01W10AABB      | 1           | 240     | NISA               | 10 12 67         | .....                      | 1.60      | 75           | 29             | 13          | 4.0           | 385                        | .....                      | 1.8           | .....        | .....                      | 371              | .....            | 364                           | 0               | .....                                  | 7.74  | 7       |   |
| 03N01W1500BA      | 1           | 200     | NISA               | 10 17 68         | .....                      | 1.37      | 84           | 27             | 8.5         | 4.0           | 434                        | 3.0                        | 1.0           | .....        | .....                      | 364              | .....            | 321                           | 0               | .....                                  | 7.32  | 7       |   |
| 03N01W2400CC      | 1           | 235     | NISA               | 10 17 68         | .....                      | 1.63      | 90           | 30             | 11          | 5.8           | 441                        | 11                         | 1.4           | .....        | .....                      | 364              | .....            | 345                           | 0               | .....                                  | 7.25  | 7       |   |
| 03N01W2400CC      | 1           | 110     | NISA               | 10 17 68         | .....                      | 1.70      | 40           | 32             | 7.5         | 1.8           | 414                        | 18                         | 1.1           | .....        | .....                      | 357              | .....            | 347                           | 17              | .....                                  | 7.20  | 7       |   |
| 03N01W2400CC      | 1           | 110     | NISA               | 10 17 67         | .....                      | 1.80      | 94           | 30             | 5.0         | 1.4           | 344                        | 73                         | 1.1           | .....        | .....                      | 345              | .....            | 341                           | 71              | .....                                  | 7.8   | 7       |   |
| 03N01W2400CC      | 1           | 96      | NISA               | 10 17 68         | .....                      | 1.1       | 86           | 30             | 3.0         | 1.8           | 404                        | 46                         | 1.4           | .....        | .....                      | 372              | .....            | 345                           | 39              | .....                                  | 7.50  | 7       |   |

TABLE A-1.--continued

| LOCAL WELL NUMBER | DEPTH, FEET | AQUIFER | DATE OF COLLECTION | TEMPERATURE (°F) | SILICA (SI02) | IRON (FE) | CALCIUM (CA) | MAGNESIUM (MG) | SODIUM (NA) | POTASSIUM (K) | BICARBONATE (HCO3) | SULFATE (SO4) | CHLORIDE (CL) | FLUORIDE (F) | NITRATE (NO3) | DISSOLVED SOLIDS |                    | HARDNESS AS CALCIUM |                | SPECIFIC CONDUCTANCE (MICRO-MHOS AT 25°C) |       | PH | ANALYST |
|-------------------|-------------|---------|--------------------|------------------|---------------|-----------|--------------|----------------|-------------|---------------|--------------------|---------------|---------------|--------------|---------------|------------------|--------------------|---------------------|----------------|-------------------------------------------|-------|----|---------|
|                   |             |         |                    |                  |               |           |              |                |             |               |                    |               |               |              |               | CALC-LATH        | EVAP-LATH AT 180°C | CAR-MONATE          | MIN-CAR-MONATE |                                           |       |    |         |
| 03N01W32ABAA 1    | 130         | NISA    | 10 17 68           | .....            | .....         | .68       | 86           | 30             | 3.0         | .6            | 334                | 79            | 5.7           | .....        | .....         | 367              | .....              | 338                 | 64             | .....                                     | 7.45  | 7  |         |
| 03N02E04ACCC 1    | 180         | NISA    | 10 24 68           | .....            | .....         | .60       | 85           | 31             | 9.0         | 3.1           | 432                | 1.0           | .9            | .....        | .....         | 343              | .....              | 340                 | 0              | .....                                     | 7.40  | 7  |         |
| 03N02E06ADDD 1    | 200         | NISA    | 09 29 64           | .....            | .....         | 1.0       | 11           | 5.0            | 272         | 1.7           | 562                | 138           | 14            | .....        | .....         | .....            | 746                | 44                  | 0              | 1180                                      | 8.5   | 1  |         |
| 03N02E12BCAD 1    | 144         | NISA    | 10 12 67           | .....            | .....         | 1.9       | 84           | 27             | 4.9         | 2.2           | 386                | 8.0           | .7            | .....        | .....         | 319              | .....              | 320                 | 4              | .....                                     | 7.90  | 7  |         |
| 03N02E15ABDC 1    | 140         | NISA    | 09 29 64           | .....            | .....         | 4.1       | 83           | 23             | 6.1         | 8.5           | 384                | 1.4           | 1.0           | .....        | .....         | .....            | 318                | 302                 | 0              | 577                                       | 7.4   | 1  |         |
| 03N02E17ADDD 1    | 295         | NISA    | 10 12 67           | .....            | .....         | .92       | 46           | 10             | 90          | 8.4           | 382                | 25            | 14            | .....        | .....         | 384              | .....              | 156                 | 0              | .....                                     | 7.70  | 7  |         |
| 03N02E25CAAA 1    | 125         | NISA    | 10 24 68           | .....            | .....         | .43       | 76           | 24             | 13          | 6.4           | 399                | 7.0           | 3.7           | .....        | .....         | 330              | .....              | 305                 | 0              | .....                                     | 7.32  | 7  |         |
| 03N02E26CCDC 1    | 32          | OCOD    | 12 12 68           | 50               | .....         | 2.1       | .....        | .....          | .....       | .....         | 362                | 18            | 1.5           | .....        | .....         | 338              | .....              | 268                 | 0              | 570                                       | 7.6   | 1  |         |
| 03N02W02DACC 1    | 98          | OCOD    | 10 24 68           | .....            | .....         | 3.3       | 83           | 27             | 3.0         | .9            | 347                | 52            | 1.6           | .....        | .....         | 362              | .....              | 318                 | 33             | .....                                     | 7.40  | 7  |         |
| 03N02W11ADAD 1    | 113         | NISA    | 11 05 68           | .....            | .....         | .61       | 75           | 25             | 2.5         | .9            | 344                | 2.0           | .9            | .....        | .....         | 276              | .....              | 290                 | 7              | .....                                     | 7.30  | 7  |         |
| 03N02W18DCB 1     | 110         | NISA    | 11 05 68           | .....            | .....         | .70       | 65           | 21             | 7.0         | 1.2           | 289                | 24            | 3.1           | .....        | .....         | 285              | .....              | 248                 | 11             | .....                                     | 7.51  | 7  |         |
| 03N02W18DCB 1     | 50          | NISA    | 11 05 68           | .....            | .....         | .88       | 86           | 32             | 5.0         | 1.4           | 424                | 2.0           | .8            | .....        | .....         | 337              | .....              | 347                 | 0              | .....                                     | 7.50  | 7  |         |
| 03N02W19CCB 1     | 100         | NISA    | 11 05 68           | .....            | .....         | .35       | 72           | 24             | 5.0         | 1.8           | 322                | 18            | 1.7           | .....        | .....         | 281              | .....              | 270                 | 15             | .....                                     | 7.47  | 7  |         |
| 03N02W21CBB 2     | 118         | NISA    | 11 05 68           | .....            | .....         | .70       | 77           | 26             | 4.0         | .9            | 346                | 27            | 1.8           | .....        | .....         | 307              | .....              | 290                 | 15             | .....                                     | 7.40  | 7  |         |
| 03N02W23ADDB 1    | 268         | NISA    | 10 14 59           | .....            | 14            | 2.2       | 87           | 30             | 2.9         | .6            | 370                | 34            | 7.0           | .....        | .....         | 341              | 467                | 341                 | 38             | 418                                       | 7.6   | 1  |         |
| 03N02W23BCDD 1    | 278         | NISA    | 10 14 59           | .....            | .....         | .....     | 24           | 27             | 5.9         | 1.4           | 700                | 11            | 12            | .....        | .....         | .....            | 198                | 171                 | 7              | 310                                       | 7.2   | 1  |         |
| 03N02W23CBAD 1    | 403         | NISA    | 06 13 68           | .....            | 13            | .60       | 94           | 30             | 3.2         | .9            | 390                | 55            | 4.0           | .2           | .....         | .....            | 438                | 360                 | .....          | 660                                       | 7.1   | 3  |         |
| 04N01E08ADAD 1    | 344         | NISA    | 10 12 67           | .....            | .....         | .95       | 68           | 18             | 29          | 5.2           | 368                | 4.0           | 1.0           | .....        | .....         | 308              | .....              | 244                 | 0              | .....                                     | 7.50  | 7  |         |
| 04N01E110CC 1     | 250         | NISA    | 10 12 67           | .....            | .....         | .60       | 54           | 24             | 16          | 4.4           | 327                | 5.0           | .6            | .....        | .....         | 267              | .....              | 236                 | 0              | .....                                     | 7.55  | 7  |         |
| 04N01E13CC4A 1    | 325         | NISA    | 04 04 68           | .....            | .....         | .78       | 124          | 24             | 20          | 5.4           | 292                | 180           | 1.7           | .....        | .....         | 500              | .....              | 499                 | 169            | .....                                     | 7.51  | 7  |         |
| 04N01E20CCA 1     | 260         | NISA    | 04 04 68           | .....            | .....         | .46       | 74           | 14             | 11          | 4.3           | 302                | 13            | 1.5           | .....        | .....         | 267              | .....              | 243                 | 0              | .....                                     | 7.55  | 7  |         |
| 04N01E20CCA 1     | 260         | NISA    | 04 04 68           | .....            | .....         | 1.2       | 176          | 21             | 26          | 6.4           | 373                | 320           | 2.7           | .....        | .....         | 688              | .....              | 525                 | 301            | .....                                     | 7.50  | 7  |         |
| 04N01E20CCBC 1    | 255         | NISA    | 10 12 67           | .....            | .....         | .80       | 80           | 10             | 10          | 4.8           | 298                | 22            | 1.1           | .....        | .....         | 277              | .....              | 242                 | 0              | .....                                     | 7.40  | 7  |         |
| 04N01W07CACD 1    | 392         | NISA    | 12 29 65           | 51               | 12            | 2.0       | 114          | 36             | 9.2         | 1.4           | 390                | 108           | 15            | .5           | .....         | .....            | 540                | 435                 | .....          | 780                                       | 7.2   | 3  |         |
| 04N01W07CACD 1    | 392         | NISA    | 02 29 68           | .....            | .....         | 1.0       | 96           | 34             | 13          | 3.0           | 385                | 76            | 12            | .....        | .....         | 430              | .....              | 380                 | 56             | .....                                     | 7.23  | 7  |         |
| 04N01W07BAC 1     | 385         | NISA    | 07 31 52           | .....            | 10            | .40       | 80           | 30             | 13          | .....         | 388                | 45            | 4.0           | .3           | .....         | .....            | 378                | 325                 | .....          | 650                                       | 7.5   | 3  |         |
| 04N01W07BAC 1     | 385         | NISA    | 04 23 53           | 51               | .....         | .....     | .....        | .....          | .....       | .....         | 374                | 40            | 3.0           | .....        | .....         | .....            | .....              | 320                 | .....          | 650                                       | ..... | 3  |         |
| 04N01W07BAC 1     | 385         | NISA    | 04 26 54           | 51               | .....         | .....     | .....        | .....          | .....       | .....         | 388                | 40            | 2.0           | .....        | .....         | .....            | .....              | 330                 | .....          | 710                                       | ..... | 3  |         |
| 04N01W07BAC 1     | 385         | NISA    | 11 19 59           | .....            | 17            | 2.9       | 116          | 44             | 10          | 1.6           | 462                | 118           | 5.0           | .2           | .....         | .....            | 445                | 470                 | .....          | 850                                       | 7.2   | 3  |         |
| 04N01W07BAC 1     | 385         | NISA    | 05 12 61           | .....            | 14            | .80       | 86           | 35             | 10          | 1.5           | 386                | 55            | 7.0           | .5           | .....         | .....            | 420                | 360                 | .....          | 680                                       | 7.4   | 3  |         |
| 04N01W07BAC 1     | 385         | NISA    | 02 29 68           | .....            | .....         | 1.2       | 85           | 32             | 12          | 1.4           | 394                | 44            | 6.2           | .....        | .....         | 376              | .....              | 345                 | 20             | .....                                     | 7.30  | 7  |         |
| 04N01W07CAB 1     | 380         | NISA    | 02 08 52           | .....            | 10            | .....     | 82           | 36             | 11          | .....         | 417                | 38            | 3.0           | .....        | .....         | .....            | 340                | 355                 | .....          | 580                                       | 7.7   | 3  |         |
| 04N01W07CAB 1     | 385         | NISA    | 04 26 54           | 51               | .....         | .....     | .....        | .....          | .....       | .....         | 400                | 35            | 3.0           | .....        | .....         | .....            | .....              | 330                 | .....          | 700                                       | ..... | 3  |         |
| 04N01W07CAB 1     | 385         | NISA    | 05 12 61           | .....            | 13            | .60       | 76           | 33             | 13          | 1.7           | 388                | 33            | 4.0           | .4           | .....         | .....            | 394                | 325                 | .....          | 620                                       | 7.4   | 1  |         |
| 04N01W07CAB 1     | 380         | NISA    | 02 29 68           | .....            | .....         | 1.0       | 80           | 34             | 9.5         | 2.7           | 414                | 32            | 4.1           | .....        | .....         | 367              | .....              | 340                 | 1              | .....                                     | 7.43  | 7  |         |
| 04N01W07DAD 1     | 391         | NISA    | 03 31 55           | 51               | 8.0           | .50       | 82           | 32             | .....       | .....         | 395                | 35            | 2.0           | .0           | .....         | .....            | 376                | 340                 | .....          | 650                                       | 7.5   | 3  |         |
| 04N01W07DAD 1     | 391         | NISA    | 02 29 68           | .....            | .....         | 4.0       | 106          | 38             | 12          | 2.3           | 436                | 93            | 9.1           | .....        | .....         | 478              | .....              | 421                 | 64             | .....                                     | 7.28  | 7  |         |
| 04N01W08CCA 1     | 411         | NISA    | 02 29 68           | .....            | .....         | 2.9       | 120          | 43             | 12          | 2.3           | 462                | 130           | 13            | .....        | .....         | 551              | .....              | 477                 | 99             | .....                                     | 7.20  | 7  |         |
| 04N01W08CDA 1     | 393         | NISA    | 02 09 68           | .....            | 12            | .20       | 76           | 26             | 20          | 2.3           | 360                | 44            | 2.0           | .6           | .....         | .....            | 368                | 295                 | .....          | 620                                       | 7.6   | 3  |         |
| 04N01W10BADA 1    | 390         | NISA    | 11 19 59           | .....            | 14            | .30       | 54           | 24             | 11          | 1.0           | 320                | 2.0           | .0            | .2           | .....         | .....            | 244                | 235                 | .....          | 500                                       | 7.8   | 3  |         |
| 04N01W10BADA 1    | 300         | NISA    | 06 07 65           | .....            | 13            | .20       | 64           | 16             | 12          | 1.1           | 310                | .0            | .0            | .5           | .....         | .....            | 262                | 225                 | .....          | 460                                       | 7.5   | 3  |         |
| 04N01W10BADA 1    | 390         | NISA    | 03 07 68           | .....            | .....         | 1.3       | 56           | 22             | 12          | 1.4           | 295                | 3.0           | 1.3           | .....        | .....         | 241              | .....              | 231                 | 0              | .....                                     | 7.83  | 7  |         |
| 04N01W11CDD 1     | 333         | NISA    | 03 07 68           | .....            | .....         | 1.2       | 62           | 23             | 8.0         | 1.6           | 317                | 7.0           | 1.5           | .....        | .....         | 240              | .....              | 250                 | 0              | .....                                     | 7.71  | 7  |         |
| 04N01W11CDDC 1    | 343         | NISA    | .....              | .....            | .....         | 2.1       | 70           | 24             | 7.0         | 1.4           | 346                | 3.0           | 1.3           | .....        | .....         | 270              | .....              | 274                 | 0              | .....                                     | 7.41  | 7  |         |
| 04N01W11CDDC 1    | 343         | NISA    | 04 05 55           | 50               | 13            | .60       | 66           | 24             | .....       | .....         | 336                | 12            | 2.0           | .3           | .....         | .....            | 294                | 245                 | .....          | 560                                       | 7.8   | 3  |         |
| 04N01W11CDDC 1    | 343         | NISA    | 11 19 59           | .....            | 15            | .30       | 58           | 23             | 10          | 1.2           | 308                | 7.0           | 1.0           | .5           | .....         | .....            | 276                | 240                 | .....          | 500                                       | 7.7   | 3  |         |
| 04N01W11CDDC 1    | 343         | NISA    | 06 07 65           | .....            | 18            | .70       | 70           | 19             | 7.6         | 1.3           | 350                | .0            | .0            | .5           | .....         | .....            | 300                | 245                 | .....          | 460                                       | 7.4   | 3  |         |
| 04N01W11CDDC 1    | 250         | NISA    | 03 07 68           | .....            | .....         | 1.2       | 62           | 23             | 8.0         | 1.6           | 317                | 7.0           | 1.5           | .....        | .....         | 260              | .....              | 240                 | 0              | .....                                     | 7.71  | 7  |         |
| 04N01W17ABAA 1    | 413         | NISA    | 04 04 68           | .....            | 12            | .40       | 76           | 27             | 15          | 2.2           | 360                | 35            | 2.0           | .5           | .....         | .....            | 364                | 300                 | .....          | 610                                       | 7.4   | 3  |         |
| 04N01W18BAD 1     | 460         | NISA    | 07 31 52           | .....            | 10            | 1.1       | 88           | 34             | 7.0         | .....         | 392                | 65            | 8.0           | .2           | .....         | .....            | 410                | 360                 | .....          | 780                                       | 7.4   | 3  |         |
| 04N01W18BAD 1     | 460         | NISA    | 04 23 53           | 51               | .....         | .....     | .....        | .....          | .....       | .....         | 374                | 52            | 5.0           | .....        | .....         | .....            | .....              | 350                 | .....          | 800                                       | ..... | 3  |         |
| 04N01W18BAD 1     | 460         | NISA    | 04 27 54           | 51               | .....         | .....     | .....        | .....          | .....       | .....         | 374                | 70            | 11            | .....        | .....         | .....            | .....              | 376                 | .....          | 800                                       | ..... | 3  |         |
| 04N01W18BAD 1     | 460         | NISA    | 05 12 61           | .....            | 14            | .80       | 86           | 32             | 18          | 1.2           | 445                | 70            | 12            | .4           | .....         | .....            | 430                | 345                 | .....          | 780                                       | 7.4   | 3  |         |
| 04N01W18BAD 1     | 460         | NISA    | 02 29 68           | .....            | .....         | 1.7       | 114          | 42             | 14          | 2.0           | 437                | 110           | 25            | .....        | .....         | 524              | .....              | 445                 | 30             | .....                                     | 7.20  | 7  |         |



