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DETERMINATION OF RECHARGE AREAS FROM GROUNDWATER QUALITY DATA, INGHAM COUNTY, MICHIGAN

By

Shahbaz Radfar

A THESIS

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ABSTRACT

DETERMINATION OF RECHARGE AREAS FROM GROUNDWATER QUALITY DATA, INGHAM COUNTY, MICHIGAN

By

SHAHBAZ RADFAR

The Saginaw Formation in southern Michigan is the principal aquifer for the city of Lansing and the surrounding tri-county region. It is composed chiefly of beds of sandstone and shale, but includes some thin beds of coal and limestone. In Ingham County the formation ranges from 0 to 135 meters (450 ft) in thickness and is overlain by 0 to 36 meters (120 ft) of glacial drift of the Pleistocene Age. The drift consists chiefly of till with scattered deposits of sand and gravel.

Chemical analyses of water from 138 domestic wells tapping the Saginaw Formation indicate that the principal source of dissolved solids in the ground water of the Saginaw Formation is from the glacial drift. Generally, the concentration of dissolved calcium, magnesium, potassium, iron and chloride in the water from the aquifer is consistantly lower than that of water from the glacial drift. The concentration of sodium ions, on the other

hand, is generally higher in the aquifer than that in the drift. In addition, zones of low ion concentrations in the ground water of the aquifer occur in areas where the glacial drift overlying the aquifer is composed chiefly of sand and gravel.

Based on the geochemical analysis of ground water in the Saginaw Formation it appears that the Saginaw Formation is naturally recharged by rain and stream water passing through the glacial drift. Most of the recharge, however, appear to be localized primarily near deposits of sand and gravel in contact with the bedrock and along stream beds underlain by alluvial materials.

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INTRODUCTION

Most of the counties in Michigan obtain their municipal and industrial water supplies from surface water sources. Ingham County, however, is one county in central Michigan which is dependent almost entirely upon ground water derived from municipal and domestic wells (Fig. 1). Most of these wells draw from the Saginaw Formation which is the principal aquifer for the city of Lansing and the surrounding tri-county region.

The thickness of the Saginaw Formation ranges from 0 to 135 meters (450 ft) and when fully developed is expected to yield approximately 197 MLD (52 MGD) of water, with the greatest share of the withdrawal being within the Lansing metropolitan area (Vanlier and Wood, 1969).

Within the last twenty years, however, rapid growth of population and industry, especially in and adjacent to the Lansing Metropolitan area, has generated serious concern among many of the industrial and domestic users of groundwater. It appears the withdrawal of large quantities of water from the Saginaw Formation within these areas has produced over the years an extensive cone of depression and has seriously lowered water levels in many producing wells.

The objective of this thesis to to determine the areas of recharge for the Saginaw Formation within Ingham County. Obviously, these areas are of prime interest to the residents of the county because their preservation is essential for insuring an adequate ground water supply in the future. Specifically, the study involves the following two programs:

1. To map, in detail, the geochemistry of the ground water in the Saginaw Formation of Ingham County and
2. To ascertain from the geochemical and geological data the pattern of recharge into the Saginaw Formation.

Previous Investigations

Since 1940 several hydrological investigations have been made of the Lansing area. For example, W. T. Stuart (1945) of the United States Geological Survey published a report entitled "Groundwater Resources of the Lansing, Michigan, Area." The study involved water level measurements in observation wells, pumping tests, and other field investigations. It has since served as a basic source of information on the area's groundwater supply. Stuart's work contains a description of the physical parameters of the aquifer, an early piezometric map of the area, and calculated coefficients of transmissibility and storage for the aquifer. His piezometric map shows a major cone of depression beneath Lansing caused by high industrial and domestic pumpage. The map also shows that the general trend of groundwater flow in Ingham County is towards the north. The report suggests that the aquifer was in equilibrium during the period from 1930 to 1935, but by 1945 it was no longer in equilibrium due to increased rates of pumpage.

For an aquifer to be in equilibrium it must be recharged at the same rate at which water is being withdrawn from the aquifer. Stuart suggested three principal paths of recharge to the Saginaw Formation: (1) water is recharged to the aquifer from streams and rivers, (2) water enters the aquifer directly where bedrock is at or near the ground surface, and (3) leakage into the aquifer is from the saturated glacial drift directly above the aquifer. The third possibility has concerned several later investigators (W. Wood, 1969; Vanlier and Brunett, 1969).

The geology of the Saginaw Formation in Ingham County, as well as in the Upper Grand River Basin, has been described in detail by Kelly (1936). An outline of the glacial history of Ingham County has also been made by Martin (1958). In addition, a more recent study of the groundwater hydrology of the Saginaw Group has been made by Mencenberg (1963). This last investigation includes a study of the relationships of the piezometric surface to the geology and discusses the extent of the aquifer and the subsurface correlations within the Saginaw Group.

A more recent piezometric map of the Lansing area was constructed by Firouzian (1963). He determined the coefficients of transmissibility of the Saginaw Formation by flow net analysis. Neither Firouzian's or Mencenberg's study goes into any great detail about the recharge capabilities of the aquifer.

A more up to date report by Vanlier (1964) contains a general discussion of the geology, hydrology, and water quality of the area of Clinton, Eaton, and Ingham Counties. A more detailed version of this report was published by Vanlier, Wood, and Brunett (1969). Another investigation of the groundwater resources of the tri-county region around Lansing (Wheeler, 1967; Vanlier and Wheeler, 1968) was recently prepared by the United States Geological Survey. This investigation contains an electric analog model of the Saginaw Formation in the Lansing area.

GEOLOGY OF THE AREA

Introduction

The chemical characteristics of water within an aquifer normally reflect the lithologic characteristics of the entire aquifer system. For example, the processes of solution, ion exchange, precipitation, and ion filtration which can and generally do occur in an aquifer are all functions of the type and distribution of rock lithologies in contact with the aquifer water. Clearly, a sound understanding of the geochemistry of an aquifer system would require not only a knowledge of the geology of the aquifer itself, but also a knowledge of the geology of the source of recharge to the aquifer.

Location

The area under investigation lies in the south central part of the Lower Peninsula of Michigan (Fig. 1). It includes all the area within Ingham County and covers approximately 1422 square kilometers (553 square miles or 353,920 acres). The Lansing metropolitan area lies in the northwest corner of the county and is the center of

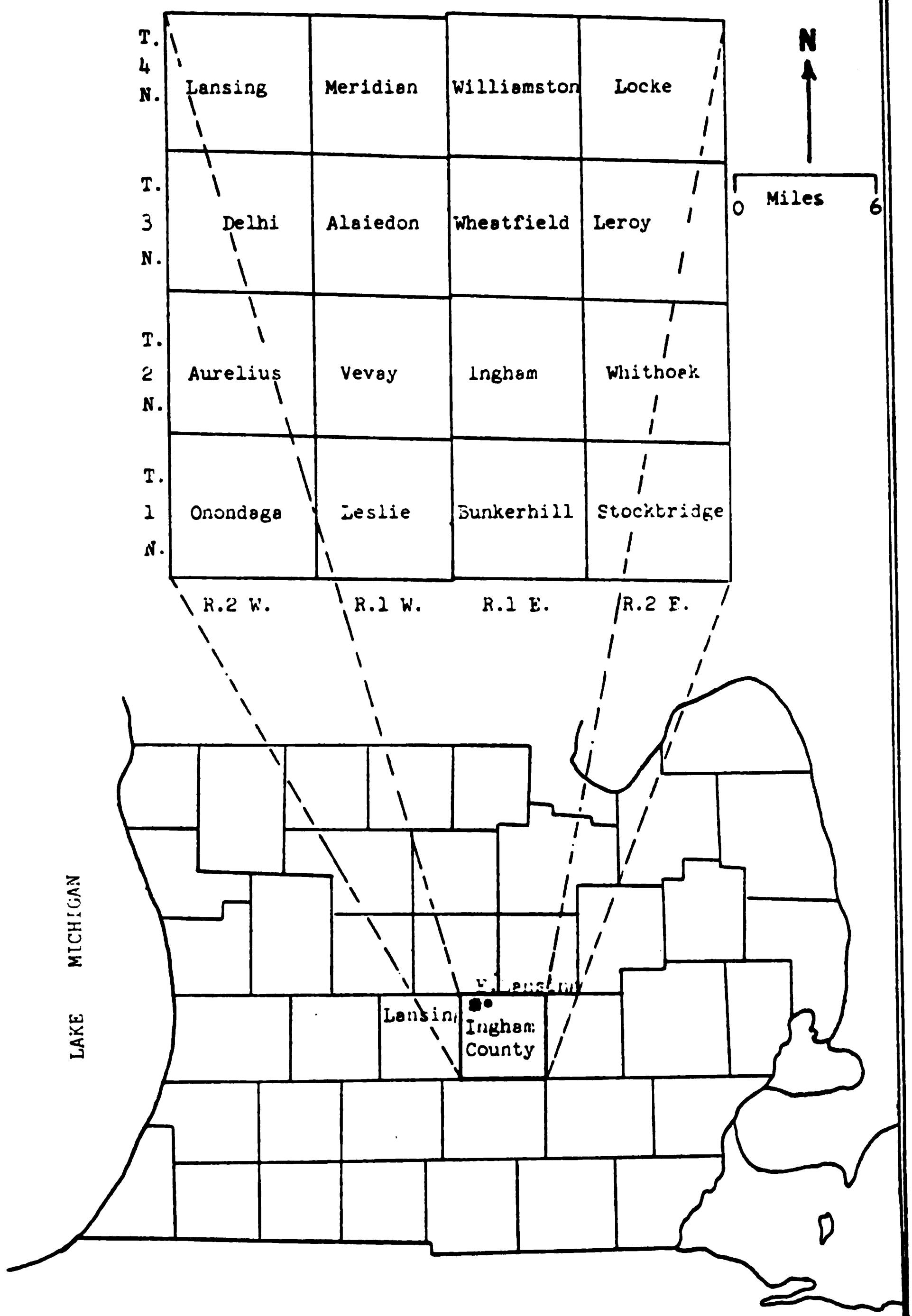

Figure 1. Map Showing Location of Ingham County, Michigan.

industrial and commercial activity in the region.

Vegetation

Presently about 15 percent of Ingham County is covered by forest which consist of various associations of hard woods. The principal hard woods are oak, hickory, beech, and ash. American linden, elm, maple, tamarack, aspen, willow, black spruce and shrubs usually grow in peat swamps. Wire grass, sedge and blue joint usually grow in marshy land. Most of the county is covered by grass and non-cultivated crops and the best land in the county is used for the production of cultivated crops (Veatch, 1941). Wheat, corn, hay, oats, rye, barley, dry beans, livestock and potatoes are staple crops of the region.

Surficial Geology

The present day topography of Ingham County is characterized by gentle morainic hills and flat undulating ground moraine. Most of the glacial drift which blankets the bedrock was deposited during the Wisconsin glaciation and in this area consists chiefly of unconsolidated clay, silt, sand and gravel.

According to Vanlier (1969), the glacial deposits are of three principal types: (1) well sorted mixtures of silt, sand, and gravel such as found in valley trains, outwash plains, eskers, kames, and buried outwashes, (2) layered sequences of silt, sand, and clay deposited in glacial lakes and glacial river channels, and (3) unsorted mixtures of clay, silt, sand, gravel, and boulders such as found in ground and recessional moraines. In local areas, thick deposits of recent alluvium also overlay the glacial drift.

Figure 2 shows a surficial map of Ingham County prepared by Martin (1958). It is evident from the map that most of the County is covered by ground and recessional moraine (till material). The major recessional moraines crossing the County are the Grand Ledge and Lansing moraines (Leverett and Taylor, 1915). The Grand Ledge moraine extends southwestward from Lake Lansing to the campus of Michigan State University and then continues northwestward towards the town of Grand Ledge. The Lansing moraine on the other hand lies south of Grand Ledge moraine and extends through the southern part of the city of Lansing. In addition, there are many short minor morainal belts which extend in an east-west arch across the southern half of the county. The thickness of the drift in the county ranges from 0 to 36 meters (120 ft) primarily because of uneven bedrock. The surface of the drift ranges in altitude from about 240 to 300 meters.

