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# Nitrate Pollution of Ground Water in Glacial Sediments Underlying a Fertigated Site in Kalamazoo County, Michigan

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# NITRATE POLLUTION OF GROUND WATER IN GLACIAL SEDIMENTS UNDERLYING A FERTIGATED SITE IN KALAMAZOO COUNTY, MICHIGAN

by

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NITRATE POLLUTION OF GROUND WATER IN GLACIAL SEDIMENTS UNDERLYING A FERTIGATED SITE IN KALAMAZOO COUNTY, MICHIGAN

Michael Wireman, M.S.

Western Michigan University, 1987

In the central part of Schoolcraft Township high yield corn crops are successfully grown on soils developed on permeable outwash deposits. The high yields are made possible with the utilization of modern irrigation techniques and regular application of nitrogen fertilizer.

Excess nitrogen which moves past the root zone is easily converted to nitrate and leached to the shallow ground water. Water quality data from 103 ground-water samples in the vicinity of a 160-acre corn field in Section 11 clearly indicate that nitrate concentrations in the ground water beneath the field and beneath the area immediately downgradient from the field are much higher than natural background levels.

Domestic water wells, located downgradient from fertilized corn fields in central Schoolcraft County, often contain nitrate concentrations in excess of the Environmental Protection Agency's primary standard of 10 mg/l (as N). Ingestion of water from these wells poses serious health threats to infants.

## ACKNOWLEDGEMENTS

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Michael Wireman

Order Number 1332220

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# INTRODUCTION

## Purpose and Scope

Nitrate pollution of shallow unconsolidated unconfined aquifers by infiltration of water containing dissolved fertilizer is a developing problem in areas where crops require regular application of nitrogen fertilizers during the growing season. A significant amount of nitrogen applied to well-drained soils as fertilizer is leached through the unsaturated zone to the water table. Excess nitrogen is oxidized to nitrite ($NO_2$) and ultimately to nitrate ($NO-_3$) by nitrifying bacteria in the soil and water. Upon reaching the water table, nitrate ions migrate freely in the direction of ground-water flow. Sustained annual use of nitrogen fertilizers can lead to nitrate concentrations in ground water which exceed the U.S. Environmental Protection Agency standard for drinking water (45 mg/l as $NO_3$, 10 mg/l as N). Nitrate concentrations, in ground water withdrawn from shallow domestic wells in agricultural areas, are often well above regional background levels. Serious and occasionally fatal poisoning has occurred in infants ingesting well water containing nitrate levels greater than 45 mg/l as $NO_3$.

The southern two-thirds of Kalamazoo County is underlain by an outwash plain developed in the interlobate area between the Saginaw and Lake Michigan ice lobes. Fluvial discharge from the retreating ice lobes deposited up to 500 feet of moderately well-sorted sand on a low relief surface developed on Paleozoic bedrock. Throughout most of the outwash plain, a ten to fifteen foot thick till layer divides the outwash sands into an upper and lower aquifer. The upper aquifer is generally less than 100 feet thick with the water table being less than twenty feet from the land surface over most of the outwash plain.

With the utilization of modern irrigation techniques and regular applications of nitrogen fertilizer, farmers are successfully growing high yield corn crops in the soils developed on the outwash sands. From 1975 to 1980 the number of irrigators in Kalamazoo County increased from 20 to more than 70. The average farm size in the county increased from 98.7 acres in 1920 to 158 acres in 1974. In 1974, 51,999 acres of corn were harvested within the county. Depending on the soil type, farmers have been able to increase their per acre corn yield by 40% to 300% by irrigating and fertilizing with nitrogen, phosphorous, and potassium. Nitrogen fertilizers are often applied dissolved in irrigation water. This process, called fertigation, is common where center pivot irrigation systems are used. Record yields in excess of 200 bushels/acre have been grown on the outwash plain in northern St. Joseph County.

Increased use of the interlobate outwash plain for growing high yield corn crops has led to an increased potential for nitrate pollution of ground water in the upper aquifer. Nitrate in excess of that extracted by corn can be easily leached into the ground water by the combined effect of high rainfall (35 in./yr.) and applied irrigation water. Shallow domestic wells adjacent to fertilized areas are then subject to contamination by high nitrate concentration. Infants ingesting the well water are subject to methemoglobinemia, commonly called blue baby disease, is a condition in which the capacity of the blood to carry oxygen is reduced.

This study was undertaken in an attempt to further document the relationship between the surface application of nitrogen fertilizer and the nitrate concentration in underlying ground waters. A ground-water sampling program was designed and implemented on a 270 acre farm which regularly fertilizes and irrigates a large corn crop. Ground-water samples were collected and analyzed for nitrate as well as other selected parameters. Analysis of this water quality data and other data indicate a definite relationship between nitrogen applied as fertilizer on the surface and nitrate concentrations in the underlying ground water.

## Previous Investigations

Nitrate pollution of ground water has been researched by many investigators across the country over the last twenty years. The relationship between excess nitrogen from applied fertilizer and high nitrate concentrations in underlying ground water has been clearly established. However, to the author's knowledge, no site specific study had been undertaken in Kalamazoo County at the time of this research.

The Kalamazoo County Health Department has tabulated and graphed monthly levels of nitrate in selected wells for the years 1960 thru 1964 (Malmquist, 1975). No conclusions were drawn from this study though recommendations were made for establishing a program for monitoring nitrate levels across the County. Norman (1982), in work completed for a master's thesis, reported on nitrate levels from various wells across the County. Some unpublished work has been completed by former students in the Geology Department at Western Michigan University. This work has primarily consisted of plotting selected nitrate levels on a County map.

# GEOGRAPHY

## Location

The site chosen for this study is a 275-acre farm located in Schoolcraft Township in southern Kalamazoo County (Figure 1). The legal description of the 275 acres is as follows: the E1/2, SW1/4 and W1/2, SE1/4, Section 11 and the N1/2, NW1/4, and NW1/4, NE1/4, Section 14, T4S, R11W. The study area is approximately four miles south of the city of Portage, three miles east of the town of Schoolcraft, and one and one-half miles northwest of the town of Vicksburg. Agriculture, especially growing corn, is the primary land use in Schoolcraft Township.

The site is located on an interlobate outwash plain about half-way between two series of northeast-southwest trending kettle lakes: Long, Austin, Gourdneck, and Hogset to the north and Indian, Sunset, Barton, and Howard to the south. Gourdneck Lake lies about 1 1/2 miles to the north and Barton Lake an equal distance to the south. Both series of kettle lakes and the study area are within the St. Joseph River drainage basin.

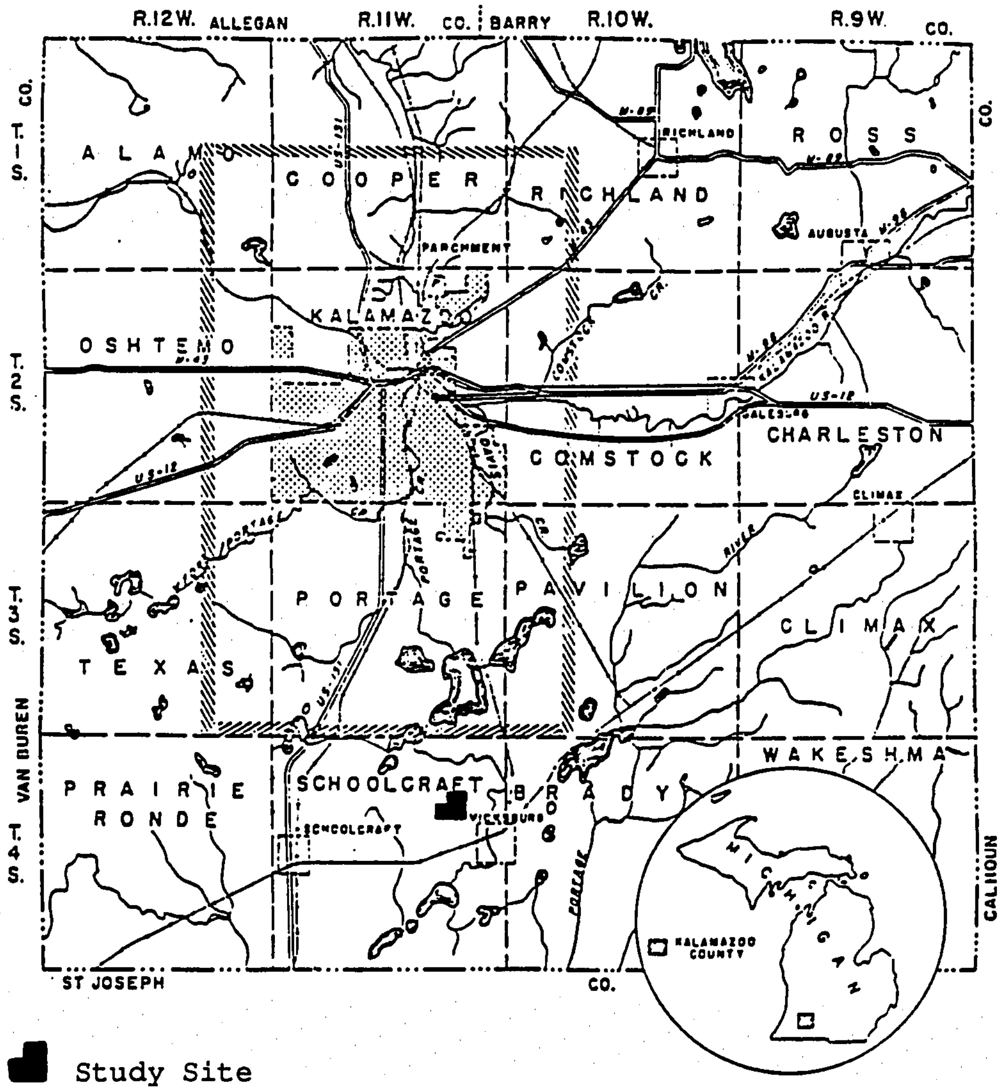


Figure 1. Location of Study Site

## Topography and Surface Drainage

The topography and surface drainage that developed on that part of the interlobate outwash plain in southern Kalamazoo County is little changed since the Lake Michigan and Saginaw ice lobes retreated from the area 15,000 to 17,000 years ago (Schmaltz, 1978). Streams draining this part of the outwash plain are small and have cut only shallow valleys. Kettle lakes and poorly drained bog areas are common.

The southern part of the outwash plain is drained by tributaries of the St. Joseph River (Figure 2). The divide between the Kalamazoo River Basin and the St. Joseph River Basin lies just to the north of the kettle lake complex which includes Long, Austin, West, Gourdneck, and Sugarloaf Lakes. Drainage from these lakes occurs via Gourdneck Creek which flows southeast to Sunset Lake. Sunset Lake is drained via Portage Creek which flows south and east to its confluence with the Portage River about four miles southeast of Vicksburg in St. Joseph County. Both Gourdneck Creek and Portage Creek flow in poorly developed channels through marshy areas. Elevations in the area range from 875 feet at the surface divide north of West Lake to 831 feet at Barton Lake.

In 1936, a diversion canal was constructed to divert water from Sugarloaf Lake to West Lake. That same year, a

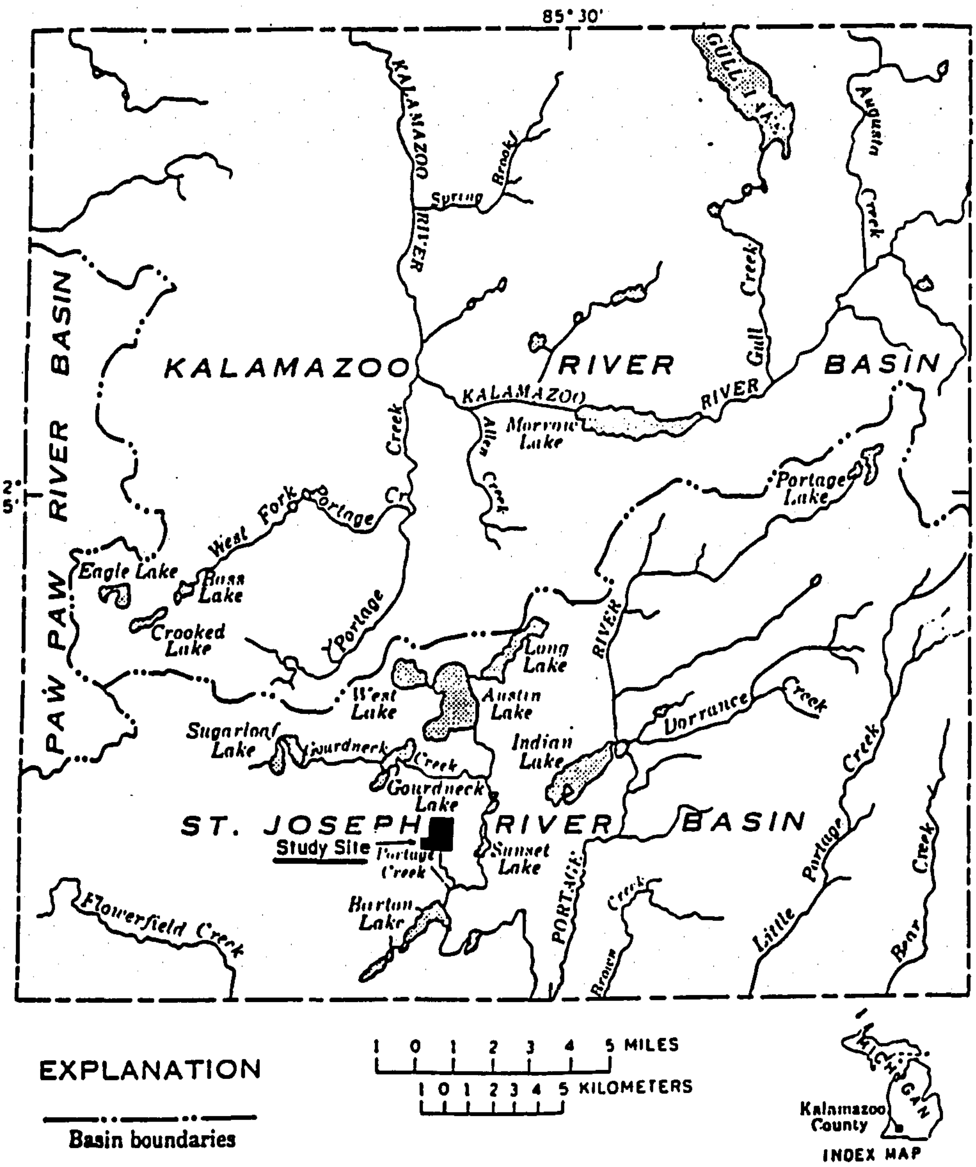


Figure 2. Map Showing Surface Water System Kalamazoo County, Michigan

Source: Allen, et al., 1972

connecting channel was constructed between West and Austin Lakes. Interflow through these canals acts to maintain equal lake levels in Long, Austin, and West Lakes. An outlet channel and spillway dam were constructed at the southeast end of Austin Lake. The outlet channel carries overflow from the three lakes southward to Gourdneck Creek. The altitude of the spillway dam is about 856 feet.

There are no lakes or ponds on the 275 acre farm chosen for this study. No streams flow across the property. Most of the cultivated land on the farm is relatively flat with little relief. The land slopes very gently to the southeast. Elevations on the farm range from 870 feet in the northwest corner of the property to about 845 feet in the southeast corner of the property.

## Climate

The average annual precipitation in Kalamazoo County is about 35 inches. About 57% of this, or 20 inches, occurs during the growing season (April - September). Precipitation is heaviest during May, which averages about 3.8 inches. February is the driest month averaging less than 2 inches of precipitation. During an average year, measurable amounts of snow fall during seven of the twelve months. The average annual snowfall is about 55 inches.

Normally about 25% of the annual snowfall occurs during the month of January.

The weather in Kalamazoo County is significantly affected by Lake Michigan about 45 miles to the west. Prevailing westerly winds are cooled in the summer and warmed in the winter as they pass over the lake. Moisture picked up over the lake by prevailing westerlies during the winter is carried eastward inducing heavy winter snowfall as far east as Kalamazoo County.

The average daily temperature in Kalamazoo County is 49.8° F. January has the lowest average daily temperature (24.8° F) and July has the highest (73.0° F). During the winter the average temperature is 27.0° F and in summer the average temperature is 71.4° F. Temperatures exceed 90° F an average of 25 times per year. Temperatures below zero occur an average of 4 times per year. The highest recorded temperature within the county (109° F) occured on July 13, 1936. The lowest temperature on record (-25° F) occured on February 10, 1885. The average last freezing date in the spring is May 9 and the average first freezing date in the fall is October 9.

## SOILS

The soils that form the surface over Kalamazoo County are derived mainly from weathered glacial drift and organic matter. The soils that developed on the interlobate outwash plain were formed in loamy material over sand and gravel. The outwash soils developed to a depth of about 40 inches.

A nearly level to undulating, well drained soil with a loamy subsoil developed on that part of the interlobate outwash plain in eastern Prairie Ronde and western Schoolcraft Townships. The United States Department of Agriculture Soil Conservation Service has classified this soil as the Schoolcraft series (Figure 3). Schoolcraft soils are well suited to cultivated crops, and most of the area covered by these soils is cultivated.

The 275 acre farm chosen for this study is underlain entirely by Schoolcraft soils with 0-2% slopes. The surface layer, or A Horizon, of typical Schoolcraft loam is comprised of very dark gray loam and extends to a depth of about 12 inches. This layer has a weak to medium granular structure and is very friable. The stratigraphy of the subsoil, or B Horizon, is as follows:

12-20 inches--dark yellowish brown clay loam with thin clay films on the surfaces of peds and in pore spaces;

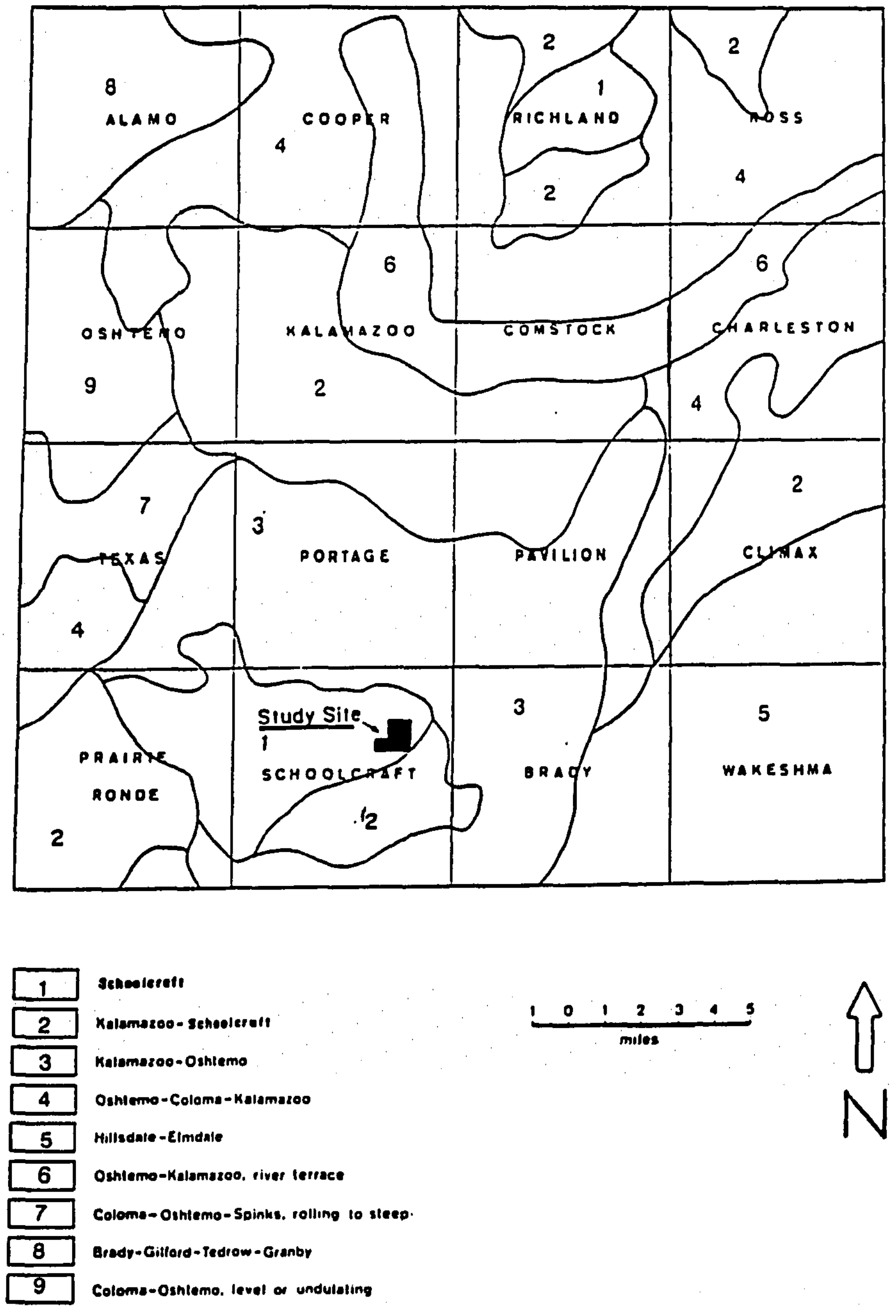


Figure 3. General Soil Map - Kalamazoo County, Michigan

20-29 inches--dark brown clay loam with thin clay films on ped surfaces and in pore spaces;

29-38 inches--dark yellowish brown sandy loam with thin clay films on ped surfaces.