TABLE A-1.--continued

| LOCAL WELL NUMBER | DEPTH, FEET | AQUIFER | DATE OF COLLECTION | TEMPERATURE (°F) | SILICA (SI02) | IRON (FE) | CALCIUM (CA) | MAGNESIUM (MG) | SODIUM (NA) | POTASSIUM (K) | BICARBONATE (HCO3) | SULFATE (SO4) | CHLORIDE (CL) | FLUORIDE (F) | NITRATE (NO3) | DISSOLVED SOLIDS |                     | HARDNESS AS CALCIUM |               | SPECIFIC CONDUCTANCE    |       | PH | ANALYST |
|-------------------|-------------|---------|--------------------|------------------|---------------|-----------|--------------|----------------|-------------|---------------|--------------------|---------------|---------------|--------------|---------------|------------------|---------------------|---------------------|---------------|-------------------------|-------|----|---------|
|                   |             |         |                    |                  |               |           |              |                |             |               |                    |               |               |              |               | CALCIUM LATED    | EVAPORATED AT 180°C | CARBONATE           | NON-CARBONATE | IN MICRO-OMEGAS AT 25°C |       |    |         |
| 04W02W12CDA 1     | 305         | NISA    | 07 31 52           | .....            | 10            | 2.5       | 112          | 36             | 7.0         | .....         | 421                | 105           | 3.0           | .2           | .0            | .....            | 418                 | 430                 | .....         | 800                     | 7.3   | 3  |         |
| 04W02W12CDA 1     | 305         | NISA    | 04 23 53           | 50               | .....         | .....     | .....        | .....          | .....       | .....         | 425                | 103           | 2.0           | .....        | .....         | .....            | .....               | 430                 | .....         | 740                     | ..... | 3  |         |
| 04W02W12CDA 1     | 305         | NISA    | 08 21 61           | .....            | 15            | 3.5       | 128          | 40             | 8.9         | 1.6           | 425                | 140           | 6.0           | .2           | .0            | .....            | 414                 | 485                 | .....         | 810                     | 7.4   | 3  |         |
| 04W02W12CDA 1     | 305         | NISA    | 02 29 68           | .....            | .....         | 3.2       | 110          | 38             | 8.5         | 2.2           | 435                | 91            | 6.9           | .....        | .....         | 473              | .....               | 431                 | 75            | .....                   | 7.23  | 7  |         |
| 04W02W16DAA 1     | 445         | NISA    | 02 08 52           | .....            | 8.4           | .30       | 110          | 36             | 46          | 2.4           | 375                | 78            | 90            | .0           | .0            | .....            | 400                 | 425                 | .....         | 910                     | 7.8   | 3  |         |
| 04W02W16DAA 1     | 445         | NISA    | 04 22 53           | 53               | .....         | .....     | .....        | .....          | .....       | .....         | 378                | 60            | 93            | .....        | .....         | .....            | .....               | 410                 | .....         | 900                     | ..... | 3  |         |
| 04W02W16DAA 1     | 455         | NISA    | 03 29 55           | 53               | .....         | .....     | .....        | .....          | .....       | .....         | 371                | 70            | 107           | .....        | .....         | .....            | .....               | 345                 | .....         | 1010                    | ..... | 3  |         |
| 04W02W18BDA 1     | 399         | NISA    | 10 27 60           | .....            | 15            | .40       | 76           | 24             | 5.7         | .8            | 344                | 10            | .0            | .4           | .0            | .....            | 320                 | 290                 | .....         | 600                     | 7.5   | 3  |         |
| 04W02W18CAAC 1    | 404         | NISA    | 04 22 53           | 50               | 2.0           | .30       | 68           | 28             | 9.7         | .....         | 346                | 5.4           | .0            | .4           | .0            | .....            | 314                 | 285                 | .....         | 580                     | 7.5   | 3  |         |
| 04W02W18CAAC 1    | 404         | NISA    | 03 22 54           | 51               | .....         | .....     | .....        | .....          | .....       | .....         | 373                | 5.0           | .0            | .....        | .....         | .....            | .....               | 275                 | .....         | 450                     | ..... | 3  |         |
| 04W02W18CAAC 1    | 404         | NISA    | 10 27 60           | .....            | 16            | .40       | 86           | 27             | 6.9         | 1.0           | 376                | 30            | 2.0           | .4           | .0            | .....            | 370                 | 325                 | .....         | 610                     | 7.6   | 3  |         |
| 04W02W18CAAC 1    | 417         | NISA    | 10 27 60           | .....            | 16            | .40       | 78           | 28             | 6.9         | .8            | 372                | 20            | .0            | .4           | .0            | .....            | 350                 | 310                 | .....         | 600                     | 7.5   | 3  |         |
| 04W02W23BCC 1     | 400         | NISA    | 04 22 53           | 51               | 11            | .50       | 106          | 39             | .....       | .....         | 415                | 93            | 8.0           | .1           | .0            | .....            | 500                 | 425                 | .....         | 750                     | 7.8   | 3  |         |
| 04W02W24ADD 1     | 425         | NISA    | 04 23 53           | 52               | 15            | 1.1       | 79           | 27             | 5.6         | 1.6           | 378                | 7.1           | .9            | .2           | 2.0           | .....            | 325                 | 308                 | .....         | 565                     | 6.9   | 1  |         |
| 04W02W24DCC 1     | 352         | NISA    | 04 23 53           | 51               | 3.3           | .25       | 70           | 27             | 7.1         | .....         | 358                | 6.6           | .0            | .0           | .0            | .....            | 300                 | 285                 | .....         | 570                     | 7.5   | 3  |         |
| 04W02W25ABA 1     | 340         | NISA    | 02 29 68           | .....            | .....         | .44       | 90           | 30             | 4.0         | 1.3           | 394                | 35            | 3.9           | .....        | .....         | 358              | .....               | 368                 | 27            | .....                   | 7.20  | 7  |         |
| 04W02W25ABA 1     | 347         | NISA    | 04 23 58           | .....            | .....         | .30       | 72           | 17             | .....       | .....         | 372                | .....         | .0            | .....        | .....         | .....            | .....               | 250                 | .....         | .....                   | 7.5   | 3  |         |
| 04W02W25ABA 1     | 347         | NISA    | 02 29 68           | .....            | .....         | .56       | 76           | 26             | 5.5         | 1.3           | 365                | 8.0           | 1.8           | .....        | .....         | 299              | .....               | 297                 | 0             | .....                   | 7.32  | 7  |         |
| 04W02W27CDA 1     | 336         | NISA    | 04 22 53           | 50               | 3.0           | .50       | 80           | 24             | 7.0         | .....         | 368                | 16            | 1.0           | .0           | .0            | .....            | 326                 | 300                 | .....         | 600                     | 7.4   | 3  |         |
| 04W02W31DCC 1     | 450         | NISA    | 07 07 61           | .....            | .....         | 1.3       | 105          | 28             | 4.4         | .9            | 387                | 74            | 3.0           | .....        | .1            | .....            | 444                 | 378                 | 68            | 687                     | 6.9   | 1  |         |
| 04W02W34DAA 1     | 375         | NISA    | 02 29 68           | .....            | .....         | .88       | 94           | 29             | 3.5         | 1.2           | 417                | 23            | 2.8           | .....        | .....         | 360              | .....               | 354                 | 12            | .....                   | 7.29  | 7  |         |

## JACKSON COUNTY

|                |     |      |          |       |       |     |       |       |       |       |     |     |     |       |       |       |       |     |     |       |      |   |
|----------------|-----|------|----------|-------|-------|-----|-------|-------|-------|-------|-----|-----|-----|-------|-------|-------|-------|-----|-----|-------|------|---|
| 01S01F080AAD   | 190 | N3RA | 11 02 67 | ..... | ..... | 1.1 | 95    | 30    | 3.1   | 1.2   | 436 | 43  | 2.4 | ..... | ..... | 380   | ..... | 360 | 24  | ..... | 7.41 | 7 |
| 01S01F22ABBB 1 | 180 | NISA | 11 02 67 | ..... | ..... | 2.3 | 64    | 15    | 3.2   | 8.0   | 208 | 6.0 | 1.2 | ..... | ..... | 264   | ..... | 223 | 0   | ..... | 7.44 | 7 |
| 01S01W22ADCA 1 | 165 | NISA | 11 02 67 | ..... | ..... | 1.9 | 58    | 17    | 3.6   | 2.6   | 200 | 38  | 2.4 | ..... | ..... | 223   | ..... | 214 | 60  | ..... | 7.40 | 7 |
| 01S01W23ABBA 1 | 100 | OGOO | 11 02 67 | ..... | ..... | 3.3 | 66    | 19    | 3.1   | .8    | 297 | 23  | 1.1 | ..... | ..... | 263   | ..... | 244 | 0   | ..... | 7.50 | 7 |
| 01S01W24DGB 1  | 164 | N3RA | 01 16 65 | ..... | ..... | .97 | ..... | ..... | ..... | ..... | 246 | 17  | 3.0 | ..... | .7    | ..... | ..... | 222 | 14  | 474   | 7.3  | 1 |
| 01S02W04CCCC 1 | 120 | NISA | 11 02 67 | ..... | ..... | .75 | 54    | 14    | 2.6   | 1.0   | 200 | 30  | 2.4 | ..... | ..... | 205   | ..... | 194 | 40  | ..... | 7.4  | 3 |
| 01S02W130DCD 1 | 60  | OGOU | 11 09 67 | ..... | ..... | 2.2 | 72    | 20    | 3.0   | 1.1   | 317 | 20  | 1.9 | ..... | ..... | 217   | ..... | 240 | 0   | ..... | 7.44 | 7 |
| 01S03W13ADDD 1 | 58  | OGOO | 11 02 67 | ..... | ..... | .60 | 73    | 18    | 2.9   | 1.4   | 214 | 29  | 4.1 | ..... | ..... | 210   | ..... | 240 | 24  | ..... | 7.45 | 7 |
| 02S01F1780DD 1 | 109 | OGOO | 11 02 67 | ..... | ..... | 3.0 | 68    | 20    | 6.1   | 1.6   | 422 | 4.0 | 2.2 | ..... | ..... | 264   | ..... | 244 | 0   | ..... | 7.41 | 7 |
| 02S01W05CCBC 1 | 125 | NISA | 11 09 67 | ..... | ..... | 2.9 | 83    | 25    | 2.0   | 5.8   | 431 | 8.0 | 2.2 | ..... | ..... | 331   | ..... | 304 | 0   | ..... | 7.41 | 7 |
| 02S01W08ADCC 1 | 110 | N3RA | 11 09 67 | ..... | ..... | 1.2 | 74    | 22    | 4.6   | 11    | 420 | 28  | 4.6 | ..... | ..... | 507   | ..... | 274 | 24  | ..... | 7.4  | 7 |
| 02S02W25CRP 1  | 109 | NISA | 01 16 65 | ..... | ..... | 9.1 | ..... | ..... | ..... | ..... | 460 | 24  | 2.0 | ..... | .4    | ..... | ..... | 244 | 14  | ..... | 7.4  | 1 |
| 02S02W31ACDD 1 | 75  | N3RA | 11 02 67 | ..... | ..... | 3.6 | 124   | 37    | 15    | 4.5   | 464 | 75  | 6.2 | ..... | ..... | 446   | ..... | 442 | 172 | ..... | 7.44 | 7 |
| 02S02W35CADA 1 | 60  | NISA | 11 02 67 | ..... | ..... | .95 | 88    | 30    | 14    | 2.4   | 207 | 32  | 1.4 | ..... | ..... | 342   | ..... | 241 | 14  | ..... | 7.4  | 7 |
| 02S02W35CADA 1 | 90  | NISA | 01 16 65 | ..... | ..... | .45 | ..... | ..... | ..... | ..... | 280 | 27  | 4.0 | ..... | 2.6   | ..... | ..... | 263 | 44  | ..... | 7.4  | 1 |
| 02S02W35CADA 1 | 65  | NISA | 11 02 67 | ..... | ..... | 4.3 | 66    | 16    | 2.0   | 1.0   | 104 | 31  | 7.4 | ..... | ..... | 224   | ..... | 241 | 44  | ..... | 7.4  | 7 |