The eskers in the region are long narrow ridges commonly sinuous in form and are composed chiefly of sand

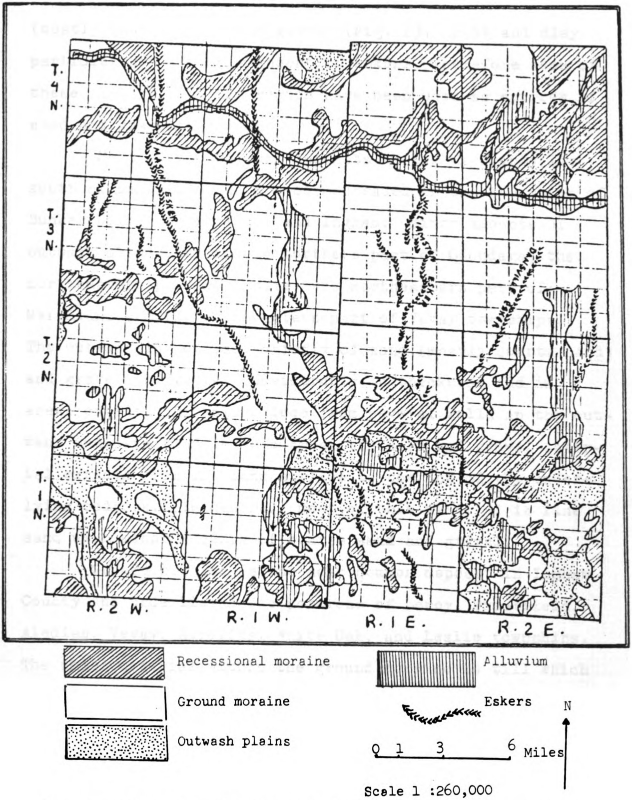

Fig. 2-- Map Showing Surficial Materials of Ingham County, Michigan (Modified from Helen M. Martin, 1958)

(mostly quartz sand) and gravel (Fig. 2). Silt and clay particles are commonly absent in eskers, therefore some of these features in this region have been used as sources of sand and gravel aggregate.

Most of the outwash deposits in Ingham County lie south of Dansville and are concentrated in the townships of Bunker Hill, Stockbridge, and Ingham. Minor amounts of outwash also occur in the northern part of Onondaga, the northeastern part of Leslie, the northeastern part of Meridian, and the southeastern part of Vevay townships. The outwash is composed chiefly of sand (mostly quartz sand) and gravel and varies considerably in thickness and in areal extent. Litholgic logs from several wells in the outwash indicate that in some areas the sand and gravel material extends from the land surface to the top of the underlying bedrock. In general, most of this material is fine sand with minor amounts of coarse sand and gravel.

Ground moraine is the most common deposit in Ingham County and underlies large portions of Leroy, Wheatfield, Aledian, Vevay, Aurelius, White Oak, and Leslie townships. The chief material within the ground moraine is till which is a mixture of sand, silt, and clay particles and large boulders. Well logs from these areas indicate that the till extends generally from the land surface to the top of the bedrock, but in the some areas it includes or overlies extensive bodies of sand and gravel.

Most of the alluvial materials which consist chiefly of silt and fine sand deposited on flood plains, occur along the Red Cedar River, Doan Creek, Deer Creek, Sloan Creek, Grand River and its tributaries.

Subsurface Geology

The glacial deposits within Ingham County rest directly upon bedrock of Pennsylvanian (Grand River formation, Saginaw formation) and Mississippian Age (Bayport Limestone) (Fig. 3). Structurally the bedrock forms the southern edge of the Michigan basin and dips about one degree toward the north. Underlying the Pennsylvanian aged rocks is about 8000 feet of sandstone, limestone, dolomite, shale, and evaporites ranging in age from Cambrian to Upper Mississippian (Dott, et al, 1954). These sediments generally have a low permeability and contain water which is highly mineralized (Stuart, 1945).

Within Ingham County there are several localities where bedrock crops out (Lane, 1902). The most extensive outcrop of the Saginaw Formation in Ingham County is located near the town of Williamston where it is quarried by Michigan Clay Products Company. In the quarry there is a small anticline with a north-south strike which exposes some of the older beds in the formation (Kelly, 1936). The outcrops exposed in the vicinity of Grand Ledge out of the study area are the most extensive of the Saginaw Formation

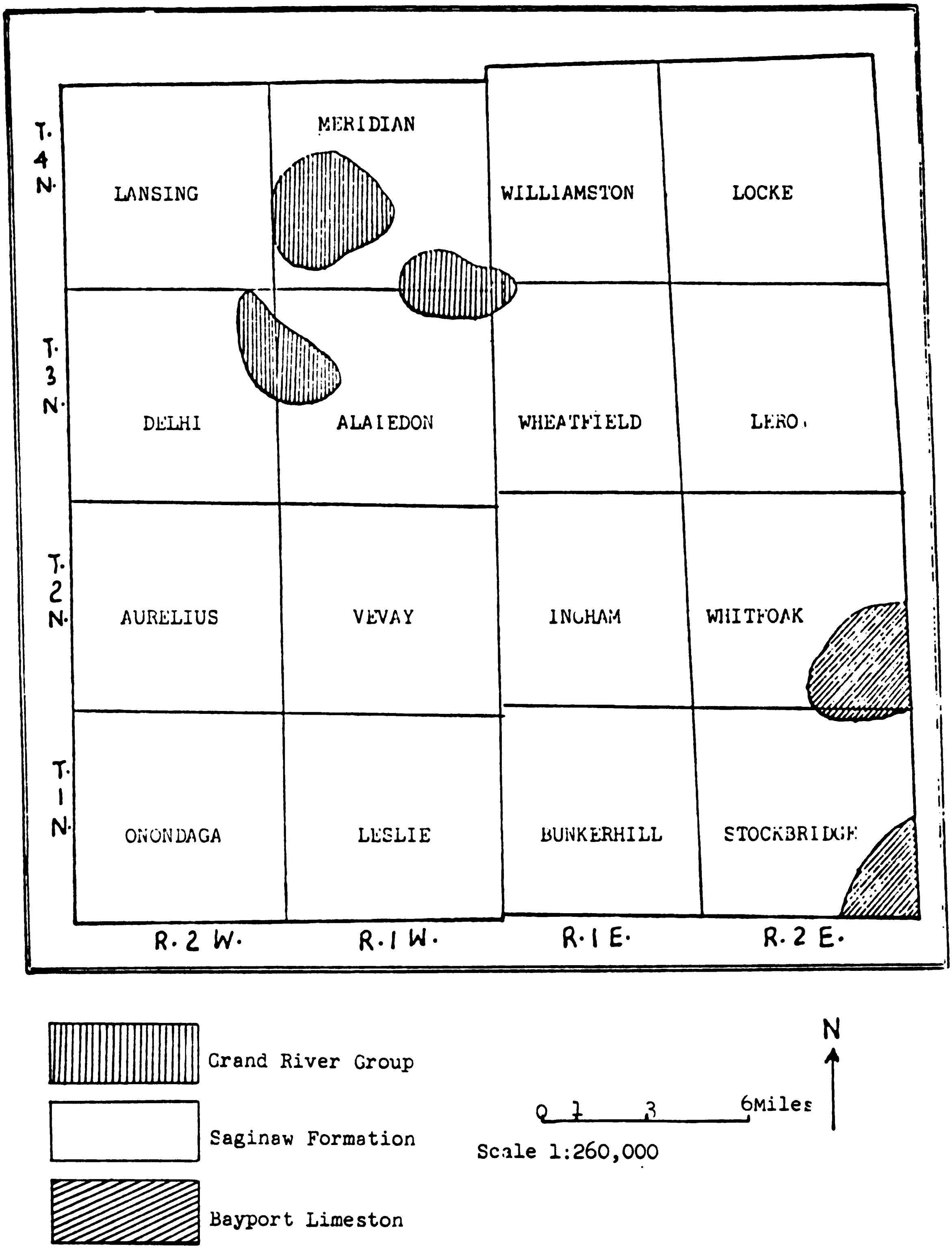

Fig. 3 --Map Showing the Bedrock of Ingham County, Michigan.

exposures within the State (Kelly, 1936). Low areas on the Saginaw surface tend to be the low areas of the present surface topography (Mencenberg, 1963). The Grand River formation and the Bayport limestone are two other formations in Ingham County which crop out in a few places.

Stratigraphic Occurrence of Saginaw Formation

The Pennsylvanian system of the Michigan Basin sedimentary sequence has been commonly subdivided into the Grand River and Saginaw Formations (Table 1). Much of the Grand River Group and younger bedrock in Ingham County were removed by pre-glacial erosion. However, some patches of red beds overlying the Saginaw have been reported by well drillers in Delhi, Alaiedan, and Meridian townships and may be remnants of the Grand River Group.

The main water bearer in Ingham County is the Saginaw Formation. It consists chiefly of sandstone and directly overlies the Bayport limestone. The edge of the Bayport limestone occurs directly under the glacial drift in the southeastern corner of White Oak and Stockbridge townships (Fig. 3).

The Saginaw Formation was deposited on the eroded surface of the Bayport limestone and Michigan Formation (Kelly, 1936, Vanlier, 1969). Originally, the type locality for the Saginaw Formation named the Jackson Formation was in an abandoned coal mine in Jackson County about

Table 1. -- Stratigraphic Occurrence of the Saginaw Formation.

PERIOD	FORMATION	MEMBER
Pennsylvanian	Grand River	Ionia, Eaton, and Woodville sandstone
	Saginaw	Verne Ls.
Mississippian	Bayport Ls.	
	Michigan	
	Marshall Ss.	
	Coldwater Sh.	

Source: Michigan Geological Survey, Chart 1, 1964.

25 miles south of the area of study. A. C. Lane (1901) replaced the name Jackson with the name Saginaw, a characteristic name, because the Saginaw Valley occupies a large part of the coal basin in Michigan.

The average thickness of the Saginaw Formation is approximately 120 meters (400 ft) (Kelly, 1936), but it reaches 135 meters (450 ft) in Ingham County. Low areas on the upper surface of the Saginaw Formation indicate erosion of the formation surface prior to the deposition of the Grand River Group. The thickness of the formation is extremely variable within the County and generally increases toward the north (Fig. 4).

Lithology of the Saginaw Formation

The Saginaw Formation is composed principally of discontinuous beds of sandstone and shale, but it includes some thin beds of coal and limestone. An individual strata can vary in lithologic character and thickness within a very short distance. Detailed investigation of this variation (Kelly, 1936) indicates that the sandstone is frequently lenticular, nonpersistent, and forms irregular beds often ending abruptly against shales generally less than 6 meters (20 ft) thick. Beds of sandstone 30 to 90 meters (100 to 300 ft) thick have been reported from several wells in Lansing Township (Kelly, 1936).

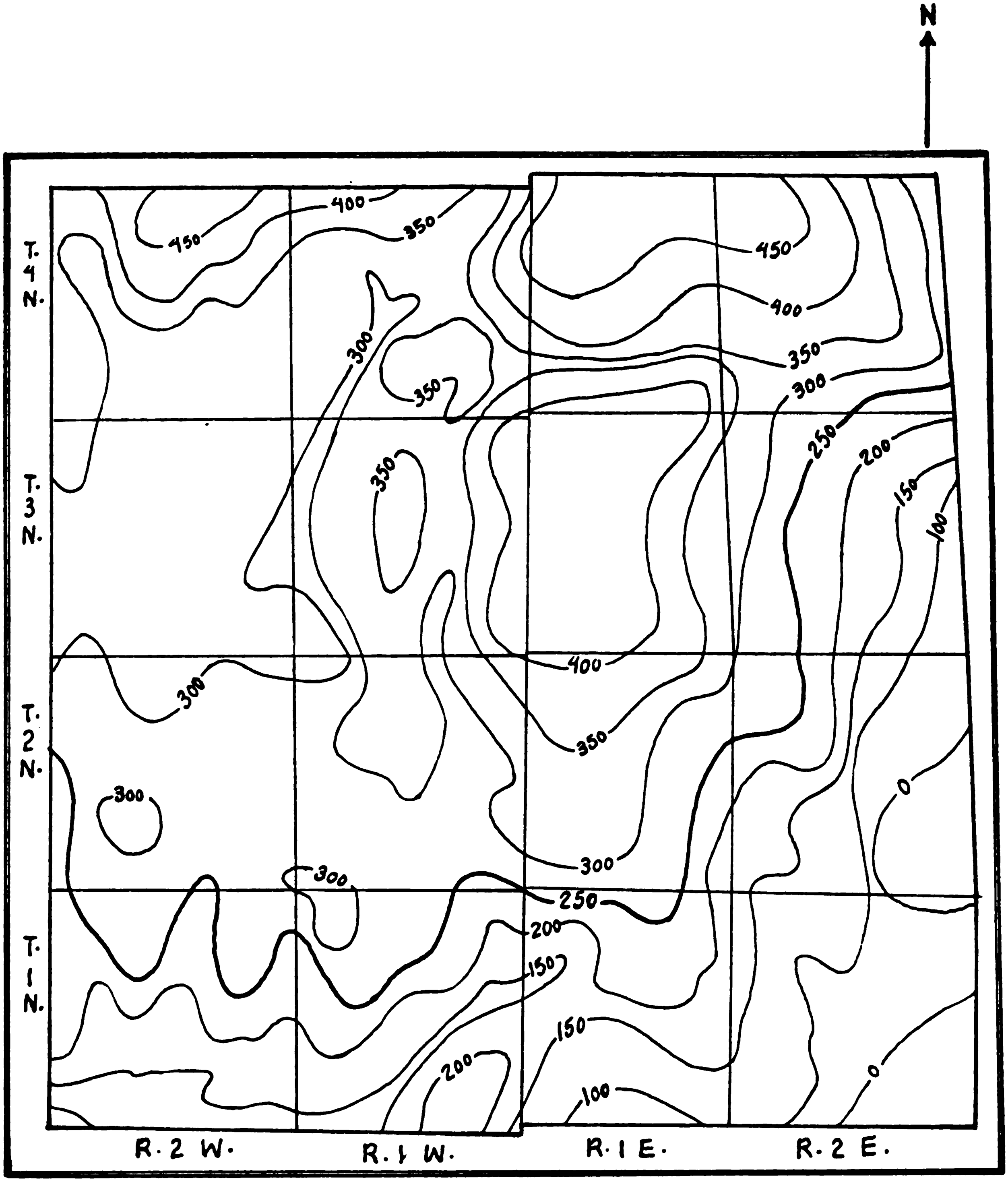

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Fig. 4 --Map Showing the Thickness of the Saginaw Formation Ingham County, Michigan (Modified from K. E. Vanlier, 1969

The texture of the sandstone in the Saginaw Formation is usually fine grained. The sand is composed chiefly of very fine quartz grains but is associated locally with decomposed feldspars and abundant light-colored micas. The dominant colors reported in drillers logs are light buff and dark gray. The sandstone contains generally less than one percent of heavy minerals such as tourmaline and zircon (Kelly, 1936). It does, however, also contain occasional fossil plant fragments. These characteristics indicate a terrestrial origin for the sand, where shifting currents with rapidly alternating erosion and deposition played a major part.