The substratum or C Horizon is comprised of yellowish brown to dark yellowish brown sand to a depth of 60 inches. In places the upper part of the substratum is calcareous, stratified sand with some gravel.

Typical Schoolcraft loam is moderately permeable in the A and B horizons and rapidly permeable in the substratum (Table 1).

Table 1

Selected Physical and Chemical Properties of the Schoolcraft Loam Soil Series

| Depth (in) | Clay (<02 mm) | Fragments (>3in) | Permeability (in/hr) | Available water capacity (in/in) | pH | Organic matter % | Shrink -swell potential |
|---|---|---|---|---|---|---|---|
| 0-12 | 12-30 | 0 | 0.6-2.0 | 0.18-0.24 | 5.6-7.3 | 1-3 | low |
| 12-29 | 18-35 | 0 | 0.6-2.0 | 0.12-0.19 | 4.5-5.5 | 1-3 | mod |
| 29-38 | 12-20 | 0 | 0.6-2.0 | 0.10-0.14 | 4.5-5.5 | 1-3 | low |
| 38-60 | 0-10 | 0 | 6.0-20.0 | 0.02-0.04 | 5.6-8.4 | 1-3 | low |

Source: Austin and Konwinski, 1979

Typical Schoolcraft loam contains from 12-35% clay. The upper part of the B horizon has a moderate shrink-swell potential due to high clay content. The pH of Schoolcraft loam ranges from 4.5-8.4. The A and C horizons are generally less acidic than the B horizon.

Soil data specific to the study site were obtained from a soil analysis completed by U.W. Stoll and Associates of Ann Arbor, Michigan. During the fall of 1973, sixty-three soil borings were taken on the property as part of a waste disposal suitability study. A total of 169 soil samples from these borings were classified in accordance with the Unified Soil Classification System (Table 2).

Table 2

Summary of Soil Classification of Soil Samples From Study Site

| Unified System Class | No. of samples |
|---|---|
| SP | 3 |
| SP-SM | 5 |
| SM | 20 |
| SC | 13 |
| OL-M1(I) | 66 |
| OL-ML(II) | 10 |
| CL-ML | 37 |
| | 15 |
| Total | 169 |

Soil classes SP, SM, and SC are sands, silty sands, and clayey sands respectively. Soil classes OL, ML and CL are organic silts, inorganic silts, and inorganic clays respectively. Of the 169 samples, 141 contained greater than 30% clay size particles and 128 contained greater than 50% clay size particles. These results indicate that the soil underlying the study site has a slightly higher clay content than typical Schoolcraft loam. Data from the 63 soil borings indicate that soil has formed to depths of 24-40 inches over the study site.

## BEDROCK GEOLOGY

Kalamazoo County is situated on the southwestern flank of the Michigan Basin, a structural basin in the central part of the North American Craton. At its center the Michigan Basin contains in excess of 14,000 feet of Paleozoic sedimentary rocks (Hinze & Merritt, 1969). Beneath Kalamazoo County the Paleozoic section is about 5000 to 7000 feet thick. The Paleozoic rocks, which are mantled with unconsolidated glacial deposits over all of Kalamazoo County, dip gently to the northeast.

The Early Mississippian Coldwater Shale subcrops beneath the drift over most of the county. This formation, about 900 to 1000 feet thick in this part of the Michigan Basin, is comprised mainly of very micaceous, grayish-blue sandy shale containing abundant brownish nodules of iron carbonate. Locally the formation contains interbedded buff to red, oolitic or fossiliferous limestones and dolomites. The Coldwater Shale conformably overlies the Late Devonian-Early Mississippian Ellsworth Shale. The Early Mississippian Marshall Sandstone stratigraphically overlies the Coldwater and is present as the subcrop or outcrop in a small area in northeastern Ross Township. Fossils indicate that these three formations were deposited in a marine environment. The Coldwater Shale strikes northwest-southeast and dips gently to the northeast. Major bedrock valleys, cut by stream channels prior to glaciation, were generally oriented parallel to the strike (Deustch, Vanlier & Giroux, 1960). Elevations of the top of the Coldwater Shale beneath Kalamazoo County range from about 300 to 800 feet above sea level (Figure 4). Regionally, the erosional surface developed on top of the formation slopes gently to the west.

In Schoolcraft Township the elevation of the top of the Coldwater ranges from 500 to 800 feet above sea level. The Coldwater surface is nearly level over the eastern two-thirds of the township sloping very gently to the west. A small bedrock high (800 feet) occurs in the southwest corner of the township.

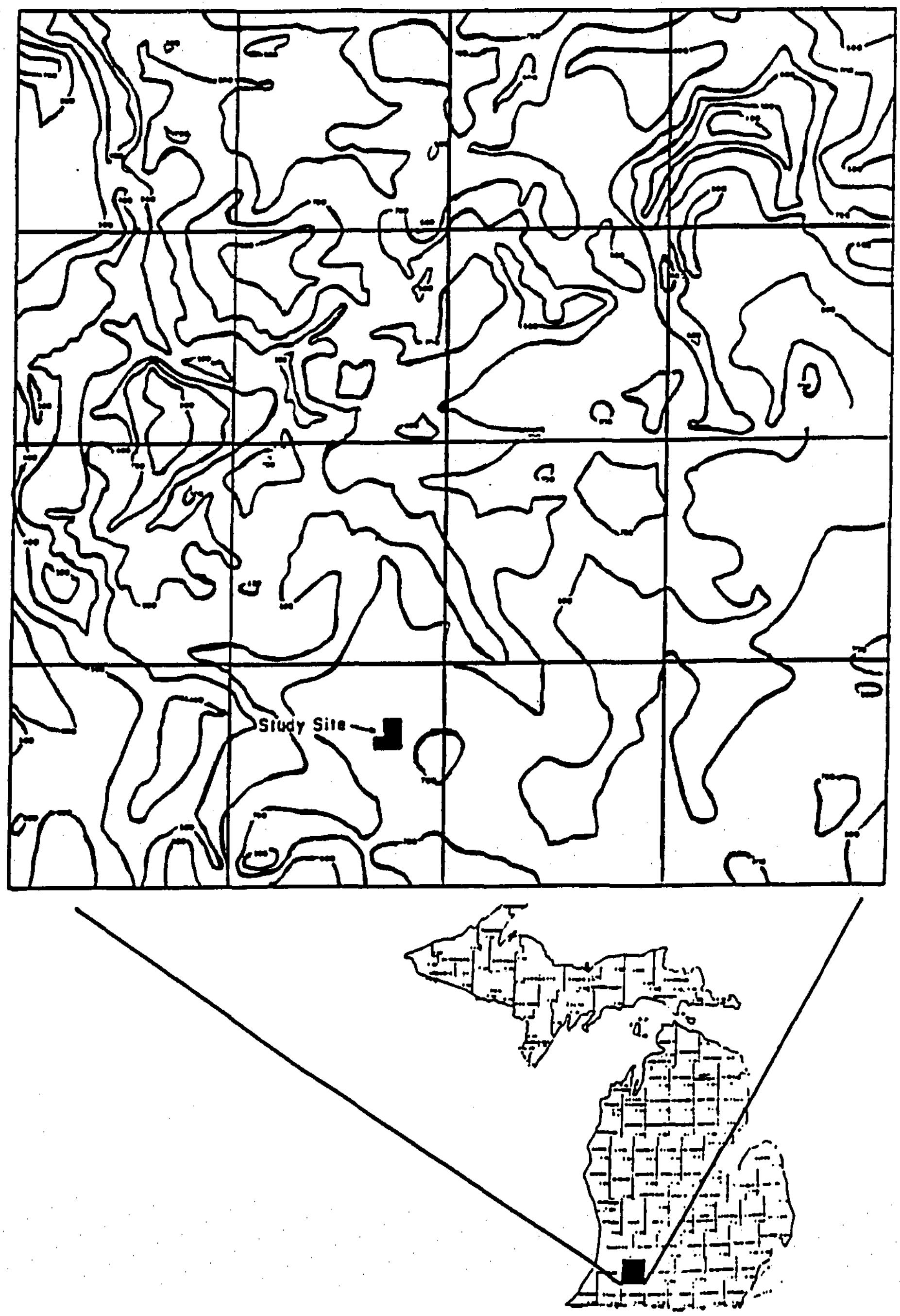


Figure 4. Elevation of Bedrock Surface - Kalamazoo County, Michigan

Source: Ibraham, 1969

# SURFICIAL GEOLOGY

## Regional

Kalamazoo County is entirely underlain by Pleistocene glacial deposits. Most of the drift in the Kalamazoo area was deposited during the Cary subglacial stage of the Wisconsin glacial stage (Wayne & Zumberge, 1965). However, a well near The Upjohn Company in Portage reportedly penetrated a buried soil profile that contained tree log fragments. This soil is thought to have developed between the Illinoian and Wisconsin Glacial stages and has been noted in well borings as far north as Bay and Oceana counties (Leverett, 1906).

Within Kalamazoo County the thickness of the drift ranges from less than 50 feet to more than 500 feet (Figure 5). It is thinnest along the present day Kalamazoo River and in certain areas of the outwash plain in the southeastern part of the county. The drift is thickest where the Kalamazoo Moraine crosses the west part of the county. Elevation of the drift surface ranges from 740 feet above sea level where the Kalamazoo River leaves the County to more than 1000 feet above sea level along the moraine in Oshtemo Township.

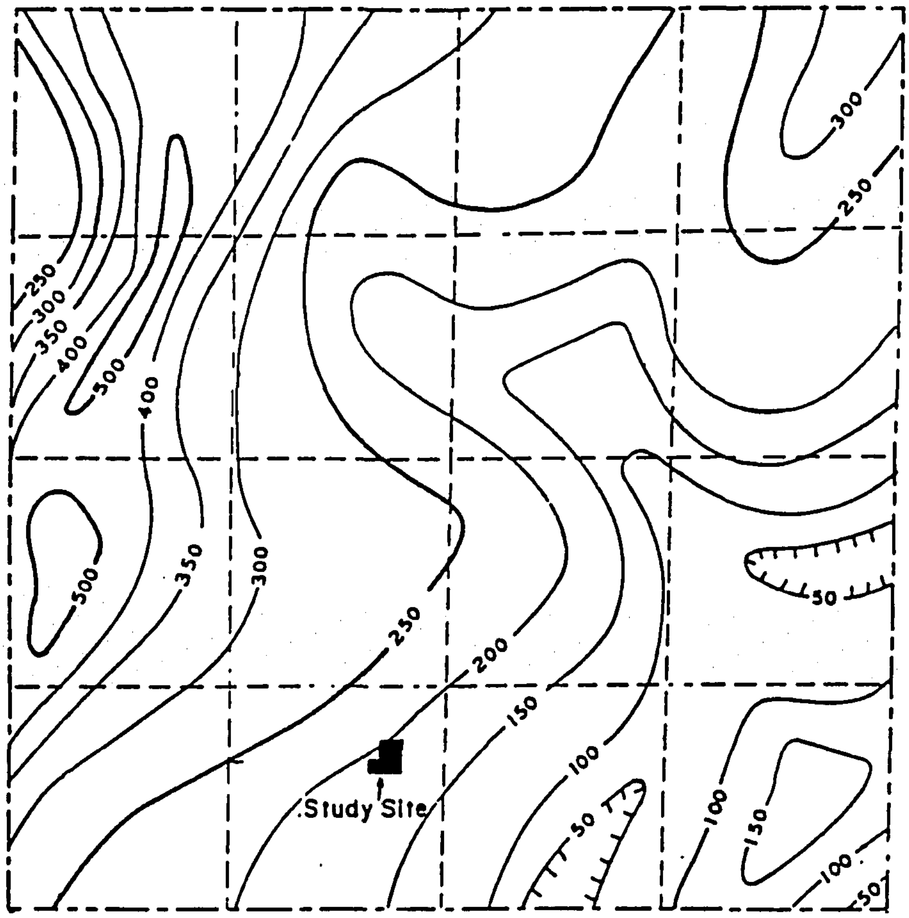


Figure 5. Generalized Drift Thickness Map - Kalamazoo County Michigan

Source: Shah, 1974

Most of what is now Kalamazoo County lies in the interlobate area between the Lake Michigan and Saginaw ice lobes. The advances and retreats of these ice lobes into and out of the Kalamazoo area resulted in a variety of ice-contact (till), glaciofluvial and glaciolacustrine deposits (Figure 6). The Saginaw Lobe probably advanced southwestward over Kalamazoo County prior to the southeastward advancement of the Lake Michigan Lobe (Deutsch et al., 1960). The Lake Michigan lobe followed, in part, the pre-Pleistocene bedrock valleys. Pre-Pleistocene surface drainage was generally from southeast to northwest in the Kalamazoo area.

The outer ridge of the Kalamazoo moraine, a recessional moraine of the Lake Michigan ice lobe, enters the County in the northwest corner of Prairie Ronde Township and trends north and east through Texas, Oshtemo, Alamo, and Cooper Townships. The outer ridge is separated from an inner ridge to the west by a narrow, continuous gravel plain. The outer ridge varies in width from one to four miles but is less than two miles wide along most of its length. The combined width of the two ridges and the intervening gravel plain is about five to seven miles. The present day Kalamazoo River has cut about two miles out of both morainal ridges about five miles north of the city of Kalamazoo.

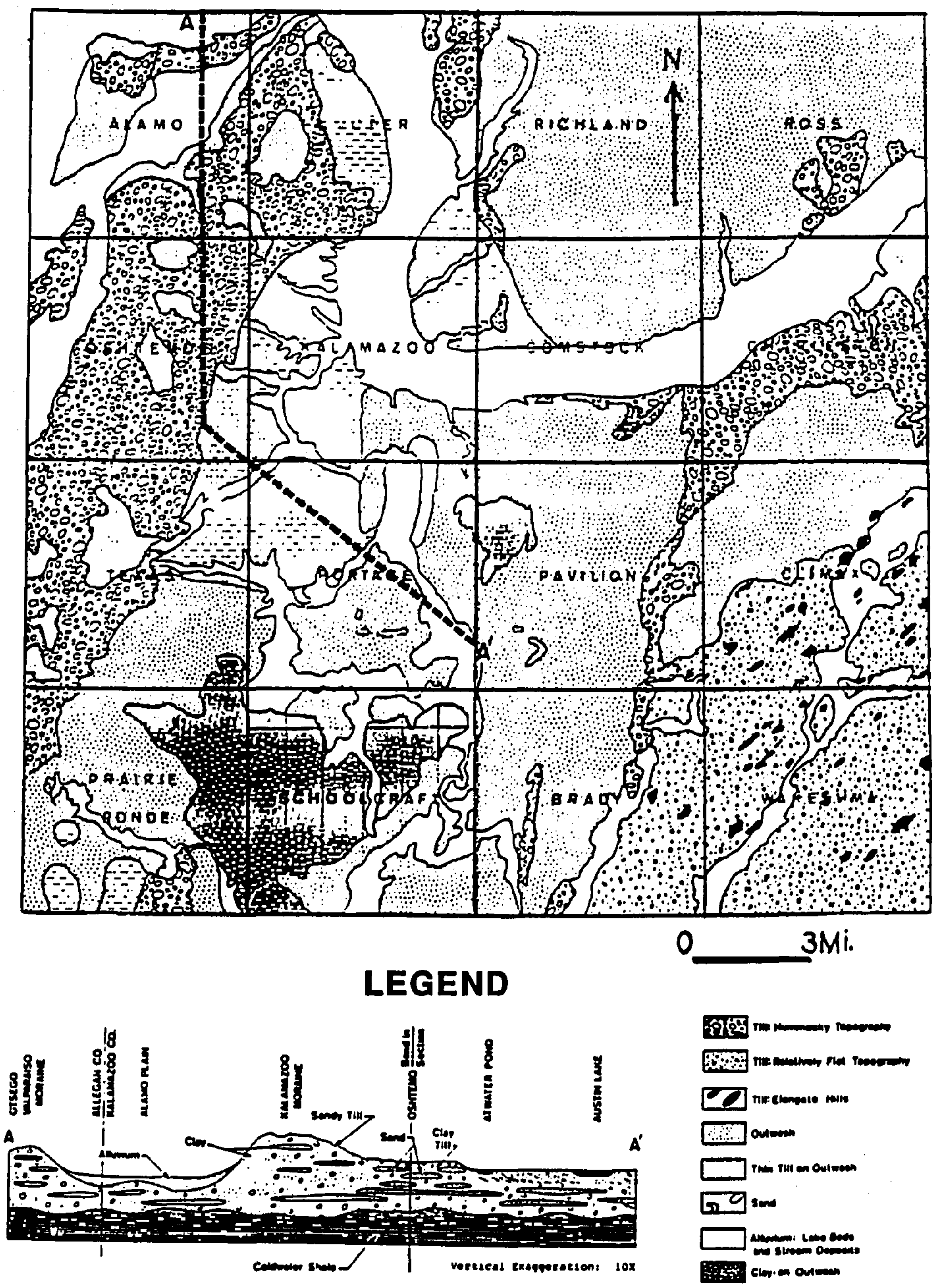


Figure 6. Glacial Geology--Kalamazoo County, Michigan

Source: Passero, 1978

The moraine is comprised of poorly sorted clay, silt, sand, gravel, and boulders. Its maximum thickness within Kalmazoo County is about 500 feet in southern Texas Township. The surface of the outer morainal ridge is commonly a loose textured bouldery clay a few feet thick (Leverett & Taylor, 1915). Regionally, this is underlain by a thick sandy section. Locally, a blue clay layer separates the surface till from the underlying sandy section.

The morainal surface is characterized by knob and kettle topography. The kettle floors are from 50 to 75 feet below the knobs and 25 to 50 feet above the adjacent outwash plain. The eastern border of the outer ridge shows only slight relief because the outwash has been built up nearly to the level of the morainal crest. Locally, valleys run from the moraine eastward to the present day Kalamazoo River Valley. These are the result of localized discharge from the ice border which cut instead of filled.