TABLE A-1.--continued

| LOCAL WELL<br>NUMBER | DEPTH,<br>FEET | ACQU-<br>FFD | DATE OF<br>COLLEC-<br>TION | TEMP-<br>PERA-<br>TURE<br>(°F) | SILICA<br>(%SiO2) | IRON<br>(FE) | CALCIUM<br>(CA) | MAG-<br>NESIUM<br>(MG) | SODIUM<br>(NA) | POT-<br>ASSIUM<br>(K) | BICAR-<br>BONATE<br>(MCO3) | SULFATE<br>(SO4) | CHLORINE<br>(CL) | FLUORIDE<br>(F) | NITRATE<br>(NO3) | DISSOLV<br>SOLIDS |                    | SAR TEST AS<br>CALCULATED |                   | SPECIFIC<br>CONDUCT-<br>ANCE<br>(MICRO-<br>MMHS<br>AT 25°C) |         | PH | ANA-<br>LYST |  |
|----------------------|----------------|--------------|----------------------------|--------------------------------|-------------------|--------------|-----------------|------------------------|----------------|-----------------------|----------------------------|------------------|------------------|-----------------|------------------|-------------------|--------------------|---------------------------|-------------------|-------------------------------------------------------------|---------|----|--------------|--|
|                      |                |              |                            |                                |                   |              |                 |                        |                |                       |                            |                  |                  |                 |                  | CALCIUM<br>LATED  | MAGNESIUM<br>LATED | CA+MAG<br>AT 25°C         | CA+MAG<br>AT 25°C | AT 25°C                                                     | AT 25°C |    |              |  |
| LIVINGSTON COUNTY    |                |              |                            |                                |                   |              |                 |                        |                |                       |                            |                  |                  |                 |                  |                   |                    |                           |                   |                                                             |         |    |              |  |
| 2W03F14CRA           | 36             | 0000         | 02 20 65                   | .....                          | .....             | .76          | .....           | .....                  | .....          | .....                 | 357                        | 47               | 8.0              | .....           | 12               | .....             | .....              | 350                       | 65                | 666                                                         | 7.6     | 1  |              |  |
| 12W03F14CRA 1        | 47             | MISA         | 02 20 65                   | .....                          | .....             | 5.9          | .....           | .....                  | .....          | .....                 | 390                        | 13               | 3.0              | .....           | .4               | .....             | .....              | 330                       | 10                | 547                                                         | 7.5     | 1  |              |  |
| 12W03F20ACD 1        | 121            | MISA         | 02 20 65                   | .....                          | .....             | 7.0          | .....           | .....                  | .....          | .....                 | 252                        | 27               | 3.0              | .....           | .5               | .....             | .....              | 230                       | 32                | 443                                                         | 7.6     | 1  |              |  |
| 02W03F20CBBC 1       | 144            | MISA         | 11 14 67                   | .....                          | .....             | 1.0          | 70              | 22                     | 3.5            | 1.0                   | 312                        | 39               | 2.5              | .....           | .....            | 281               | .....              | 266                       | 10                | .....                                                       | 7.67    | 7  |              |  |
| 03W03F02D0C 1        | 110            | MISA         | 02 20 65                   | .....                          | .....             | .....        | .....           | .....                  | .....          | .....                 | 350                        | 3.2              | 375              | .....           | .8               | .....             | .....              | 372                       | 44                | 1560                                                        | 7.7     | 1  |              |  |
| 03W03F02D0C 1        | 110            | MISA         | 02 20 65                   | .....                          | .....             | 1.1          | .....           | .....                  | .....          | .....                 | 360                        | 10               | 202              | .....           | 1.1              | .....             | .....              | 372                       | 76                | 1180                                                        | 7.9     | 1  |              |  |
| 03W03F10A88D 1       | 64             | 0000         | 11 14 67                   | .....                          | .....             | 1.7          | 99              | 32                     | 3.0            | 1.0                   | 361                        | 91               | 7.7              | .....           | .....            | 412               | .....              | 379                       | 43                | .....                                                       | 7.54    | 7  |              |  |
| 03W03F24C00D 1       | 132            | MISA         | 11 14 67                   | .....                          | .....             | .85          | 110             | 36                     | 5.5            | 2.0                   | 519                        | 14               | 2.4              | .....           | .....            | 410               | .....              | 423                       | 0                 | .....                                                       | 7.30    | 7  |              |  |
| 03W03F24C00D 1       | 207            | MISA         | 11 14 67                   | .....                          | .....             | 6.4          | 102             | 38                     | 6.5            | 1.9                   | 530                        | 8.0              | 1.7              | .....           | .....            | 411               | .....              | 411                       | 0                 | .....                                                       | 7.39    | 7  |              |  |
| 12W03F24C00D 1       | 170            | MISA         | 02 20 65                   | .....                          | .....             | 7.9          | .....           | .....                  | .....          | .....                 | 430                        | 38               | 16               | .....           | .5               | .....             | .....              | 444                       | 41                | 793                                                         | 7.6     | 1  |              |  |
| 12W03F14C88A 1       | 135            | MISA         | 11 14 67                   | .....                          | .....             | 1.7          | 98              | 33                     | 5.5            | 1.3                   | 480                        | 8.0              | 1.9              | .....           | .....            | 389               | .....              | 441                       | 0                 | .....                                                       | 7.43    | 7  |              |  |
| SUIAVASSEE COUNTY    |                |              |                            |                                |                   |              |                 |                        |                |                       |                            |                  |                  |                 |                  |                   |                    |                           |                   |                                                             |         |    |              |  |
| 04W01F10CCCC         | 77             | 0000         | 11 30 67                   | .....                          | .....             | .80          | 71              | 27                     | 8.0            | 1.4                   | 371                        | 12               | 2.0              | .....           | .....            | 306               | .....              | 288                       | 0                 | .....                                                       | 7.41    | 7  |              |  |
| 04W01F21A80D 1       | 265            | MISA         | 11 30 67                   | .....                          | .....             | .47          | 60              | 18                     | 16             | 4.3                   | 319                        | 2.0              | 3.4              | .....           | .....            | 261               | .....              | 224                       | 0                 | .....                                                       | 7.41    | 7  |              |  |
| 04W01F35D08A 1       | 75             | 0000         | 11 30 67                   | .....                          | .....             | .85          | 54              | 19                     | 9.5            | 1.2                   | 305                        | 1.0              | 1.1              | .....           | .....            | 261               | .....              | 223                       | 0                 | .....                                                       | 7.40    | 7  |              |  |
| 04W02F01C0UD 1       | 140            | MISA         | 11 30 67                   | .....                          | .....             | .85          | 76              | 30                     | 10             | 2.0                   | 405                        | 11               | 2.1              | .....           | .....            | 352               | .....              | 313                       | 0                 | .....                                                       | 7.47    | 7  |              |  |

TABLE A-2.--Chemical analyses of stream water.

Results in milligrams per liter except as indicated. Agency making analyses: (1) U.S. Geological Survey, (2) Michigan Department of Public Health. R=Over land runoff S=Base flow

| Station Number                                              | Source          | Location                 | Date Sampled   | Discharge (cfs) | Silica (SiO <sub>2</sub> ) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Bicarbonate (HCO <sub>3</sub> ) | Carbonate (CO <sub>3</sub> ) | Sulfate (SO <sub>4</sub> ) | Chloride (Cl) | Nitrate NO <sub>3</sub> | Dissolved solids (residue on evaporation at 180°C) | Ca, Mg | Non-carb. | Specific conductance (microhm 25°C) | pH  | Color in Hazen color unit | Analyst |
|-------------------------------------------------------------|-----------------|--------------------------|----------------|-----------------|----------------------------|-----------|--------------|----------------|-------------|---------------|---------------------------------|------------------------------|----------------------------|---------------|-------------------------|----------------------------------------------------|--------|-----------|-------------------------------------|-----|---------------------------|---------|
| Stream Tributary to Battle Creek                            |                 |                          |                |                 |                            |           |              |                |             |               |                                 |                              |                            |               |                         |                                                    |        |           |                                     |     |                           |         |
| 4-1042.8                                                    | Battle Creek    | SW 1/4 sec 2, T.1N.R.5W  | July 11, 1967  | B               | —                          | —         | —            | —              | —           | —             | 342                             | 0                            | 77                         | 36            | 7.4                     | 479                                                | 375    | 94        | 760                                 | 7.7 | —                         | 1       |
| do                                                          | do              | do                       | June 28, 1968  | R               | —                          | .18       | —            | —              | —           | —             | 136                             | 0                            | 43                         | 6.0           | 12                      | 254                                                | 166    | 54        | 335                                 | 7.3 | 75                        | 1       |
| 4-1042.9                                                    | Big Creek       | SW 1/4 sec 15, T.1N.R.5W | July 11, 1967  | B               | —                          | —         | —            | —              | —           | —             | 348                             | 0                            | 125                        | 8.0           | 3.6                     | 513                                                | 425    | 140       | 147                                 | 7.3 | —                         | 1       |
| do                                                          | do              | do                       | June 28, 1968  | R               | —                          | .13       | —            | —              | —           | —             | 198                             | 0                            | 109                        | 4.0           | 20                      | 432                                                | 294    | 132       | 548                                 | 7.3 | 100                       | 1       |
| 4-1043.0                                                    | Indian Creek    | SW 1/4 sec 20, T.1N.R.5W | Oct. 6, 1964   | 4.08            | —                          | —         | —            | —              | —           | —             | 320                             | 0                            | 60                         | 16            | 1.3                     | 415                                                | 347    | 84        | 652                                 | 7.8 | —                         | 1       |
| 4-1044.5                                                    | Battle Creek    | NE 1/4 sec 26, T.1N.R.6W | June 28, 1968  | R               | —                          | .14       | —            | —              | —           | —             | 156                             | 0                            | 62                         | 8.0           | 21                      | 284                                                | 212    | 84        | 423                                 | 7.3 | 125                       | 1       |
| Stream Tributary to the Upper Grand River and Portage River |                 |                          |                |                 |                            |           |              |                |             |               |                                 |                              |                            |               |                         |                                                    |        |           |                                     |     |                           |         |
| 4-1089.0                                                    | Grand River     | NE 1/4 sec 35, T.1S.R.1W | Sept. 13, 1963 | 3.99            | —                          | .28       | 60           | 23             | 5.4         | 1.0           | 272                             | 0                            | 30                         | 6.0           | —                       | 278                                                | 244    | 21        | 467                                 | 7.1 | —                         | 1       |
| 4-1095.0                                                    | Orchard Creek   | SW 1/4 sec 32, T.1S.R.2E | Sept. 2, 1959  | R               | 16                         | .7        | 98           | 28             | 4.6         | 1.6           | 288                             | 0                            | 105                        | 6             | 2.5                     | 430                                                | 360    | 124       | 610                                 | 8.0 | 35                        | 3       |
| do                                                          | do              | do                       | Dec. 17, 1959  | R               | 7                          | .3        | 114          | 28             | 4.6         | 1.2           | 264                             | 0                            | 170                        | 7             | 20                      | 510                                                | 400    | 184       | 700                                 | 7.8 | 100                       | 3       |
| do                                                          | do              | do                       | Apr. 21, 1960  | R               | 6                          | .6        | 98           | 24             | 4.6         | 2.0           | 230                             | 0                            | 125                        | 10            | 16                      | 466                                                | 345    | 140       | 650                                 | 7.9 | 80                        | 3       |
| do                                                          | do              | do                       | July 7, 1960   | B               | 7                          | .7        | 108          | 29             | 4.6         | 1.2           | 318                             | 0                            | 121                        | 4             | 1.5                     | 430                                                | 390    | 130       | 700                                 | 7.8 | 30                        | 3       |
| 4-1097.0                                                    | Orchard Creek   | NE 1/4 sec 30, T.1N.R.2E | June 28, 1968  | R               | —                          | 2.7       | —            | —              | —           | —             | 118                             | 0                            | 78                         | 3.0           | 17                      | 298                                                | 194    | 98        | 370                                 | 6.9 | 200                       | 1       |
| 4-1105.9                                                    | Batawsee Creek  | SW 1/4 sec 28, T.1N.R.1E | July 11, 1967  | B               | —                          | —         | —            | —              | —           | —             | 284                             | 0                            | 80                         | 7.0           | 2.6                     | 384                                                | 320    | 87        | 589                                 | 7.6 | —                         | 1       |
| do                                                          | do              | do                       | June 28, 1968  | R               | —                          | .30       | —            | —              | —           | —             | 130                             | 0                            | 43                         | 1.0           | 4.9                     | 246                                                | 160    | 54        | 297                                 | 7.6 | 180                       | 1       |
| 4-1106.0                                                    | do              | NE 1/4 sec 27, T.1S.R.1E | Sept. 19, 1963 | .16             | —                          | .27       | 67           | 22             | 4.6         | 2.2           | 242                             | 0                            | 65                         | 7.0           | —                       | 340                                                | 298    | 99        | 503                                 | 7.4 | —                         | 1       |
| 4-1106.2                                                    | Portage River   | SE 1/4 sec 11, T.2S.R.3W | Sept. 2, 1959  | R               | 16                         | .8        | 82           | 26             | 4.8         | 3.7           | 285                             | 0                            | 59                         | 69            | 1.0                     | 540                                                | 310    | 77        | 730                                 | 7.7 | 75                        | 3       |
| do                                                          | do              | do                       | Dec. 17, 1959  | R               | 7                          | .3        | 94           | 23             | 7.8         | 1.6           | 220                             | 0                            | 125                        | 15            | 13                      | 440                                                | 330    | 150       | 640                                 | 7.6 | 90                        | 3       |
| do                                                          | do              | do                       | Apr. 21, 1960  | R               | 3                          | .4        | 75           | 16             | 15          | 1.5           | 205                             | 0                            | 85                         | 27            | 7.5                     | 368                                                | 255    | 87        | 590                                 | 7.9 | 80                        | 3       |
| do                                                          | do              | do                       | Sept. 7, 1960  | B               | 9                          | .5        | 85           | 21             | 9.2         | .8            | 282                             | 0                            | 60                         | 11            | 1.0                     | 400                                                | 300    | 69        | 580                                 | 7.5 | 100                       | 3       |
| 4-1106.4                                                    | Huntton Creek   | SE 1/4 sec 20, T.1N.R.1W | June 28, 1968  | R               | —                          | .02       | —            | —              | —           | —             | 260                             | 0                            | 152                        | 26            | 38                      | 574                                                | 420    | 207       | 793                                 | 7.2 | 25                        | 1       |
| 4-1106.5                                                    | Huntton Creek   | SW 1/4 sec 28, T.1N.R.1W | Oct. 6, 1964   | 1.45            | —                          | —         | —            | —              | —           | —             | 352                             | 0                            | 164                        | 30            | —                       | 604                                                | 469    | 180       | 938                                 | 7.4 | —                         | 1       |
| 4-1107.0                                                    | Sandstone Creek | NE 1/4 sec 21, T.1S.R.2W | Sept. 19, 1963 | 6.98            | —                          | .68       | 67           | 23             | 7.3         | 1.3           | 278                             | 0                            | 41                         | 8.0           | —                       | 307                                                | 262    | 34        | 513                                 | 7.0 | —                         | 1       |
| do                                                          | do              | do                       | Sept. 2, 1959  | R               | 12                         | .3        | 64           | 18             | 4.6         | 1.2           | 254                             | 0                            | 33                         | 3             | 0                       | 270                                                | 236    | 34        | 450                                 | 8.0 | 15                        | 3       |
| do                                                          | do              | do                       | Dec. 17, 1959  | R               | 6                          | .2        | 86           | 22             | 5.7         | .8            | 254                             | 0                            | 100                        | 7             | 4                       | 376                                                | 305    | 97        | 540                                 | 7.7 | 35                        | 3       |
| do                                                          | do              | do                       | Apr. 21, 1960  | R               | 4                          | .3        | 76           | 20             | 6.0         | 1.2           | 298                             | 0                            | 98                         | 13            | 2.0                     | 323                                                | 270    | 99        | 530                                 | 8.1 | 40                        | 3       |
| do                                                          | do              | do                       | July 7, 1960   | B               | 10                         | .3        | 80           | 20             | 5.1         | .8            | 303                             | 0                            | 32                         | 5             | 0                       | 350                                                | 280    | 32        | 540                                 | 7.9 | 60                        | 3       |
| 4-1108.0                                                    | Grand River     | SW 1/4 sec 2, T.1N.R.3W  | Sept. 2, 1959  | R               | 14                         | .4        | 76           | 23             | 36          | 3.5           | 290                             | 0                            | 66                         | 41            | 2.0                     | 430                                                | 284    | 46        | 700                                 | 7.9 | 25                        | 3       |
| do                                                          | do              | do                       | Dec. 17, 1959  | R               | 6                          | .1        | 86           | 22             | 13          | 1.6           | 234                             | 0                            | 110                        | 17            | 12                      | 420                                                | 305    | 114       | 600                                 | 7.7 | 40                        | 3       |
| do                                                          | do              | do                       | Apr. 21, 1960  | R               | 4                          | .4        | 72           | 18             | 8.3         | 2.6           | 222                             | 0                            | 73                         | 14            | 6.4                     | 352                                                | 225    | 43        | 520                                 | 8.0 | 60                        | 3       |
| do                                                          | do              | do                       | July 7, 1960   | B               | 11                         | .7        | 74           | 18             | 8.5         | 1.2           | 270                             | 0                            | 33                         | 11            | 1.5                     | 370                                                | 260    | 39        | 520                                 | 7.8 | 70                        | 3       |
| 4-1108.9                                                    | Spring Brook    | SW 1/4 sec 27, T.1N.R.3W | June 28, 1968  | R               | —                          | .18       | —            | —              | —           | —             | 166                             | 0                            | 26                         | 2.0           | 1.6                     | 196                                                | 164    | 28        | 317                                 | 7.3 | 115                       | 1       |
| 4-1109.0                                                    | Spring Brook    | N 1/4 sec 3, T.1N.R.3W   | Sept. 19, 1963 | 1.86            | —                          | .07       | 78           | 12             | 4.2         | 1.3           | 262                             | 0                            | 35                         | 5.0           | —                       | 282                                                | 244    | 30        | 472                                 | 7.0 | —                         | 1       |
| do                                                          | do              | do                       | Sept. 2, 1959  | R               | 16                         | 1.0       | 64           | 23             | 3.7         | .9            | 299                             | 0                            | 42                         | 3             | 2.0                     | 318                                                | 255    | 43        | 500                                 | 7.9 | 30                        | 3       |
| do                                                          | do              | do                       | Dec. 17, 1959  | R               | 9                          | .0        | 76           | 19             | 4.6         | .8            | 244                             | 0                            | 63                         | 3             | 5.0                     | 330                                                | 270    | 70        | 510                                 | 7.9 | 70                        | 3       |
| do                                                          | do              | do                       | Apr. 21, 1960  | R               | 2                          | .3        | 64           | 17             | 3.5         | 1.2           | 230                             | 0                            | 43                         | 5             | 1.2                     | 276                                                | 230    | 42        | 450                                 | 8.1 | 60                        | 3       |
| do                                                          | do              | do                       | July 7, 1960   | B               | 10                         | .7        | 68           | 17             | 2.8         | .8            | 240                             | 0                            | 23                         | 7             | .5                      | 296                                                | 240    | 23        | 450                                 | 8.4 | 70                        | 3       |