As mentioned above, the shales of the Saginaw Formation and some of the sandstones are not persistent over great distances. The shales are often truncated by channel sands in many instances. Kelly (1936) divided the shales of the Saginaw Formation into three subdivisions: (a) shales with considerable sandy material, (b) shales with little or no sandy material, and (c) underclays. Plant fossils are often found in the shales which also suggests a terrestrial origin. The colors recorded for the shales in drillers logs are black, blue, brown, buff, gray, and white. Black or dark gray is the most common color. Underclay often occurs below coal seams and commonly contains irregular nodules of iron carbonate (Kelly, 1936).

In the study area, coal beds are not abundant in the Saginaw Formation, however, there are occasional thin and discontinuous beds which vary in thickness from a few to several meters. Most coal that has been mined in Ingham County averages about thirty inches in thickness (Mencenberg, 1963).

HYDROLOGY

Introduction

It is well known that the amount of water entering a groundwater reservoir over a fixed period of time is influenced by several factors; these include the duration, intensity, and type of precipitation, the density and type of vegetation, the topography and drainage system of the ground surface, and the lithologic and hydrologic properties of the soil, surficial materials and underlying rock formations. Hence, with the Saginaw Formation, it is necessary first to identify the source and availability of water to the aquifer before the path and volume of water flow into the aquifer can be adequately investigated.

Precipitation

As mentioned above, precipitation is one of the major factors that controls the general groundwater condition in any area.

According to Michigan Department of Agriculture (1978) rate of precipitation in Ingham County is fairly uniform throughout the year. Annual precipitation generally ranges from 24 to 36 inches, but averages about 31 inches. The wettest months of the year are normally May and June (3.5 inches per month). February is usually the month of minimum precipitation (about 1.6 inches). The maximum 24-hour rainfall recorded within the region was 5.89 inches, which occurred in Webberville on June 5-6, 1905. Snowfall has been recorded in every month except June, July, August, and September. About 90 percent of the snowfall takes place in the months of December through March (Vanlier, 1969).

The annual precipitation for the area in 1977 was 28.32 inches which was 2.28 inches below the average of 30.60 inches. The variation of precipitation from 1968 to 1977 is shown in Table 2.

Drainage of the Study Area

Most of the northern part of Ingham County is drained by the Red Cedar River and its major tributaries; Sycamore Creek, Deer Creek, Doan Creek, and Sloan Creek (Fig. 5). The western part of the County, on the other hand, is drained by the Grand River and the southern part is drained by several tributaries of Portage Creek. The average flow of the Red Cedar in East Lansing is about 5 CMS (190 CFS) and its annual 7-day low flow, where it enters the Grand River, is about 0.8 CMS (30 CFS) (Vanlier, 1969).

Table 2. -- Annual Precipitation, Annual Departure, and Cumulative Departure of Precipitation.

Year	Annual Precipitation in Inches	Annual Departure of Precipitation in Inches	Cumulative Departure of Precipitation in Inches
1968	31.89	+1.29	+1.29
1969	27.79	-2.81	-1.52
1970	34.67	+4.07	+2.55
1971	24.56	-6.04	-3.49
1972	30.50	-0.10	-3.59
1973	34.79	+4.19	+0.60
1974	28.86	-1.74	-1.14
1975	36.13	+5.53	+4.39
1976	28.74	-1.86	+2.53
1977	28.32	-2.28	+0.25

Source: Michigan Weather Service, 1978.

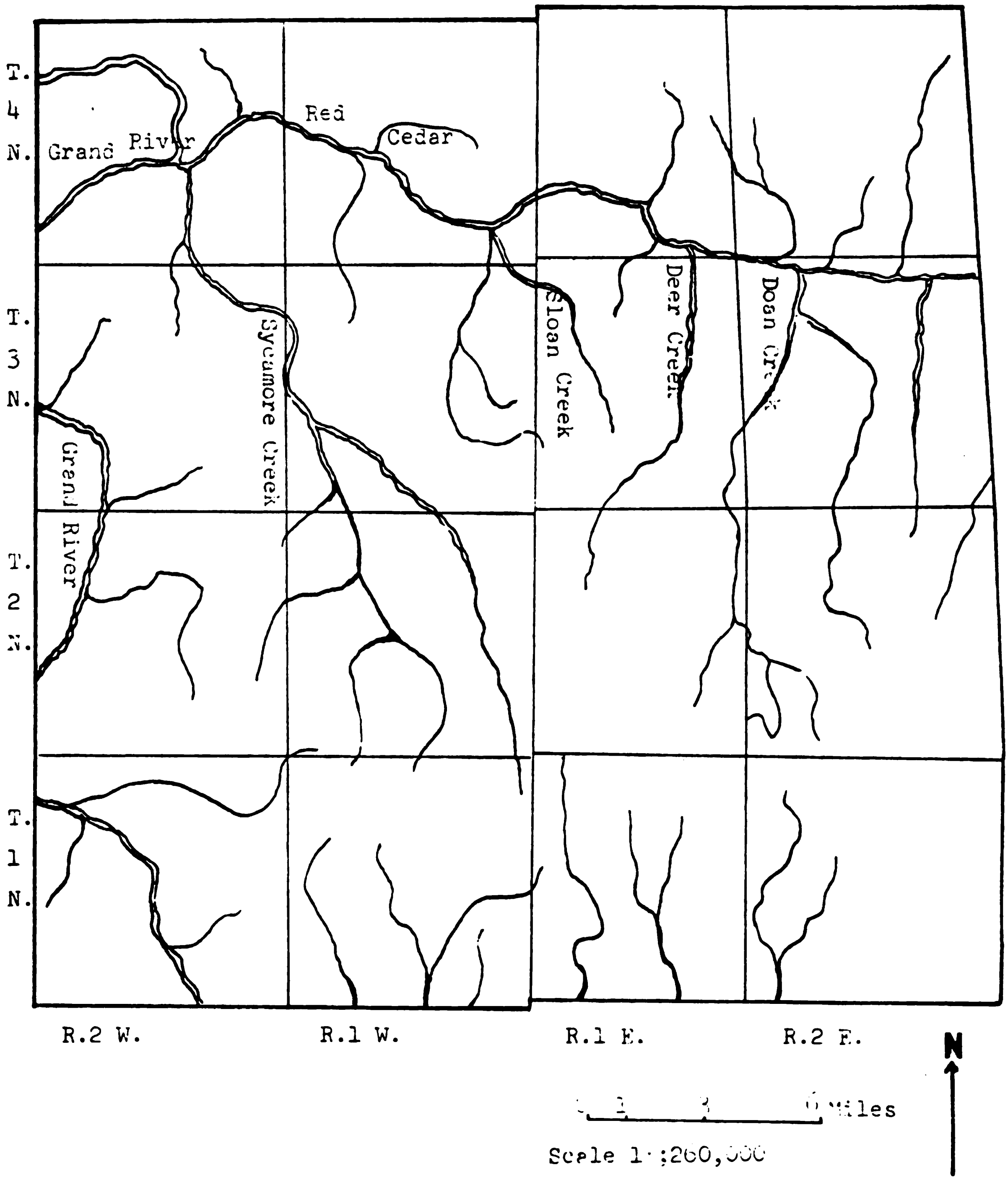

Fig.5--Streams Draining Ingham County, Michigan.

The Grand River enters Ingham County from the south and flows north through Lansing and then westward to Grand Ledge. Its drainage area south of Lansing is approximately 1230 square miles which represents 22 percent of its total drainage area (Firouzian, 1963).

The Red Cedar River, on the other hand, enters the county from the east and flows west until it joins the Grand River in Lansing. Its drainage area above East Lansing is 3198 sq. km (355 square miles)(Firouzian, 1963). Sycamore Creek generally flows in a northwestwardly direction from the city of Mason and joins the Red Cedar River just east of Lansing. Doan Creek, Deer Creek, and Sloan Creek also flow towards the north and join the Red Cedar within the boundaries of Ingham County.

The Grand River basin in the western part of the county is gently rolling and is underlain predominantly by sandy loam soil. According to hydrologic studies of the U. S. Geological Survey (Firouzian, 1963) the base flow for the Grand River south of Lansing in 1963 is approximately 3×10^{-4} CMS per sq. km (0.26 CFS per square mile). The amount of base flow for the Red Cedar River in East Lansing, on the other hand, is estimated to be approximately 2×10^{-4} CMS per sq. km (0.16 CFS per square mile) and is equivalent to 2.17 inches per year (Firouzian, 1963).

Table 3. -- Mean Flow of Streams in Ingham County (in CFS).

Year	Red Cedar at E. Lansing	Grand River at Lansing	Deer Creek	Sloan Creek	Sycamore Creek
1968	287	1145	14.6	9.12	--
1969	267	1118	12.8	6.60	--
1970	161	702	9.88	4.17	--
1971	197	780	10.0	6.00	--
1972	169	715	10.2	5.21	--
1973	351	1286	17.7	10.5	--
1974	356	1372	18.2	9.33	--
1975	307	1083	13.8	9.49	--
1976	318	1215	16.0	8.57	76.4
1977	112	509	4.63	2.24	26.4

Source: United States Geological Survey. Stream Flow Publication. 1968 to 1977.

Recharge to the Aquifer

The initial source of all fresh groundwater in the Saginaw Formation is from precipitation. As mentioned earlier it is one of the major factors that controls directly or indirectly the amount of recharge to the formation.

The average annual precipitation over Ingham County is about 31 inches (Vanlier, 1969). Most of this water, however, does not enter the groundwater reservoir but is lost due to evaporation, transpiration especially in the summer, and surface run off to the drainage system (especially when the ground is frozen). The average surface run off within the County is about 7 inches annually, and the difference, 24 inches, is the average annual loss through evaporation and transpiration (Vanlier, 1969) plus the amount recharging into the ground water supply.

Run off can be separated into its components of overland and groundwater flow. Of the 7 inches of run off in the study area, direct overland flow amounts are about 3 inches and while ground water flow accounts for about 4 inches (Vanlier, 1969).

GEOHYDROLOGY OF THE SAGINAW FORMATION

By definition a water-bearing formation that yields water in usable quantities is termed an aquifer. The amount of water available to a well, however, depends upon the regional and local lithologic and hydrologic characteristics of both the aquifer and the overlying and underlying units.

Hydrologically, an aquifer may be classified as either water table or artesian. In the water table variety, the aquifer is unconfined and the water surface within the aquifer is termed the water table. Often, in a glaciated region, water table conditions predominate, where discontinuous and unrelated lenses of clay occur within the drift. In addition, impermeable lenses of clay often cause the water table to be "perched" in local areas. These small "perched" water bodies are generally unimportant to groundwater development except for occasional domestic wells.

In an artesion aquifer, such as occurs within the Saginaw Formation, groundwater is confined under pressure between relatively impermeable strata. Under natural conditions, the water in a well completed in the Saginaw Formation and tightly cased through the overlying drift will rise above the drift-bedrock contact even while water is being removed. The imaginary surface consisting of all points to which water would rise in wells that tap the Saginaw Formation is called the piezometric surface. In the Lansing area, however, the high rate of pumpage has locally drawn the piezometric surface below the drift/ bedrock contact, producing a water table condition within the Saginaw.