In eastern Kalamazoo County the Tekonsha moraine trends southwestward from Charleston Township through Pavillion Township and into Brady Township. Straw (1976) interpreted this to be an end moraine of the Lake Michigan lobe. Leverett and Taylor (1915) considered this moraine to be correlative with the Tekonsha moraine of the Saginaw lobe. The Tekonsha moraine of the Lake Michigan lobe is a relatively small morainal deposit. It is unclear whether this is because only a small moraine was formed or a larger moraine was formed and subsequently obliviated by the Lake Michigan ice lobe. A small outwash plain is developed immediately south of the Tekonsha moraine in southern Charleston and northern Climax Townships. The Tekonsha moraine forms the drainage basin divide between the Kalamazoo and St. Joseph River basins in this area.

That part of the Tekonsha moraine in Kalamazoo County ranges in width from less than one mile to more than three miles. The thickness of the morainal drift ranges from less than 50 to slightly more than 200 feet. This is considerably less than the outer ridge of the Kalamazoo moraine in western Kalamazoo County. The relief between the Tekonsha moraine and the outwash fan on its outer border is slight, being less than 50 feet in most places.

The drift of the Tekonsha moraine is sandier than that of the Kalamazoo moraine. The surface is commonly a yellow to blue-gray, bouldery clay to a depth of 10 feet. Boulders are common throughout the moraine. The majority of the boulders are igneous or metamorphic rock. Knob and kettle topography is not very well developed along the Tekonsha moraine in Kalamazoo County.

About 60% of Kalamazoo County is covered by outwash plains of both the Saginaw and Lake Michigan ice lobes. Vigorous lines of fluvial discharge produced wide and thick outwash deposits extending away from the major terminal and recessional moraines. The interlobate outwash plain extends from the reentrant area, near Prairieville in Barry County, southwestward through the center of Kalamazoo County. The present day Kalamazoo River flows westward, across the outwash plain, through Comstock and Kalamazoo Townships before bending to the north and breaching the Kalamazoo moraine in Cooper Township. The outwash plain is about 15 miles wide throughout most of its' extent in Kalamazoo County.

North of the Kalamazoo River the outwash plain is dissected and streams are entrenched as much as 160 feet below the surface of the plain. South of the Kalamazoo River the outwash plain is topographically lower and has been extensively cut and filled by streams. Thick outwash deposits (up to 500 feet) cover many square miles in Portage, Prairie Ronde, and Schoolcraft Townships. Elevations of the surface of the outwash plain range from about 880 feet at north of Austin Lake to 720 feet near its southern terminus at South Bend, Indiana.

The stratigraphy of the outwash deposits is a function of the drainage related to the melting of the ice lobes. Most of the outwash in Kalamazoo County was deposited in front of the retreating Lake Michigan ice lobe. The basal drift is a dark blue, clay till derived mainly from the underlying Coldwater Shale. This layer was deposited directly by the ice. As the ice lobe retreated, a complex series of shallow, braided streams carried meltwater and sediments southeastward away from the outer Kalamazoo moraine. Meltwater from these streams joined the mainstream of the glacial Kalamazoo River which flowed southward from the reentrant angle of the interlobate area. This stream passed east of the city of Kalamazoo, past Vicksburg before reaching the St. Joseph River between Mendon and Three Rivers.

In the central part of Kalamazoo County, meltwater draining from the Lake Michigan lobe ponded against the ice front and formed glacial Lake Kalamazoo. This lake covered parts of present day Cooper, Kalamazoo, Comstock, Pavillion, and Portage Townships (Martin, 1958). Most of the sediments deposited in this lake were removed when the Kalamazoo River cut its present valley.

After the Lake Michigan lobe retreated to the position of the inner Kalamazoo moraine, the Kalamazoo River abandoned its southward course and flowed northward through a lower outlet in southeastern Allegan County (Deutsch et al., 1960). This new Kalamazoo River cut 80-100 feet into the outwash plain. The outwash sediments were extensively reworked and deposited as channel deposits. Meltwater from Lake Kalamazoo and the Saginaw ice lobe to the northeast also drained via the lower outlet in Allegan County. As a result of altering its course the amount of water draining via the Kalamazoo River was greatly reduced. Consequently, the present day river occupies only a portion of the glacial river valley.

A number of kettle lakes presently occupy depressions in the outwash plain; created by the melting of detached ice blocks. These lakes are aligned parallel to the retreating margin of the Lake Michigan ice lobe. In the south-central part of Kalamazoo County, two distinct belts of kettle lakes occur within the outwash plain. These are Long, Austin-West, Gourdneck, Hogset, and Sugarloaf to the north, and Indian, Sunset, and Barton to the south (Figure 2).

The outwash material is coarse along the edges of the moraines. Cobbles and coarse boulders are common within one-half mile of the morainal edge. Away from the morainal edge, the average grain size decreases and the outwash consists primarily of sand and fine gravel. Locally, layers of imbricated cobbles within the sand and gravel, suggest torrential flow of meltwater.

In places the outwash sands and gravels are separated by a till-like layer occurring at about 60-80 feet below the land surface (Allen, Miller & Wood, 1972). This till layer is extensive, though not continuous, especially to the south of the present day Kalamazoo River. In the northern part of the outwash plain, well logs indicate the presence of a thin blue clay about 30-40 feet deep

(Leverett and Taylor, 1915). The areal extent of this layer is unknown. Lenticular, discontinuous clay layers occur locally throughout the outwash deposits. These are the result of local ponding of meltwater. Much of the clayey drift is indurated to various degrees due to diagenetic changes.

Much of the outwash plain is capped by a 2-to-4 foot thick layer of silt and clay due to shallow ponding of meltwaters. Extensive areas of this clay capping occur in Prairie Ronde, Schoolcraft, and Pavillion Townships. Most of the basins within the outwash plain are also underlain by clay.

## Study Site

The site chosen for this study, located in Sections 11 and 14 in Schoolcraft Township, is situated upon the interlobate outwash plain developed between the Lake Michigan and Saginaw ice lobes. Geologic data from water well logs indicate that the outwash sediments are from 150 to 200 feet thick in this part of the outwash plain. A United States Geological Survey well located in the SE1/4 of the SW 1/4 of Section 3, Schoolcraft Township, about one mile northwest of the study site, hit the Coldwater Shale at 200 feet. Two City of Vicksburg wells located about one mile southeast of the study site, in the NE 1/4 of the NW 1/4 of Section 13, are 147 and 148 feet deep. Neither of these wells reached bedrock. The geologic logs of these wells are included in Appendix .

Data for determining the stratigraphy of the outwash sediments in the vicinity of the study site were obtained from geologic logs of onsite piezometers, soil borings and offsite domestic and municipal wells (Appendix). Selected logs were used to construct three cross-sections which extend across the site from northwest to southeast and northeast to southwest (Figure 7). Cross-section A-B (Figure 8) and cross-section B-C (Figure 9) extend from northwest corner of the site southeastward to the town of Vicksburg. Cross-section D-E (Figure 10) extends from the northeast corner of the site southwestward to V Avenue. The wells used to construct the cross sections range in depth from 64 to 144 feet. None of the wells penetrated bedrock, therefore the stratigraphy of the lower few feet of the outwash is not known.

Most of the outwash beneath the study site is comprised of gray to brown, moderately sorted, fine to very coarse-grained sand and gravel. However, at least two clay or till layers occur within the sand and gravel and appear to extend over most of the site. A reddish-brown to brown to gray, clay till layer occurs at a depth of 70 to 80 feet below the ground surface. This till layer is about 15 feet thick and appears to be continuous beneath the study

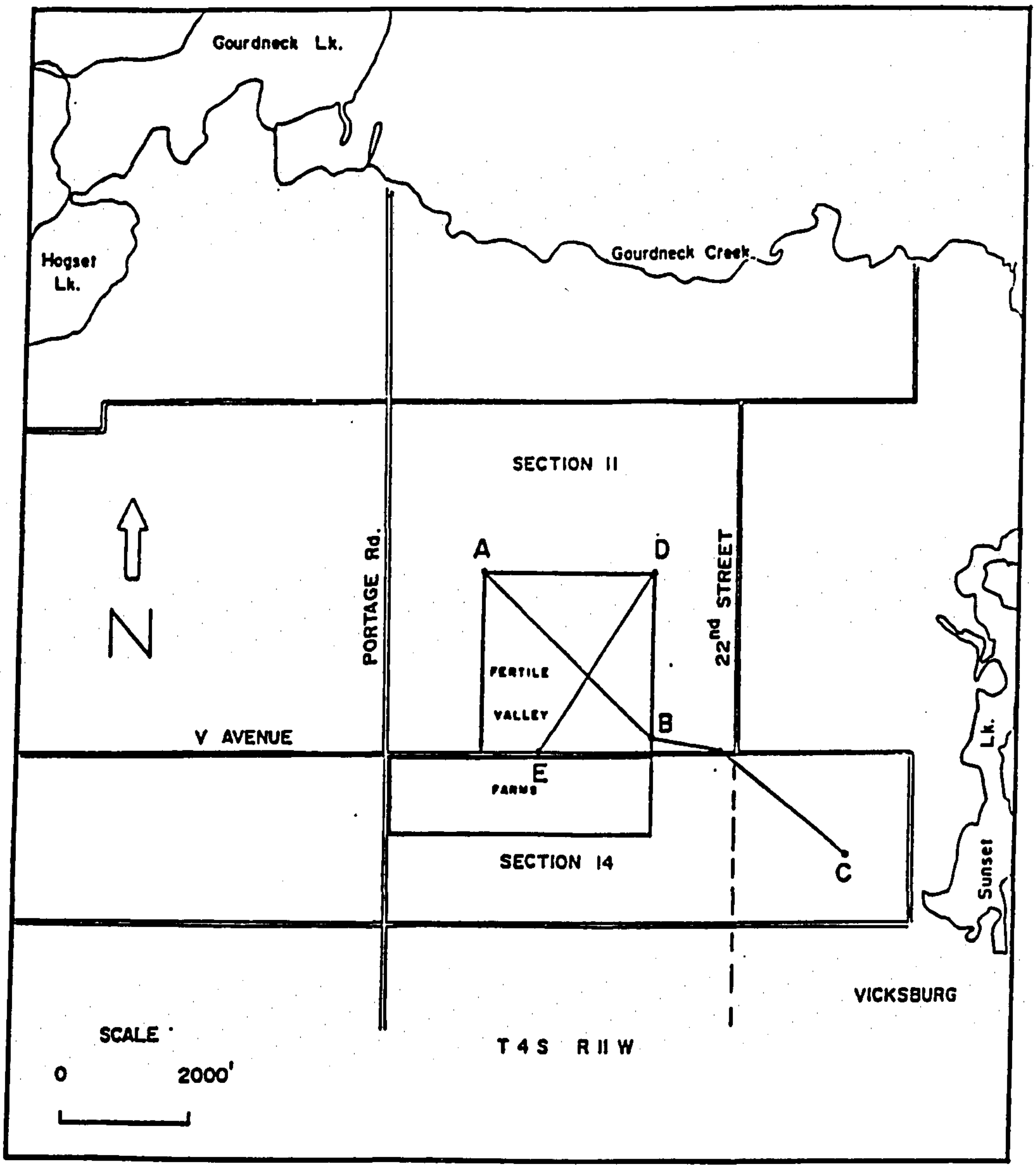


Figure 7. Location of Cross-Sections

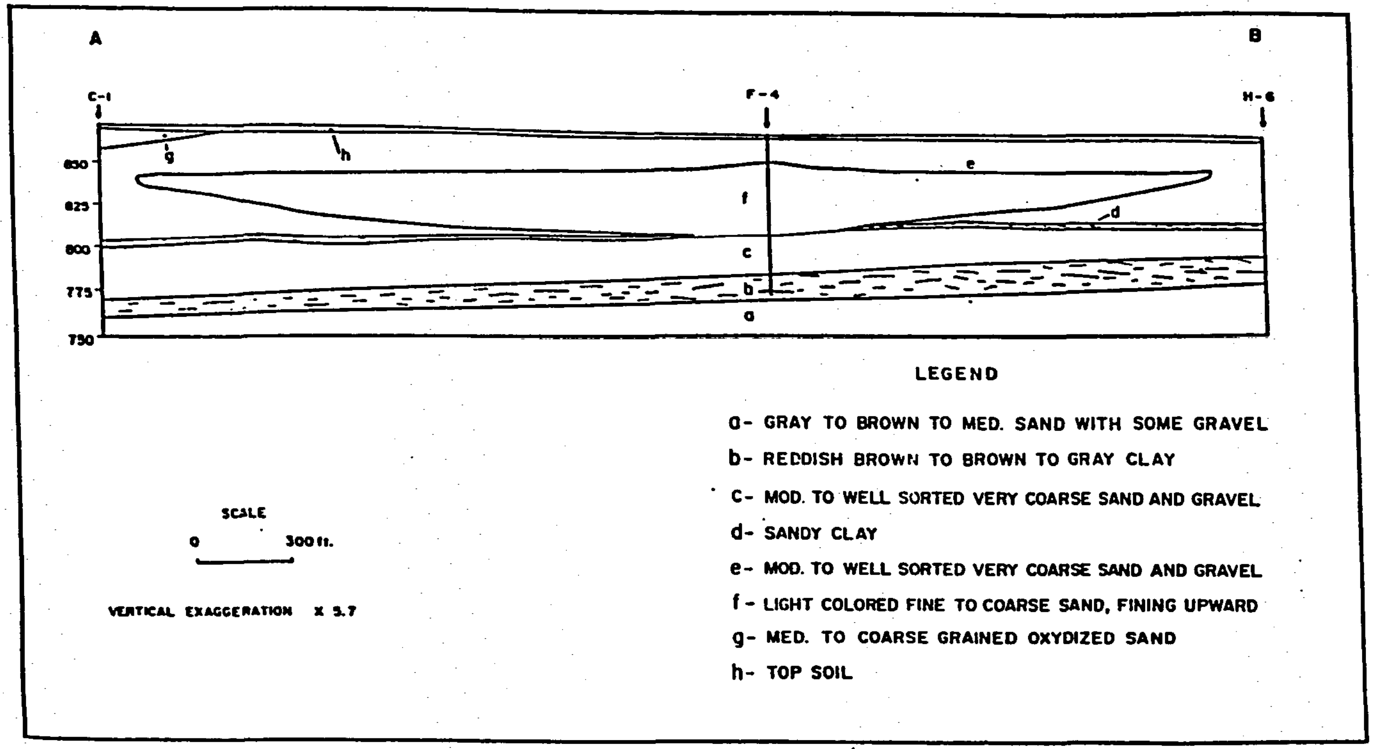


Figure 8. Cross-Section A-B

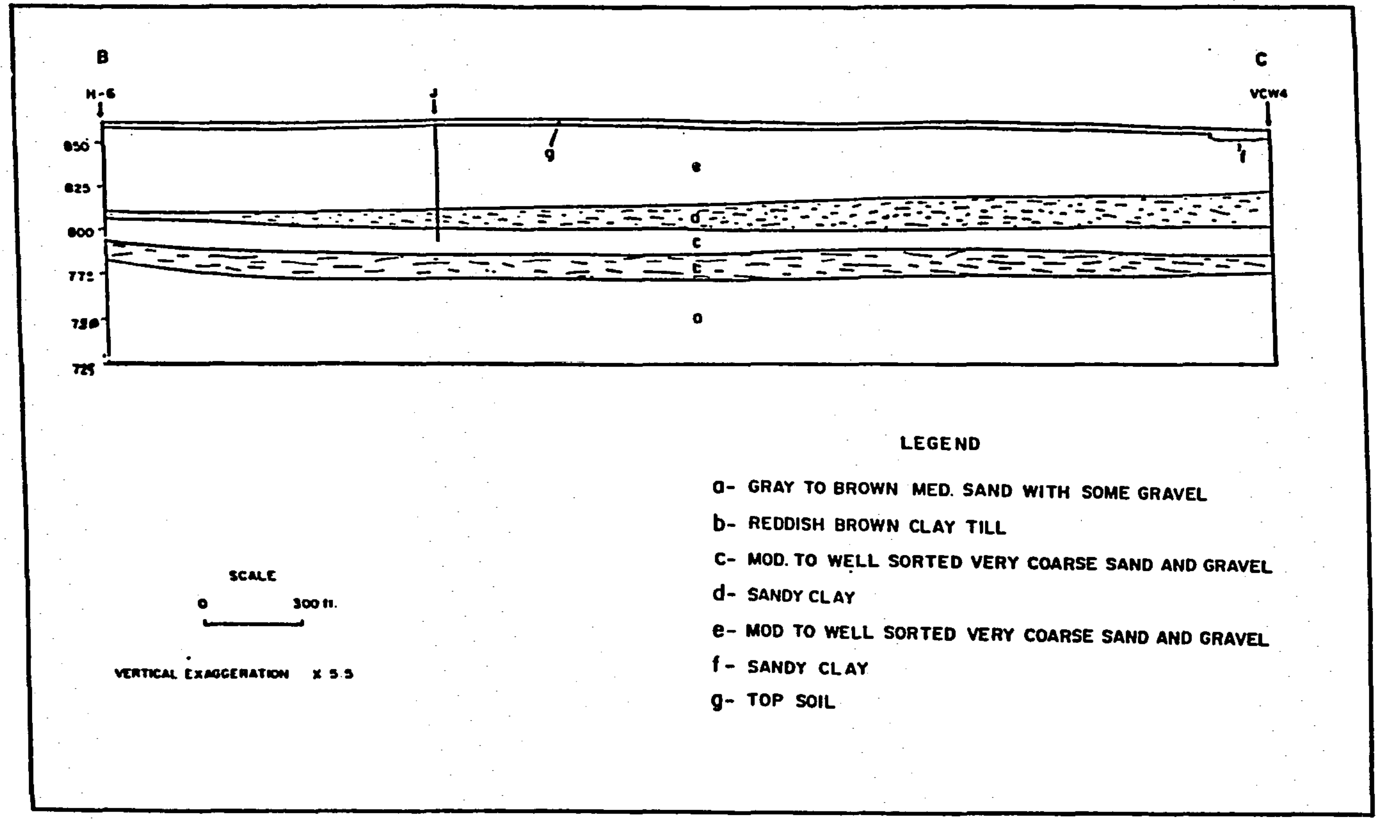


Figure 9. Cross-Section B-C

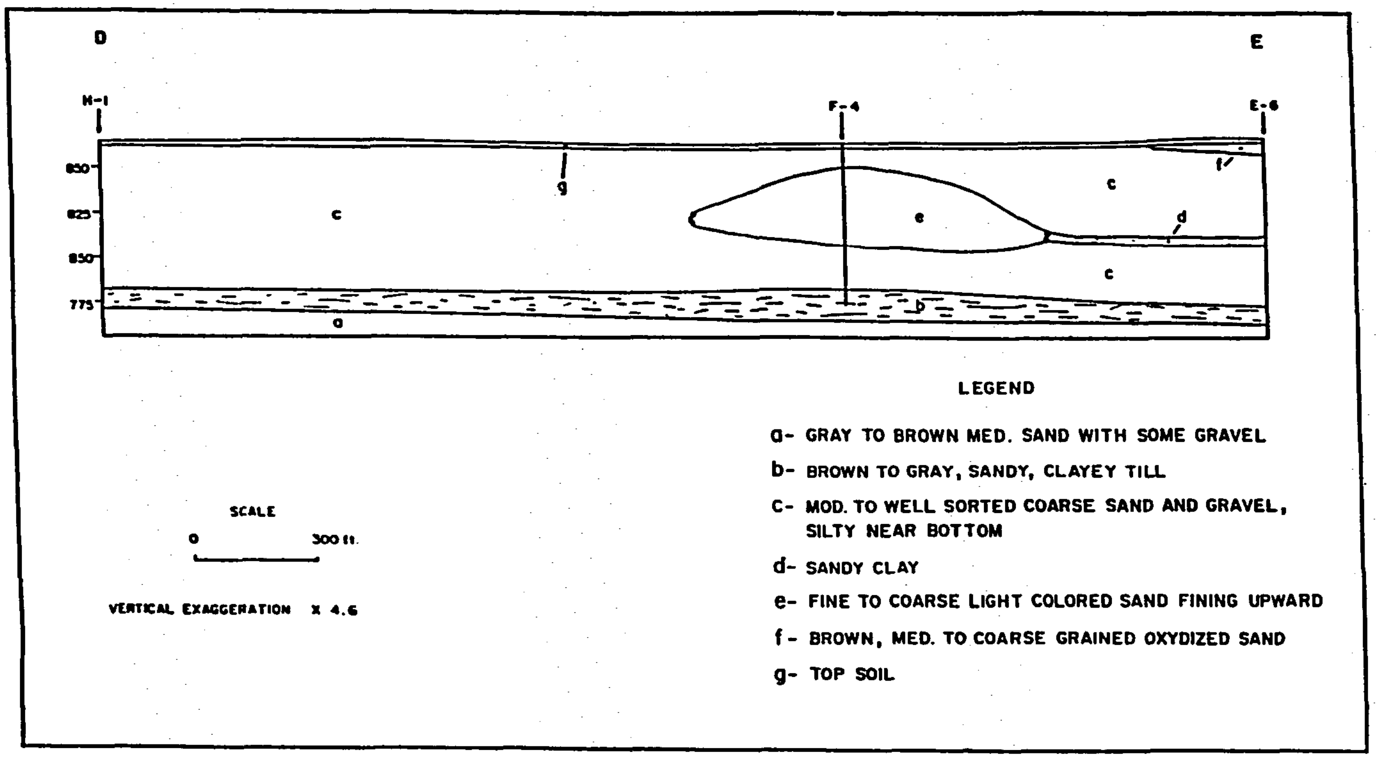


Figure 10. Cross-Section D-E

site. A hard, gray, sandy clay occurs at a depth of 50 to 60 feet. This layer is about ten feet thick beneath most of the site, thickening to the southeast. The occurrence

Interpretation of geologic logs suggests that a lenticular body of fining upward sand trends southeastward through the 160 acre parcel of the study area that lies north of V avenue. It is about 40 feet thick at the intersection of cross-section A-B and D-E (Figures 8 and 10) and is encountered at about 15 feet below the ground surface. Based on the available information this is interpreted to be a channel deposit with the fining upward sequence attributed to waning current velocities as a channel is infilled. Due to inadequate log control, the exact geometry and dimensions of the sand body are unknown. Well logs indicate that it does not extend beyond the 160 acre parcel north of V Avenue.