TABLE A-2.--continued

| Station Number                             | Source                               | Location                  | Date Sampled   | Discharge (cfs) | Salinity (ppt) | Iron (ppm) | Calcium (mg) | Magnesium (mg) | Sodium (mg) | Potassium (mg) | Bicarbonate (HCO <sub>3</sub> ) | Carbonate (CO <sub>3</sub> ) | Sulfate (SO <sub>4</sub> ) | Chloride (Cl) | Nitrate (NO <sub>3</sub> ) | Dissolved solids (residue on evaporation at 180°C) | Hardness as CaCO <sub>3</sub> | Specific conductance (microhms/cm) | pH  | Color in hazen color units | Analyst |   |
|--------------------------------------------|--------------------------------------|---------------------------|----------------|-----------------|----------------|------------|--------------|----------------|-------------|----------------|---------------------------------|------------------------------|----------------------------|---------------|----------------------------|----------------------------------------------------|-------------------------------|------------------------------------|-----|----------------------------|---------|---|
| Stream Tributary to Red Cedar River        |                                      |                           |                |                 |                |            |              |                |             |                |                                 |                              |                            |               |                            |                                                    |                               |                                    |     |                            |         |   |
| 4-1112.0                                   | Red Cedar River                      | NE 1/4 sec 5, T.3N.R.1E   | Sept 19, 1963  | 4.01            | —              | .32        | 79           | 25             | 37          | 4.6            | 334                             | 0                            | 57                         | 42            | —                          | 443                                                | 300                           | 229                                | 7.0 | —                          | 1       |   |
| 4-1112.8                                   | Salmon Creek                         | SW 1/4 sec 23, T.2N.R.2E  | July 11, 1967  | —               | —              | —          | —            | —              | —           | —              | 337                             | 0                            | 71                         | 7.0           | 2.1                        | 414                                                | 354                           | 630                                | 8.1 | —                          | 1       |   |
| do                                         | do                                   | do                        | June 28, 1968  | —               | —              | .18        | —            | —              | —           | —              | 216                             | 0                            | 83                         | 6.0           | 30                         | 428                                                | 290                           | 113                                | 7.7 | 150                        | 1       |   |
| 4-1113.0                                   | do                                   | SW 1/4 sec 2, T.3N.R.2E   | Oct 5, 1964    | 1.23            | —              | —          | —            | —              | —           | —              | 362                             | 0                            | 98                         | 18            | .5                         | 488                                                | 424                           | 107                                | 7.7 | —                          | 1       |   |
| 4-1113.6                                   | Red Cedar River                      | NW 1/4 sec 4, T.3N.R.2E   | Sept 2, 1959   | —               | 15             | .90        | 88           | 27             | 11          | 2.9            | 317                             | 0                            | 52                         | 15            | 5.0                        | 422                                                | 330                           | 70                                 | 7.5 | —                          | 1       |   |
| do                                         | do                                   | do                        | Dec. 17, 1959  | —               | 7              | .40        | 94           | 24             | 5.8         | 1.0            | 305                             | 0                            | 70                         | 11            | 10                         | 420                                                | 333                           | 83                                 | 613 | 7.6                        | 110     | 1 |
| do                                         | do                                   | do                        | Apr. 20, 1960  | —               | 4.5            | .20        | 76           | 19             | 4.6         | 2.0            | 265                             | 0                            | 55                         | 10            | 4.4                        | 340                                                | 270                           | 53                                 | 530 | 7.9                        | —       | 1 |
| do                                         | do                                   | do                        | July 7, 1960   | —               | 9.0            | .50        | 92           | 28             | 7.8         | 1.6            | 350                             | 0                            | 63                         | 7.0           | 2.2                        | 420                                                | 345                           | 59                                 | 821 | 8.2                        | —       | 1 |
| 4-1114.02                                  | Donn Creek                           | SE 1/4 sec 36, T.3N.R.1E  | July 11, 1967  | —               | —              | —          | —            | —              | —           | —              | 348                             | 0                            | 117                        | 12            | 4.1                        | 496                                                | 420                           | 135                                | 724 | 8.1                        | —       | 1 |
| do                                         | do                                   | do                        | June 28, 1968  | —               | —              | .19        | —            | —              | —           | —              | 190                             | 0                            | 73                         | 10            | 23                         | 318                                                | 260                           | 124                                | 493 | 7.3                        | 150     | 1 |
| 4-1114.0                                   | Squaw Creek                          | SW 1/4 sec 32, T.4N.R.2E  | Oct. 5, 1964   | —               | —              | —          | —            | —              | 8.0         | —              | 364                             | 0                            | 82                         | 10            | .2                         | 452                                                | 396                           | 98                                 | 713 | 7.9                        | —       | 1 |
| 4-1114.05                                  | Metz Creek                           | SW 1/4 sec 33, T.3N.R.2E  | July 11, 1967  | —               | —              | —          | —            | —              | —           | —              | 380                             | 0                            | 153                        | 14            | 4.4                        | 592                                                | 490                           | 178                                | 856 | 7.7                        | —       | 1 |
| 4-1114.1                                   | Donn Creek                           | SW 1/4 sec 8, T.3N.R.2E   | Sept. 2, 1959  | —               | 14             | 1.2        | 93           | 26             | 4.6         | 3.8            | 317                             | 0                            | 98                         | 10            | 5.0                        | 474                                                | 379                           | 119                                | 826 | 7.7                        | 70      | 1 |
| do                                         | do                                   | do                        | Dec. 17, 1959  | —               | 7.0            | .30        | 102          | 25             | 5.7         | 1.6            | 314                             | 0                            | 100                        | 9.0           | 8.0                        | 478                                                | 360                           | 104                                | 640 | 7.8                        | —       | 1 |
| do                                         | do                                   | do                        | Apr. 20, 1960  | —               | 2.0            | .30        | 85           | 22             | 4.6         | 2.0            | 280                             | 0                            | 62                         | 11            | 6.6                        | 360                                                | 305                           | 75                                 | 600 | 7.8                        | 50      | 1 |
| do                                         | do                                   | do                        | July 7, 1960   | —               | 7.0            | .40        | 96           | 29             | 6.4         | 1.2            | 338                             | 0                            | 92                         | 5.0           | 1.0                        | 454                                                | 360                           | 83                                 | 650 | 8.4                        | 30      | 1 |
| do                                         | do                                   | do                        | Oct. 5, 1964   | —               | 2.15           | —          | —            | —              | —           | —              | 298                             | 0                            | 103                        | 8.0           | .3                         | 398                                                | 356                           | 112                                | 649 | 8.1                        | —       | 1 |
| 4-1115.0                                   | Deer Creek                           | E 1/2 sec 33, T.3N.R.1E   | Sept. 26, 1963 | —               | —              | .56        | 78           | 24             | 6.9         | 3.2            | 307                             | 0                            | 44                         | 8.0           | —                          | 340                                                | 293                           | 43                                 | 561 | 7.2                        | —       | 1 |
| do                                         | do                                   | do                        | Apr. 5, 1967   | —               | 23.0           | —          | —            | —              | —           | —              | 242                             | 0                            | 76                         | 14            | —                          | —                                                  | 297                           | 99                                 | 540 | 8.7                        | —       | 1 |
| do                                         | do                                   | do                        | June 28, 1968  | —               | 115            | —          | .13          | —              | —           | —              | 194                             | 0                            | 46                         | 8.0           | 12                         | 312                                                | 200                           | 41                                 | 424 | 7.3                        | 100     | 1 |
| 4-1115.8                                   | Deer Creek                           | NE 1/4 sec 11, T.3N.R.1E  | Sept. 2, 1959  | —               | 11             | .30        | 94           | 23             | 6.0         | 2.7            | 330                             | 0                            | 57                         | 9.0           | 4.5                        | 444                                                | 330                           | 60                                 | 613 | 8.0                        | 80      | 1 |
| do                                         | do                                   | do                        | Dec. 17, 1959  | —               | 7.0            | .30        | 94           | 24             | 5.7         | 1.6            | 310                             | 0                            | 75                         | 10            | 8.0                        | 430                                                | 335                           | 79                                 | 610 | 7.7                        | 35      | 1 |
| do                                         | do                                   | do                        | Apr. 20, 1960  | —               | 5.5            | .30        | 82           | 22             | 5.8         | 1.8            | 298                             | 0                            | 55                         | 11            | 7.0                        | 366                                                | 295                           | 61                                 | 990 | 7.9                        | —       | 1 |
| do                                         | do                                   | do                        | July 7, 1960   | —               | 6.0            | .30        | 84           | 27             | 6.9         | 1.2            | 312                             | 0                            | 60                         | 7.0           | 2.0                        | 400                                                | 320                           | 64                                 | 990 | 8.4                        | 25      | 1 |
| 4-1116.1                                   | Unnamed tributary to Red Cedar River | SW 1/4 sec. 25, T.4N.R.1E | July 1, 1967   | —               | —              | —          | —            | —              | —           | —              | 376                             | 0                            | 46                         | 7.0           | 3.2                        | 392                                                | 360                           | 52                                 | 639 | 7.9                        | —       | 1 |
| do                                         | do                                   | do                        | June 28, 1968  | —               | —              | .04        | —            | —              | —           | —              | 282                             | 0                            | 86                         | 14            | 22                         | 446                                                | 342                           | 111                                | 639 | 7.9                        | 50      | 1 |
| 4-1116.3                                   | Coon Creek                           | SW 1/4 sec 23, T.4N.R.1E  | July 10, 1967  | —               | —              | —          | —            | —              | —           | —              | 356                             | 0                            | 45                         | 8.0           | 3.6                        | 396                                                | 345                           | 53                                 | 627 | 7.7                        | —       | 1 |
| do                                         | do                                   | do                        | June 28, 1968  | —               | —              | .04        | —            | —              | —           | —              | 286                             | 0                            | 37                         | 6.0           | 2.8                        | 306                                                | 280                           | 45                                 | 509 | 7.6                        | 70      | 1 |
| 4-1120.0                                   | Sloan Creek                          | E 1/2 sec 1, T.3N.R.1W    | Sept. 26, 1963 | —               | —              | .45        | 85           | 28             | 8.1         | 2.3            | 314                             | 0                            | 58                         | 22            | —                          | 408                                                | 327                           | 70                                 | 622 | 7.2                        | —       | 1 |
| do                                         | do                                   | do                        | Apr. 5, 1963   | —               | 10.4           | —          | —            | —              | —           | —              | 239                             | 3                            | 58                         | 18            | —                          | —                                                  | 286                           | 88                                 | 520 | 8.3                        | —       | 1 |
| do                                         | do                                   | do                        | June 28, 1968  | —               | 60.0           | .06        | —            | —              | —           | —              | 162                             | 0                            | 34                         | 11            | 11                         | 194                                                | 182                           | 49                                 | 368 | 7.3                        | 75      | 1 |
| 4-1124.0                                   | Red Cedar River                      | SE 1/4 sec 21, T.4N.R.1W  | Sept. 2, 1959  | —               | 11             | .30        | 88           | 23             | 8.0         | 3.0            | 308                             | 0                            | 57                         | 11            | 4.0                        | 404                                                | 315                           | 63                                 | 602 | 7.9                        | 75      | 1 |
| do                                         | do                                   | do                        | Dec. 16, 1959  | —               | 8.0            | .30        | 90           | 24             | 6.0         | 1.6            | 296                             | 0                            | 70                         | 11            | 12                         | 410                                                | 345                           | 83                                 | 606 | 8.0                        | 90      | 1 |
| do                                         | do                                   | do                        | Apr. 20, 1960  | —               | 4.5            | .30        | 76           | 21             | 5.1         | 1.8            | 265                             | 0                            | 55                         | 11            | 5.2                        | 340                                                | 275                           | 58                                 | 540 | 8.0                        | 80      | 1 |
| do                                         | do                                   | do                        | July 8, 1960   | —               | 7.0            | .30        | 92           | 27             | 9.2         | 1.6            | 345                             | 0                            | 62                         | 10            | 2.0                        | 418                                                | 340                           | 84                                 | 630 | 8.2                        | 45      | 1 |
| Stream Tributary to the Lookingglass River |                                      |                           |                |                 |                |            |              |                |             |                |                                 |                              |                            |               |                            |                                                    |                               |                                    |     |                            |         |   |
| 4-1141.5                                   | Lookingglass River                   | NW 1/4 sec 34, T.6N.R.2E  | Sept 2, 1959   | —               | 14             | .40        | 98           | 25             | 8.7         | 2.0            | 300                             | 0                            | 100                        | 7.0           | 4.0                        | 454                                                | 346                           | 100                                | 640 | 8.0                        | 70      | 1 |
| do                                         | do                                   | do                        | Dec 16, 1959   | —               | 6.0            | .20        | 96           | 28             | 7.4         | 1.6            | 300                             | 0                            | 100                        | 12            | 9.0                        | 450                                                | 355                           | 109                                | 650 | 7.7                        | 90      | 1 |
| do                                         | do                                   | do                        | Apr 20, 1960   | —               | 3.7            | .20        | 84           | 23             | 5.8         | 1.6            | 295                             | 0                            | 70                         | 11            | 2.0                        | 370                                                | 305                           | 63                                 | 600 | 7.9                        | 85      | 1 |
| do                                         | do                                   | do                        | July 8, 1960   | —               | 6.0            | .00        | 82           | 28             | 11          | 1.2            | 334                             | Tr.                          | 50                         | 11            | 0.0                        | 374                                                | 320                           | 46                                 | 620 | 8.6                        | 25      | 1 |
| 4-1142.0                                   | Lookingglass River                   | SE 1/4 sec 34, T.6N.R.1E  | Sept 19, 1963  | —               | —              | —          | 72           | 26             | 11          | 2.1            | 286                             | 0                            | 62                         | 12            | —                          | 363                                                | 287                           | 52                                 | 577 | 7.3                        | —       | 1 |
| 4-1142.5                                   | Vermilion Creek                      | NE 1/4 sec 36, T.6N.R.1W  | July 10, 1967  | —               | —              | —          | —            | —              | —           | —              | 349                             | 0                            | 65                         | 12            | 3.2                        | 443                                                | 365                           | 78                                 | 656 | 7.8                        | —       | 1 |
| 4-1143.0                                   | Mad Creek                            | NW 1/4 sec 4, T.5N.R.1W   | July 10, 1967  | —               | —              | —          | —            | —              | —           | —              | 364                             | 0                            | 56                         | 9.0           | 1.9                        | 437                                                | 365                           | 66                                 | 657 | 7.6                        | —       | 1 |
| 4-1144.0                                   | Lookingglass River                   | NE 1/4 sec 9, T.5N.R.2W   | Oct 5, 1964    | —               | —              | —          | —            | —              | —           | —              | 292                             | 0                            | 60                         | 9.0           | .6                         | 356                                                | 306                           | 66                                 | 567 | 7.9                        | —       | 1 |
| 4-1144.5                                   | Lookingglass River                   | NW 1/4 sec 17, T.5N.R.3W  | Sept 2, 1959   | —               | 16             | .80        | 72           | 23             | 6.0         | 2.7            | 268                             | 0                            | 45                         | 10            | 5.0                        | 380                                                | 276                           | 54                                 | 510 | 7.8                        | 75      | 1 |
| do                                         | do                                   | do                        | Dec. 16, 1959  | —               | 7.0            | .20        | 86           | 24             | 6.5         | 1.6            | 270                             | 0                            | 70                         | 12            | 10                         | 390                                                | 312                           | 90                                 | 600 | 7.9                        | 90      | 1 |
| do                                         | do                                   | do                        | Apr. 20, 1960  | —               | 2.0            | .20        | 74           | 21             | 4.6         | 2.0            | 260                             | 0                            | 56                         | 11            | 2.4                        | 374                                                | 275                           | 57                                 | 551 | 7.6                        | 75      | 1 |
| do                                         | do                                   | do                        | July 8, 1960   | —               | 9.0            | .70        | 86           | 27             | 8.7         | 1.2            | 340                             | 0                            | 52                         | 9.0           | 2.0                        | 420                                                | 345                           | 86                                 | 600 | 8.0                        | —       | 1 |
| 4-1144.95                                  | Unnamed trib to Lookingglass River   | SE 1/4 sec 1, T.5N.R.4W   | July 10, 1967  | —               | —              | —          | —            | —              | —           | —              | 324                             | 0                            | 96                         | 20            | 8.2                        | 460                                                | 395                           | 129                                | 715 | 7.8                        | —       | 1 |
| do                                         | do                                   | do                        | June 30, 1968  | —               | —              | .06        | —            | —              | —           | —              | 216                             | 0                            | 52                         | 14            | 20                         | 344                                                | 256                           | 72                                 | 491 | 8.1                        | 80      | 1 |
| 4-1145.0                                   | Lookingglass River                   | SW 1/4 sec 10, T.5N.R.4W  | Sept 26, 1963  | —               | —              | .24        | 72           | 29             | 8.5         | 1.8            | 328                             | 0                            | 43                         | 12            | —                          | 347                                                | 299                           | 51                                 | 562 | 8.0                        | —       | 1 |
| do                                         | do                                   | do                        | March 31, 1967 | —               | 673            | —          | —            | —              | —           | —              | 187                             | 0                            | 87                         | 12            | —                          | —                                                  | 452                           | 39                                 | 445 | 8.0                        | —       | 1 |
| do                                         | do                                   | do                        | June 30, 1968  | —               | —              | .09        | —            | —              | —           | —              | 196                             | 0                            | 51                         | 10            | 9.6                        | 304                                                | 226                           | 56                                 | 435 | 8.0                        | 85      | 1 |