As mentioned earlier, the Saginaw Formation is the principal source of water for the city of Lansing and Ingham County. The aquifer is confined to various degrees by shaley aquicludes and, in some areas, in the county the aquicludes are quite extensive and form regional aquicludes. Sometimes, the glacial till in contact with the top of a sandstone bed of the Saginaw Formation also acts as an aquiclude.

The Bayport limestone, which directly underlies the Saginaw Formation in the study area, is a dense limestone approximately 12 meters (40 ft) thick (Wood, 1969). This limestone effectively acts as a base to the flow system in the Saginaw and prevents the passage of large quantities of water from moving either into the Saginaw Formation from below or from the Saginaw into the underlying beds. It is possible, however, that in areas where faults or fractures are present in the Bayport limestone, some water could be transmitted between the two formations.

Table 4 lists the yield and specific capacity of major wells drawing water from the Saginaw Formation. It is evident from the data in the table that the yields vary from 378 to 3780 L/min (100 to 1000 gal/min). The variability of yield is controlled primarily by the thickness of sandstone penetrated. Generally, the more sandstone penetrated the higher the yield. Availability of recharge water is also a major factor controlling the yield. Generally, the long-term yield is greater where sandstones of the formation are overlain by permeable sand and gravel of glacial origin than where the upper part of the formation is composed of shale and/or is overlain by clayey glacial deposits such as ground moraine and lake plain (Vanlier, 1969).

Recharge from streams into glacial drift also tends to increase long-term yield. In most areas the groundwater level is higher than the water surface in adjacent streams. However, withdrawal by pumpage in some areas in Ingham County has reversed this relationship and, as a consequence, water is being forced by gravity from the stream into the ground. This is especially true in areas where the streams are underlain by sand and gravel that are in turn underlain by permeable sandstone beds of the Saginaw Formation (Vanlier, 1969). This form of induced recharge has recently been employed to increase the yield in areas along the Red

Table 4. -- Yield of Wells Topping the Sandstone of the Saginaw Formation in Ingham County.

Area	Yield (gal/min)	Specific Capacity (gal/min/ft of drawdown)
City of Lansing	100 to 700	3 to 10
City of Mason	675 to 700	--
East Lansing and Meridian Township	280 to 1,000	2 to 12
Lansing Township	260 to 500	3 to 8
Michigan State University	147 to 654	1 to 11

Source: Ground-water Data for Michigan by G. C. Huffman. U. S. Geological Survey, 1976.

Cedar River and its tributaries and also along the Grand River (Firouzian, 1963; Vanlier, 1969).

Discharge from the Aquifer

Water is discharged from the groundwater reservoir by evaporation, transpiration and by pumpage of wells drilled into the aquifer. The rate of discharge directly to the atmosphere is not accurately known, although for Ingham County it is estimated to be about 2 inches per year (Vanlier, 1969). (Natural discharge may occur where the piezometric surface is above the stream level.)

The greatest amount of water discharging from the groundwater reservoir is through pumping of domestic and industrial wells. In Ingham County most of the urban areas are serviced by municipal water systems, although some industries, commercial establishments, and urban residents also have their own water wells. In addition, Michigan State University has its own well system. The average urban resident in Ingham County uses about 189 liters per day (50 gallons per day) at his place of residence (Vanlier, 1969), but the amount of withdrawal water in most communities is much larger because industry and commercial firms also consume large quantities of water.

The rate of groundwater pumpage varies greatly throughout the County (Table 5). For example, Lansing with a total pumpage of about 34,100 million liters (8,976 million

Table 5. -- Annual Pumpage of Groundwater (in millions of gallons).

Area	1972	1973	1974	1975	1976
City of Lansing	8,559	8,850	8,053	8,099	8,976
Michigan State University	1,712	1,805	1,800	1,800	1,731
East Lansing and Meridian Township	--	--	1,487	1,566	1,599
Lansing Township	717	750	631	725	586
City of Mason	192	179	222	211	218

Source: Ground-water Data for Michigan by G. C. Huffman. U. S. Geological Survey, 1976.

gallons) in 1976 has been the biggest user of groundwater in the County during the entire past decade. Michigan State University and East Lansing also rely exclusively on groundwater and rank second and third, respectively, in the County as consumers of water.

Permeability of the Saginaw Formation

Several pumping tests made in the Saginaw Formation indicate that the aquifer has an average permeability of about 420 cm pd (100 gpd per sq. ft.) (Wood, 1969). In some areas, however, the sandstone is not very permeable owing to the filling of the pore spaces between sand grains with mineral matter (Vanlier, 1969). Also, in most areas sandstone at shallow depth is more permeable than deeply buried sandstone. The higher permeability may result, in part, from openings along fractures in the shallow beds, which in deeper beds may be closed by the weight of overlying sediments (Vanlier, 1969).

The permeability of the shale units in the Saginaw Formation is generally much lower and more variable than in the sandstone units and ranges from 0.042 to 4.2 cm pd (0.01 to 1.0 gpd per sq. ft.) (Wood, 1969). Therefore, the total permeability of the Saginaw Formation varies considerably from one locality to another and is controlled chiefly by the composition of the beds within the formation.

Transmissibility

Little work has been done to determine the transmissibility of the aquifer. For example, Stuart (1945) calculated that the average coefficient of transmissibility is approximately 2,802 liters per day per centimenter (23,400 gpd/ft.). The highest value recorded is 9,859 liters per day per centimeter (79,500 gpd/ft.) in the North Cedar Street field and the lowest 496 liters per day per centimeter (4,000 gpd/ft.) in the northwest field (Mencenberg, 1963). In 1963, Firouzian found the average transmissibility in the Lansing area is 2,930 liters per day per centimeter (23,628 gpd/ft.), with the values ranging from a high of 4,608 liters per day per centimeter (37,156 gpd/ft.) in the Michigan State University well field to a low of 1,349 liters per day per centimeter (10,880 gpd/ft.) in the East Lansing fields. Vanlier (1968) suggests that within the Lansing metropolitan area, transmissibility of the Saginaw Formation can be expected to range from about 124 liters per day per centimeter (1,000 gpd/ft.) to about 2,480 liters per day per centimeter (20,000 gpd/ft.). As with the permeability, the variance in transmissibility for the Saginaw Formation reflects the variation in the total thickness and permeability of the sandstone beds in the formation.

Fluctuation of the Piezometric Surface

Groundwater levels within the Saginaw sandstone fluctuate with seasonal changes in the rate of recharge to and discharge from the aquifer. During the spring thaw, for example, water levels in wells normally rise in response to the infiltration of rain and melting snow. In summer, however, water levels generally lower in response to increased evapotranspiration.

Water levels are also affected by pumpage of the aquifer. For instance, if the rate of groundwater withdrawal is greater than the rate of recharge to the Saginaw Formation the piezometric surface will drop. The amount of drop is directly related to the rate of withdrawal and the length of time that the wells are pumped. The glacial drift water table is always below the levels of the surface streams; the natural discharge of groundwater in the glacial drift to the streams will stop or water may begin to infiltrate from the streams to the glacial deposits and finally to the sandstone beds of the Saginaw Formation. This will be most evident in areas of permeable sand and gravel underlying the alluvial materials.

However, the piezometric surface of the aquifer in the study area is deep toward north and it ranges from 285 m (350 ft) in the south to 210 m (700 ft) in the north of the County. This suggests that there is a hydrologic connection between the overlying glacial drift and the Saginaw Formation.

GEOCHEMISTRY OF THE GROUND WATER IN THE SAGINAW FORMATION

During the month of May, 1978, 138 water samples were collected from one hundred and thirty-eight private wells (approximately nine samples per township) which tapped the Saginaw Formation in Ingham County. Each sample taken measured 500 ml. and was kept refrigerated for no more than 72 hours prior to analysis. The location and lithologic description of the sampled wells are shown in Figure 6 and were obtained from drillers logs filed with the Geologic Division of the Michigan Department of Natural Resources.

Many of the water samples were collected from pressure tanks and plumbing associated with domestic wells. Therefore, to insure a fresh sample from each well, water was pumped for five minutes after the pump of the sample well was started, or until the temperature of the water reflected the normal aquifer temperature (approximately 11° C) (Wood, 1969).

Sample Analysis

The water samples collected were analyzed in the water analysis laboratory of the Department of Geology,

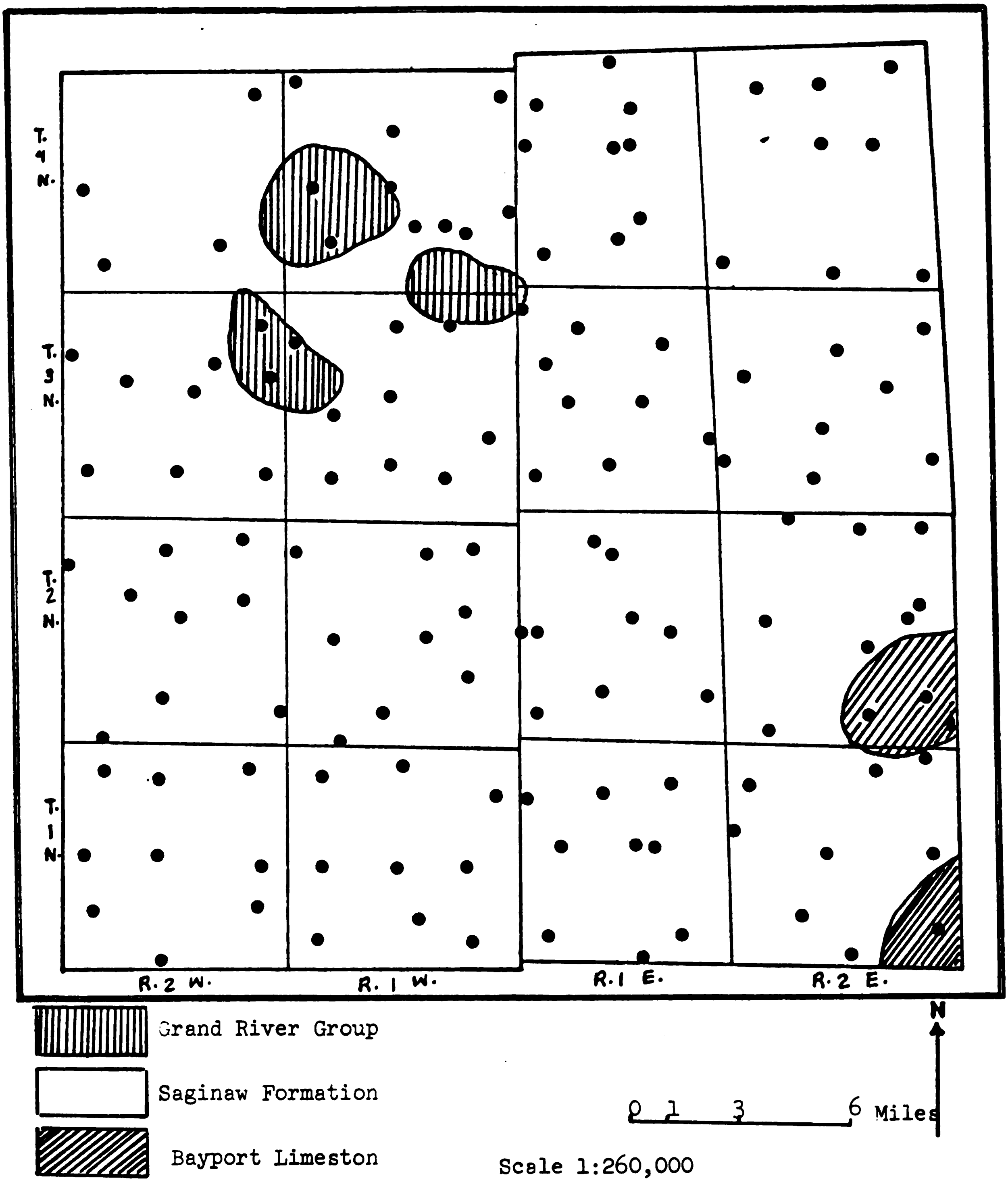

Fig. 6 --Map Showing the Location of Wells Sampled in Ingham County, MI

Michigan State University. Concentrations of calcium, potassium, magnesium, sodium, and iron were determined by spectrophotometry. Chloride concentration was determined by silver nitrate ($AgNO_3$) titration and total hardness was determined by EDTA (Ethylenediamine tetraacetic acid) titrimetric analyses (Rainwater and Thatcher, 1960). No analyses were made for nitrate, flouride, or silica because these ions are normally absent or in such low concentration that analyses for them would be impracticable (Vanlier, 1969). In addition, bicarbonate was not determined because it is normally measured at the time of sample collection and no apparatus was available for this analysis. Sulfate, likewise, was not determined because the apparatus for turbidimetric analysis was also not available and other methods of analysis are generally not sensitive enough to determine normal groundwater concentrations.