A thin layer of clay (1-2 feet) caps the outwash sand and gravel over most of the study site. A black, organic, clayey soil is developed on top of this clay to a depth of 2.5 to 3 feet. Locally, the coarse sand and gravel is oxidized within a few feet of the surface.

Petrographic data indicates that the study area is underlain by outwash sediments deposited by the Lake Michigan ice lobe. Shah (1974) made a lithologic analysis of a spot sample (2 liters) of outwash sediments from the SW 1/4, SE 1/4 Section 6 in Schoolcraft Township about 3.8

miles northwest of the study site. Data from this analysis are presented in Table 3. The gravel fraction of this sample contains 28.82 percent crystalline rocks and 63.17 percent carbonate and chert. The sand fraction contains 21.66 percent crystalline fragments and 45.67 percent carbonate and chert. The sand fraction contains significantly more chert and quartz than the gravel fraction.

According to Shah (1974), gravel fractions of the Saginaw lobe deposits generally contain greater than 30 percent Precambrian crystalline rocks while those of the Lake Michigan lobe generally contain less than 30 percent. The combined carbonate and chert of the Lake Michigan lobe sediments is generally greater that that of Saginaw lobe deposits. The crystalline rock fragments were derived from Precambrian rocks of the Canadian Shield and the carbonate and chert fragments from Paleozoic rocks.

TABLE 3

Lithology of Outwash Deposits
From Schoolcraft Township
Kalamazoo County, Michigan

| Size Fraction | Lithology (in weight percent) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Clastic | Feldspar | Carbonate | Basil Igneous | Acid Igneous | Foliated Metamorphic | Non-Foliated Metamorphic |
| Gravel 1/2 to 1 inch | — | — | 56.56 | 10.73 | 8.18 | 5.62 | 4.29 |
| Sand 1 to 2 mm | 4.33 | 8.00 | 33.67 | 9.33 | 7.33 | 5.00 | 5.00 |

| Fraction | Lithology (in weight percent) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Dense Chert | Pourous Chert | Quartz | Siltstone & Shale | Sandstone | Clay Ironstone Concentration | Others | Total |
| Gravel 1/2 to 1 inch | 3.47 | 3.14 | — | 1.73 | 2.73 | 1.65 | 1.90 | 100.00 |
| Sand 1 to 2 mm | 12.00 | 12.00 | 20.00 | — | — | — | 0.33 | 99.99 |

Source: Shah, 1974

## GROUND-WATER HYDROLOGY

### Regional

Beneath Kalamazoo County ground water occurs in the unconsolidated glacial deposits, modern day alluvial deposits and the underlying bedrock. The unconsolidated glacial and alluvial deposits are hydraulically connected and comprise a regional aquifer which underlies an area roughly equal to that of the Kalamazoo River Basin. The same type of unconsolidated deposits form a regional aquifer which underlies the area drained by the St. Joseph River. Ground water contained in the underlying Coldwater Shale is not easily withdrawn by wells due to the low permeability and storage properties of the shale. This formation functions as an effective basal aquiclude throughout its subcrop area.

The glacial deposits which comprise most of the regional aquifer are outwash and till deposits. Over large parts of the regional aquifer these deposits are poorly stratified and lenticular in nature. Sorting is poor to moderate especially for the till deposits. However, in the central and southern parts of the County, large, thick, moderate to well sorted outwash deposits comprise the regional aquifer. Lenses of sandy material occur within the generally fine-grained till deposits and lenses of fine grained material are common within the outwash. Modern day alluvial deposits occur locally stratigraphically above the glacial deposits. These deposits tend to be fairly permeable and are hydraulically connected to the underlying glacial deposits. The complex stratigraphy and moderate variation in sorting result in a complex ground-water system within the regional aquifer.

Studies completed by the United States Geological Survey (Allen et al., 1972) indicate that the regional aquifer generally can be divided into four hydraulic units: (1) an upper aquifer generally comprised of outwash, sandy till and/or alluvium, (2) an intervening aquiclude generally comprised of fine-grained clay till, (3) a lower aquifer generally comprised of outwash and/or sandy till and (4) a basal aquiclude (the Coldwater Shale). The aquifer units are not continuous nor are the aquicludes, however, they occur over a large enough area to allow the regional aquifer to be effectively divided into two aquifer units. There is some hydraulic connection between the two aquifer units because the aquicludes tend to be leaky.

The upper aquifer is more widespread than the lower aquifer. It occurs over most of the county (very limited in Wakeshma Township). The lower aquifer unit occurs primarily in the interlobate area south of the Kalamazoo River where thick outwash deposits occur over large areas. Both of the aquifer units include lenses of fine-grained relatively impermeable material. Thickness of the upper aquifer ranges from 0 to 140 feet. Thickness of the lower aquifer ranges from 0 to 160 feet.

The U.S.G.S. (Allen et al., 1972) has identified ten areas within the county where the regional aquifer will yield especially large volumes of ground water to wells. There are six such areas for the upper aquifer and four for the lower aquifer. Within these areas thick deposits of saturated permeable materials yield sufficient quantities of ground-water for large development. The four ground-water reservoirs in the lower aquifer are located in southern Kalamazoo County where the lower aquifer is comprised of thick outwash deposits. The six ground-water resevoirs in the upper aquifer are located where thick alluvial deposits overlie permeable glacial deposits. Most of the upper aquifer reservoirs are in the northern part of the County.

Ground water contained in the upper aquifer and, to a lesser degree, the lower aquifer is hydraulically connected to the surface water system. Most streams in Kalamazoo County are effluent, in that the base flow of the stream is provided by ground-water discharge. U.S.G.S. data indicate that in 1966 an estimated 73% of the flow in the Kalamazoo River was base flow and an estimated 79% of the flow in the St. Joseph River was base flow. Streams can become influent along certain stretches during periods of high streamflow. Kettle lakes also exhibit a high degree of hydraulic connection with surrounding glacial materials.

Due to the heterogeneous character of the glacial drift, ground water in the regional aquifer occurs under varying piezometric pressures. The lower aquifer unit is confined over most of its extent. It is confined above by a fine-grained till layer and below by the Coldwater Shale. In some areas in the County, the piezometric surface of the lower aquifer is higher than the water table surface of the upper aquifer. Historically the piezometric surface of the lower aquifer along the flank of the Kalamazoo moraine has been above the surface of the ground and piezometric levels in the City of Kalamazoos' East Kilgore well field have been above the ground surface. These wells are developed in the lower aquifer. Historical water level data indicate that locally the piezometric surface of the lower aquifer has declined.

Ground water in the upper aquifer unit occurs under water table conditions over most of its extent. The elevation of the water table fluctuates with seasonal changes in the rate of recharge and discharge. The water table generally rises in the spring and fall and declines during the summer and winter. Historical data from observation wells indicate that one inch of rainfall generally causes a three inch rise of the water level in the upper aquifer unit (Reed, Deutsch & Wiitala, 1966).

Ground water within the regional aquifer flows from areas of high hydraulic head to areas of low hydraulic head or from areas of recharge to points of discharge. Ground water within the regional aquifer that extends over the Kalamazoo River Basin flows towards the Kalamazoo River and its tributaries. The Kalamazoo River is topographically low and is in hydraulic connection with both the lower and upper aquifer units. Ground water within the regional unconsolidated aquifer that extends over the St. Joseph River Basin flows towards the St. Joseph River. The ground-water divide that hydraulically separates these two aquifers sub-parallels the topographic boundary that separates the Kalamazoo River Basin from the St. Joseph River Basin. Ground-water flow velocity within the aquifer units is dependent on the aquifer permeability and the slope of the water table or piezometric surface.

Recharge to the regional aquifer occurs primarily by infiltration of precipitation and locally from inflow of surface water. Recharge from precipitation is greatest during months of low evapotranspiration (November through May) though some recharge occurs in all months. Recharge by inflow of surface water is greatest in spring and occurs where there is permeable material between the overlying surface water and the water table. The lower aquifer unit is recharged by ground water moving downward from the upper aquifer unit through leaky aquicludes. Where the piezometric surface of the lower aquifer unit is higher than the water table of the upper aquifer unit water moves from the lower aquifer unit to the upper aquifer unit. Discharge from the regional aquifer occurs primarily by seepage to streams, lakes and springs. A minor amount of discharge occurs through evapotranspiration.

The U.S.G.S. (Allen, 1972) has estimated ground-water recharge to the regional aquifer within the Kalamazoo River Basin and to that part of the regional aquifer within the St. Joseph River Basin that lies in Kalamazoo County. Based on data from 1963 - 1966 average annual ground-water recharge was estimated to be about 490 acre-feet per square mile within the Kalamazoo River Basin and 580 acre-feet per square mile for that part of the St. Joseph River Basin within Kalamazoo County. These recharge estimates were based on the relationship between ground-water recharge and ground-water runoff, ground-water evapotranspiration, subsurface underflow and change in ground-water storage.

Hydraulic properties for the regional aquifer units have been estimated based on numerous aquifer tests conducted by the U.S.G.S. (Table 4). All but three of the thirty-eight wells are located within the regional aquifer that extends over the Kalamazoo River Basin. Twelve of the 30 wells are located in Portage Township, twelve in Texas Township, and seven in Kalamazoo Township. The estimated values for the hydraulic properties were derived

Table 4

Range of Estimated Values for Selected Hydraulic Properties of Regional Unconsolidated Aquifer

| Aquifer unit | No. of wells | Transmissivity (gpd/ft) | Storage coefficient | Permeability (gpd/ft2) |
|---|---|---|---|---|
| Upper | 8 | 71,000-190,000 | 0.00006-0.19 | 1600-3200 |
| Lower | 30 | 16,000-230,000 | 0.00002-0.0003 | 700-3500 |

Source: Allen et al.,1972

from analyses of time - drawdown data. Table 4 indicates that the unconsolidated deposits which form the regional aquifer units will yield appreciable amounts of water to wells. Specific capacities for wells developed in outwash deposits are often greater than 25 gallons per foot of drawdown.

Ground water in the regional aquifer is primarily of the calcium-bicarbonate type. The major dissolved cations include calcium, magnesium and sodium while the major anions include biocarbonate, sulphate and chloride. Concentration of total dissolved solids normally increases away from the recharge areas. Shallow ground water in recharge areas is lower in dissolved solids than water that is deeper in the same aquifer and lower than water in shallow zones in discharge areas. Bicarbonate is commonly the dominant ion in that part of the aquifer characterized by active ground-water flushing.

The natural chemistry of the ground water which occurs in the glacial deposits in Kalamazoo County is primarily a result of carbonate-mineral dissolution in an open or partially open system. Chloride and sulphate concentrations rarely exceed 100 milligrams per liter (Freeze and Cherry, 1979). These waters are hard to very hard with values generally greater than 200 milligrams per liter (as $CaCO_3$). Ground water within the regional aquifer is slightly alkaline with pH values generally between 7.5 and 8.0. Concentrations of dissolved solids are generally less than 500 milligrams per liter.

## Study Site

The 275 acre farm chosen for this study is located between two areas designated by the U.S.G.S. as ground-water reservoirs. The study site is less than one mile east of the Schoolcraft Ground-water Reservoir and less than one mile northwest of the Vicksburg Ground-water Reservoir. The site is located about three miles south of the ground-water divide which separates the regional aquifer which extends over the Kalamazoo River Basin from the regional aquifer which extends over the St. Joseph River Basin. Thus ground water beneath the study area flows toward and eventually discharges to the St. Joseph River and its tributaries.

Beneath the study area the regional aquifer is comprised primarily of interlobate outwash deposits. Geologic logs from nearby water wells indicate that the glacial deposits are from 150 to 200 feet thick in the vicinity of the study area. Geologic logs from on-site water wells and observation holes indicate that there are two fine-grained layers within the generally medium- to coarse-grained sand and gravel which comprises the outwash in this area. The upper layer, comprised of sandy clay, occurs at a depth of 50 to 60 feet and is about 5 to 10 feet thick. The lower layer, comprised of brown to gray clay occurs at a depth of 70 to 80 feet and is about 15 feet thick. The lower clay layer appears to be continuous beneath the study site. The upper sandy clay layer does not appear to be continuous over the study area. The lower clay layer functions as an aquiclude which separates the outwash into upper and lower aquifer units. Ground water in the lower aquifer unit is confined by the clay layer. The upper sandy clay layer occurs within the upper aquifer unit and locally creates semi-confined conditions in the lower 20 to 30 feet of the upper aquifer unit.

For purposes of this study, the upper aquifer unit is of greater interest. It is from this aquifer that ground water is withdrawn to supply the irrigation and domestic requirements of the farm. It is also this aquifer to which excess nitrogen from applied fertilizers is leached. Depth to the water table of the upper aquifer ranges from about 12 to 20 feet across the study site depending on the land surface elevation. The upper aquifer unit is about 90 feet thick across the study site and the saturated thickness is generally about 70 to 80 feet. Well yields in excess of 500 gallons per minute (gpm) are easily obtained from the upper aquifer beneath the site. The on-site irrigation well, equipped with a 75 horsepower reciprocating pump will yield 650 gpm with a specific capacity of 20 gallons per minute per foot of drawdown.

Values of hydraulic parameters for the upper aquifer beneath the study site were estimated using data obtained by Keck Consulting Service, Inc. during a sewage disposal feasibility study conducted on the study site by Keck in 1972 - 1973. Vertical permeability in the upper 15 feet of the upper aquifer unit was determined for 53 samples obtained from auger borings. These samples were tested for vertical permeability using a constant head permeameter. Vertical permeability values ranged from 305 to 610 gallons per day per square foot (gpd/ft2). The average value was 495 gpd/$ft^2$.

Transmissivity and horizontal permeability were estimated by Keck using distance - drawdown data from nine short aquifer tests which were conducted using nine onsite observation wells which ranged in depth from 60 to 110 feet. For each test two temporary observation wells were installed adjacent to the pumping wells at distances of 2.5 and 5.0 feet. Transmissivity values obtained from analyses of the aquifer test data ranged from about 31,000 to 350,000 gpd/ft. All but one of the nine estimated transmissivity values were between 31,000 and 155,000 gpd/ft. The highest transmissivity value was obtained from a well in the northeast corner of the property and the lowest from a well adjacent to V Avenue in the south central part of the property. Estimated values for horizontal permeability were calculated by dividing the transmissivity by the saturated thickness at each of the nine well sites. Estimated values ranged from 617 to 5109 gpd/$ft^2$. Estimated storage coefficient values were calculated by the author using the distance-drawndown graphs from the aquifer tests. These values ranged from .0004 to 0.22. Three of the nine storage-coefficient values are less than 0.01 reflecting semi-confined conditions.

The direction of ground-water flow in the upper aquifer unit beneath the study site has been determined by the author using depth to water table data obtained by Keck during November of 1973. At that time, depth to water was measured in nine on-site observation wells completed in the upper aquifer unit. These data were used to prepare a water-table contour map (Figure 11). As shown in Figure 11, ground water flow in the upper aquifer unit beneath the study site is towards the southeast. Probable discharge points for ground water flowing past the study site include Portage Creek, Sunset Lake, and down gradient wells. The municipal well field for the town of Vicksburg, about 1 1/2 miles down gradient from the study site, includes one well which withdraws water solely from the upper aquifer unit and one well which is completed in both the upper and lower aquifer units. Total pumpage from the Vicksburg well field, which includes three wells, is in excess of two million gallons (6 acre feet) per day.

Ground-water velocity in the upper aquifer unit beneath the study site was estimated based on the average horizontal permeability, the hydraulic gradient and porosity. Using an average horizontal permeability value of 1200 $gpd/ft^2$ (Keck, 1973) a hydraulic gradient of 0.002, and a porosity of 20% the average linear velocity across the study site is about 0.46 feet per day.