TABLE A-2.--continued

| Station Number                           | Source             | Location                | Date Sampled  | Discharge (cfs) | Million (lb/d) | Iron (ppm) | Calcium (ppm) | Magnesium (ppm) | Sodium (ppm) | Potassium (ppm) | Bicarbonate (HCO <sub>3</sub> ) | Carbonate (CO <sub>3</sub> ) | Sulfate (SO <sub>4</sub> ) | Chloride (Cl) | Nitrate (NO <sub>3</sub> ) | Dissolved Solids (mg/l at 180°C) | Ca, Mg (mg/l at 180°C) | Non-amp. hardness as CaCO <sub>3</sub> | Specific conductance (microhm/cm at 25°C) | pH  | Color in Mason color unit | Analyte |
|------------------------------------------|--------------------|-------------------------|---------------|-----------------|----------------|------------|---------------|-----------------|--------------|-----------------|---------------------------------|------------------------------|----------------------------|---------------|----------------------------|----------------------------------|------------------------|----------------------------------------|-------------------------------------------|-----|---------------------------|---------|
|                                          |                    |                         |               |                 |                |            |               |                 |              |                 |                                 |                              |                            |               |                            |                                  |                        |                                        |                                           |     |                           |         |
| Stream Tributary to the Maple River      |                    |                         |               |                 |                |            |               |                 |              |                 |                                 |                              |                            |               |                            |                                  |                        |                                        |                                           |     |                           |         |
| 4-114.5                                  | Maple River        | MI § sec 3, T.6N, R.2E  | Sept 2, 1959  | B               | 12             | 1.80       | 102           | 28              | 7.0          | 2.0             | 296                             | 0                            | 78                         | 5.0           | 0.0                        | 270                              | 320                    | 78                                     | 600                                       | 7.8 | 15                        |         |
| do                                       | do                 | do                      | Dec 16, 1959  | B               | 7.0            | .50        | 102           | 27              | 6.9          | 1.7             | 320                             | 0                            | 100                        | 5.0           | 5.6                        | 460                              | 365                    | 103                                    | 680                                       | 7.8 | 15                        |         |
| do                                       | do                 | do                      | Apr 20, 1960  | B               | 4.5            | .07        | 90            | 25              | 6.9          | 1.6             | 310                             | 0                            | 78                         | 10            | 2.0                        | 400                              | 360                    | 76                                     | 630                                       | 7.9 | 25                        |         |
| 4-115.8                                  | Maple River        | SE § sec 11, T.7N, R.1W | July 8, 1960  | B               | 9.0            | .60        | 98            | 30              | 8.5          | 1.2             | 360                             | 0                            | 75                         | 7.0           | 1.5                        | 430                              | 70                     | 75                                     | 700                                       | 8.0 | 25                        |         |
| 4-115.9                                  | Little Maple River | SE § sec 33, T.7N, R.1W | Oct 5, 1964   | B               | 5.96           |            |               |                 |              |                 | 333                             | 0                            | 96                         | 14            | 1.5                        | 425                              | 372                    | 98                                     | 703                                       | 8.0 |                           |         |
| 4-115.92                                 | do                 | do                      | July 10, 1967 | B               |                | .19        |               |                 |              |                 | 362                             | 0                            | 54                         | 5.0           | 2.2                        | 415                              | 340                    | 93                                     | 676                                       | 7.9 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | June 30, 1968 | B               |                |            |               |                 |              |                 | 238                             | 0                            | 83                         | 5.0           | 4.6                        | 354                              | 268                    | 72                                     | 486                                       | 7.8 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Feb 16, 1954  | B               | 8.0            | .15        | 90            | 32              | 11           |                 | 348                             | 0                            | 83                         | 8.0           | 0.0                        | 424                              | 355                    | 70                                     | 720                                       | 7.8 | 10                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 19, 1963 | B               |                |            | 73            | 28              | 18           | 6.3             | 308                             | 0                            | 72                         | 19            |                            | 395                              | 310                    | 58                                     | 658                                       | 7.1 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 19, 1963 | B               |                |            | 94            | 28              | 14           |                 | 248                             | 0                            | 119                        | 20            |                            | 483                              | 330                    | 127                                    | 713                                       | 7.0 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 27, 1963 | B               |                | .99        | 63            | 26              | 25           | 5.3             | 230                             | 0                            | 76                         | 38            |                            | 410                              | 264                    | 76                                     | 617                                       | 7.0 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Apr 15, 1967  | B               |                | .03        |               |                 |              |                 | 176                             | 0                            | 45                         | 12            |                            | 372                              | 300                    | 68                                     | 400                                       | 7.9 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | June 28, 1968 | B               |                |            |               |                 |              |                 | 290                             | 0                            | 51                         | 18            | 4.9                        | 372                              | 300                    | 68                                     | 582                                       | 7.5 | 25                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 10, 1967 | B               |                |            |               |                 |              |                 | 312                             | 0                            | 94                         | 30            | 15                         | 534                              | 410                    | 138                                    | 764                                       | 7.8 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | June 30, 1968 | B               |                | .06        |               |                 |              |                 | 160                             | 0                            | 44                         | 16            | 28                         | 308                              | 308                    | 75                                     | 424                                       | 8.0 | 60                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 10, 1967 | B               |                | .12        |               |                 |              |                 | 308                             | 0                            | 122                        | 14            |                            | 494                              | 390                    | 137                                    | 774                                       | 7.9 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | June 30, 1968 | B               |                |            |               |                 |              |                 | 174                             | 0                            | 56                         | 18            |                            | 330                              | 236                    | 94                                     | 481                                       | 7.4 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 10, 1967 | B               |                |            |               |                 |              |                 | 280                             | 0                            | 49                         | 8.0           |                            | 365                              | 305                    | 75                                     | 569                                       | 8.0 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 30, 1968 | B               |                | .02        |               |                 |              |                 | 216                             | 0                            | 60                         | 13            |                            | 382                              | 294                    | 100                                    | 546                                       | 8.5 | 22                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 2, 1959  | B               | 12             | .20        | 84            | 26              | 18           | 3.5             | 312                             | 0                            | 68                         | 17            |                            | 400                              | 315                    | 99                                     | 640                                       | 8.1 | 15                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Dec 16, 1959  | B               | 5.0            | .40        | 100           | 28              | 12           | 2.2             | 286                             | 0                            | 120                        | 18            |                            | 486                              | 370                    | 136                                    | 710                                       | 7.7 | 25                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Apr 20, 1960  | B               | 2.0            | .20        | 96            | 28              | 9.2          | 2.4             | 288                             | 0                            | 110                        | 18            |                            | 450                              | 355                    | 119                                    | 700                                       | 7.8 | 15                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 8, 1960  | B               | 6.0            | .30        | 86            | 28              | 14           | 2.0             | 316                             | 0                            | 88                         | 13            |                            | 424                              | 330                    | 72                                     | 630                                       | 8.0 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 19, 1963 | B               |                |            | 79            | 11              | 26           | 4.2             | 316                             | 0                            | 83                         | 28            |                            | 438                              | 325                    | 66                                     | 706                                       | 7.2 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 2, 1959  | B               | 12             | .0         | 64            | 32              | 17           | 4.5             | 288                             | 0                            | 67                         | 22            |                            | 448                              | 290                    | 54                                     | 640                                       | 7.6 | 35                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Dec 16, 1959  | B               | 5              | .6         | 84            | 24              | 9.1          | 2.3             | 234                             | 0                            | 95                         | 17            |                            | 420                              | 310                    | 119                                    | 610                                       | 7.6 | 25                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Apr 20, 1960  | B               | 2              | .2         | 74            | 22              | 7.0          | 2.3             | 234                             | 0                            | 75                         | 5             |                            | 344                              | 276                    | 79                                     | 590                                       | 7.9 | 30                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 8, 1960  | B               | 6              | 1.5        | 94            | 29              | 12           | 2.4             | 350                             | 0                            | 70                         | 14            |                            | 472                              | 355                    | 68                                     | 864                                       | 7.9 | 50                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 19, 1963 | B               |                |            | 70            | 25              | 17           | 1.9             | 254                             | 0                            | 54                         | 38            |                            | 406                              | 278                    | 70                                     | 598                                       | 7.2 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 19, 1963 | B               | 34.7           |            |               |                 |              |                 | 254                             | 0                            | 88                         | 30            |                            | 406                              | 340                    | 92                                     | 625                                       | 8.4 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 10, 1967 | B               |                | .05        |               |                 |              |                 | 398                             | 0                            | 135                        | 20            |                            | 543                              | 450                    | 156                                    | 810                                       | 8.2 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | June 30, 1968 | B               |                |            |               |                 |              |                 | 168                             | 0                            | 56                         | 14            |                            | 326                              | 226                    | 88                                     | 446                                       | 7.2 | 7                         |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Oct 5, 1964   | B               | 3.05           |            |               |                 |              |                 | 362                             | 0                            | 95                         | 12            |                            | 450                              | 382                    | 95                                     | 714                                       | 8.2 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 10, 1967 | B               |                | .13        |               |                 |              |                 | 338                             | 0                            | 98                         | 11            |                            | 466                              | 385                    | 108                                    | 708                                       | 7.8 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 2, 1959  | B               |                |            |               |                 |              |                 | 166                             | 0                            | 99                         | 10            |                            | 414                              | 322                    | 86                                     | 431                                       | 7.3 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Dec 16, 1959  | B               | 14             | .90        | 85            | 37              | 8.7          | 3.1             | 361                             | 0                            | 75                         | 5.0           |                            | 438                              | 364                    | 68                                     | 660                                       | 7.6 | 25                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Apr 20, 1960  | B               | 4.0            | .30        | 80            | 24              | 4.6          | 2.4             | 255                             | 0                            | 90                         | 6.0           |                            | 374                              | 300                    | 91                                     | 600                                       | 7.9 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 8, 1960  | B               | 6.0            | .10        | 88            | 34              | 12           | 2.0             | 360                             | 0                            | 73                         | 4.0           |                            | 428                              | 340                    | 48                                     | 680                                       | 8.2 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Oct 5, 1964   | B               | 2.28           |            |               |                 |              |                 | 382                             | 0                            | 85                         | 6.0           |                            | 479                              | 392                    | 78                                     | 714                                       | 8.2 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 10, 1967 | B               |                | .08        |               |                 |              |                 | 330                             | 0                            | 122                        | 24            |                            | 493                              | 400                    | 129                                    | 768                                       | 7.9 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | June 30, 1968 | B               |                |            |               |                 |              |                 | 196                             | 0                            | 48                         | 10            |                            | 458                              | 226                    | 66                                     | 444                                       | 7.3 |                           |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 2, 1959  | B               | 13             | .90        | 70            | 36              | 8.3          | 3.7             | 286                             | 0                            | 57                         | 7.0           |                            | 432                              | 325                    | 57                                     | 600                                       | 7.8 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Dec 16, 1959  | B               | 8.0            | .60        | 98            | 29              | 7.4          | 2.3             | 286                             | 0                            | 105                        | 12            |                            | 468                              | 365                    | 131                                    | 680                                       | 7.8 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Apr 20, 1960  | B               | 4.0            | .40        | 86            | 24              | 6.0          | 2.0             | 268                             | 0                            | 90                         | 11            |                            | 386                              | 315                    | 95                                     | 600                                       | 7.9 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | July 8, 1960  | B               | 4.0            | .50        | 84            | 33              | 11           | 3.2             | 306                             | 0                            | 79                         | 10            |                            | 440                              | 345                    | 67                                     | 630                                       | 8.2 | 20                        |         |
| 4-116.0                                  | Maple River        | MI § sec 33, T.7N, R.1W | Sept 19, 1963 | B               | 9.06           |            |               |                 |              |                 | 306                             | 0                            | 55                         | 10            |                            | 352                              | 296                    | 45                                     | 572                                       | 7.5 |                           |         |
| Stream Tributary to the Thornapple River |                    |                         |               |                 |                |            |               |                 |              |                 |                                 |                              |                            |               |                            |                                  |                        |                                        |                                           |     |                           |         |
| 4-1167.0                                 | Thornapple River   | SE § sec 7, T.3N, R.4W  | Oct 6, 1964   | B               | 8.36           |            |               |                 |              |                 | 355                             | 0                            | 125                        | 16            |                            | 514                              | 422                    | 151                                    | 777                                       | 8.1 |                           |         |
| 4-1168.0                                 | Thornapple River   | SE § sec 23, T.3N, R.6W | Sept 19, 1963 | B               | 8.77           |            |               |                 |              |                 | 328                             | 0                            | 99                         | 8.0           |                            | 392                              | 326                    | 96                                     | 620                                       | 7.1 |                           |         |
| 4-1168.05                                | Thornapple River   | SE § sec 36, T.3N, R.6W | July 10, 1967 | B               |                |            |               |                 |              |                 | 304                             | 0                            | 65                         | 10            |                            | 386                              | 325                    | 76                                     | 591                                       | 7.3 |                           |         |
| 4-1168.1                                 | Thornapple River   | SE § sec 26, T.3N, R.6W | Dec 3, 1962   | B               | 7.0            |            |               |                 |              |                 | 352                             | 0                            | 70                         | 9.0           |                            | 410                              | 355                    | 67                                     | 620                                       | 8.0 |                           |         |
| 4-1168.2                                 | Thornapple River   | SE § sec 33, T.3N, R.6W | Apr 1, 1963   | B               |                |            |               |                 |              |                 | 285                             | 0                            | 137                        | 10            |                            | 480                              | 395                    | 162                                    | 700                                       | 7.3 |                           |         |
| 4-117.0                                  | Stacy Brook        | MI § sec 13, T.2N, R.7W | July 10, 1967 | B               |                | .40        | 110           | 29              | 5.8          | 1.8             | 364                             | 0                            | 36                         | 7.0           |                            | 372                              | 315                    | 36                                     | 607                                       | 8.2 |                           |         |
| 4-117.0                                  | Stacy Brook        | MI § sec 13, T.2N, R.7W | Sept 20, 1963 | B               | 1.30           | .33        | 76            | 27              | 5.0          | 1.3             | 306                             | 0                            | 61                         | 4.0           |                            | 346                              | 321                    | 5                                      | 458                                       | 7.6 |                           |         |