The results of these analyses are listed in the Appendix A of this report and are reported in parts per million (ppm). Since the concentration of ions in the samples are relatively low, the unit parts per million can be considered numerically equal to milligrams per liter (mg/l).

Type and Concentration of Major Ions

Most of the water obtained from the Saginaw Formation underlying Ingham County contains appreciable amounts of dissolved calcium, magnesium, sodium, potassium, iron, and chloride (Table 6). Generally, calcium and magnesium ions constitute more than 50 percent of the cations measured. This is particularly true of water from the sandstone beds of the Saginaw Formation. The concentration of sodium ions, on the other hand, does not vary considerably over the region, and in most water samples analyzed, constitutes only about 17 percent of cations measured. The average concentration of dissolved chloride is about 10 mg/L. Some water samples, however, did show unusually high concentrations of sodium and chloride (100 ppm) but these are probably the direct result of brine waters migrating from underlying formations. For instance, an unusually high concentration of sodium and chloride was obtained from a well drilled in section 27 of Williamston Township, T 4 N R I E, and is probably the result of brine water entering the Saginaw Formation from the underlying Bayport limestone. Iron and potassium concentrations constitute generally less than 3 percent of the ions measured in the groundwater of the Saginaw Formation.

In 50 percent of the water samples, hardness ranges from 250 to 350 mg/l (milligrams per liter). Only 5 percent of the samples have a hardness greater than 400 mg/l.

Table 6. -- Variations of Concentration of Ions Measured in the Groundwater of the Saginaw Formation, based on 138 Water Samples, 1978.

Chemical Parameter	Concentrations In ppm (mg/l)		
	Maximum	Minimum	Average
Ca^{++}	151	1.00	50.6
Mg^{++}	40	0.7	24.7
Na^{+}	260	0.6	16.9
Cl^{-}	127	0.0	10.58
K^{+}	5.8	0.2	1.6
Fe^{+}	8.6	0.0	0.83
Hardness (Carbonate)	535.5	6.6	230

Source of Dissolved Solids in Groundwater

The results of chemical analyses of the samples (Appendix A) were used to construct geochemical maps showing the distribution of each ion in the ground water within the Saginaw Formation (Figs. 7-13, see Appendix B). These maps together with available geological data were then integrated to determine areas of recharge and direction of water movement into the Saginaw Formation. Before discussing the occurrence of these constituents in the ground water it might be useful to review the possible sources of the ions.

Precipitation

Rain and snow contribute very little in the way of ions to the ground water of the Saginaw Formation. Wood (1969) analyzed several samples of rain water for common ions and found small amounts of some ions which are also found in ground water of the Saginaw Formation. Since much of the precipitation returns to the atmosphere by evaporation and transpiration, it is natural to expect that some of these ions are concentrated in water not completely evaporated, i.e. ponds and lakes.

Soil

Another source of dissolved solids entering the ground water is from the soil. It is generally accepted that rain and melting snow in contact with soluble minerals in the soil provide some dissolved solids to the groundwater system. This has been supported by chemical analysis of surface run off passing over soil (Wood, 1969). These analyses show that the run off has a chemical character very similar to the soils in contact with the run off.

Glacial Drift

The principal source of dissolved solids in the groundwater of the Saginaw Formation appears to be from the glacial drift. Wood (1969), for example, measured the change in dissolved solids in distilled water after it had been in contact with glacial drift for a period of 5 to 7 days. He found that water obtained from these leaching experiments was, in general, similar to that observed in the upper beds of the Saginaw Formation and suggested that drift material was a source of most of the dissolved solids in the groundwater.

Much of the dissolved calcium and sulfate from the drift is a result of solution of gypsum ($Ca\ SO_4$, $2H_2O$) and/or anhydrite ($Ca\ SO_4$). These two minerals are irregularly distributed in the glacial materials and are probably originally derived from the Michigan Formation (Martin, 1936).

The major source of magnesium, calcium, and bicarbonate in the glacial drift is the result of solution of limestone (Ca CO_3) and dolomite Ca Mg $(CO_3)_2$. The following equations show the reaction:

$$CO_2 + H_2O \rightleftharpoons H_2\,CO_3$$

$$Ca(CO_3) + H_2\,CO_3 \longrightarrow Ca^{2+} + 2(HCO_3)^-$$

$$MgCa\,(CO_3)_2 + 2H_2CO_3 \longrightarrow Ca^{2+} + Mg^{2+} + 4(HCO_3)^-$$

Carbon dioxide is taken from atmosphere in the photosynthesis of plants and is returned to it and soil by the respiration of both plants and animals. 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 factors which control 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).

Sodium can be obtained by ion exchange with calcium ions in certain clay minerals present in the glacial drift and shale beds of the Saginaw Formation (Wood, 1969).

Saginaw Formation

Another possible source of the dissolved solids in the groundwater is the Saginaw Formation itself. The sandstone of the Saginaw Formation could yield minor amounts of dissolved solids, but the black shales of the Formation no doubt contribute a considerable amount of dissolved solids to the water of the aquifer. Sodium ions of the shale bed can contribute to the water of the aquifer by ion exchange with calcium and magnesium when these ions are present in the recharging water.

Beds of coal in the Saginaw Formation may also be a source for bicarbonate ions because coal generally decays with time and produces carbon dioxide and subsequently bicarbonate (Foster, 1950).

Underlying Formations

The source of some dissolved solids in the Saginaw Formation may be from the underlying Bayport limestone and other stratigraphically lower formations. The water from the Bayport limestone and older formations is generally highly mineralized and usually contains considerable amounts of sulfate, calcium, sodium and chloride (Vanlier, 1969).

DISSOLVED SOLIDS DISTRIBUTION

Areal Distribution

Knowledge of the two dimensional distribution of dissolved solids in the ground water of the Saginaw Formation is basic in determining the areas of recharge and the movement of water into the aquifer. In addition, this information sheds new light as to the nature of chemical processes that affect chemical composition of ground water.

The concentration of major chemical constituents in water of the Saginaw Formation are plotted on the maps shown in Figures 7 to 13. The maps indicate that the concentration of ions measured in ground water vary considerably within Ingham County. The areal distribution of chemical parameters are described as follows:

Calcium

Figure 7 shows the areal distribution of calcium ion in the groundwater of the Saginaw Formation. The map indicates that the high concentration of dissolved calcium in the ground water occurs more in the south part of the county especially in the south part of Stockbridge, west part of Leslie, north part of White Oak townships. Also high concentration of calcium occurs in the western part of Lansing township. On the other hand, low concentration of dissolved calcium in the ground water are more in the north part of the County especially in Williamston, Locke, eastern part of Alaiedon, north part of Meridian, south of Lansing and north of Delhi townships. In the south of the county low concentrations of calcium are in the north part of Stockbridge, western part of Bunker Hill and south part of Ingham townships.

Magnesium

Figure 8 shows the areal distribution of magnesium ions in the ground water of the Saginaw Formation. The map indicates that high concentration of magnesium in ground water generally occurs more in the western part of the county. The high concentrations are in Onondaga, White Oak, Leroy, western part of Lansing, south part of Stockbridge, western part of Leslie and western part of Alaiedon townships. The low concentration of calcium occurs more in the eastern and northeast part of the county especially in Locke, Williamston, Vevay, eastern part of Alaiedon, north part of Stockbridge and western part of Bunker Hill, eastern part of Meridian and south of Lansing townships.

Sodium

Figure 9 shows the areal distribution of sodium ions in the ground water of the Saginaw Formation. The map indicates that the concentration of sodium in ground water generally does not vary in the south of the county. High concentration of sodium ions generally occurs more in the north part of the county especially in the Locke, Lansing, east part of Meridian, south part of Williamston and Aurelius townships. On the other hand, low concentrations are more in the south part of the county.

Chloride

Figure 10 shows the distribution of chloride ions in the ground water of the Saginaw Formation. The map indicates that the concentration of chloride in the ground water does not vary considerably within the county region. Higher concentration of chloride occurs in the Stockbridge, Vevay, Leroy, south of Lansing and north part of Delhi and Alaiedon townships. Lower concentration of chloride occurs in most areas of the county.

Potassium

Figure 11 shows the distribution of potassium ions in the ground water of the Saginaw Formation. The map indicates that high concentration of potassium occurs mostly in the northeast area of the County especially in Locke, Leroy and Williamston townships. In addition, high concentrations are also observed in the Lansing, Alaiedon, south of Bunker Hill and Leslie townships. On the other hand, the low concentration of potassium generally occurs in the west and southeast part of the county.

Iron

Figure 12 shows the distribution of iron ions in the ground water of the Saginaw Formation. The map indicates that the concentration of iron does not vary considerably within the north part of the county. Low concentrations are observed in the north and east part of the region. High concentrations of iron occur in the south and southwest part of the county, especially in Delhi, Aurelius, and Leslie and south of Stockbridge townships.

Hardness (carbonate)

Figure 13 shows the distribution of hardness (carbonate) in the ground water of the Saginaw Formation. The map indicates that high concentration occurs in the south and west part of the county especially in White Oak, Vevay, east part of Onondaga, south part of Stockbridge, west part of Lansing, north part of Aurelius and south part of Meridian townships. On the other hand, low concentrations of hardness are generally observed in the northeast part of the county especially in the townships of Locke, Williamston, Meridian, Alaiedon, and Leroy. In addition low concentrations are also observed in the south part of Lansing, south part of Ingham, north part of Stockbridge, west part of Bunker Hill and Aurelius townships.

Vertical Distribution

Table 7 shows vertical distribution of ions measured in ground water of the Saginaw Formation. The vertical distribution of ions in water within the formation was statistically analyzed by comparing well water quality with depth of well penetrating into the aquifer. The results of this analysis indicate that the concentration of chemical constituents in the aquifer is generally inversely proportional to the depth of the Saginaw Formation penetration. In particular, the tabulated data show that with the exception of sodium, potassium, and chloride water from beds immediately beneath the drift is generally higher in most dissolved solids than water obtained from deeper beds. Based on this relationship, it is evident that most of the dissolved calcium, magnesium, and iron in the water of the Saginaw Formation is derived chiefly from the overlying drift. Chemical analyses published by Wood (1969) for wells penetrating both the drift and bedrock also tend to support this relationship. It is also evident from

Table 7. -- Vertical Distribution of Ions Measured in Ground Water of the Saginaw Formation, Ingham County, Based on 138 Wells Penetrating 23 to 293 Feet into the Aquifer, 1978.

Depth of Saginaw Penetrated (In Feet)	Well No.	Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	K^{+}	Fe^{+}	Hardness (Carbonate) (mg/l)
		Average Concentration in ppm						
0 - 50	28	54.5	26.2	2.9	6.6*	0.7	0.88	244
51 - 100	89	53.4	26.0	8.6	9.0	1.7	0.96	241
101 - 150	17	52.4	24.2	19.9	9.0*	2.4	0.70	230
Over 150	4	40.6	22.3	21.0	20.4	2.8	0.20	194

*Does not include two samples.

Table 7 that most of the dissolved sodium, potassium and chloride in the water of the Saginaw Formation is probably the result of brine water entering the aquifer from the underlying formations.

RECHARGE TO THE SAGINAW FORMATION

It is apparent from the geochemical maps shown in Figures 7 to 13 (See Appendix A) that the distribution of dissolved solids in ground water of the Saginaw Formation is not homogeneous. However, the maps do indicate that low concentrations of calcium, magnesium, sodium, potassium, chloride, iron and hardness occur where the overlying glacial drift is composed chiefly of sand and gravel. For instance, in areas where the aquifer is overlain directly by outwash and esker deposits (Figure 2), the concentrations of calcium, magnesium, potassium, chloride, iron and hardness appear to be low because the outwash and esker deposits are free of soluble minerals. Other factors might be dilution of the ions present by large volume of water which move down through these permeable deposits and the short time involved for dissolution. This would suggest that considerable quantities of water of good quality are being recharged into the aquifer primarily where there are permeable sand and gravel deposits directly over the bedrock.

Outwash Plains

Several outwash plains in Ingham County also appear capable of transmitting considerable quantities of water to the bedrock aquifer. Most of these outwash deposits are concentrated in the southeast part of the County (Fig. 2).

It is evident from Figures 7 through 13 that low concentration of calcium, magnesium, sodium, chloride, potassium, iron and hardness in ground water occur where these outwash deposits directly overlie the Saginaw Formation. Figure 9, however, does show a high concentration of sodium below outwash deposit of northwestern part of Meridian township. This is probably the result of brine water entering the aquifer from below.