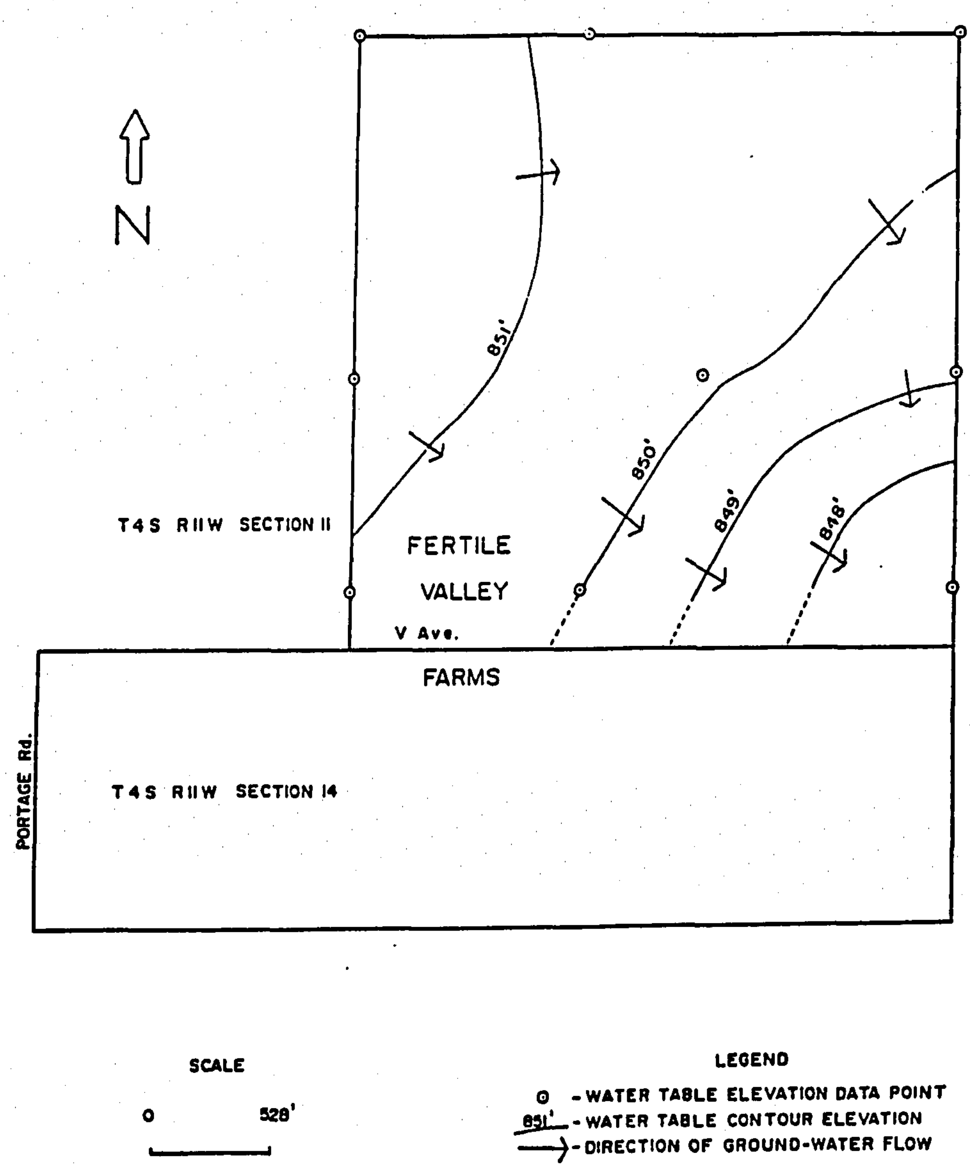


Figure 11. Water Table Contour Map for Upper Aquifer Unit Beneath Study Site

# NITRATE NITROGEN

## Occurrence and Source

Nitrogen is essential for all living things. Both nucleic acids and proteins require nitrogen for their formation. The air we breathe is nearly 80% nitrogen ($N_2$). However, the free nitrogen of the atmosphere cannot be used by plants for organic synthesis. It must first be combined with hydrogen. Nitrogen-fixing bacteria in the soil reduce nitrogen to ammonia ($NH_3$), a gas, and then to ammonium ($NH^+_4$), an ion. Other nitrifying bacteria oxidize ammonium in the soil to nitrite ($NO_2^-$) and nitrate ($NO_3^-$). The nitrate ion is the thermodynamically stable form of combined nitrogen for terrestrial oxygenated systems. Nitrate is the main source of nitrogen for plants.

In addition to atmospheric nitrogen, ammonia, ammonium, nitrite, and nitrate, two other components of the nitrogen cycle are important. These are the amide and amino groups. These groups are important in the generation of nucleotides and amino acids respectively. All seven of these nitrogen forms contribute to total nitrogen concentrations in ground water. There is a tendency for all nitrogenous materials in natural waters to be converted to nitrate. Therefore, all seven components of the nitrogen cycle are potential sources of nitrate.

Major point sources of combined nitrogen are municipal and industrial waste water, landfill leachate, feed lots, and septic tanks. Sewage effluent contains bound nitrogen (in organic matter), ammonia and nitrate. The nitrate concentration of sewage effluent is generally 15-40 mg/l higher than that of natural waters. Septic tank waste is also high in bound nitrogen and nitrate. Animal feed lots contribute nitrogen in the form of urea ($[NH_2]_2$ CO) which is found in animal excretion.

Non-point sources of nitrogen include leaching of nitrogen fertilizers, urban drainage, decomposition of plants and animals, decomposition of organic material in clays, rainwater (0.1 mg/l) and atmospheric fallout. Decomposition of plants and animals produces nitrogen as ammonium and nitrate as well as nitrogen bound in the organic matter.

With the exception of rainfall, agricultural practices probably contribute the greatest amount of nitrogen to the surface of the earth. Leaching of applied nitrogen fertilizer contributes more nitrogen, by far, than any other single agricultural practice. Nitrogen fertilizers vary in composition, however there are only four main types: anhydrous ammonia ($NH_3$) which has to be stored under pressure to maintain a liquid state, ammonium nitrate ($NH_4$ $NO_3$), ammonium phosphate ($NH_4$ $PO_4$) and urea. Ammonium nitrate and ammonium phosphate are nitrogen salts. Anhydrous ammonia and ammonium nitrate are dissolved in water to make a nitrogen solution.

## Behavior in the Subsurface

Only part of the total nitrogen applied at the surface as fertilizer reaches the ground-water table as nitrate. In the unsaturated zone complex biochemical processes act on the combined nitrogen forms entering the subsurface. In a process called ammonification free atmospheric nitrogen ($N_2$) is converted to ammonium ions ($NH_4$) by nitrogen-fixing bacteria. Ammonium ions are oxidized to nitrite and ultimately to nitrate by nitrifying bacteria in both the soil and the water. Nitrification takes place in the unsaturated zone under aerobic conditions.

The rate at which the nitrate ion is formed varies and is dependent upon factors other than the presence of nitrogen-fixing bacteria and nitrifying bacteria. In natural oxygenated water systems nitrite is rapidly oxidized to nitrate. Denitrification occurs when anaerobic conditions are created in the zone of aeration. When this happens nitrate and nitrite contained in the soil or water are broken down by denitrifying bacteria and $N_2$ is liberated. Anaerobic conditions are not prevalent in the zone of aeration, therefore, ammonification and nitrification are the dominant processes.

Some of the combined nitrogen that enters the zone of aeration is attenuated by the soil column. All three ionic nitrogen forms can be attenuated but ammonium is the only form that is attenuated to any degree. The ammonium ion has a positive charge and is therefore attracted to soils, which are generally negative. Attenuation of ammonium is greater in the winter because of the decrease in activity of nitrifying bacteria. This leads to a buildup of ammonium in the soil which is subject to oxidation in the spring. Under natural conditions, increased plant activity in spring and summer increases the uptake of nitrogen and effectively reduces this surplus.

The nitrate ion has a negative charge and a low ion-exchange capacity, therefore attenuation by soils is not as likely. During the winter when ammonium attenuation is greatest the nitrate ion is more readily leached. In addition to being subject to nitrification, dentrification and attenuation, both the ammonium and nitrate ion are assimilated by plants and converted to protein. In a natural system almost all ammonium and nitrate available in the zone of aeration is assimilated, thus background concentrations of nitrate are generally low. However, when the amount of nitrogen within the root zone exceeds the nutritional requirements of the crop the ability of plant uptake to remove the nitrogen before it is leached beyond the root zone is reduced.

Mercado (1976), in a study done in Israel, assumed a linear relationship between the amount of nitrogen released on the surface as crop fertilizer and the amount of nitrogen reaching the ground water as nitrate. He designed a mathematical model which incorporated the following factors: (a) $NO_3$ content of rainwater, (b) $NO_3$ content of ground water, (c) return flow coefficient of irrigation water, (d) water consumption for irrigation, (e) nitrate consumed by plants, (f) denitrification and nitrification and (g) a linear proportion coefficient. The model was developed to predict average concentrations as a function of time and the effects of disconnection of pumping wells from domestic water supply systems. Two things should be added to this list: (1) attenuation potential and (2) presence or absence of large pores which increase the vertical movement of nitrate ions in the unsaturated zone. Caldwell and Buzicky. (1979) considered the factors that would affect the transit time of nitrate through the unsaturated zone. These factors are: (a) thickness, (b) volume of moisture in unsaturated zone, (c) average replenishment, (d) irrigation quantity and (e) return flow coefficient. These two studies indicate a range of 2-24 years. In 1976 Mercado produced a table

(Table 5) in which he attempted to give the percentage of nitrogen released at the surface that can potentially reach the water table as nitrate. In this study the zone of aeration consists of sand and calcereous layers interspersed with clay and loams and is 81.25 feet thick.

Table 5

Percentage of Nitrogen Applied at Surface That Can Potentially Reach Water Table as Nitrate

| Nitrogen Source | % Reaching Water Table as Nitrate |
|---|---|
| Fertilizer surplus | 63.0 |
| Sewage | 20.8 |
| Livestock Excretion | 0.6 |
| Leachate | 0.6 |
| Rainfall | 5.0 |

Source: Mercado, 1976

A study done by Hooks and Kardos, (1978) determined that 90% of the nitrogen leaching past 120 cm (4 ft) is nitrate. The nitrogen was applied as ammonium. For nitrate introduced at or near the soil surface an increasingly broad concentration peak will form with depth. The broad spreading is caused by hydrodynamic dispersion.

The ionic forms of combined nitrogen move vertically through the zone of aeration but upon reaching the water table movement is in the direction of ground water flow. Two modes of transport are responsible for ionic movement below the ground-water table, dispersion and advection. Ground-water velocity and direction of flow at any given point is dependent on slope, permeability, porosity, and head. The relationship between these parameters and nitrate ion transport is not fully understood. Nitrate generally moves somewhat slower than the ground water it is dissolved in. This could be due to different ionic densities or the effects caused by nitrate ions coming in contact with sediment particles.

## Health Effects

The primary health hazard associated with the ingestion of water with a high concentration of nitrate is a condition known as methemoglobinemia. Methemoglobinemia is a condition in which the capacity of the blood to carry oxygen is reduced. This happens when a portion (10%) of the hemoglobin in the blood is converted to methemoglobin. If 20% of the total hemoglobin is converted to methemoglobin the condition is serious and can be fatal.

Methemglobin normally comprises 2% of the total hemoglobin. Methemoglobinemia can result from the ingestion, inhalation, absorption or medicinal administration of any one of several drugs which cause an oxidizing reaction with hemoglobin in the blood. The condition can also result from congenital heart disease.

Nitrate in drinking water was first associated with methemoglobinemia in 1945 by Comley. Between 1945 and 1970, 2000 cases of infantile methemoglobinemia were reported from Europe and North America (Winton, Jorcliff & McCabe, 1970). Seven to eight percent were fatal. Since methemoglobinemia is not required to be reported these numbers may represent only a part of the total. Only one case of methemoglobinemia associated with a public water supply has been reported in the United States (Virgil, Warburton & Haynes, 1965).

When a dose of nitrate is ingested via drinking or cooking water, nitrate reducing organisms within the gastrointestinal tract will reduce some of the nitrate to nitrite before the nitrate can be absorbed. Nitrite is then absorbed by the blood and reacts with hemoglobin to form methemoglobin. Conant (1932) noted that this is an oxidation reaction in which ferrous iron in hemoglobin is oxidized to ferric iron in methemoglobin. The oxygen in methemoglobin is so firmly bound that methemoglobin cannot function as an oxygen carrier by alternate oxygenation and deoxygenation. This leads to the physiologic effect of suffocation.

Methemoglobinemia is largely confined to infants that are 6 months or younger in age. In 1948 Cornblath and Hartman did a series of experiments to determine the effect of the acidity of gastric juices on susceptibility to methemoglobinemia. They found that nitrate-reducing bacteria in the gastrointestinal tract are active at pH levels above 4.9. On studying several methemoglobinemia cases they found that there was no free acidity in the gastric juices of the infants studied. The pH level of the individuals studied was greater than 5. Thus, it was concluded that the lack of acidity in the gastric juices of newborn infants allows nitrate reducing organisms to grow in the upper part of the gastrointestinal tract. In older infants the acidity of the gastric juices inhibits the growth of nitrate-reducing organisms, thus reducing the susceptibility to methemoglobinemia.

A number of toxicological studies have attempted to determine the dose of nitrate containing drinking water that is capable of converting 10% of total hemoglobin to methemoglobin. These studies indicate that water with a nitrate concentration of 50 mg/l (as nitrate) may provide sufficient nitrate to cause this condition. When feeding formula water is boiled the nitrate concentration is increased by up to 40%.

In addition to methemoglobinemia the ingestion of water with high nitrate concentrations may enhance the formation of nitrosamine carcinogens in the stomach, which may cause stomach cancer in adults. This occurs when nitrite reacts with amino or amides in food or water to form N-Nitroso compounds. This reaction occurs more frequently after meals when the pH of gastric juices is approximately 1.5 or less. N-Nitroso compounds may be carcinogenic. The research is uncertain at this time, therefore, a direct correlation between high nitrate concentrations in drinking water and stomach cancer has not been postulated. Nitrate caused methemoglobinemia is reversible with no damage to the red blood cells if diagnosed in time. Also, vitamin C has been shown to be an effective preventative against the health effects of nitrate.

## Standards and Analytical Techniques

Nitrate concentrations in drinking water can be reported as nitrogen or as nitrate. These differ by a factor of 4.4, thus 10 mg/l as nitrate nitrogen is equal to 44 mg/l as nitrate. Nitrate is most often reported as nitrate nitrogen. Both the United States Environmental Protection Agency and the Michigan Department of Public Health report nitrate as nitrate nitrogen. The Environmental Protection Agency has set 10 mg/l (as N) as the standard in the Federal Primary Drinking Water Standards. This limit has been set in response to research on methemoglobinemia. The 10 mg/l level was chosen by E.P.A. because of the potential risk of methemogloinemia to bottle-fed infants, and in view of the absence of substantiated physiological effects at concentrations below 10 mg/l.

Analytical techniques most often utilized when analyzing for nitrate are specific ion electrode, spectrophotometric and wet chemical methods. Wet chemical methods include the Brucine method and the cadmium reduction method. The wet chemical methods and the specific ion electrode are most often employed. Wolterink (1979) used stable nitrogen isotopes to determine nitrate concentrations in soil and ground water. Three-hundred samples from throughout the United States were analyzed. Nitrate was separated from the other nitrogen species, converted to gas, purified and analyzed. Initial results of this research indicate that nitrate from artificial sources (barnyards, feedlots, etc.) can be distinguished from natural soil nitrate on the basis of delta N 15 values.

# METHOD OF INVESTIGATION

## Farming Practice

The site selected for this study has been used exclusively for agriculture since the land was first developed. For at least the past sixteen years corn has been the primary cash crop, and since 1977 the land has been used exclusively to grow corn. In 1981, about 250 - 260 acres of corn were harvested on the farm.

In 1977, the 275 acre farm was acquired by Fertile Valley Farms. The new owners commissioned a water well driller to drill and develop an irrigation well to be used for irrigating the corn crop. The irrigation water is applied using a center pivot irrigation system. Since 1977, the farm operators have been periodically applying nitrogen fertilizers through the irrigation water in a process known as fertigation. Through this process, liquid fertilizer, injected into the irrigation system at the proper concentration and rates, can be applied uniformly over the corn crop. Field trials in western Nebraska have shown that fertigation can increase the per acre corn yield by eight bushels.

In southern Michigan, corn grown on sandy, well-drained soils is usually planted from April 15 to May 5. In 1981, three 110 day hybrids were planted during the first week of May on about 250-260 acres of the 275 acre farm. A 110 day hybrid requires about 2500 growing-degree days. Growing-degree days for Kalamazoo County are shown in Table 6.

Table 6

Growing-Degree Days for Kalamazoo County, Michigan (Base 50$^{o}$ F.)

| Month | Average Growing-Degree Days |
|---|---|
| May | 318 |
| June | 589 |
| July | 736 |
| August | 694 |
| September | 452 |
| Total | 2789 |

The corn was planted in rows 30 inches apart which results in a density of 27,000 plants per acre. The corn crop was harvested during the first two weeks of October.

Prior to planting, anhydrous ammonia ($NH_3$) was applied directly to the soil at a rate of 50 pounds per acre. On June 23rd and 24th, anhydrous ammonia was again applied to the soil at a rate of 160 pounds per acre. From July 21 through July 24, a 28% nitrogen solution was applied through the irrigation system at a rate of 40 pounds per acre. These three applications resulted in a total application of 250 pounds of nitrogen per acre over about a three month period. Total nitrogen application for the years prior to 1980 is unknown. The amount was probably about the same, as corn grown on outwash soils requires a minimum of 200 pounds of nitrogen per acre per year.

Kalamazoo County received about 33 inches of rainfall during 1980. Of this, about 23 inches occurred between April 15 and October 15. Rain data were obtained from onsite rain gauges and from data collected and tabulated by the National Oceanic and Atmospheric Administration from weather bureau stations 4244 at the Kalamazoo State Hospital and 3504 at Gull Lake. The corn crop on the farm was irrigated four separate times during the growing season: July 5-8, July 12-15, July 21-24 and August 10-13. One inch of water was applied each time.

## Monitoring Wells

In order to collect ground water for nitrate analysis throughout the growing season a number of water wells and piezometers were incorporated into a monitoring program. These included three piezometers constructed and installed by the author, a domestic well and an irrigation well located on the farm, a domestic water well located adjacent to the farm on the east and nine domestic water wells located in Prairie View Park about one mile northwest of the study site (Figure 12). Water samples were also collected from a leak at the pivot point of the center pivot irrigation system. This was groundwater withdrawn by the onsite irrigation well.

The three piezometers installed by the author were constructed of black steel pipe with an outside diameter of two inches (Figure 13). Five and ten foot sections were coupled together with threaded couplings. A 1 1/2 inch factory slotted well point was used as a screen on each piezometer. Used well points were obtained from local water-well drillers and cleaned with hydrochloric acid to remove calcium carbonate buildup. The well points were coupled to the lowest section of pipe with threaded step-down couplings.