TABLE A-3.--A comparison of  $K_{sp}$  and  $K_{iap}$  for gypsum, anhydrite, calcite, aragonite, dolomite and siderite.

| Local well<br>number | Aquifer | $CaSO_4$<br>$K_{iap} \times 10^{-8}$ | Gypsum<br>$\frac{K_{iap}}{K_{sp}}$ | Anhydrite<br>$\frac{K_{iap}}{K_{sp}}$ | $CaCO_3$<br>$K_{iap} \times 10^{-9}$ | Calcite<br>$\frac{K_{iap}}{K_{sp}}$ | Aragonite<br>$\frac{K_{iap}}{K_{sp}}$ | $CaMg(CO_3)_2$<br>$K_{iap} \times 10^{-17}$ | Dolomite<br>$\frac{K_{iap}}{K_{sp}}$ | $FeCO_3$<br>$K_{iap} \times 10^{-10}$ | Siderite<br>$\frac{K_{iap}}{K_{sp}}$ |
|----------------------|---------|--------------------------------------|------------------------------------|---------------------------------------|--------------------------------------|-------------------------------------|---------------------------------------|---------------------------------------------|--------------------------------------|---------------------------------------|--------------------------------------|
| Clinton County       |         |                                      |                                    |                                       |                                      |                                     |                                       |                                             |                                      |                                       |                                      |
| 05N01W18 CBC-1       | NISA    | 7.80                                 | .003                               | .002                                  | 8.75                                 | 1.52                                | 1.15                                  | 2.68                                        | .85                                  | .364                                  | .83                                  |
| 05N02W09 BBC-1       | QG00    | 26.5                                 | .010                               | .005                                  | 26.5                                 | 4.60                                | 3.50                                  | 33.9                                        | 10.7                                 | 9.68                                  | 22.1                                 |
| 05N02W16 AAAA-1      | NISA    | 2.28                                 | .001                               | .000                                  | 9.79                                 | 1.70                                | 1.29                                  | 4.07                                        | 1.29                                 | 1.13                                  | 2.59                                 |
| 05N02W18 DCD-1       | NISA    | 1.77                                 | .001                               | .000                                  | 6.64                                 | 1.15                                | .88                                   | 2.37                                        | .75                                  | .485                                  | 1.11                                 |
| 05N02W22 DCDA-1      | NISA    | 6.78                                 | .003                               | .001                                  | 10.7                                 | 1.85                                | 1.41                                  | 5.58                                        | 1.77                                 | .539                                  | 1.23                                 |
| 05N02W22 DCDC-1      | NISA    | 14.6                                 | .006                               | .003                                  | 2.94                                 | .51                                 | .39                                   | .509                                        | .16                                  | .035                                  | .08                                  |
| 05N02W27 CAAA-1      | QG00    | 91.0                                 | .035                               | .018                                  | 4.76                                 | .82                                 | .63                                   | 1.21                                        | .38                                  | 1.20                                  | 2.75                                 |
| 05N02W27 CBDB-1      | NISA    | 9.59                                 | .004                               | .002                                  | 2.62                                 | .45                                 | .35                                   | .263                                        | .08                                  | .779                                  | 1.78                                 |
| 05N02W27 CCAB-1      | QG00    | 33.5                                 | .013                               | .007                                  | 9.50                                 | 1.65                                | 1.25                                  | 3.58                                        | 1.13                                 | .642                                  | 1.47                                 |
| 05N02W27 CCAD-1      | NISA    | 7.76                                 | .003                               | .002                                  | 3.83                                 | .66                                 | .51                                   | .741                                        | .23                                  | .261                                  | .59                                  |
| 05N02W27 CDBA-1      | QG00    | 16.3                                 | .006                               | .003                                  | 4.89                                 | .85                                 | .64                                   | 1.04                                        | .33                                  | .602                                  | 1.38                                 |
| 05N02W28 BBDA-1      | NISA    | 98.1                                 | .038                               | .020                                  | 10.3                                 | 1.79                                | 1.36                                  | 4.62                                        | 1.46                                 | 1.65                                  | 3.78                                 |
| 05N02W28 DCAC-1      | NISA    | 180                                  | .070                               | .036                                  | 6.05                                 | 1.05                                | .80                                   | 1.80                                        | .57                                  | 1.00                                  | 2.28                                 |
| 05N02W33 AAAB-1      | --      | 37.1                                 | .014                               | .007                                  | 8.79                                 | 1.53                                | 1.16                                  | 2.96                                        | .94                                  | .873                                  | 2.00                                 |
| 05N02W33 ABAB-1      | NISA    | 229                                  | .089                               | .046                                  | 6.70                                 | 1.16                                | .88                                   | 2.01                                        | .64                                  | .260                                  | .60                                  |
| 05N02W33 ACB-1       | NISA    | 19.5                                 | .007                               | .003                                  | 3.65                                 | .63                                 | .48                                   | .592                                        | .19                                  | .157                                  | .36                                  |
| 05N02W33 BAAA-1      | NISA    | 447                                  | .174                               | .089                                  | 7.69                                 | 1.33                                | 1.01                                  | 2.24                                        | .71                                  | .353                                  | .81                                  |
| 05N02W33 CDDB-1      | NISA    | 360                                  | .140                               | .072                                  | 11.5                                 | 2.00                                | 1.52                                  | 6.37                                        | 2.02                                 | 2.05                                  | 4.69                                 |
| 05N03W05 CCDD-1      | N3GR    | 7.90                                 | .003                               | .002                                  | 6.55                                 | 1.14                                | .86                                   | 3.10                                        | .98                                  | .554                                  | 1.27                                 |
| 05N03W15 BBCC-1      | NISA    | 9.02                                 | .004                               | .002                                  | 8.20                                 | 1.42                                | 1.08                                  | 3.70                                        | 1.17                                 | .349                                  | .80                                  |
| 05N03W18 AAB-1       | NISA    | 9.15                                 | .004                               | .002                                  | 9.61                                 | 1.67                                | 1.27                                  | 5.49                                        | 1.74                                 | 1.36                                  | 3.11                                 |
| 05N03W18 CCAA-1      | NISA    | 8.62                                 | .003                               | .002                                  | 5.23                                 | .91                                 | .69                                   | 1.51                                        | .48                                  | .211                                  | .48                                  |

|          |        |      |      |      |      |      |      |      |      |      |      |      |
|----------|--------|------|------|------|------|------|------|------|------|------|------|------|
| 05N03W21 | BBB-1  | NISA | 5.47 | .002 | .001 | 14.0 | 2.43 | 1.85 | 12.2 | 3.86 | .850 | 1.94 |
| 05N03W23 | BABB-1 | NISA | 8.12 | .003 | .002 | 7.21 | 1.25 | .95  | 2.82 | .89  | .286 | .65  |
| 05N03W27 | BCBB-1 | NISA | 45.3 | .018 | .009 | 9.37 | 1.63 | 1.23 | 3.45 | 1.09 | 1.28 | 2.93 |
| 05N04W12 | DDDD-1 | NISA | 48.8 | .019 | .010 | 18.9 | 3.28 | 2.49 | 27.3 | 8.64 | 2.89 | 6.61 |
| 05N04W16 | ACBA-1 | NISA | 11.4 | .004 | .002 | 5.60 | .97  | .74  | 2.05 | .65  | .774 | 1.77 |
| 05N04W18 | CBDA-1 | NISA | 11.0 | .004 | .002 | 18.9 | 3.28 | 2.49 | 21.2 | 6.71 | 1.62 | 3.71 |
| 05N04W21 | ADCD-1 | NISA | 9.98 | .004 | .002 | 6.69 | 1.16 | .88  | 2.82 | .89  | .487 | 1.11 |
| 05N04W21 | BDAC-1 | NISA | 49.6 | .019 | .010 | 9.97 | 1.73 | 1.32 | 6.91 | 2.19 | .881 | 2.02 |
| 05N04W24 | ABBB-1 | NISA | 45.8 | .018 | .009 | 14.4 | 2.50 | 1.90 | 12.1 | 3.83 | .938 | 2.15 |
| 06N01W12 | BDBD-1 | QG00 | 22.3 | .008 | .004 | 9.96 | 1.73 | 1.31 | 5.76 | 1.82 | 2.01 | 4.60 |
| 06N01W14 | DBDD-1 | NISA | 1.30 | .000 | .000 | 5.80 | 1.01 | .76  | 2.10 | .66  | .456 | 1.04 |
| 06N01W19 | ACDC-1 | NISA | .097 | .000 | .000 | 13.7 | 2.38 | 1.81 | 12.7 | 4.02 | 5.30 | 12.1 |
| 06N02W09 | CCBC-1 | N3GR | 8.93 | .003 | .002 | 4.65 | .81  | .61  | .164 | .052 | .117 | .27  |
| 06N02W09 | DCCC-1 | NISA | 6.08 | .002 | .001 | 4.79 | .83  | .63  | 1.99 | .63  | .293 | .67  |
| 06N02W14 | CBBB-1 | N3GR | 7.02 | .003 | .001 | 10.1 | 1.75 | 1.33 | 7.95 | 2.52 | 1.29 | 2.95 |
| 06N02W22 | DAAA-1 | N3GR | 4.75 | .002 | .001 | 7.64 | 1.33 | 1.01 | 4.52 | 1.43 | 2.40 | 5.49 |
| 06N02W23 | CAAA-1 | N3GR | 16.0 | .006 | .003 | 8.59 | 1.49 | 1.13 | 5.13 | 1.62 | 2.58 | 5.90 |
| 06N02W24 | ACCD-1 | N3GR | 6.80 | .003 | .001 | 7.79 | 1.35 | 1.03 | 2.98 | .94  | .202 | .46  |
| 06N02W24 | ADDC-1 | QG00 | 12.6 | .005 | .003 | 16.2 | 2.81 | 2.14 | 13.8 | 4.37 | --   | --   |
| 06N02W25 | BCBB-1 | --   | 4.19 | .002 | .001 | 9.79 | 1.70 | 1.29 | 6.19 | 1.96 | .925 | 2.12 |
| 06N02W28 | ADAA-1 | N3GR | 6.43 | .003 | .001 | 10.7 | 1.86 | 1.41 | 5.85 | 1.85 | 1.73 | 3.96 |
| 06N02W29 | BAAA-1 | NISA | 2.65 | .001 | .000 | 11.2 | 1.94 | 1.48 | 7.85 | 2.48 | .320 | .73  |
| 06N02W29 | BAAA-1 | QG00 | 16.3 | .006 | .003 | 9.50 | 1.65 | 1.25 | 5.88 | 1.86 | 1.23 | 2.81 |
| 06N02W30 | CDDD-1 | NISA | 18.5 | .007 | .004 | 6.25 | 1.09 | .82  | 3.02 | .96  | .382 | .87  |
| 06N03W08 | BAB-1  | QG00 | 9.79 | .004 | .002 | 12.5 | 2.17 | 1.65 | 10.6 | 3.35 | 1.63 | 3.73 |
| 06N03W13 | AAAA-1 | NISA | 16.2 | .006 | .003 | 5.27 | .91  | .70  | 1.90 | .60  | .594 | 1.36 |
| 06N03W15 | BABB-1 | N3GR | 34.1 | .013 | .007 | 18.0 | 3.12 | 2.37 | 19.9 | 6.29 | 1.80 | 4.12 |
| 06N03W36 | DDAA-2 | N3GR | 21.8 | .008 | .004 | 9.70 | 1.68 | 1.28 | 5.55 | 1.76 | 2.17 | 4.96 |
| 06N04W05 | AAAA-1 | QG00 | 20.3 | .008 | .004 | 8.45 | 1.47 | 1.14 | 4.89 | 1.55 | 2.19 | 5.00 |
| 06N04W23 | BABB-1 | NISA | 16.2 | .006 | .003 | 11.1 | 1.93 | 1.46 | 8.46 | 2.67 | 1.16 | 2.65 |
| 06N04W25 | ACB-1  | QG00 | 22.0 | .008 | .004 | 17.1 | 2.97 | 2.25 | 21.8 | 6.89 | 3.93 | 8.99 |
| 06N04W34 | CCBB-1 | NISA | 16.8 | .007 | .003 | 8.46 | 1.47 | 1.12 | 5.36 | 1.70 | .559 | 1.28 |
| 07N01W30 | DAA-1  | NISA | 12.2 | .005 | .002 | 13.2 | 2.29 | 1.74 | 14.8 | 4.68 | .250 | .57  |
| 07N02W13 | BAA-1  | NISA | 15.1 | .006 | .003 | 4.57 | .79  | .60  | 1.01 | .32  | .258 | .59  |
| 07N02W15 | CBAA-1 | NISA | 3.00 | .001 | .000 | 7.10 | 1.23 | .94  | 4.06 | 1.28 | .412 | .94  |
| 07N02W15 | CBAB-1 | QG00 | 82.7 | .032 | .016 | 9.20 | 1.60 | 1.21 | 5.85 | 1.85 | .351 | .80  |