Esker Deposits

Other areas of recharge appear to be the Mason, Williamston, and Dansville eskers and other minor esker and kame deposits in Ingham County. This is evident from Figures 7 to 13 which show low concentrations of calcium, magnesium, sodium, chloride, potassium, iron and hardness in the ground water where the aquifer is overlain by these sand and gravel deposits. High sodium and chloride concentration just south of Lansing township where the aquifer is overlain by Mason esker may be the result of brine water entering the aquifer from its underlying formation.

Mined out parts of eskers, most notably the Mason esker appear to be potentially important as recharge pits supplying water to adjacent buried outwash and underlying sandstone beds of the Saginaw Formation.

Alluvial Valleys

The alluvial materials along the Red Cedar River, Doan Creek, Deer Creek, Sloan Creek, Grand River and its tributaries (Figure 2) might be potential areas of recharge to the aquifer. Recharge through alluvium is dependent on the glacial drift which underlies these materials. Recharge will be most evident in areas where permeable sand and gravel underlie the alluvium. This is evident from Figures 7 to 13 which show low concentration of calcium, magnesium, sodium, chloride, potassium, iron and hardness in ground water in some areas where the alluvial materials overlie the permeable sand and gravel. High concentrations of sodium and chloride in ground water in the south part of Williamston township again is probably the result of brine water entering the aquifer from underlying formation.

Ground and Recessional Moraine

Ground and recessional moraines, on the other hand, appear to transmit only a small amount of water of poor quality to the underlying aquifer because of the impermeability of the till materials. This is evident from Figures 7, 8, 11, 12, and 13 which show high concentrations of calcium, magnesium, potassium, iron and hardness in the ground water generally occurring in areas covered predominantly by till. For example, large portions of the north and central parts of the County are covered by till material (Fig. 2), and the water in the bedrock beneath this drift is generally high in ion concentration.

In areas where moraine deposits include or are associated with minor deposits of stratified outwash, small amounts of water may be recharged to the aquifer. However, the permeability of these morainal deposits is generally low and varies with the degree of sorting, the clay content in the till, and the amount of interbedded sand and gravel.

Pattern of Water Flow

From the chemical analysis of ground water in the Saginaw Formation (Table 6) it is evident that recharge to the bedrock is primarily straight down from the overlying drift. In addition, the data (Figures 7 through 13) show that the areal distribution of dissolved solids in the bedrock varies considerably from one locality to another and is dependent in part on both the lithologic character of the glacial deposits overlying the bedrock and the amount of shale in the upper part of the bedrock.

A schematic representation of water flow through the drift is presented in Figure 14. Although highly generalized downward, movement of ground water into the aquifer, the figure can be applied to most of Ingham County and suggests that recharge to the Saginaw Formation is localized and most rapid where permeable sand and gravel deposits (eskers, outwashes) directly overlie and are in contact with beds of sandstone. It is also evident from the figure that downward movement of ground water would be least rapid where thicknesses of till, lake clay or moraine directly overlie and are in contact with shale units of the bedrock. The general concentration of soluble ions in both till and bedrock is also presented in Figure 14. Ions such as calcium, magnesium, potassium, iron, chloride and sodium appear associated more with till deposits whereas the sand and gravel deposits appear relatively free of soluble ions.

Once the downward moving water has passed through the drift and entered the Saginaw Formation, the general flow direction is controlled by both the piezometric gradient within the formation and the lateral extent of individual sandstone beds. Undoubtedly in some areas, the flow within the Saginaw Formation is strongly influenced by withdrawal of water from wells which top the formation. For instance, high industrial and domestic pumpage of water within the Lansing area has not only resulted in declining

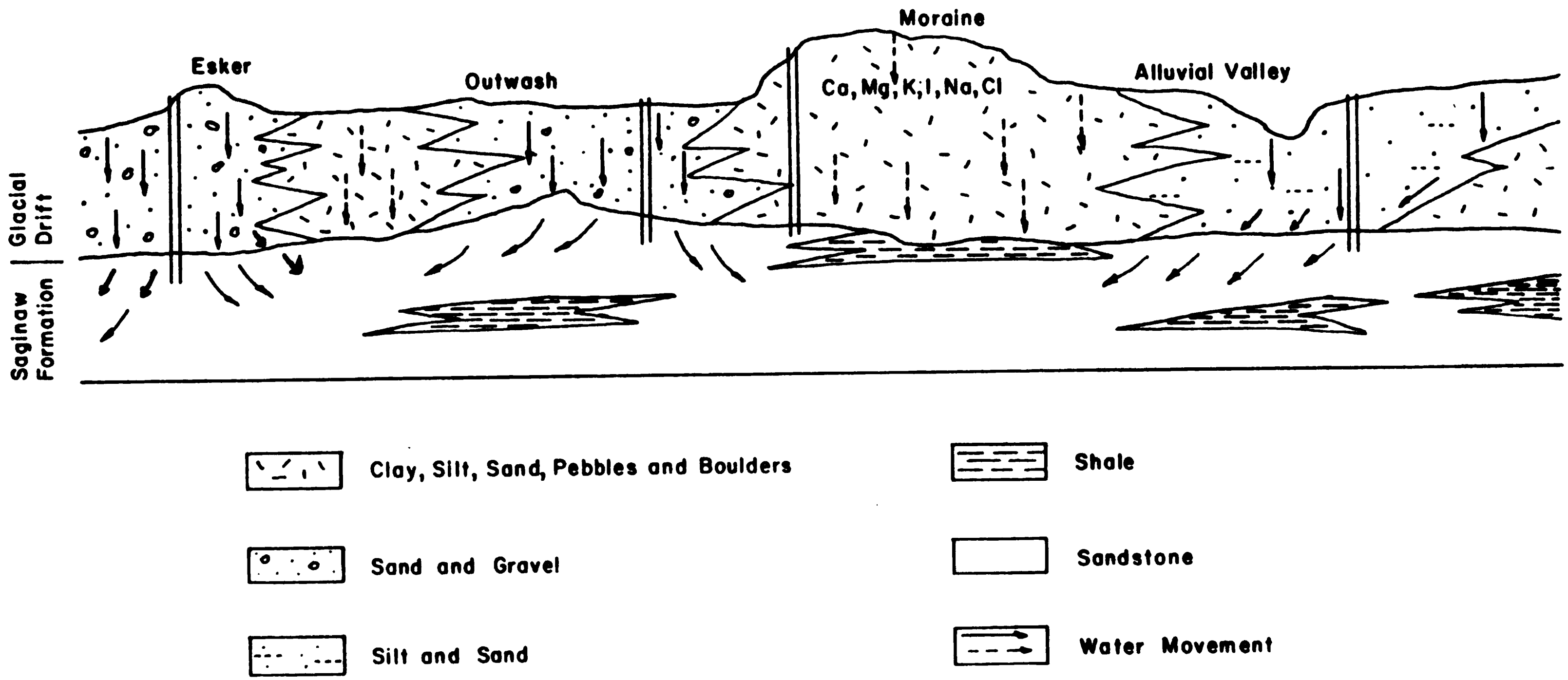

Figure 14--Diagram Showing Downward Movement of Water Through Glacial Drift into The Saginaw Formation.

piezometric surface beneath the City but has locally reversed the normal piezometric gradient. For most of Ingham County, however, flow within the Saginaw is generally towards the north.

Discussion

Wood (1969) also showed that water obtained from the Saginaw Formation is generally lower in most dissolved solids than that obtained from the glacial drift. To explain this difference in water chemistry he suggested a process of osmotic filtration. This process requires that shale membranes of the Saginaw Formation filter out certain ions as the water passes through them. His hypothesis does not appear to be supported by this investigation, because it is evident from Figure 15 that shale beds are not presented in the Saginaw Formation in the southeastern part of Lansing township, while low concentration of calcium, magnesium, chloride, potassium, iron and hardness are shown in Figures 7 to 13 in this area. Therefore, the lowering of these ions in ground water of the Saginaw Formation is the result of water passing through the esker and alluvium deposits (Figure 2) which overlies directly the sandstone bed of the Saginaw Formation in this area.

In addition, water cannot pass through a layer of an impermeable shale bed. Even if the shale beds were semipermeable initially, ion precipitation on the clay particle surface will reduce the permeability considerably.

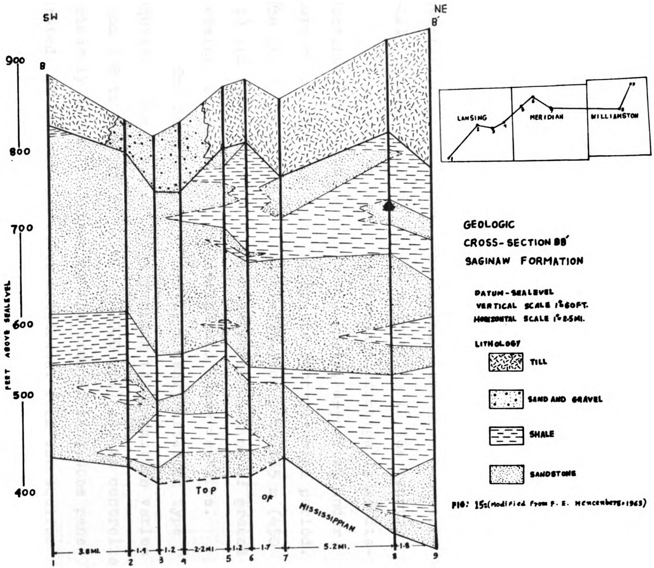

FIG: 15: (Modified from F. E. Mencenberg, 1963)

SUMMARY AND CONCLUSIONS

The Saginaw Formation is a highly productive aquifer in Ingham County, Michigan, and for several decades has been utilized to supply fresh water for industrial centers, farms, rural households, and municipalities within the county. However, more recently, withdrawals of large quantities of water from the Saginaw Formation has seriously lowered water levels in many wells in the county.

The aquifer itself is composed principally of discontinuous beds of sandstone and shale, deposited under terrestrial environments during the Pennsylvanian period. The thickness of the aquifer ranges from 0 to 135 m (450 ft) and is overlain by glacial drift consisting of ground moraine, outwash, esker, alluvium and kames deposits.

The Saginaw is essentially a leaky artesian type aquifer. The yield of wells tapping the Formation varies from 378 to 3780 L/min. (100 to 1000 gpm) and is controlled primarily by the thickness of the beds of sandstone penetrated. Today the amount of withdrawal from the aquifer through pumpage within the county is more than 52,200 million liters per year (14,000 million gallons per year). The aquifer has a relatively constant permeability of about 420 cm pd (100 gpd per sq. ft).

Several processes affect the chemical quality of the ground water in the Saginaw Formation. It appears most of the dissolved solids (Ca^{++}, Mg^{++}, Fe^{++}, K^{+}, Na^{+}, Cl^{-}) in the Saginaw Formation result from the reaction of atmospheric precipitation with soluble minerals in the glacial drift and chemically active soil zone. In addition, the Saginaw Formation itself and underlying formations are other possible sources of the potassium, sodium, and chloride.

In general, calcium and magnesium ions constitute more than 50 percent of the cations occurring in the ground water of the Saginaw Formation. Sodium, on the other hand, constitutes only about 17 percent of the cations and iron and potassium ions constitute generally less than 3 percent of the cations. The average concentration of dissolved chloride is about 10 mg/L and the average hardness is about 230 mg/L. In addition, water obtained from the Saginaw Formation is generally lower in most dissolved solids than that obtained from the glacial drift. Except for sodium and potassium the concentration of ions in beds immediately beneath the drift is generally higher than in the deeper beds of the Saginaw Formation.

The geochemical data from the Saginaw Formation suggest that the single most important source of recharge to the aquifer is from leakage through the overlying glacial drift. In general, low concentrations of dissolved solids in the Saginaw are observed in areas where the glacial drift is composed chiefly of sand and gravel relatively free of soluble minerals. On the other hand, high concentrations of ions occur in areas where only ground moraine overlies the formation. This correlation between chemistry and type of surficial deposit would suggest that relatively ion free water is recharged to the Saginaw Formation mostly in areas of permeable outwash and esker deposits. Water is also recharged to the aquifer in areas where alluvial materials overlie permeable sands and gravel. These areas are shown in Figure 16.