For each of the three piezometer installations a 2 1/2 inch hand auger was used to auger to the water table. Below the water table the hole would not stay open and the casing had to be driven with a cable tool. The cable tool was constructed by building a tripod from three fifteen-foot sections of four-inch steel pipe connected at the top by drilling a hole through each pipe and bolting them together. A pulley was hung from the top and a post hole

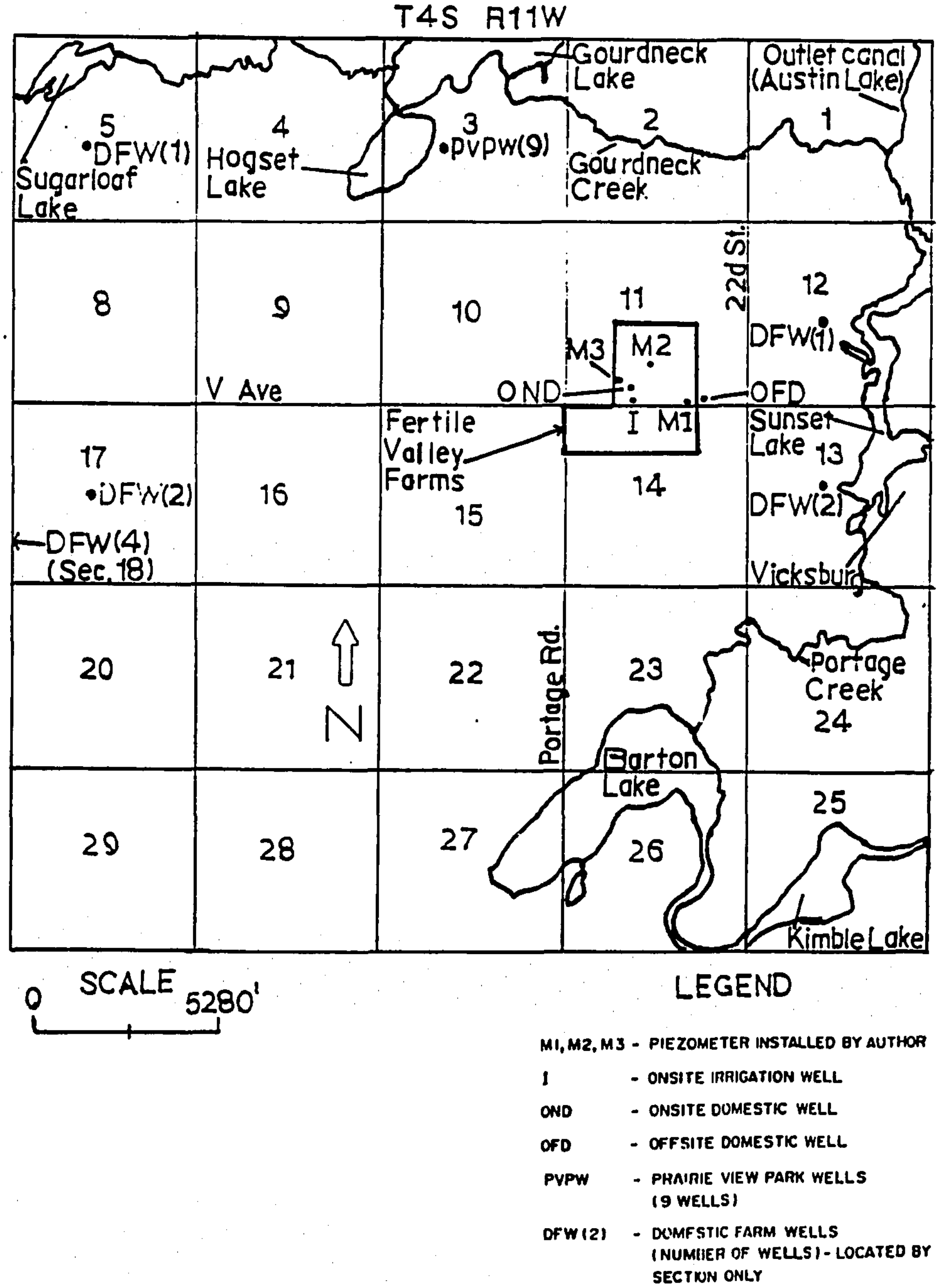


Figure 12. Location of Wells and Piezometers Included in Monitoring Program

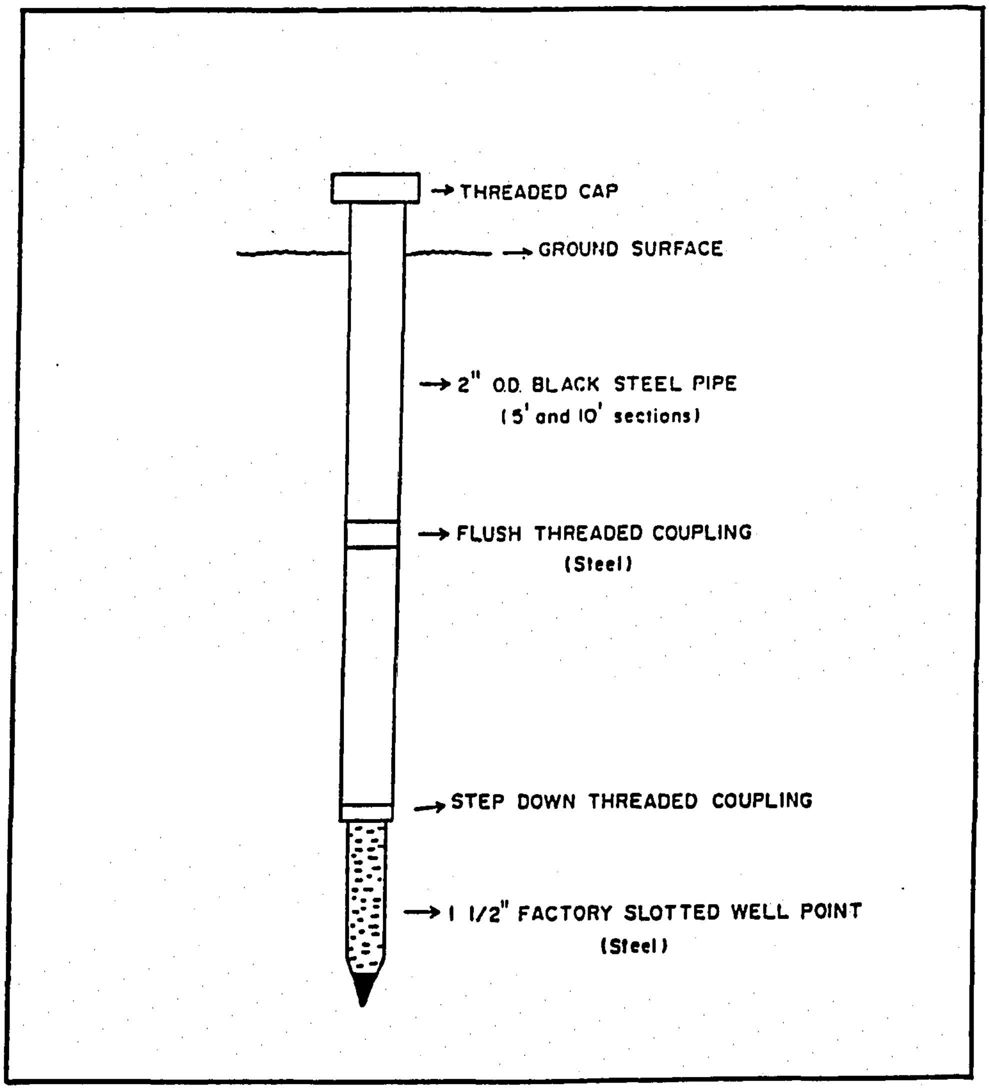


Figure 13. Piezometer Design

driver attached to the pulley. A drive coupling was attached to the section of casing being driven and the post hole driver was repeatedly dropped on the drive coupling driving the casing downward.

Each of the piezometers was gravel packed and developed with the use of a pitcher pump which could be screwed onto the top section of casing. Bentonite clay was placed in the top foot of the annulus to prevent inflow of surface water. The wells were capped with a screw-on steel cap. The casing of each piezometer extended about 1.25 feet above the ground surface. The three piezometers were installed during May and June of 1981.

Piezometer M1, located near the southeast corner of the 160 acre parcel north of V avenue (Figure 12) is 18.5 feet deep with the screened interval extending from 15 to 17 feet. Static water level at this location is about 13.3 feet below the ground surface. Piezometer M2, located near the center of the 160 acre parcel is 20.75 feet deep with the screened interval extending from 19.25 to 20.50 feet. Static water level at this location is about 12.5 feet below the ground surface. Piezometer M3, located near the southwest corner of the 160 acre parcel is 22.5 feet deep with the screened interval extending from 18.75 to 22.25 feet. Static water level at this location is about 15.2 feet below the ground surface.

The onsite irrigation well, located about 1700 feet west of piezometer M1, is 90 feet deep and 14 inches in diameter. A 14 inch stainless steel screen was installed from 60 to 90 feet. The well is equipped with a 75 horsepower reciprocating pump with a capacity of 650 gallons per minute. Static water level at this location is about 20 feet below the ground surface.

Neither of the domestic water wells are registered with the State, consequently little information exists about them. The onsite domestic well, located about 300 feet northwest of the irrigation well is reportedly about 35 feet deep with the lower five to ten feet being screened. The well casing is six inches in diameter at the ground surface. The static water level is reported to be about 15 to 20 feet below the ground surface. This could not be confirmed, however, as the wellhead was not accessible. The offsite domestic well is located on the farm immediately east of the study area. This well is reportedly less than 50 feet deep with the bottom 5 to 10 feet being screened. Static water level at this location is unknown but thought to be less than 20 feet from the ground surface.

## Sampling Program

During the course of this study 63 ground-water samples were collected from the five onsite wells and piezometers, the offsite domestic well and the center pivot leak. All samples were collected and analyzed for nitrate between July 13, 1981 and September 22, 1981. Twenty-three of the samples were also analyzed for iron, sodium, chloride, flouride and hardness (as $CaCO_3$).

Ground-water samples from all wells and piezometers were collected in glass sample bottles obtained from the Kalamazoo County Health Department. These bottles were washed with hydrochloric acid and rinsed with distilled water and deionized water prior to collecting a sample. The sample bottles have a capacity of 500 milliliters. Two milliliters of sulfuric acid were added to each sample for preservation purposes. All samples were refrigerated at about $4^{\circ}$ C from the time of collection until the analyses were performed.

Samples from the three piezometers were collected by using a vacuum pump to withdraw water from the piezometers. The sample was drawn into a glass beaker through a rubber tube which was lowered into the piezometer to a position below the water table. The top of the beaker was sealed with a rubber stopper through which the rubber tube from the piezometer passed. A second rubber tube connected the glass beaker to the vacuum pump. The glass beaker was prepared in the same manner as the sample bottles. Once the sample was collected it was transferred to the glass sample bottle for delivery to the laboratory. Prior to collecting a sample from a piezometer a volume of water equal to three times the volume of the piezometer was removed with the use of a pitcher pump. This was to assure that the sample obtained was withdrawn from the aquifer.

Ground-water samples from the onsite irrigation well were collected from the wellhead when the well was pumping. Since this well was always hooked up to the center pivot system and could not be turned on unless needed for irrigation water, samples could not be collected at any other time.

Samples from the two domestic wells were collected from outside faucets at the two houses. Prior to collecting a sample the faucets were left open until a volume of water approximately equal to three volumes of the well was discharged. Ground-water samples were also collected from a leak at the pivot point of the center pivot irrigation system. The pivot point was located near the center of the 160 acre parcel north of V Avenue. A sample was collected during three of the four times the center pivot was used to irrigate the corn crop.

In order to determine the nitrate concentration in ground water upgradient from the study site nitrate concentration data for water withdrawn from nine shallow wells located in Prairie View Park were obtained from the Kalamazoo County Health Department. Prairie View Park, which is located adjacent to Hogset and Gourdneck Lakes, is about 11/3 miles northwest of the study site. As far as can be determined this land has never been used for agriculture. These wells are sampled on a regular basis by the Kalamazoo County Health Department. Concentration data for nitrate and five other parameters were obtained for May 1979, May 1980 and June 1981.

Nitrate concentration data were also obtained from the Kalamazoo County Health Department for ten other wells in Schoolcraft Township. Seven of these wells are upgradient from the study area and are located in Sections 5, 17 and 18 about three to four miles west and north of the site (Figure 12). The other three wells are located in Section 12 and 13 about 1 to 1 1/2 miles east and south of the study site. These wells are downgradient from the study site. All ten of these wells are shallow wells located on farms and provide water for domestic purposes. The nitrate data are from samples collected between May 1979 and August 1981.

In addition to collecting ground-water samples from various wells and piezometers for nitrate analyses, four sediment samples were leached to obtain an aqueous solution to be analyzed to estimate the amount of nitrate being attenuated by the unconsolidated sediments that comprise the upper aquifer unit. The procedure involves the shaking of a known weight of sediment with water of specified composition and separation of the aqueous phase for analysis. The physical description and depth intervals for the four sediment samples for which a leachate analyses was completed are shown in Table 7. Two of the sediment samples were collected at piezometer M1 and two at piezometer M2. All four samples were collected with a hand auger during installation of the two piezometers.

Table 7

Physical Description and Depth Interval of Sediment Samples Used For Leachate Analyses

| Sample No. | Location | Depth interval (ft. below surface) | Physical description | Weight (grams) |
|---|---|---|---|---|
| M1S | piez. M1 | 3.5 to 4.5 | mod. to well sorted, med. to coarse sand, minor gravel. | 701.7 |
| M1D | piez M1 | 6.7 to 7.7 | mod. to well sorted, med. to coarse sand w/ minor silt and gravel | 702.5 |
| M2S | piez M2 | 3.5 to 4.5 | well sorted, fine to med. sand | 700.0 |
| M2D | piez M2 | 7.25 to 8.25 | well sorted, fine to med sand | 701.0 |

To separate the attenuated nitrate from the sediment, the sediment samples were put in a one gallon Nalgene bottle along with 2800 milliliters of deionized water. the bottles were then put on a Tyler portable sieve shaker (Model No 10017) for 48 hours. After shaking, the sample was put in a centrifuge (International Equipment - Model HN-5) to separate the bulk of the sediment from the leachate. The leachate was then filtered through No. 500 Sargent Filter Paper and then through HA 0.45 UM Filter Paper. The leachate was then collected in a pre-prepared sample bottle and delivered to the lab for nitrate analysis.

Most of the ground-water and leachate samples obtained for this study were analyzed by the Michigan Department of Public Health (MDPH) at their laboratory in Lansing. All samples analyzed by the MDPH were analyzed for nitrate, sodium, iron, fluoride, chloride and hardness (as $CaCO_3$). The MDPH uses the cadmium reduction method for nitrate analysis. Some of the samples were sent to Kar Laboratories in Kalamazoo for nitrate analysis only. Kar Laboratory uses the modified Brucine method for nitrate analysis. All samples were analyzed within six days of delivery to the laboratory.

# RESULTS OF INVESTIGATION

## Water Quality Data

Nitrate nitrogen concentration data for ground-water samples collected from piezometers M1, M2, M3, the onsite domestic well, the onsite irrigation well, the offsite domestic well and the center pivot leak are presented in the Table 8. Fifty-nine ground-water samples from the five onsite wells and piezometers were analyzed for nitrate nitrogen concentration. In addition, one sample from the offsite domestic well and three samples from the center pivot leak were analyzed for nitrate nitrogen concentration. Thus a total of sixty-three groundwater samples were collected for nitrate analysis. All samples were collected during the growing season (July 7 to September 22, 1981).

The exact nitrate concentration for four samples, two each from piezometer M2 and M3, is unknown. This is because the Michigan Department of Public Health does not report the exact nitrate concentration for samples that contain greater than 22 mg/l nitrate nitrogen. Concentrations greater than 22 mg/l are reported merely as >22mg/l. Four of the onsite samples analyzed by the Michigan Department of Public Health contained nitrate nitrogen concentrations in excess of 22 mg/l. For calculating average and median nitrate concentrations for onsite ground-water samples these four samples were considered to have a concentration value of 22 milligrams per liter.

Nitrate nitrogen concentration values for the onsite ground-water samples ranged from 5.5 to at least 42.8 mg/l. The average concentration for the 59 onsite samples is 21.9 mg/l. The median nitrate concentration value for the 59 samples is 17.9 mg/l. Standard deviation for the 59 onsite nitrate values is 8.93. As shown in Table 9, the average and median nitrate concentration values for each of the onsite wells and piezometers are very close. This indicates that the nitrate concentration for each well did not vary greatly over the study period.

The three samples collected from the leak at the center pivot were analyzed by the Michigan Department of Public Health. All these samples were collected while the center pivot system was being used to irrigate the corn crop. Samples were collected on July 7, July 24, and August 12, 1981. Nitrate concentrations in all three samples was greater than 22 mg/l. The water leaking from the center pivot point of the center pivot system is ground water that has been withdrawn from the upper aquifer unit by the onsite irrigation well. One ground-water sample was obtained from an offsite domestic well located immediately

Table 8

Nitrate Nitrogen Concentration Data
for Onsite Wells/Piezometer and
Offsite Domestic Well

| Date Sample Collected | Nitrate Concentration (mg/l) | | | | | | |
|---|---|---|---|---|---|---|---|
| | M1 | M2 | M3 | I | onsite domestic | offsite domestic | CP |
| 7-07-81 | | | | | | | >22.0 |
| 7-13-81 | 15.5 | 36.3 | | | | | |
| 7-15-81 | 13.4 | | | | | | |
| 7-17-81 | 17.5 | 33.4 | 25.8 | 17.0 | 18.3 | | |
| 7-22-81 | 21.1 | 31.8 | 30.8 | 14.9 | 20.6 | | |
| 7-22-81 | 14.0 | 31.0 | | | | | |
| 7-24-81 | 16.2 | >22.0 | >22.0 | 15.3 | 15.8 | | >22.0 |
| 7-24-81 | | 34.0 | 25.3 | | 15.1 | | |
| 8-02-81 | 16.2 | >22.0 | >22.0 | | 14.7 | | |
| 8-02-81 | 14.0 | 39.1 | 25.0 | | 15.4 | | |
| 8-05-81 | 14.2 | 40.0 | 28.8 | | 14.8 | | |
| 8-12-81 | 14.5 | 42.8 | 27.2 | 5.5 | 14.7 | | 15.2 |
| 8-12-81 | | | | | 17.5 | | |
| 8-16-81 | 17.9 | 34.96 | 22.3 | | 15.1 | | |
| 8-16-81 | 14.2 | | | | 16.4 | | |
| 8-21-81 | 17.1 | 40.9 | 27.2 | | 17.9 | | |
| 8-31-81 | 6.9 | 38.4 | 22.8 | | 14.3 | | |
| 9-21-81 | | 37.3 | 24.1 | | 14.5 | | |
| 9-22-81 | 14.6 | | | | | 12.2 | |

Table 9

Average and Median Values of
Nitrate Nitrogen Concentration
for Onsite Wells and Piezometers

| Onsite Well/ piezomer | No. of samples | Average NO3 concentration | Median NO3 concentration |
|---|---|---|---|
| M1 | 15 | 15.2 | 14.6 |
| M2 | 14 | 34.6 | 35.6 |
| M3 | 12 | 25.3 | 25.2 |
| onsite domestic | 14 | 16.1 | 15.3 |
| irrigation | 4 | 13.2 | 15.1 |
| total | 59 | 21.9 | 17.9 |

east of the 160-acre irrigated field north of V avenue. This sample was collected on September 22, 1981 and analyzed on September 28, 1981. The sample was analyzed for nitrate, iron, sodium, chloride, fluoride and hardness (as $CaCO_3$). The sample contained 12.2 mg/l nitrate nitrogen.

Ground-water quality data for 26 samples from nine shallow wells located in Prairie View Park are presented in Table 10. The water quality data were obtained from the Kalamazoo County Health Department and include concentration data for iron, sodium, chloride, fluoride and hardness (as $CaCo_3$) in addition to nitrate. The water quality data from the Prairie View Park wells are from quality data from the Prairie View Park wells are from three separate sampling dates; May 9, 1979, May 8, 1980, and June 9, 1981. Nitrate concentration values for the 26 samples range from 0.0 to 7.1 mg/l. The average nitrate concentration value is 2.0 mg/l and the median concentration value is 1.5 mg/l. None of the samples exceeded the Environmental Protection Agency standard of 10 mg/l.

Water quality data for the four leachate samples obtained from the unsaturated zone beneath the study site are shown in Table 11. All four leachate samples were analyzed for nitrate. Nitrate concentration values ranged from 0.3 to 3.1 mg/l. The highest nitrate concentration was found in leachate obtained from the 3.5 to 4.5 feet interval at piezometer M1. The lowest nitrate concentration was found in leachate obtained from the 6.66 to 7.66 feet interval at piezometer M1. All sediment samples for leachate analysis were collected on September 3, 1981.