TABLE A-3.--continued

| Local well<br>number | Aquifer | $\text{CaSO}_4$<br>Kiap x 10 <sup>-8</sup> | Gypsum<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | Anhydrite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | $\text{CaCO}_3$<br>Kiap x 10 <sup>-9</sup> | Calcite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | Aragonite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | $\text{CaMg}(\text{CO}_3)_2$<br>Kiap x 10 <sup>-17</sup> | Dolomite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | $\text{FeCO}_3$<br>Kiap x 10 <sup>-10</sup> | Siderite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ |
|----------------------|---------|--------------------------------------------|--------------------------------------------|-----------------------------------------------|--------------------------------------------|---------------------------------------------|-----------------------------------------------|----------------------------------------------------------|----------------------------------------------|---------------------------------------------|----------------------------------------------|
| Clinton County       |         |                                            |                                            |                                               |                                            |                                             |                                               |                                                          |                                              |                                             |                                              |
| 07N02W36 CDDD-1      | NISA    | 5.79                                       | .002                                       | .001                                          | 9.38                                       | 1.63                                        | 1.24                                          | 6.77                                                     | 2.14                                         | .707                                        | 1.62                                         |
| 07N03W13 ADDD-1      | QG00    | 5.70                                       | .002                                       | .001                                          | 3.85                                       | .67                                         | .51                                           | 1.15                                                     | .36                                          | .301                                        | .69                                          |
| 07N03W14 BBBB-1      | NISA    | 14.1                                       | .005                                       | .003                                          | 4.46                                       | .77                                         | .59                                           | 1.31                                                     | .41                                          | .283                                        | .65                                          |
| 07N03W16 BBBA-1      | NISA    | 127                                        | .049                                       | .025                                          | 5.86                                       | 1.02                                        | .77                                           | 1.58                                                     | .50                                          | .664                                        | 1.52                                         |
| 07N03W27 DDDD-1      | NISA    | 23.3                                       | .009                                       | .005                                          | 8.51                                       | 1.48                                        | 1.12                                          | 4.13                                                     | 1.31                                         | .608                                        | 1.39                                         |
| 07N04W08 DDCC-1      | QG00    | 75.6                                       | .029                                       | .015                                          | 24.0                                       | 4.17                                        | 3.16                                          | 32.1                                                     | 10.2                                         | .858                                        | 1.96                                         |
| 07N04W24 DDDDB-1     | QG00    | 35.5                                       | .014                                       | .007                                          | 12.4                                       | 2.15                                        | 1.63                                          | 14.3                                                     | 4.52                                         | 1.78                                        | 4.07                                         |
| 07N04W30 BADD-1      | QG00    | 16.1                                       | .006                                       | .003                                          | 6.68                                       | 1.16                                        | .88                                           | 2.59                                                     | .82                                          | .249                                        | .57                                          |
| 08N01W09 ADD-1       | NISA    | 55.9                                       | .022                                       | .011                                          | 5.53                                       | .96                                         | .73                                           | 1.97                                                     | .62                                          | .223                                        | .51                                          |
| 08N01W19 DADD-1      | QG00    | 10.7                                       | .004                                       | .002                                          | 7.70                                       | 1.34                                        | 1.02                                          | 4.94                                                     | 1.56                                         | .641                                        | 1.47                                         |
| 08N01W35 AADD-1      | QG00    | 78.1                                       | .030                                       | .016                                          | 7.68                                       | 1.33                                        | 1.01                                          | 3.16                                                     | 1.00                                         | .787                                        | 1.80                                         |
| 08N02W09 ADDD-1      | NISA    | 1.26                                       | .000                                       | .000                                          | 6.21                                       | 1.08                                        | .82                                           | 6.14                                                     | 1.94                                         | 1.16                                        | 2.65                                         |
| 08N02W31 AADD-1      | NISA    | 21.1                                       | .008                                       | .004                                          | 10.2                                       | 1.77                                        | 1.35                                          | 7.70                                                     | 2.44                                         | .561                                        | 1.28                                         |
| 08N03W27 CDDD-1      | NISA    | 24.0                                       | .009                                       | .005                                          | 12.5                                       | 2.17                                        | 1.65                                          | 6.77                                                     | 2.14                                         | 1.38                                        | 3.16                                         |
| 08N03W32 DAAD-1      | NISA    | 30.1                                       | .011                                       | .006                                          | 6.62                                       | 1.15                                        | .87                                           | 2.58                                                     | .82                                          | .397                                        | .91                                          |
| 08N04W02 DCC-1       | NISA    | 1080                                       | .420                                       | .210                                          | 20.5                                       | 3.36                                        | 2.70                                          | 14.2                                                     | 4.49                                         | 2.95                                        | 6.75                                         |
| 08N04W06 ADDD-1      | QG00    | 1.60                                       | .000                                       | .000                                          | 6.78                                       | 1.18                                        | .89                                           | 2.54                                                     | .80                                          | 1.01                                        | 2.31                                         |
| 08N04W11 BBC-1       | QG00    | 44.4                                       | .017                                       | .009                                          | 14.7                                       | 2.55                                        | 1.94                                          | 11.5                                                     | 3.64                                         | .264                                        | .60                                          |

Eaton County

|          |        |      |      |      |      |      |      |      |      |       |      |       |
|----------|--------|------|------|------|------|------|------|------|------|-------|------|-------|
| 01N04W13 | ABA-1  | NISA | .646 | .000 | .000 | 10.5 | 1.82 | 1.38 | 6.55 | 2.07  | 3.29 | 7.53  |
| 01N05W29 | AABA-1 | NISA | 45.6 | .018 | .009 | 13.5 | 2.34 | 1.78 | 8.26 | 2.61  | 2.94 | 6.73  |
| 01N05W32 | DADD-1 | NISA | 98.1 | .038 | .020 | 10.8 | 1.87 | 1.42 | 9.03 | 2.86  | 3.91 | 8.95  |
| 01N06W15 | DDD-1  | M3MI | 1.52 | .001 | .000 | 12.4 | 2.15 | 1.63 | 7.93 | 2.51  | 1.45 | 3.32  |
| 01N06W28 | AAC-1  | --   | 104  | .040 | .021 | 6.81 | 1.18 | .90  | 2.16 | .68   | .338 | .77   |
| 02N03W30 | DAB-1  | NISA | 39.4 | .015 | .008 | 11.6 | 2.01 | 1.53 | 5.36 | 1.70  | 2.61 | 5.97  |
| 02N03W32 | DDD-1  | QG00 | 19.0 | .007 | .004 | 16.2 | 2.81 | 2.13 | 15.3 | 4.84  | 4.65 | 10.60 |
| 02N03W34 | DDDC-1 | NISA | 106  | .041 | .021 | 19.5 | 3.39 | 2.57 | 15.8 | 5.00  | .530 | 1.21  |
| 02N04W04 | CBBC-1 | M3BA | 29.9 | .012 | .006 | 9.48 | 1.65 | 1.25 | 4.53 | 1.43  | 2.10 | 4.80  |
| 02N04W10 | ABCC-1 | NISA | 60.3 | .020 | .010 | 6.42 | 1.11 | .85  | 1.92 | .61   | .402 | .92   |
| 02N05W03 | BCCC-1 | M3BA | 11.0 | .004 | .002 | 14.3 | 2.48 | 1.89 | 9.03 | 2.86  | 7.38 | 16.90 |
| 02N05W23 | ACDC-1 | NISA | 4.79 | .002 | .001 | 16.0 | 2.78 | 2.11 | 13.2 | 4.18  | 2.80 | 6.41  |
| 02N05W25 | ADDA-1 | NISA | 201  | .082 | .040 | 25.1 | 4.36 | 3.31 | 31.9 | 10.10 | 5.59 | 12.80 |
| 02N05W26 | CCB-1  | NISA | 16.3 | .006 | .003 | 11.7 | 2.03 | 1.54 | 7.62 | 2.41  | 2.31 | 5.29  |
| 02N05W30 | DADD-1 | NISA | 5.81 | .002 | .001 | 21.7 | 3.77 | 2.86 | 23.4 | 7.40  | 1.82 | 4.16  |
| 02N05W33 | DCCD-1 | NISA | 42.3 | .016 | .008 | 16.4 | 2.85 | 2.16 | 15.1 | 4.78  | 1.33 | 3.04  |
| 02N06W28 | ADD-1  | NISA | 9.58 | .004 | .002 | 8.10 | 1.41 | 1.07 | 2.80 | .89   | 2.74 | 6.27  |
| 03N03W05 | BAB-1  | N3GR | 20.8 | .008 | .004 | 15.1 | 2.62 | 1.99 | 15.3 | 4.84  | 3.42 | 7.82  |
| 03N03W35 | BAB-1  | NISA | 1.86 | .001 | .000 | 17.3 | 3.00 | 2.28 | 16.5 | 5.22  | 2.18 | 4.99  |
| 03N04W09 | DCCD-1 | NISA | 20.4 | .008 | .004 | 8.67 | 1.51 | 1.14 | 4.40 | 1.39  | 1.32 | 3.02  |
| 03N04W26 | BBBB-1 | NISA | 105  | .041 | .021 | 17.0 | 2.95 | 2.24 | 15.3 | 4.84  | 7.38 | 16.9  |
| 03N04W29 | BAAA-1 | NISA | 38.4 | .015 | .008 | 10.7 | 1.86 | 1.41 | 6.63 | 2.10  | 1.19 | 2.72  |
| 03N05W23 | AAA-1  | NISA | 3.74 | .001 | .000 | 8.11 | 1.41 | 1.07 | 3.79 | 1.20  | .655 | 1.50  |
| 03N05W23 | AAA-2  | NISA | 9.25 | .004 | .002 | 11.3 | 1.96 | 1.49 | 7.94 | 2.51  | 2.88 | 6.59  |
| 03N05W25 | CBB-1  | NISA | 1.30 | .001 | .000 | 12.3 | 2.14 | 1.62 | 9.78 | 3.09  | 1.11 | 2.54  |
| 03N05W29 | BAB-1  | QG00 | 70.5 | .027 | .014 | 25.2 | 4.37 | 3.33 | 36.1 | 11.4  | 3.98 | 9.11  |
| 03N06W27 | AAB-1  | M3MI | 213  | .083 | .042 | 9.98 | 1.73 | 1.32 | 4.10 | 1.30  | .760 | 1.74  |
| 04N03W07 | ABBB-1 | NISA | 8.13 | .003 | .002 | 9.70 | 1.68 | 1.28 | 6.72 | 2.13  | .504 | 1.15  |
| 04N04W10 | BBBA-1 | NISA | 19.2 | .007 | .004 | 13.1 | 2.27 | 1.73 | 12.7 | 4.02  | 1.14 | 2.61  |
| 04N04W23 | DDC-1  | NISA | 22.7 | .009 | .005 | 12.6 | 2.19 | 1.66 | 11.2 | 3.54  | 1.11 | 2.54  |
| 04N05W03 | CDC-1  | NISA | 4.69 | .002 | .001 | 15.2 | 2.64 | 2.00 | 24.2 | 7.66  | 1.41 | 3.23  |
| 04N06W28 | CDC-1  | M3MI | 7.48 | .003 | .001 | 13.2 | 2.29 | 1.74 | 9.53 | 3.02  | 3.49 | 7.99  |

100

TABLE A-3.--continued

| Local well<br>number | Aquifer | $\text{CaSO}_4$<br>$\text{Kiap} \times 10^{-8}$ | Gypsum<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | Anhydrite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | $\text{CaCO}_3$<br>$\text{Kiap} \times 10^{-9}$ | Calcite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | Aragonite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | $\text{CaMg}(\text{CO}_3)_2$<br>$\text{Kiap} \times 10^{-17}$ | Dolomite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ | $\text{FeCO}_3$<br>$\text{Kiap} \times 10^{-10}$ | Siderite<br>$\frac{\text{Kiap}}{\text{Ksp}}$ |
|----------------------|---------|-------------------------------------------------|--------------------------------------------|-----------------------------------------------|-------------------------------------------------|---------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|----------------------------------------------|--------------------------------------------------|----------------------------------------------|
| Ingham County        |         |                                                 |                                            |                                               |                                                 |                                             |                                               |                                                               |                                              |                                                  |                                              |
| 01N01E23 DDDD-1      | NISA    | 43.8                                            | .017                                       | .009                                          | 19.8                                            | 3.44                                        | 2.61                                          | 21.7                                                          | 6.86                                         | 1.72                                             | 3.94                                         |
| 01N01W02 CAAA-1      | NISA    | 2.33                                            | .001                                       | .000                                          | 18.6                                            | 3.23                                        | 2.45                                          | 13.6                                                          | 4.30                                         | 1.66                                             | 3.80                                         |
| 01N01W17 BBBB-1      | NISA    | 50.1                                            | .019                                       | .010                                          | 17.0                                            | 2.95                                        | 2.24                                          | 14.8                                                          | 4.68                                         | 2.82                                             | 6.45                                         |
| 01N01W29 DDAD-1      | NISA    | 33.1                                            | .012                                       | .007                                          | 22.3                                            | 3.87                                        | 2.94                                          | 25.9                                                          | 8.19                                         | 3.34                                             | 7.64                                         |
| 01N02W29 CAAC-1      | NISA    | 14.6                                            | .006                                       | .003                                          | 9.63                                            | 1.67                                        | 1.27                                          | 3.43                                                          | 1.08                                         | .593                                             | 1.36                                         |
| 02N01E15 DDBB-1      | NISA    | 1.11                                            | .000                                       | .000                                          | 23.1                                            | 4.01                                        | 3.04                                          | 25.5                                                          | 8.07                                         | 1.50                                             | 3.43                                         |
| 02N01E25 CDDA-1      | NISA    | 2.38                                            | .001                                       | .000                                          | 11.2                                            | 1.94                                        | 1.48                                          | 8.05                                                          | 2.54                                         | 1.11                                             | 2.54                                         |
| 02N01E28 DACC-1      | NISA    | 1.43                                            | .001                                       | .000                                          | 5.58                                            | .97                                         | .74                                           | 1.62                                                          | .51                                          | .366                                             | .84                                          |
| 02N01W13 BCBB-1      | NISA    | --                                              | .000                                       | .000                                          | 6.27                                            | 1.09                                        | .83                                           | 2.66                                                          | .84                                          | .310                                             | .71                                          |
| 02N01W18 DCCC-1      | NISA    | 72.8                                            | .028                                       | .015                                          | 19.4                                            | 3.37                                        | 2.56                                          | 17.6                                                          | 5.57                                         | 2.46                                             | 5.63                                         |
| 02N01W26 BDBB-1      | NISA    | 60.1                                            | .023                                       | .012                                          | 7.07                                            | 1.23                                        | .93                                           | 3.17                                                          | 1.00                                         | .643                                             | 1.47                                         |
| 02N01W28 CB BB-1     | NISA    | 19.9                                            | .009                                       | .004                                          | 7.08                                            | 1.23                                        | .93                                           | 2.59                                                          | .82                                          | --                                               | --                                           |
| 02N02E02 ACDD-1      | NISA    | 43.3                                            | .017                                       | .009                                          | 28.6                                            | 4.96                                        | 3.77                                          | 52.0                                                          | 16.5                                         | 3.44                                             | 7.87                                         |
| 02N02E24 DAAA-1      | MIMA    | 91.2                                            | .035                                       | .018                                          | 23.7                                            | 4.11                                        | 3.13                                          | 29.5                                                          | 9.33                                         | 2.78                                             | 6.36                                         |
| 02N02E34 CAA-1       | --      | 124                                             | .048                                       | .025                                          | 19.7                                            | 3.42                                        | 2.60                                          | 20.0                                                          | 6.33                                         | 1.07                                             | 2.45                                         |
| 02N02E34 CAA-2       | --      | 112                                             | .043                                       | .022                                          | 18.2                                            | 3.15                                        | 2.40                                          | 13.2                                                          | 4.17                                         | 6.32                                             | 14.5                                         |
| 02N02W19 AABA-1      | NISA    | 7.28                                            | .003                                       | .001                                          | 4.65                                            | .81                                         | .61                                           | 2.44                                                          | .77                                          | .285                                             | .65                                          |
| 03N01E08 ABAB-1      | NISA    | 2.84                                            | .001                                       | .000                                          | 10.9                                            | 1.89                                        | 1.43                                          | 5.01                                                          | 1.59                                         | .581                                             | 1.33                                         |
| 03N01E08 DDCC-1      | NISA    | 5.58                                            | .002                                       | .001                                          | 13.7                                            | 2.37                                        | 1.81                                          | 11.8                                                          | 3.73                                         | 1.44                                             | 3.29                                         |
| 03N01E12 BCC-1       | NISA    | 1.99                                            | .001                                       | .000                                          | 10.7                                            | 1.86                                        | 1.41                                          | 6.38                                                          | 2.02                                         | .939                                             | 2.15                                         |
| 03N01E22 BAAD-1      | NISA    | 2.37                                            | .001                                       | .000                                          | 12.4                                            | 2.15                                        | 1.64                                          | 9.97                                                          | 3.15                                         | .990                                             | 2.26                                         |
| 03N01E32 BBCC-1      | NISA    | 4.34                                            | .002                                       | .001                                          | 6.00                                            | 1.04                                        | .79                                           | 4.86                                                          | 1.53                                         | .480                                             | 1.10                                         |
| 03N01E34 BCB-1       | QG00    | 3.35                                            | .001                                       | .000                                          | 17.8                                            | 3.09                                        | 2.35                                          | 18.3                                                          | 5.79                                         | 1.00                                             | 2.29                                         |
| 03N01W03 BABB-1      | NISA    | 24.2                                            | .009                                       | .005                                          | 7.11                                            | 1.23                                        | .94                                           | 2.79                                                          | .88                                          | .425                                             | .97                                          |