The specific conclusions of this study are outlined as following:

1. Chemical analyses show that most of the recharge into the Saginaw Formation is localized primarily in areas of permeable outwash and esker deposits. This is evident from the correlation between the geo-chemical maps (Figures 7 to 13) and type of surficial deposit of Ingham County (Figure 2). Specifically, low concentrations of calcium, magnesium, sodium, chloride, potassium, iron and hardness occur in areas where the glacial drift overlying the aquifer is composed chiefly of sand and gravel.
2. The concentration of calcium, magnesium, potassium, iron, chloride and hardness in the ground

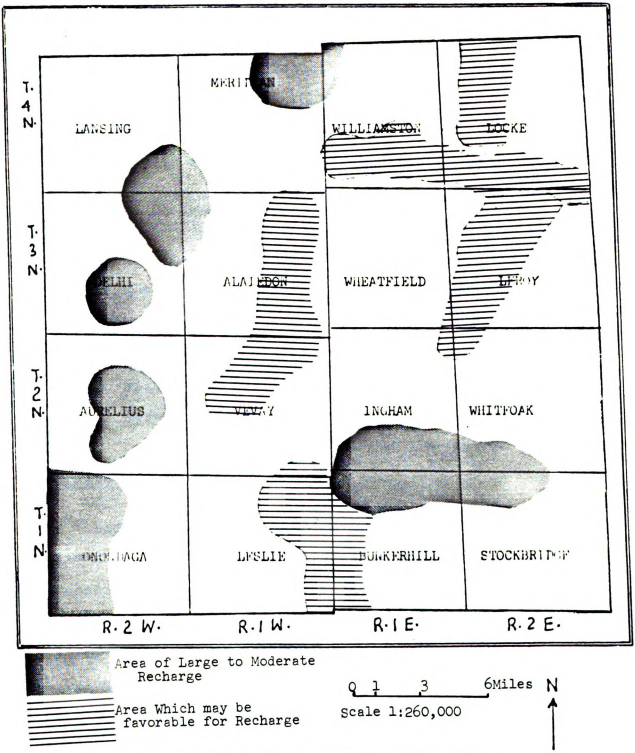

Fig. 16 --Areas of Probable Groundwater Recharge to the Saginaw Formation, Ingham County, Michigan

water of the Saginaw Formation is related to the composition of overlying glacial drift.

3. With the exception of sodium and potassium, the concentration of ions in the ground water of the Saginaw Formation is generally inversely proportional to the depth of the Saginaw penetration.
4. Osmotic filtration is not a dominant process to cause the difference in water quality of glacial drift and the Saginaw Formation.
5. Most of the recharge is in the south and southwest part of the County. This is due to the extensive sand and gravel deposits in the south and alluvium deposited by Grand River in the southwest corner of the County.

Recommendations:

Ensurement of a long-term supply of ground water for Ingham County will require careful management of the areas of recharge to the Saginaw Formation. Steps to be considered in management include: (a) Keeping the localized areas of recharge associated with the Saginaw Formation and glacial deposits as they are at the present time, (b) Investigating the possibility of artificially recharging the aquifer through the mined out part of sand and gravel deposits, and (c) Shifting the well field to specific areas in order to promote induced recharge through these sand and gravel deposits.

Finally, the results obtained from this study will contribute significantly to understanding the hydrologic system operating within the Saginaw Formation. In addition, the water quality information obtained will be of considerable use to state and local agencies involved with developing the region's ground water resources.

BIBLIOGRAPHY

BIBLIOGRAPHY

Boynton, D., and Reuther, W. 1938. A way of sampling soil gases in dense subsoil and some of its advantages and limitations. Soil Sci. Soc. Ann. Proc., V. 3, p. 37-42.

Dott, Robert H., and Murray, Grover E. Geological cross-section of paleozoic rocks, central Mississippi to northern Michigan: AAPG, 1954.

Firouzian, Assadolah. 1963. Hydrological studies of the Saginaw Formation in the Lansing, Michigan, area: Unpublished Master of Science Thesis, Michigan State University.

Foster, M. D. 1950. The origin of high sodium bicarbonate waters in the Atlantic and Gulf Coastal Plains: Geochim. et Cosmochim. Acta, V. 1, p. 33-48.

Huffman, G. C. 1976. Groundwater data for Michigan: U. S. Geol. Survey Water Resources Division, p. 21-24.

Johnsgard, G. A., Nivison, T. E., Rogers, H. T., Donahue, R. L., Stone, J. T., and Welles, G. M. 1942. Soil survey of Clinton County, Michigan: U.S. Dept. Agr. Ser. 1936, No. 12, 71 p.

Kelly, W. A. 1936. The Pennsylvanian system in Michigan: Mich. Dept. of Conserv. Geol. Survey Div. Pub. 40, Geol. Ser. 34, p. 155-219.

Lane, A. C. 1901. Suggested changes in nomenclature of Michigan Formations: Mich. Miner., V. 3, No. 10, p. 9.

Lane, A. C. 1902, Coal of Michigan: Geol. Surv. of Michigan, V. 8, Pt. 2.

Leverett, F., and Taylor, F. B. 1915. The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U. S. Geol. Survey Mon. 53, 529 p.

Martin, H. M., Compiler. 1936. The centennial geological map of the southern penninsula of Michigan: Mich. Dept. Conserv., Geol. Survey Div. Pub. 39, Geol. Ser. 33.

Martin, H. M. 1958. Outline of the geologic history of Ingham County, Michigan: Mich. Dept. of Conserv., Geol. Survey Div. Pub., 5 p.

Mencenberg, F. E. 1963. Groundwater geology of the Saginaw Group in the Lansing, Michigan, area: Unpublished Master of Science Thesis, Michigan State University.

Michigan Department of Conservation. 1964. Stratigraphic succession in Michigan: Chart 1.

Michigan Department of Agriculture. 1978. Michigan Weather Service Publications.

Rainwater, F. H., and Thatcher, L. L. 1960. Methods for collection and analysis of water samples: U. S. Geol. Survey Water-Supply Paper 1454, 301 p.

Stuart, W. T. 1945. Groundwater resources of the Lansing area, Michigan: Mich. Geol. Survey Prog. RPT. 13.

U. S. Geological Survey. Stream Flow Publications. 1968-1977.

Vanlier, K. E. 1964. Groundwater in the Tri-County region, Michigan: Tri-County Regional Planning Commission, Lansing, Michigan, 19 p.

Vanlier, K. E., and Wheeler, M. L. 1968. Groundwater potential of the Saginaw Formation in the Lansing metropolitan area, Michigan: Tri-County Regional Planning Commission, Lansing, Michigan.

Vanlier, K. E., Wood, W. W., and Brunett, J. O. 1969. Water-supply development and management alternatives for Clinton, Eaton, and Ingham Counties, Michigan: U. S. Geol. Survey Water-Supply Paper.

Veatch, J. O., Adams, H. G., Hubbard, E. H., Dorman, C., and Jones, L. R. 1941. Soil survey of Ingham County, Michigan: U. S. Dept. Agr. Ser. 1933, No. 36, 43 p.

Wheeler, M. L. 1967. Electric analog model study of the hydrology of the Saginaw Formation in the Lansing, Michigan, area: Unpublished Master of Science Thesis, Michigan State University.

Wood, Warren W. 1969. Geochemistry of groundwater of the Saginaw Formation in the upper Grand River basin, Michigan: Mich. State Univ. Geol. Dept., unpub. Ph.D. dissert.

APPENDIX

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. Location of well is shown with four principal parts. For example, T1NR2W2SE¼NE¼SE¼ can be broken down as follows: T1N, designating township; R2W, designating range; 2, designating section; SE¼NE¼SE¼, designating location within the section.

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
				Alaiedon Township					
T3NR1W2NW¼SE¼SW¼	240	5/22/78	28.0	31.0	10.5	4.6	<0.1	2.9	120.6
T3NR1W4NW¼SE¼SE¼	183	"	7.7	46.5	34.5	2.3	2.15	2.9	258.1
T3NR1W7SW¼NW¼NW¼	155	"	7.2	43.5	28.5	1.6	<0.1	3.9	225.9
T3NR1W16NW¼NW¼SE¼	227	"	19.0	34.0	33.5	3.5	0.5	0.0	222.7
T3NR1W20NW¼NW¼NW¼	170	"	3.3	47.5	29.5	0.8	1.0	36.0	240.0
T3NR1W24NW¼SW¼SW¼	200	"	9.0	14.0	12.0	4.0	0.15	3.9	84.35
T3NR1W26SE¼SW¼SW¼	185	"	6.2	44.0	29.0	1.2	1.2	1.0	229.2
T3NR1W28SW¼SW¼NE¼	180	"	2.5	34.5	25.0	2.2	0.15	2.5	189.0
T3NR1W29SW¼SW¼SW¼	155	"	3.4	57.5	31.5	1.0	0.8	2.9	273.2
				Aurelius Township					
T2NR2W2SE¼SE¼NE¼	118	5/ 5/78	3.4	56.5	29.0	0.5	1.2	31.0	260.40
T2NR2W4SE¼SE¼SE¼	120	"	1.8	57.0	28.7	0.4	<0.1	6.9	260.45
T2NR2W7SW¼SW¼NW¼	110	"	3.9	57.0	28.5	1.3	1.0	2.9	259.6
T2NR2W14NE¼SE¼NE¼	100	"	1.4	65.5	32.0	0.7	<0.1	1.9	295.2
T2NR2W15NW¼NW¼SW¼	120	"	12.6	<1.0	<1.0	0.1	<0.1	0.0	6.6
T2NR2W17NE¼NE¼NE¼	120	"	3.2	40.0	37.5	1.2	3.65	13.9	254.2
T2NR2W28NE¼SE¼SE¼	115	"	1.2	60.5	30.5	0.8	3.5	3.9	276.6
T2NR2W32SW¼SW¼SW¼	125	"	1.8	58.5	29.0	0.8	<0.1	13.9	265.4
T2NR2W36NE¼NE¼NE¼	80	"	5.7	68.0	31.5	3.0	<0.1	31.0	299.4

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
			Bunker Hill						
T1NR1E7NW¼NW¼SE¼	140	4/20/78	1.2	56.0	25.3	0.5	3.35	20.0	243.9
T1NR1E9SW¼SE¼NE¼	140	"	1.7	15.5	23.5	1.0	1.85	4.9	210.3
T1NR1E11SW¼NW¼NE¼	100	"	3.0	40.5	21.0	0.6	0.8	4.9	187.5
T1NR1E14NE¼SW¼SW¼	86	"	1.4	63.5	33.5	0.2	1.0	8.9	296.4
T1NR1E15NE¼SW¼SE¼	100	"	1.7	52.5	26.5	0.2	1.2	6.9	240.1
T1NR1E17NW¼NW¼SE¼	186	"	2.9	36.5	18.5	0.6	1.2	2.9	167.2
T1NR1E32NW¼SE¼NW¼	180	"	39.2	40.0	19.0	5.8	1.0	1.9	178.0
T1NR1E34SE¼SE¼SE¼	139	"	3.0	55.0	22.5	3.5	1.2	1.9	229.9
T1NR1E35NE¼NE¼NE¼	127	"	5.5	57.0	27.5	3.4	1.3	6.9	255.5
			Delhi						
T3NR2W1SE¼SE¼SW¼	110	5/ 6/78	3.3	59.0	31.5	1.2	1.0	7.9	276.5
T3NR2W7NW¼NW¼SW¼	125	"	7.0	65.0	33.0	0.8	0.4	21.0	298.1
T3NR2W11SW¼SW¼SW¼	125	"	8.5	77.5	34.0	0.7	1.85	51.0	333.46
T3NR2W13NW¼NW¼NE¼	120	"	2.7	59.0	30.0	0.7	1.45	3.9	270.8
T3NR2W15SE¼NW¼SE¼	110	"	22.2	12.0	9.0	1.4	<0.1	19.9	67.0
T3NR2W17SW¼SE¼NE¼	110	"	3.2	56.5	29.5	0.6	0.5	11.9	262.5
T3NR2W25SW¼NW¼SW¼	110	"	1.8	60.0	32.0	0.5	2.15	7.9	281.5
T3NR2W27NW¼NW¼SW¼	140	"	2.7	59.0	31.0	0.8	0.8	5.9	274.9
T3NR2W30NW¼NE¼SE¼	95	"	1.4	38.5	24.5	0.5	8.6	3.9	196.9