Nitrate nitrogen concentration data for ground-water samples collected from ten shallow domestic wells in the vicinity of the study area are presented in Table 12. The data shown in Table 12 were obtained from the Kalamazoo County Health Department. Nine of the ten wells are located on land currently used for agriculture, primarily growing corn. All ten wells are located within four miles of the study site (Figure 12). Seven of the wells are upgradient from the study site and three are downgradient

Table 10

Partial Chemistry Data for
Prairie View Park Wells

| Well Number | Iron (mg/l) | Sodium (mg/l) | Hardness (as CaCO3) (mg/l) | Chloride (mg/l) | Fluoride (mg/l) | Nitrate (as N) (mg/l) |
|---|---|---|---|---|---|---|
| June 9, 1981 | | | | | | |
| 1 | 0.0 | 0.0 | 172 | 7.0 | 0.1 | 7.0 |
| 2 | 0.0 | 1.0 | 169 | 0.0 | 0.1 | 1.2 |
| 3 | 0.1 | 1.0 | 233 | 0.0 | 0.1 | 0.0 |
| HP4 | 0.8 | 2.0 | 256 | 3.0 | 0.2 | 0.0 |
| 5 | 1.0 | 1.0 | 234 | 150.0 | 0.2 | 0.0 |
| 6 | 1.1 | 7.0 | 223 | 73.0 | 0.1 | 0.0 |
| 7 | 0.1 | 0.0 | 160 | 1.0 | 0.0 | 1.6 |
| 8 | 0.4 | 1.0 | 166 | 4.0 | 0.1 | 1.9 |
| 9 | 0.2 | 0.0 | 200 | 1.0 | 0.1 | 6.5 |
| May 9, 1980 | | | | | | |
| 1 | 0.3 | 1.0 | 167 | 3.0 | 0.0 | 3.7 |
| 3 | 0.3 | 1.0 | 195 | 1.0 | 0.0 | 1.4 |
| HP4 | 0.6 | 2.0 | 237 | 1.0 | 0.1 | 0.0 |
| 4 | 0.3 | 1.0 | 255 | 3.0 | 0.0 | 0.2 |
| 5 | 0.0 | 1.0 | 238 | 1.0 | 0.1 | 0.0 |
| HP5 | 0.7 | 6.0 | 236 | 8.0 | 0.1 | 0.0 |
| 7 | 0.0 | 2.0 | 147 | 4.0 | 0.0 | 2.1 |
| 9 | 0.4 | 0.0 | 169 | 4.0 | 0.0 | 7.1 |
| BEACH | 0.3 | 1.0 | 157 | 1.0 | 0.0 | 2.0 |

Table 10--Continued

| May 9, 1979 | | | | | | |
|---|---|---|---|---|---|---|
| Well Number | Iron (mg/l) | Sodium (mg/l) | Hardness (as CaCO3) (mg/l) | Chloride (mg/l) | Fluoride (mg/l) | Nitrate (as N) (mg/l) |
| 1 | 0.1 | 0.0 | 166 | 1.0 | 0.0 | 4.5 |
| 3 | 0.0 | 0.0 | 204 | 0.0 | 0.0 | 1.6 |
| 4 | 0.1 | 0.0 | 248 | 0.0 | 0.0 | 0.0 |
| 5 | 0.1 | 3.0 | 256 | 4.0 | 0.2 | 0.0 |
| 5 | 0.0 | 0.0 | 233 | 1.0 | 0.0 | 0.0 |
| 7 | 0.0 | 0.0 | 154 | 4.0 | 0.0 | 2.1 |
| 9 | 0.3 | 0.0 | 148 | 2.0 | 0.0 | 5.8 |
| BEACH | 0.0 | 0.0 | 169 | 0.0 | 0.0 | 2.0 |

Table 11

Water Quality Data for
Leachate Samples

| Piezometer | Sampled Interval | Parameters (mg/l) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Fe | Na | Hardness | Cl | Fl | N03 |
| M1 | 3.5'-4.5' | | | | | | 3.1 |
| M1 | 6.66'-7.66' | | | | | | 0.3 |
| M2 | 3.5'-4.5' | 0.0 | 0.0 | 26 | 2 | 0.0 | 0.8 |
| M2 | 7.25'-8.25' | 1.2 | 1.0 | 57 | 21 | 0.1 | 0.4 |

from the study site. Nitrate concentration values for the 10 wells ranged from 10.2 to >22 mg/l. Nitrate concentration data for all but one of the ten wells are for samples collected in 1981.

Of the 103 ground-water samples for which nitrate concentration data are presented in Tables 8, 10, 11 and 12, fifty-one samples were analyzed for iron, sodium, chloride, fluoride and hardness (as $CaCO_3$) (Tables 10, 11, and 13). Twenty-three of the ground-water samples collected by the author were analyzed for the above parameters. The 26 samples from Prairie View Park wells and two of the soil leachate samples were analyzed for these parameters. All partial chemical analyses were completed by the Michigan Department of Public Health. These analyses were also completed to provide data for characterizing the natural chemistry of the ground water in the upper aquifer unit.

The range of concentration values, average concentration value and median concentration value of the partial chemistry data for the onsite ground-water samples are shown in Table 14.

As shown in Table 14, the median concentration value for iron, sodium, chloride and fluoride is significantly lower than the average concentration value. This is due to the unusually high concentration of these parameters contained in a ground-water sample collected on August 31,

Table 12

Nitrate Nitrogen Concentration Data for Ground Water Samples Collected From Selected Shallow Domestic Wells in Vicinity of Study Site

| Well location (all wells in T4S, R11W) | Date of Sample Collection | Nitrate nitrogen concentration (mg/l) |
|---|---|---|
| 1880 V Ave. Section 5 | May 6, 1981 | 16.0 |
| VW Ave. Section 18 | April 16, 1981 | 15.4 |
| 575 VW Ave. Section 13 | March 25, 1981 | 17.2 |
| 4700 West VW Ave. Section 18 | April 6, 1981 | >22.0 |
| 4928 VW Ave. Section 18 | March 25, 1981 | >22.0 |
| 4928 VW Ave. Section 18 | March 25, 1981 | >22.0 |
| 2033 West VW Ave. Section 17 | March 11, 1981 | 15.5 |
| 4734 West VW Ave. Section 13 | April 30, 1981 | >22.0 |
| 2382 West W Ave. Section 17 | April 8, 1981 | 14.1 |
| Plainsman Motel U.S. 131 Section 12 | May 1, 1980 | 10.2 |

1981 from piezometer M1. The concentration values of these four parameters for the August 31, 1981 sample were as follows: iron > 5.5 mg/l, sodium = 11mg/l, chloride = 166 mg/l, fluoride = 0.4 mg/l. It is unknown if this sample was contaminated during collection or transport or if these concentrations were present in the ground water. Based on the other onsite partial chemistry data, the author suspects that the August 31, 1981 sample from piezometer M1 was contaminated.

The range of concentration values, average concentration value and median concentration values of partial chemistry data for the 26 ground-water samples from the Prairie View Park wells are shown in Table 15.

The average chloride concentration (10.7 mg/l) for the 26 Prairie View Park samples is significantly higher than the median chloride concentration value (1.5). This is because of two samples collected on June 9, 1981 form Prairie View Park wells 5 and 6. The values for these two samples, 150 and 73 mg/l respectively, are probably due to contamination of the samples.

A partial chemical analysis was also completed for the one ground-water sample from the offsite domestic well (Table 13). This sample was collected on September 22, 1981. Results of the partial chemical analysis are as follows: iron = 0.3 mg/l, sodium = 0.0 mg/l, hardness = 226 mg/l, chloride = 8.0 mg/l and fluoride = 0.0 mg/l. A

Table 13

Partial Chemistry Data for Onsite
Wells and Piezometers, Offsite
Domestic Wells and Center
Pivot Leak

| Date | Iron (mg/l) | Sodium (mg/l) | Hardness (as CaCO3) (mg/l) | Chloride (mg/l) | Fluoride (mg/l) |
|---|---|---|---|---|---|
| Piezometer M1 | | | | | |
| 8-02-81 | 0.2 | 0.0 | 253 | 11.0 | 0.0 |
| 8-05-81 | 0.3 | 0.0 | 239 | 6.0 | 0.0 |
| 8-12-81 | 0.5 | 0.0 | 288 | 7.0 | 0.0 |
| 8-16-81 | 0.5 | 0.0 | 283 | 14.0 | 0.0 |
| 8-31-81 | >5.5 | 11.0 | 310 | 166.0 | 0.4 |
| 9-22-81 | 0.5 | 0.0 | 262 | 7.0 | 0.0 |
| Piezometer M2 | | | | | |
| 7-24-81 | 1.4 | 0.0 | 324 | 7.0 | 0.1 |
| 8-02-81 | 0.7 | 0.0 | 343 | 7.0 | 0.0 |
| 9-22-81 | 2.6 | 2.0 | 362 | 12 | 0.1 |
| Piezometer M3 | | | | | |
| 7-24-81 | 0.2 | 0.0 | 322 | 13.0 | 0.1 |
| 8-02-81 | 0.7 | 0.0 | 334 | 14.0 | 0.0 |
| 9-22-81 | 0.2 | 2.0 | 340 | 5.0 | 0.0 |

Table 13--Continued

| Date | Iron (mg/l) | Sodium (mg/l) | Hardness (as CaCO3) | Chloride (mg/l) (mg/l) | Fluoride (mg/l) |
|---|---|---|---|---|---|
| | | | Onsite Domestic Well | | |
| 7-24-81 | 0.1 | 1.0 | 235 | 6.0 | 0.0 |
| 8-02-81 | 0.1 | 0.0 | 229 | 10.0 | 0.0 |
| 8-05-81 | 0.2 | 2.0 | 210 | 6.0 | 0.0 |
| 8-12-81 | 0.3 | 1.0 | 237 | 7.0 | 0.0 |
| 8-16-81 | 1.6 | 1.0 | 244 | 17.0 | 0.0 |
| 8-31-81 | 4.9 | 0.0 | 231 | 15.0 | 0.0 |
| 9-22-81 | 0.2 | 1.0 | 238 | 10.0 | 0.0 |
| | | | Irrigation Well | | |
| 7-24-81 | 0.0 | 0.0 | 256 | 4 | 0.1 |
| 8-12-81 | 0.2 | 2.0 | 257 | 6.0 | 0.1 |
| | | | Center Pivot Leak | | |
| 7-24-81 | 0.0 | 0.0 | 251 | 5.0 | 0.1 |
| | | | Offsite Well (Neighbor to East) | | |
| 9-22-81 | 0.3 | 0.0 | 226 | 8.0 | 0.0 |

Table 14

Range of Concentration Values, Average Concentration Values and Median Concentration Values of Partial Chemistry Data for 22 Onsite Ground-Water Samples

| Parameter | Range of Concentration Value (mg/l) | Average Concentration Value (mg/l) | Median Concentration Value (mg/l) |
|---|---|---|---|
| Iron | 0.0 - 5.5 | 0.9 | 0.3 |
| Sodium | 0.0 - 11.0 | 1.1 | 0.0 |
| Fluoride | 0.0 - 0.4 | 0.05 | 0.0 |
| Chloride | 5.0 - 166.0 | 16.1 | 7.0 |
| Hardness | 210 - 362 | 274.9 | 256.5 |

Table 15

Range of Concentration Values, Average Concentration Value and Median Concentration Values of Partial Chemistry Data for Prairie View Park Ground-Water Samples

| Parameter | Range of Concentration Value (mg/l) | Average Concentration Value (mg/l) | Median Concentration Value (mg/l) |
|---|---|---|---|
| Iron | 0.0 - 1.1 | 0.3 | 0.2 |
| Sodium | 0.0 - 7.0 | 1.2 | 1.0 |
| Fluoride | 0- 0.2 | 0.06 | 0.0 |
| Chloride | 0.0 - 150 | 10.7 | 1.5 |
| Hardness | 147 - 256 | 200 | 98 |

partial chemical analysis was also completed for two of the four leachate samples obtained from the unsaturated zone beneath the study site (Table 11). The values shown in Table 11 represent concentrations that have been leached from sediments.

Depth to water was measured in piezometers M1, M2 and M3 from July 3, 1981 until September 3, 1981. During this period the ground-water level fluctuated about one foot in piezometers M1 and M2 and about nine inches in piezometer M3. The water level in each of the three piezometers fluctuated in response to infiltration of precipitation and applied irrigation water. Pumping of the irrigation well did not significantly effect the water level in the three piezometers.

## Discussion and Conclusions

Partial chemistry data from forty nine ground-water samples from onsite wells and piezometers, the offsite domestic well and the Prairie View Park wells were used to characterize the natural chemistry of the ground water in the upper aquifer unit in the vicinity of the study area. The chemical quality of ground water in the glacial outwash is determined largely by the mineralogy of the outwash deposits and its location within the aquifer with respect to recharge areas. The upper aquifer unit is unconfined and the water table is within 20 feet of the ground surface. This results in an open ground-water system characterized by active ground-water flushing. A lithologic analysis of outwash in Schoolcraft Township (Shah, 1974) indicate that the outwash deposits are comprised primarily of fragments of carbonate rocks, igneous rocks, and chert. The outwash sediment contains very little feldspar or shale.

Analysis of the partial chemical data indicate that ground-water in the upper aquifer unit in the vicinity of the study site is typical of shallow ground water found in glacial deposits of this type. The water is hard to very hard with hardness concentrations ranging from 147 to 362 mg/l (as $CaCO_3$). Thirty seven of the forty-nine samples contained hardness concentrations greater than 180 mg/l which is considered very hard. Hardness concentrations were consistantly higher in piezometers M2 and M3. Both of these piezometers were located in the corn field. The higher hardness values from these two piezometers could be a result of liming the corn field.

Chloride concentration in ground water in these types of glacial deposits are generally less than 100 mg/l due to the absence of evaporite fragments (Freeze & Cherry, 1979). Chloride concentrations in the forty-nine samples ranged from 0.0 to 166.0 mg/l. However only three of the samples contained chloride in concentrations greater than 17 mg/l. Two of these samples are from Prairie View Park (wells 5 and 6) and one from piezometer M1. As discussed previously the high chloride concentration (166 mg/l) in the August 31, 1981 sample from piezometer M1 may be due to contamination of the sample. Contamination may be due to infiltration of road salt or to improper cleaning of sample bottles with hydrochloric acid.

Sodium concentrations in the forty nine samples were very low ranging from 0 to 11 mg/l. This reflects the relative scarcity of feldspar fragments in the outwash deposits. The lithologic analysis completed by Shah (1974) for outwash sediment in Schoolcraft Township indicated that only 8% of the sand fraction of the outwash is comprised of feldspar fragments and none of the gravel fraction contained feldspar.

Iron concentrations for the forty nine ground-water samples ranged from 0.0 to >5.5 mg/l. However only six of the samples contained iron concentrations in excess of 1.0 mg/l. The median iron concentration value was 0.25 mg/l. Only a small percentage of the rock fragments which comprise the outwash deposits are likely to contain iron. The iron found in the forty nine ground-water samples may be due to corrosion and encrustation of steel well screens and casing. Fluoride concentrations in the forty nine ground-water samples ranged from 0.0 to 0.4 mg/l with a median concentration value of 0.05 mg/l. The concentration of fluoride in most natural water with less than 1000 mg/l total dissolved solids, is less than 1 mg/l.

Primary maximum contaminant levels have been established by the Environmental Protection Agency for fluoride concentrations in community water systems. The maximum concentration levels for fluoride depend on the annual average of the maximum daily air temperatures. The maximum contaminant level ranges from 1.4 to 2.4 mg/l decreasing with increased average maximum air temperature. None of the forty nine ground water samples analyzed for this report contained fluoride concentrations in excess of 0.4 mg/l. Secondary maximum contaminant levels have been established by the EPA for iron and chloride concentrations in drinking water. The maximum contaminant level is 0.3 mg/l for iron and 250 mg/l for chloride. Secondary maximum contaminant levels apply to water quality parameters which may affect the aesthetic quality of water. Seventeen of the forty nine ground-water samples contained iron in excess of 0.3 mg/l. None of the forty-nine samples contained chloride in excess of 250 mg/l.

Nitrate nitrogen concentration data from 99 ground-water samples collected from the upper aquifer unit in the vicinity of the study site were tabulated and analyzed to determine if a relationship existed between surface application of nitrogen fertilizer and excess nitrate concentrations in ground water in the underlying shallow, unconfined upper aquifer unit. Four leachate samples obtained from the unsaturated zone beneath the study site were also analyzed for nitrate to see if nitrate ions were being adsorbed by sediment particles.

Nitrate nitrogen concentrations in naturally occurring ground water are generally very low. There are a few inorganic sources of nitrogen and rainfall contains small concentrations of nitrate. However neither of these sources is thought to contribute much nitrate to ground water. Nitrate in ground water generally originates from nitrogen sources on the ground surface and in the soil zone. Through the processes of ammonification representative of the naturally occurring ground water in the glacial deposits.

The nitrate nitrogen concentration data from the 26 Prairie View Park samples indicate that the upper aquifer unit in the vicinity of the study area contains little naturally occurring nitrate. Land use at Prairie View Park has never included agriculture or waste disposal. The land underlying the Park is bordered to the northwest or upgradient side by Hogset and Gourdneck Lakes. Water in these lakes contains low concentrations of nitrates. The 26 ground-water samples from Prairie View Park contained nitrate concentrations ranging from 0.0 to 7.1 mg/l. The median concentration value was 1.5 mg/l and the average concentration value was 2.0 mg/l. Average and median nitrate concentration values for each of the three sample dates are very close. The two highest nitrate concentration values (7.0 and 7.1 mg/l) were from samples collected in 1980 and 1981. In 1979 and 1980 three of the nine Prairie View Park wells had nitrate concentrations of 0.0 mg/l. In 1981, four of the nine wells had nitrate concentrations of 0.0 mg/l. None of the samples exceeded the E.P.A. primary standard of 10 mg/l.

Nitrate nitrogen concentration data from the fifty nine ground-water samples collected from onsite wells and piezometers indicate very clearly that ground water in the upper aquifer unit beneath the study site contains nitrate nitrogen in concentrations significantly above naturally occurring background levels. The fifty nine onsite samples were collected from July 13 to September 22, 1981. The first sample was collected about 8 weeks after the corn was planted. Prior to planting anhydrous ammonia ($NH_3$) was applied directly to the soil at a rate of 50 pounds per acre. On June 23rd and 24th anhydrous ammonia was again applied to the soil at a rate of 160 pounds per acre. Thus a total of 210 pounds of nitrogen per acre has been applied to the land surface prior to collection of the first ground-water samples from the onsite wells and piezometers. A final application of fertilizer (28% nitrogen solution) was applied through the irrigation system from July 21 through July 24 at a rate of forty pounds per acre. The three split applications resulted in a total nitrogen fertilizer application of 250 pounds per acre.

Nitrate concentration values for the 59 onsite samples ranged from 5.5 to at least 42.8 mg/l. All but two of the onsite samples contained nitrogen in excess of the E.P.A. primary contaminant level (10 mg/l as N). The average concentration value for the 59 onsite samples was 21.9 mg/l and the median concentration value was 17.9 mg/l. Of the five onsite wells and piezometers, samples from piezometer M2 had the highest average (34.6 mg/l) and median (35.6 mg/l) concentration values. Ground-water samples from the onsite irrigation well had the lowest average concentration.

Nitrate concentration versus time for the five onsite wells and piezometers are shown in Figure 14. Also shown on Figure 14 are the rainfall and irrigation events fo the period July 6 through September 24, 1981. Nitrate concentrations in ground water collected from piezometers M2 and M3 were consistantly higher than nitrate concentrations from piezometer M1, the irrigation well and the onsite domestic well. Piezometer M2 was located adjacent to the pivot point of the center pivot system in the middle of the 160 acre corn field north of V avenue. Whenever the center pivot system is being used water is continuously being applied to the area around the pivot point. Approximately 72 hours are required to irrigate the 160-acre field. Thus the area around piezometer M2 receives water continuously for 72 hours. This occurred four separate times during the study period.