|          |        |      |      |      |      |      |      |      |      |      |      |      |
|----------|--------|------|------|------|------|------|------|------|------|------|------|------|
| 03N01W07 | AAAA-1 | NISA | 14.3 | .006 | .003 | 8.58 | 1.49 | 1.13 | 4.18 | 1.32 | .315 | .72  |
| 03N01W10 | ABBC-1 | NISA | 6.99 | .003 | .001 | 18.5 | 3.21 | 2.44 | 15.2 | 4.80 | .581 | 1.33 |
| 03N01W15 | BBDA-1 | NISA | 3.15 | .001 | .000 | 7.86 | 1.36 | 1.04 | 3.18 | 1.01 | .235 | .54  |
| 03N01W17 | BBBC-1 | NISA | 64.5 |      |      | 6.80 | 1.18 | .90  | 2.20 | .70  | 1.25 | 2.86 |
| 03N01W23 | DCCC-1 | NISA | 11.2 | .004 | .002 | 6.64 | 1.15 | .88  | 2.46 | .78  | .334 | .76  |
| 03N01W25 | ADAA-1 | NISA | 18.3 | .007 | .004 | 5.56 | .97  | .73  | 1.83 | .58  | .339 | .78  |
| 03N01W29 | CCAA-1 | NISA | 75.8 | .029 | .015 | 20.6 | 3.58 | 2.72 | 23.3 | 7.37 | 1.26 | 2.88 |
| 03N01W31 | BBAA-1 | NISA | 53.1 | .021 | .011 | 11.2 | 1.94 | 1.48 | 6.49 | 2.05 | .998 | 2.28 |
| 03N01W32 | ABAA-1 | NISA | 78.8 | .031 | .016 | 12.2 | 2.12 | 1.61 | 8.65 | 2.73 | .685 | 1.57 |
| 03N02E02 | DACC-1 | QG00 | 48.7 | .019 | .010 | 6.81 | 1.18 | .90  | 2.50 | .79  | 1.91 | 4.37 |
| 03N02E04 | ACCC-1 | NISA | .99  | .000 | .000 | 8.63 | 1.50 | 1.14 | 4.51 | 1.43 | .432 | .98  |
| 03N02E12 | BCAD-1 | NISA | 7.87 | .003 | .002 | 24.9 | 4.32 | 3.28 | 33.4 | 10.6 | 3.95 | 9.04 |
| 03N02E17 | ADDD-1 | NISA | 13.7 | .005 | .002 | 8.61 | 1.49 | 1.13 | 2.73 | .86  | 1.19 | 2.72 |
| 03N02E25 | CAAA-1 | NISA | 5.97 | .002 | .001 | 5.96 | 1.03 | .79  | 2.18 | .69  | .239 | .55  |
| 03N02W11 | ADAD-1 | NISA | 1.81 | .001 | .000 | 5.02 | .87  | .66  | 1.40 | .44  | .288 | .66  |
| 03N02W18 | DCB-1  | NISA | 1.90 | .001 | .000 | 11.1 | 1.93 | 1.46 | 7.65 | 2.42 | .812 | 1.86 |
| 03N02W19 | CCCB-1 | NISA | 15.0 | .006 | .003 | 5.81 | 1.01 | .77  | 1.88 | .59  | .200 | .46  |
| 03N02W21 | CBB-2  | NISA | 24.1 | .009 | .005 | 6.76 | 1.17 | .89  | 2.58 | .82  | .444 | 1.02 |
| 04N01E08 | DADA-1 | NISA | 3.33 | .001 | .000 | 7.87 | 1.37 | 1.04 | 2.76 | .87  | .773 | 1.77 |
| 04N01E11 | DCC-1  | NISA | 3.46 | .001 | .000 | 6.36 | 1.10 | .84  | 3.08 | .97  | .504 | 1.15 |
| 04N01E20 | CCA-1  | NISA | 12.3 | .005 | .002 | 8.03 | 1.39 | 1.06 | 2.07 | .65  | .356 | .82  |
| 04N01E20 | CCAA-1 | NISA | 507  | .197 | .100 | 12.3 | 2.13 | 1.62 | 3.00 | .95  | .594 | 1.36 |
| 04N01E20 | CCBC-1 | NISA | 22.3 | .009 | .004 | 7.68 | 1.33 | 1.01 | 1.25 | .39  | .541 | 1.24 |
| 04N01W07 | CACD-1 | NISA | 79.6 | .031 | .016 | 5.88 | 1.02 | .77  | 2.05 | .65  | .432 | .99  |
| 04N01W07 | DBBC-1 | NISA | 42.0 | .016 | .083 | 6.29 | 1.09 | .83  | 2.50 | .79  | .625 | 1.43 |
| 04N01W07 | DCAB-1 | NISA | 28.8 | .011 | .006 | 8.36 | 1.45 | 1.10 | 4.95 | 1.57 | .736 | 1.68 |
| 04N01W07 | DDAD-1 | NISA | 99.3 | .039 | .020 | 7.65 | 1.33 | 1.00 | 3.54 | 1.12 | 2.04 | 4.67 |
| 04N01W08 | CCCA-1 | NISA | 150  | .058 | .030 | 7.42 | 1.29 | .98  | 3.34 | 1.06 | 1.27 | 2.91 |
| 04N01W10 | BADA-1 | NISA | 2.18 | .001 | .000 | 11.3 | 1.96 | 1.49 | 8.75 | 2.77 | 1.86 | 4.26 |
| 04N01W11 | CDDC-1 | NISA | 2.54 | .001 | .000 | 9.64 | 1.67 | 1.27 | 5.30 | 1.68 | 2.03 | 4.64 |
| 04N01W11 | CDDC-1 | NISA | 5.29 | .002 | .001 | 10.1 | 1.75 | 1.33 | 6.30 | 1.99 | 1.38 | 3.16 |
| 04N01W18 | BAD-1  | NISA | 124  | .048 | .025 | 7.03 | 1.22 | .93  | 3.08 | .97  | .743 | 1.70 |
| 04N01W19 | CCAA-1 | NISA | 38.4 | .015 | .008 | 6.65 | 1.15 | .88  | 2.47 | .78  | 1.57 | 3.59 |
| 04N01W24 | DAAD-1 | NISA | 18.0 | .007 | .004 | 7.79 | 1.35 | 1.03 | 1.44 | .45  | .266 | .61  |
| 04N01W24 | DDAA-1 | NISA | 335  | .130 | .067 | 13.3 | 2.31 | 1.75 | 3.99 | 1.26 | 1.13 | 2.59 |
| 04N01W26 | BCA-1  | NISA | 5.10 | .002 | .001 | 8.67 | 1.51 | 1.14 | 3.41 | 1.08 | 1.11 | 2.54 |

TABLE A-3.--continued

| Local well<br>number | Aquifer | $\text{CaSO}_4$<br>$K_{1ap} \times 10^{-8}$ | Gypsum<br>$\frac{K_{1ap}}{K_{sp}}$ | Anhydrite<br>$\frac{K_{1ap}}{K_{sp}}$ | $\text{CaCO}_3$<br>$K_{1ap} \times 10^{-9}$ | Calcite<br>$\frac{K_{1ap}}{K_{sp}}$ | Aragonite<br>$\frac{K_{1ap}}{K_{sp}}$ | $\text{CaMg}(\text{CO}_3)_2$<br>$K_{1ap} \times 10^{-17}$ | Dolomite<br>$\frac{K_{1ap}}{K_{sp}}$ | $\text{FeCO}_3$<br>$K_{1ap} \times 10^{-10}$ | Siderite<br>$\frac{K_{1ap}}{K_{sp}}$ |
|----------------------|---------|---------------------------------------------|------------------------------------|---------------------------------------|---------------------------------------------|-------------------------------------|---------------------------------------|-----------------------------------------------------------|--------------------------------------|----------------------------------------------|--------------------------------------|
| Ingham County        |         |                                             |                                    |                                       |                                             |                                     |                                       |                                                           |                                      |                                              |                                      |
| 04N01W27 BABB-1      | NISA    | 18.6                                        | .007                               | .004                                  | 7.35                                        | 1.28                                | .97                                   | 2.76                                                      | .87                                  | --                                           | --                                   |
| 04N01W27 CBBA-1      | NISA    | 3.78                                        | .001                               | .000                                  | 6.72                                        | 1.17                                | .89                                   | 2.55                                                      | .81                                  | 1.03                                         | 2.36                                 |
| 04N01W29 BBBB-1      | NISA    | 173                                         | .067                               | .034                                  | 6.69                                        | 1.16                                | .88                                   | 2.42                                                      | .77                                  | 1.67                                         | 3.82                                 |
| 04N01W29 BBBB-2      | NISA    | 113                                         | .044                               | .022                                  | 8.37                                        | 1.45                                | 1.10                                  | 3.93                                                      | 1.24                                 | 1.06                                         | 2.43                                 |
| 04N01W30 BBAA-1      | NISA    | 14.8                                        | .006                               | .003                                  | 5.86                                        | 1.02                                | .77                                   | 2.00                                                      | .63                                  | .237                                         | .54                                  |
| 04N01W30 BCDD-1      | NISA    | 19.4                                        | .008                               | .004                                  | 6.32                                        | 1.10                                | .83                                   | 2.26                                                      | .71                                  | .293                                         | .67                                  |
| 04N02E16 DDD-1       | QG00    | 5.28                                        | .002                               | .001                                  | 6.72                                        | 1.17                                | .88                                   | 3.08                                                      | .97                                  | .892                                         | 2.04                                 |
| 04N02W12 CCD-1       | NISA    | 120                                         | .047                               | .024                                  | 6.32                                        | 1.10                                | .83                                   | 2.21                                                      | .70                                  | .464                                         | 1.06                                 |
| 04N02W12 CDA-1       | NISA    | 99.5                                        | .039                               | .020                                  | 7.08                                        | 1.23                                | .93                                   | 2.89                                                      | .91                                  | .145                                         | .33                                  |
| 04N02W25 AABA-1      | NISA    | 36.3                                        | .014                               | .007                                  | 5.38                                        | .93                                 | .71                                   | 1.62                                                      | .51                                  | .184                                         | .42                                  |
| 04N02W25 BADA-1      | NISA    | 7.34                                        | .003                               | .001                                  | 5.59                                        | .97                                 | .73                                   | 3.03                                                      | .96                                  | .290                                         | .66                                  |
| 04N02W36 DAAD-1      | NISA    | 24.3                                        | .009                               | .005                                  | 7.16                                        | 1.24                                | .94                                   | 2.64                                                      | .83                                  | .474                                         | 1.08                                 |
| Jackson County       |         |                                             |                                    |                                       |                                             |                                     |                                       |                                                           |                                      |                                              |                                      |
| 01S01E08 DAAD-1      |         | 47.3                                        | .018                               | .009                                  | 7.78                                        | 1.36                                | 1.03                                  | 3.19                                                      | 1.01                                 | .691                                         | 1.58                                 |
| 01S01E22 ABBA-1      |         | 4.99                                        | .002                               | .001                                  | 9.49                                        | 1.65                                | 1.25                                  | 3.49                                                      | 1.10                                 | 2.39                                         | 5.47                                 |
| 01S01W22 ADCA-1      |         | 29.6                                        | .012                               | .006                                  | 7.78                                        | 1.35                                | 1.03                                  | 2.97                                                      | .94                                  | 1.79                                         | 4.10                                 |
| 01S02W04 CCCC-1      |         | 21.3                                        | .008                               | .004                                  | 18.6                                        | 3.23                                | 2.45                                  | 15.4                                                      | 4.84                                 | 1.84                                         | 4.21                                 |
| 01S02W13 DDCD-1      |         | 17.1                                        | .007                               | .003                                  | 7.68                                        | 1.33                                | 1.01                                  | 2.71                                                      | .86                                  | 1.65                                         | 3.78                                 |
| 01S02W13 ADDD-1      |         | 26.1                                        | .010                               | .005                                  | 8.76                                        | 1.52                                | 1.16                                  | 3.11                                                      | .98                                  | .506                                         | 1.16                                 |
| 02S01E17 BDDD-1      |         | 6.84                                        | .003                               | .001                                  | 9.02                                        | 1.57                                | 1.19                                  | 3.94                                                      | 1.25                                 | 2.78                                         | 6.36                                 |

|                 |      |      |      |      |      |      |      |      |      |      |
|-----------------|------|------|------|------|------|------|------|------|------|------|
| 02S01W05 CCBC-1 | 8.01 | .003 | .002 | 6.91 | 1.20 | .91  | 2.40 | .76  | 1.70 | 3.89 |
| 02S01W08 ADCC-1 | 25.4 | .010 | .051 | 19.0 | 3.30 | 2.51 | 17.3 | 5.47 | 2.12 | 4.80 |
| 02S02W31 BCDD-1 | 92.4 | .036 | .018 | 7.55 | 1.31 | 1.00 | 2.84 | .90  | 1.54 | 3.52 |
| 02S02W35 CADA-1 | 32.3 | .013 | .006 | 8.11 | 1.41 | 1.07 | 3.77 | 1.19 | .625 | 1.43 |
| 02S03W25 CDBB-1 | 26.6 | .010 | .005 | 21.5 | 3.73 | 2.83 | 4.00 | 1.27 | 4.93 | 11.3 |
| 02S03W28 DBAA-1 | 25.6 | .010 | .005 | 10.4 | 1.81 | 1.37 | 5.15 | 1.63 | 3.38 | 7.73 |

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Livingston County

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|                 |      |      |      |      |      |      |      |      |      |      |
|-----------------|------|------|------|------|------|------|------|------|------|------|
| 02N03E20 CBBC-1 | 32.9 | .013 | .007 | 10.0 | 1.74 | 1.32 | 5.21 | 1.65 | 1.00 | 2.29 |
| 03N03E10 AAAD-1 | 98.3 | .038 | .020 | 12.4 | 2.15 | 1.64 | 8.29 | 2.62 | 1.50 | 3.43 |
| 03N03E26 CDDD-1 | 18.5 | .007 | .004 | 10.2 | 1.77 | 1.35 | 5.77 | 1.83 | .564 | 1.29 |
| 03N03E26 CDDD-2 | 4.64 | .002 | .001 | 8.38 | 1.45 | 1.10 | 6.35 | 2.01 | 5.39 | 12.3 |
| 04N03E16 CAAA-1 | 9.08 | .004 | .002 | 12.2 | 2.12 | 1.61 | 8.33 | 2.64 | 1.50 | 3.43 |

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Shiawassee County

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|                 |      |      |      |      |      |      |      |      |      |      |
|-----------------|------|------|------|------|------|------|------|------|------|------|
| 05N01E10 CCCC-1 | 10.0 | .004 | .002 | 6.59 | 1.14 | .87  | 2.74 | .87  | .524 | 1.20 |
| 06N01E21 AADD-1 | 1.62 | .001 | .000 | 5.08 | .88  | .67  | 1.29 | .41  | .282 | .64  |
| 06N01E35 DDAA-1 | .728 | .000 | .000 | 11.5 | 2.00 | 1.52 | 7.29 | 2.31 | 1.20 | 2.75 |
| 06N02E01 DCDD-1 | 9.68 | .004 | .002 | 8.64 | 1.50 | 1.14 | 4.92 | 1.56 | .683 | 1.56 |

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