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
			Ingham						
T2NR1E4NE¼SE¼SE¼	185	4/15/78	18.3	49.0	20.5	2.5	<0.1	3.9	206.7
T2NR1E10NW¼NE¼NW¼	96	"	1.0	52.5	22.5	2.0	<0.1	3.9	223.7
T2NR1E15NW¼SE¼SE¼	1170	"	15.5	59.5	23.5	2.7	<0.1	3.9	245.2
T2NR1E19NE¼NE¼NE¼	126	"	1.2	48.5	21.5	0.3	3.5	5.9	209.5
T2NR1E20NW¼NW¼NW¼	140	"	3.2	75.0	36.0	0.6	0.8	17.9	335.4
T2NR1E23NE¼NW¼NE¼	100	"	2.0	55.0	25.0	0.6	<0.1	1.9	240.2
T2NR1E25NW¼SW¼SE¼	136	"	2.8	44.5	22.5	0.5	1.3	1.9	203.7
T2NR1E28SE¼NE¼SE¼	126	"	4.4	38.5	17.0	0.6	0.8	7.9	166.1
T2NR1E32NW¼SW¼NW¼	126	"	0.8	55.0	23.7	0.4	0.4	5.9	234.8
			Lansing						
T4NR2W1SW¼NE¼SW¼	200	5/ 6/78	6.7	54.0	27.0	2.2	0.2	2.9	245.9
T4NR2W19NW¼SW¼NE¼	158	"	32.0	138.0	40.0	3.2	1.85	---	509.2
T4NR2W26SW¼NE¼SW¼	153	"	55.0	10.5	8.0	2.0	0.2	33.0	59.1
T4NR2W32NE¼SW¼NW¼	150	"	7.0	50.0	26.5	2.4	0.8	0.0	233.9
			Leroy						
T3NR2E10SE¼NE¼SW¼	155	2/24/78	17.7	37.0	20.0	4.3	2.15	---	174.7
T3NR2E18SE¼SE¼NE¼	115	"	6.5	37.5	25.0	1.3	0.15	---	196.5
T3NR2E21SE¼SE¼SE¼	110	"	9.3	41.0	25.0	5.5	0.15	---	205.2
T3NR2E30NW¼NW¼SW¼	110	"	33.5	50.0	29.5	4.2	<0.1	---	246.2
T3NR2E12NE¼NW¼NE¼	118	4/ 7/78	4.7	53.0	21.5	0.4	1.3	33.0	220.8
T3NR2E14SW¼NW¼SE¼	120	"	8.5	53.5	19.5	2.2	0.25	31.0	213.8
T3NR2E25NW¼NW¼SE¼	110	"	6.5	54.0	27.5	1.7	0.15	49.0	248.0
T3NR2E33NW¼NW¼NE¼	115	"	5.8	46.5	21.5	1.7	0.5	3.9	204.6

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^{+}	Ca^{++}	Mg^{++}	K^{+}	Fe^{+}	Cl^{-}	Hardness (carbonate)
			Leslie						
T1NR1W4NE¼NE¼SE¼	100	4/22/78	1.4	61.5	30.3	0.4	1.7	0.0	278.2
T1NR1W6SE¼SE¼SE¼	89	"	1.2	75.0	35.0	0.5	3.2	12.9	331.3
T1NR1W12SE¼NE¼NW¼	139	"	2.9	34.5	16.5	0.6	<0.1	1.0	154.0
T1NR1W19NE¼NE¼NE¼	105	"	4.2	81.0	36.5	0.3	1.0	54.0	352.4
T1NR1W21NE¼NW¼NE¼	80	"	2.0	56.0	27.5	0.2	<0.1	14.9	253.0
T1NR1W23NW¼NW¼NE¼	199	"	1.5	57.0	26.5	0.2	1.0	4.9	251.4
T1NR1W27SE¼SW¼NW¼	240	"	2.8	59.0	25.5	0.6	1.0	4.9	252.2
T1NR1W31NE¼NW¼NE¼	84	"	1.6	65.0	32.5	0.3	0.4	6.9	296.0
T1NR1W35SW¼NE¼NE¼	76	"	4.0	59.0	29.5	4.2	<0.1	12.9	268.7
			Locke						
T4NR2E1SE¼NW¼	155	5/11/78	10.4	38.0	32.0	3.8	1.45	1.0	226.59
T4NR2E3NE¼NE¼SW¼	130	"	68.50	20.0	4.6	5.0	<0.1	0.0	68.8
T4NR2E5SW¼SW¼SW¼	201	"	38.4	40.5	20.5	4.7	<0.1	2.9	185.5
T4NR2E14NW¼NW¼NE¼	200	"	10.6	38.5	28.0	3.2	<0.1	0.0	211.3
T4NR2E15NE¼NW¼NW¼	175	"	50.7	23.5	0.7	4.2	<0.1	2.9	61.5
T4NR2E31SW¼SW¼NE¼	170	"	4.1	44.5	25.0	1.3	0.5	0.0	214.5
T4NR2E34NE¼NE¼SW¼	135	"	11.5	43.0	21.0	5.0	0.2	2.9	193.8
T4NR2E36SW¼NW¼SE¼	124	"	17.7	82.5	22.5	3.7	0.2	1.9	298.6

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
			Meridian						
T4NR1W1SE¼SW¼SE¼	215	5/10/78	12.6	1.0	1.0	1.3	<0.1	10.9	6.6
T4NR1W6NW¼NE¼NW¼	170	"	1.3	47.0	29.0	1.6	2.44	8.9	236.7
T4NR1W9SW¼NE¼SE¼	150	"	19.4	25.0	26.5	1.6	<0.1	8.9	171.4
T4NR1W19NW¼NE¼	108	"	9.0	55.5	29.5	1.0	<0.1	10.0	260.0
T4NR1W21NW¼NW¼NE¼	125	"	2.9	56.0	31.0	1.2	0.4	10.0	267.4
T4NR1W24SW¼SE¼SE¼	230	"	14.7	<1.0	<1.0	0.2	<0.1	0.0	6.6
T4NR1W26NW¼NW¼	100	"	12.6	<1.0	<1.0	0.6	<0.1	8.9	6.6
T4NR1W26NW¼SW¼NE¼	185	"	4.5	126.5	38.5	1.8	0.4	1.0	474.3
T4NR1W27NW¼NE¼NW¼	140	"	0.9	58.5	22.7	4.0	2.25	6.9	239.5
T4NR1W29SW¼NW¼SW¼	120	"	10.0	59.0	29.5	0.6	2.95	26.0	268.7
			Onondaga						
T1NR2W2SE¼NE¼SE¼	110	4/22/78	1.6	60.5	31.5	0.8	1.0	4.9	280.7
T1NR2W4SW¼SW¼SE¼	110	"	0.6	57.5	28.5	0.2	1.0	4.9	260.8
T1NR2W5NW¼SW¼SW¼	125	"	1.7	60.5	27.0	0.3	2.65	10.9	262.2
T1NR2W16SW¼SW¼SW¼	80	"	0.9	48.5	22.3	0.2	0.15	---	212.8
T1NR2W18SW¼SW¼SW¼	110	"	1.0	62.5	31.0	0.2	1.45	3.9	283.6
T1NR2W24NE¼NW¼NW¼	100	"	1.0	46.5	21.5	0.3	0.8	7.9	204.6
T1NR2W25NW¼SW¼NW¼	80	"	1.0	49.0	28.5	0.3	3.1	1.0	239.6
T1NR2W30SE¼SE¼NE¼	124	"	1.6	61.5	32.0	0.3	1.0	6.9	285.2
T1NR2W33NE¼SE¼SE¼	100	"	0.9	55.5	30.0	0.8	0.5	1.0	262.0

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
				Stockbridge					
T1NR2E1SW¼NW¼NW¼	125	4/15/78	5.5	52.0	21.5	0.6	<0.1	7.9	218.3
T1NR2E3SW¼NW¼SE¼	264	"	8.5	69.0	29.5	0.6	<0.1	69.0	293.7
T1NR2E13SW¼SE¼SW¼	93	"	5.4	88.0	37.0	0.8	<0.1	41.0	372.0
T1NR2E16NW¼SW¼SE¼	128	"	5.2	56.5	25.0	2.2	<0.1	15.9	243.9
T1NR2E25NE¼SE¼SW¼	110	"	2.0	66.0	28.5	0.6	<0.1	25.9	282.1
T1NR2E34NE¼SW¼SW¼	185	"	7.0	55.0	26.0	1.7	<0.1	1.9	244.3
T1NR2E7NE¼NE¼NE¼	128	4/20/78	6.0	52.5	32.5	1.5	0.15	2.9	264.8
T1NR2E18SW¼SW¼NW¼	94	"	2.3	26.0	13.0	0.3	<0.1	1.9	118.43
T1NR2E29NE¼NE¼SE¼	185	"	16.8	151.0	38.5	3.0	2.8	20.0	535.5
				Wheatfield					
T3NR1E25NE¼NE¼NE¼	109	4/13/78	14.5	46.0	19.0	1.3	0.8	0.0	193.0
T3NR1E27NW¼NW¼NE¼	185	"	26.7	28.0	8.7	3.2	0.4	0.0	105.7
T3NR1E6NE¼SE¼	140	"	260.0	5.0	<1.0	2.3	<0.1	127.0	16.6
T3NR1E9NE¼NW¼NE¼	105	"	4.0	59.5	31.0	0.7	<0.1	5.9	276.1
T3NR1E11NE¼NW¼NW¼	180	"	3.8	65.0	30.3	1.2	1.45	7.9	287.0
T3NR1E17NE¼NW¼NW¼	100	"	6.2	57.0	30.3	1.0	<0.1	5.9	267.0
T3NR1E21NE¼NE¼NE¼	95	"	7.0	62.5	23.3	2.0	0.8	1.9	251.9
T3NR1E23SE¼SE¼SW¼	140	"	13.7	51.0	31.5	1.2	1.2	1.9	257.0
T3NR1E32NE¼NW¼NW¼	110	"	3.2	54.5	30.0	0.5	0.8	3.9	259.5

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
			White Oak						
T2NR2E1SW¼NE¼NW¼	91	4/15/78	1.4	79.0	29.5	0.6	2.15	53.0•	318.6
T2NR2E3SW¼SW¼NE¼	94	"	3.7	55.5	34.0	1.2	<0.1	1.9	278.5
T2NR2E5NE¼NE¼NE¼	130	"	6.3	51.5	31.0	1.5	<0.1	0.0	256.1
T2NR2E13SW¼NW¼NW¼	101	"	2.5	61.5	33.0	0.5	3.1	0.0	289.3
T2NR2E14NE¼NE¼SE¼	154	"	2.7	67.5	34.0	0.6	2.15	5.9	308.4
T2NR2E17SW¼SW¼SW¼	135	"	4.8	70.5	35.0	1.2	0.4	5.9	320.0
T2NR2E22SE¼SW¼NE¼	140	"	2.3	60.0	30.0	0.5	0.4	5.9	273.3
T2NR2E25SW¼NW¼SW¼	140	"	2.0	51.0	23.5	0.5	<0.1	10.0	224.0
T2NR2E32NW¼NW¼SW¼	125	"	1.2	38.0	15.5	0.5	0.65	10.0	158.6
T2NR2E34NW¼NW¼NE¼	130	"	3.7	50.5	28.0	0.8	0.8	11.9	256.3
			Williamston						
T4NR1E3SW¼NE¼NE¼	220	5/11/78	6.7	50.5	27.5	3.7	0.2	1.0	239.2
T4NR1E8SE¼NE¼NE¼	150	"	33.4	41.5	20.0	4.2	<0.1	0.0	185.9
T4NR1E11NE¼SE¼NW¼	140	"	13.3	41.5	23.0	4.0	0.1	1.0	198.2
T4NR1E14SW¼NW¼NW¼	245	"	18	38.5	8.7	4.5	<0.1	1.0	131.9
T4NR1E17SW¼SW¼NW¼	185	"	13.4	41.5	24.0	2.5	0.25	1.9	202.4
T4NR1E26NE¼NE¼NW¼	145	"	12.1	20.5	5.5	4.5	<0.1	1.9	73.8
T4NR1E27SW¼SW¼SW¼	170	"	210.9	<1.0	<1.0	2.7	<0.1	50.0	6.6
T4NR1E32NW¼NE¼NE¼	190	"	72.5	21.5	14.3	4.0	<0.1	1.0	112.5
T4NR1E15NE¼SE¼NE¼	240	"	5.5	21.0	20.5	4.2	0.2	0.0	136.8

Appendix A: Chemical Analyses of Ground Water in the Saginaw Formation. (Continued)

Location of Well	Depth (feet)	Date of Collection	Na^+	Ca^{++}	Mg^{++}	K^+	Fe^+	Cl^-	Hardness (carbonate)
			Vevay						
T2NR1W2NE¼SE¼SE¼	346		28.5	28.5	16.0	2.8	<0.1	10.0	137.0
T2NR1W3SW¼SW¼SE¼	140		3.8	47.5	16.5	2.5	<0.1	19.9	186.5
T2NR1W6SW¼SE¼SW¼	155		5.4	81.5	28.0	0.8	1.3	---	318.7
T2NR1W14SE¼NE¼NE¼	140	4/13/78	71.5	75.0	36.0	0.8	<0.1	21.9	335.4
T2NR1W20SW¼NW¼NW¼	102	"	1.8	28.0	12.0	1.3	<0.1	13.9	119.3
T2NR1W22NE¼NW¼NE¼	110	"	3.0	63.0	29.5	0.8	<0.1	27.9	278.7
T2NR1W26SE¼NW¼NE¼	130	"	2.5	67.0	31.0	0.5	1.0	5.9	294.8
T2NR1W32SW¼SE¼SE¼	120	"	1.2	56.5	29.0	0.6	2.95	10.0	260.4
T2NR1W33NE¼NE¼NE¼	111	"	10.5	56.0	25.0	0.3	<0.1	15.9	242.7