Nitrate concentrations in samples from piezometers M2 and M3 correlate with irrigation and high precipitation events. This is shown on Figure 14 by the increase in nitrate concentrations in these two piezometers after irrigation events on July 15, July 24 and August 13. The concentration versus time graphs for piezometer M1, the onsite domestic well and the irigation well do not show

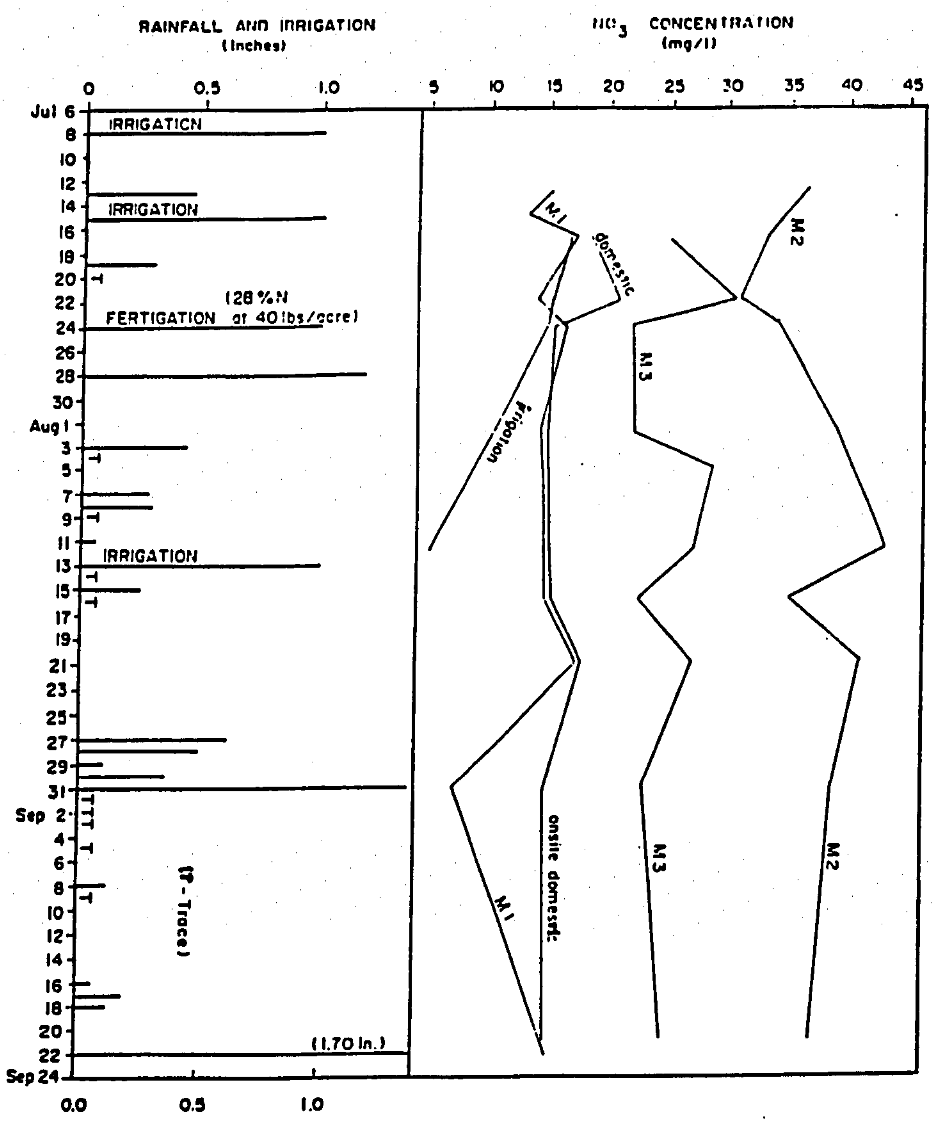


Figure 14. Graphs Showing Nitrate Concentration vs. Time for Onsite Wells and Piezometers, Rainfall and Irrigation Events

any correlation between nitrate concentrations and irrigation and rainfall events.

Three ground-water samples were collected from a leak at the pivot point of the center pivot system. These samples were collected on July 7, July 24 and August 12, 1981. The center pivot point system was in use on all three dates. From July 21 to July 24 a 28% nitrogen solution was injected into the water being delivered to the center pivot from the irrigation well. This was the only time that nitrogen fertilizer was applied while irrigating. The nitrate concentration values of the three samples collected from the center pivot point leak were all greater than 22 mg/l. A ground-water sample was also collected from the irrigation well during each of the three irrigation events for which samples were collected from the center pivot leak. The nitrate concentration from the center pivot leak and from the irrigation well are presented in Table 16.

Table 16

Nitrate Nitrogen Concentrations in Ground-Water Samples From Onsite Irrigation Well and Center Pivot Leak

| Date | Nitrate nitrogen concentrations (mg/l) Center pivot leak | Irrigation well |
|---|---|---|
| 7-07-81 | >22 | 17.0 |
| 7-24-81 | >22 | 15.3 |
| 8-12-81 | >22 | 5.5 |

Because fertilizer was not applied during the July 5-8 and August 10-13 irrigation events, the nitrate concentrations values for the center pivot leak and the irrigation well should be about the same for the samples collected on July 7 and August 12. As shown in Table 16 the center pivot leak contained a significantly higher concentration of nitrate than the samples from the irrigation well. The reason for this is unknown. It may be that excess nitrogen fertilizer remains in the delivery pipes and is then flushed out on subsequent irrigation events. In any event the data indicate that the irrigation water that is applied in the vicinity of piezometer M2 contains high concentrations of nitrate.

Nitrate concentrations for ground-water samples collected from piezometer M1, the onsite domestic well and the irrigation well were somewhat lower than those of samples from piezometers M2 and M3. This is clearly indicated by the significantly higher average and median nitrate concentration values for piezometer M2 and M3. Piezometers M2 and M3 were both located in the 160-acre corn field. Piezometer M1, the irrigation well and the onsite domestic well were all located a few hundred feet south of the corn field. Therefore no nitrogen fertilizer was applied to the land surface in the immediate vicinity of piezometer M1 or the two onsite wells.

The nitrate nitrogen concentration data from the onsite wells and piezometers indicate that nitrate is being leached to the water table beneath the 160-acre corn field and then moving downgradient with the ground water. Nitrate concentrations are highest in ground water immediately beneath the fertilized, irrigated 160-acre corn field. Excessively high nitrate concentrations are also found in wells and piezometers immediately downgradient from the corn field. A ground-water sample was collected on September 22, 1981, from an offsite domestic well located a few hundred feet east of the southeast corner of the corn field. The nitrate nitrogen concentration of this sample was 12.2 mg/l. This well is also downgradient from the corn field.

Nitrogen fertilizer that is applied at the surface is subject to ammonification and nitrification in the unsaturated zone. Through these two processes organic nitrogen is converted to nitrate. Both ammonification and nitrification normally occur above the water table where oxygen is readily abundant. The unsaturated zone beneath the 160-acre corn field is comprised of well-drained permeable sediments and oxygen is relatively abundant. Very little nitrate is attenuated by sediment particles in the unsaturated zone. Nitrate concentrations in the four leachate samples obtained from the unsaturated zone beneath the study site ranged from 0.3 to 3.1 mg/l. Only the leachate sample obtained from the 3.5 feet to 4.5 feet interval at piezometer M1 contained nitrate in excess of 1 mg/l. At both piezometer M1 and piezometer M2 the nitrate concentration was less in the leachate sample collected from the lower sediment sample.

Ground water in shallow aquifers is generally high in dissolved oxygen. Because of this and the high solubility of the nitrate ion, nitrate that reaches the water table will migrate freely in the downgradient direction. The nitrate moves downgradient at velocities very close to that of the ground water in which it is dissolved. The distribution of nitrate concentrations beneath the corn field is shown in Figure 15. As shown in Figure 15 nitrate in the ground water beneath the corn field is spreading out and declining in concentration in the direction of flow. As discussed previously the estimated average linear velocity across the study site is 0.46 feet per day. Thus it is readily apparent that nitrate

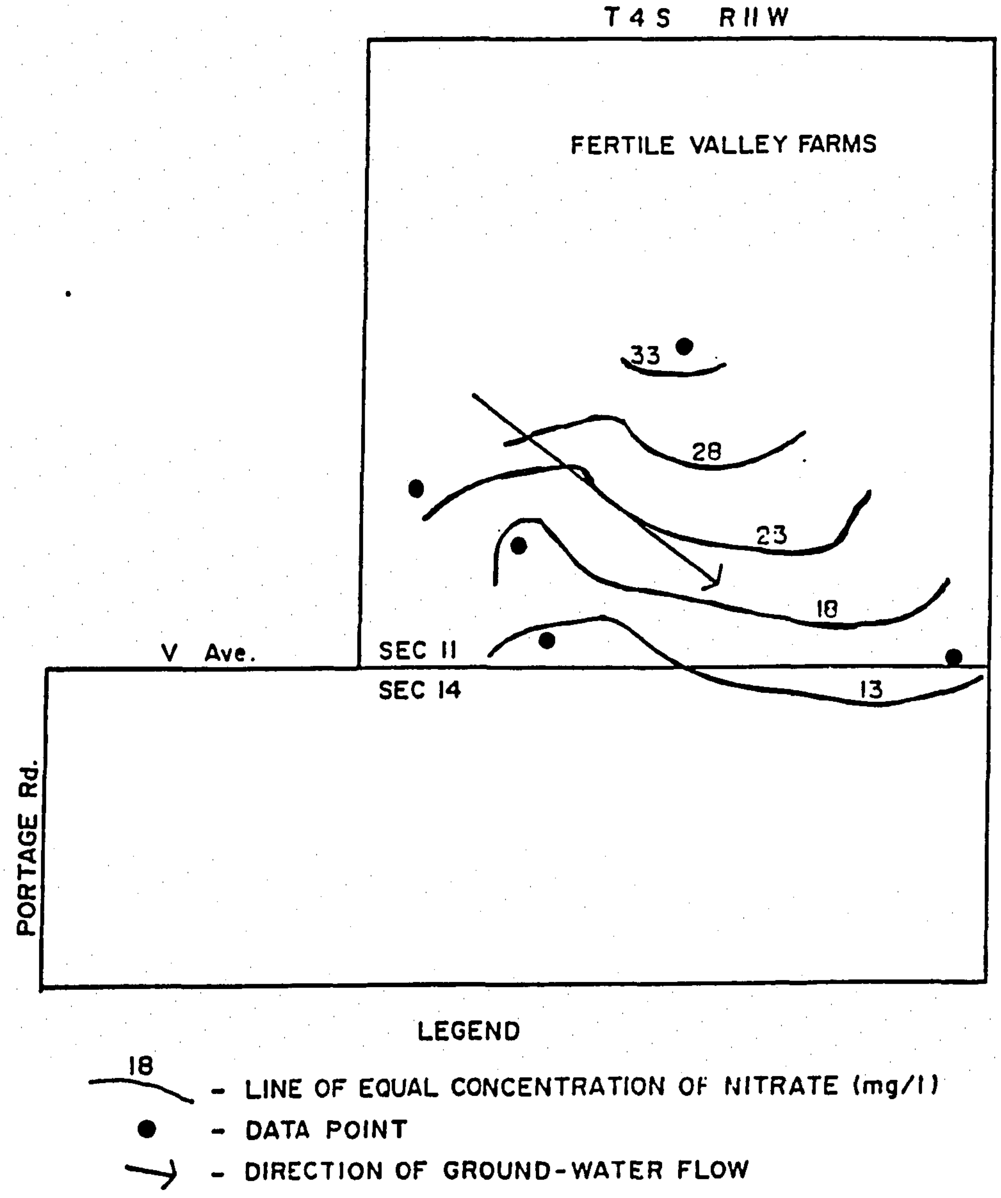


Figure 15. Map Showing Contours of Nitrate Concentration in Ground Water Beneath Study Site

entering the ground water beneath the corn field can easily migrate downgradient to the location of the onsite domestic well, the irrigation well, the offsite domestic well and piezometer M1.

Data were not available for this study site to determine seasonal changes in nitrate concentration of ground water in the upper aquifer unit. Due to the low water-holding capacity of the outwash sediments and the permeable nature of the unsaturated zone sediments it is likely that most of the excess nitrate from a given years' fertilizer application would be leached to the water table by the following spring. The fact that all of the onsite wells and piezometer had high nitrate concentrations from the beginning of the study period indicate that the groundwater contained high nitrate concentrations prior to the first application of fertilizer in late April.

The lack of appreciable organic material in the upper aquifer probably inhibits denitrification and subsequently little nitrate is removed this way. Some studies (Buresh and Maraghan, 1976) have indicated that nitrate is reduced to nitrogen ($N_2$) by ferrous iron present in the anaerobic region of the aquifer. This is accomplished by denitrifying bacteria. This is probably not a dominant process in the upper aquifer unit beneath the study site due to the lack of ferrous iron and the probable decrease in nitrate concentration with depth below the water table.

Nitrate nitrogen concentration data from 10 shallow wells, located on or near other farms in Schoolcraft Townwhip which grow corn, indicate that leaching of excess nitrate is a problem throughout the area. Nitrate nitrogen concentration from the ten wells, located within four miles of the study site, ranged from 10.2 to > 2 mg/l. All but one of the ten wells were sampled in the spring of 1981. The nitrate concentrations in water from these wells indicate that the upper aquifier unit in Schoolcraft Township contains high nitrate concentrations over wide areas where corn is grown on soils that developed on the outwash deposits.

# SUMMARY

Water quality data from 103 ground-water samples collected from the upper aquifer unit in central Schoolcraft Township were analyzed to determine if there is a relationship between organic nitrogen fertilizer applied to the land surface and high nitrate concentration in the underlying ground water. Sixty-two ground water samples were collected from the upper aquifer unit beneath a 160-acre corn field on which nitrogen fertilizer was applied in three applications that resulted in a total applications of 250 pounds per acre. One ground-water sample was collected from a shallow domestic well on property adjacent to the corn field on the east and four leachate samples were obtained from the unsaturated zone beneath the corn field. In addition ground-water quality data were obtained from the Kalamazoo County Health Department for 26 ground-water samples from the Prairie View Park wells and 10 samples from other domestic water wells located on or near other corn farms in Schoolcraft Township.

Nitrate nitrogen concentration data from the Prairie View Park wells indicate that naturally occurring ground water in the upper aquifer unit in Schoolcraft Township is

very low in nitrate concentration. The land that comprises Prairie View Park has remained essentially undeveloped. Hogset and Gourdneck Lakes are adjacent to the Park on the upgradient side.

The nitrate nitrogen concentration data from the sixty-two onsite ground-water samples clearly indicate that ground water in the upper aquifer unit beneath the 160-acre corn field and beneath thearea immediately downgradient from the corn field contains nitrate concentrations that are far above those at Prairie View Park. All but two of the 62 samples contained nitrate in excess of 10 mg/l. Nitrate concentrations were highest in two piezometers located in the 160 acre field. The three other onsite wells and piezometers and the offsite domestic well contained nitrate in concentrations greater than 10 mg/l but less than the concentrations from the two piezometers in the field.

The 160-acre corn field is underlain by up to 200 feet of permeable outwash deposits which are hydraulically divided into two aquifer units. The upper aquifer unit is unconfined and about 90 feet thick. Depth to water is less than 20 feet in the vicinity of the study site. The soils developed on the outwash are sandy loams with a low water holding capacity. Corn is commonly grown on the outwash soils. Large per acre yields are obtained by fertilizing and irrigating egularly. A center pivot system was used to irrigate the 160-acre field. The crop was irrigated four times during 1981. One inch of water was applied each time. Kalamazoo County received about 33 inches of rain during 1981.

A portion of the nitrogen fertilizer applied at the surface moves past the root zone before the corn plant can take up the nitrogen and use it. The excess nitrogen is converted to nitrate in the unsaturated zone by dentrification. The nitrate moves vertically through the unsaturated zone until it reaches the water table where it migrates freely with the ground water. The well drained soil, the permeable sediments which comprise the aquifer and the shallow water table create hydrogeologic conditions which enhance the conversion of excess nitrogen to nitrate and the mobility of nitrate in the unsaturated zone and underlying ground water. Analyses of leachate samples obtained from sediments from the unsaturated zone beneath the study indicate that very little nitrate is attenuated by sediment particles.

Nitrate concentration in samples from the onsite domestic well were consistently over the E.P.A. standard of 10 mg/l (as N). The sample obtained from the offsite domestic well contained 12.2 mg/l nitrate nitrogen. Water containing more than 10 mg/l nitrate (as N) poses a serious health threat to infants. Ingestion of high nitrate water over an extended period of time can cause methemoglobinemia in infants. This is a condition where the bloods' capacity to carry oxygen is reduced and the infant may suffocate. At least one case of methemoglobinemia has occured in Kalamazoo County.

Nitrate nitrogen concentration data from other shallow domestic farm wells in Schoolcraft Township indicate that nitrate contamination of shallow ground water may be a widespread problem in areas where corn is grown on permeable outwash sediments. Efforts should be undertaken by the Kalamazoo County Health Department and the local office of the United States Department of Agriculture to alleviate this problem by combining improved agricultural practices with appropriate water quality treatment.

APPENDIX

Geologic logs of onsite piezometers

| Depth below surface (ft) | Thickness (ft) | Lithology |
|---|---|---|
| | Piezometer M1 | |
| 0-0.5 | 0.5 | topsoil |
| 0.5-6.6 | 6.0 | fine sand |
| 6.5-8.5 | 2.0 | med. sand w/ gravel |
| 8.5-13.3 | 4.8 | med. to coarse sand |
| | Piezometer M1 | |
| 0-3.5 | 3.5 | topsoil |
| 3.5 | 1.7 | fine sand |
| 5.2-7.1 | 1.9 | med sand |
| 7.1-7.6 | 0.5 | med to cause |
| 7.6-12.5 | 4.9 | med sand |
| | Piezometer M3 | |
| 0-3.0 | 3.0 | topsoil |
| 3.0-11.7 | 8.7 | med. sand |
| 11.7-14.8 | 2.5 | fine sand |
| 14.8-15.2 | 0.4 | gravel |

Geologic logs of selected obervation holes
(from Keck, 1973)

| Depth below surface (ft) | Thickness (ft) | Lithology |
|---|---|---|
| | C-1 | |
| 0-2.25 | 2.25 | topsoil |
| 2.25-15.0 | 12.75 | med. to coarse sand |
| 15.0-67.0 | 52.0 | coarse sand w/ gravel |
| 67.0-72.5 | 7.5 | gray clay |
| 72.5-101.0 | 28.5 | sand and gravel |
| 101-110 | 9.0 | clay till |
| | F-4 | |
| 0-2 | 2.0 | topsoil |
| 2-4 | 2.0 | silty clay |
| 4-14 | 10.0 | sand and gravel |
| 14-20 | 6.0 | fine to med. sand |
| 20-52 | 32.0 | coarse sand |
| 52-80 | 28.0 | sand and gravel |
| 80-90 | 10.0 | brown to gray till |
| | H-1 | |
| 0-83 | 83 | sand and gravel |
| 83-93 | 10 | sandy clay till |

Geologic logs of selected observation holes (continued)

| | | |
|---|---|---|
| | H-6 | |
| 0-2.5 | 2.5 | topsoil |
| 2.5-52 | 49 | coarse sand |
| 52--54 | 2.0 | clay |
| 54-69 | 15.0 | gravel |
| 69-79 | 10.0 | clay till |
| | J | |
| 0-2.5 | 2.5 | topsoil |
| 2.5-15 | 12.5 | sand and gravel |
| 15-45 | 30.0 | course sand and gravel |
| 45-50 | 5.0 | gavel w/ clay |
| 50-63 | 13.0 | clay till |
| 63-64 | 1.0 | course gravel |
| | UCW4 | |
| 0-2 | 2.0 | topsoil |
| 2-4 | 2.0 | sandy clay |
| 4-34 | 30.0 | sandy w/ gravel |
| 34-54 | 20.0 | clay w/ gravel |
| 54-70 | 16.0 | coarse gravel |
| 70-81 | 11.0 | clay |
| 81-100 | 19.0 | med. sand |
| 100-144 | 44.0 | med. sand w./ gravel |

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