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An Analysis of Nitrate Concentrations in the Ground-Water of Antwerp Township, Van Buren County, Michigan

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AN ANALYSIS OF NITRATE CONCENTRATIONS IN THE GROUND-WATER OF ANTWERP TOWNSHIP, VAN BUREN COUNTY, MICHIGAN

by

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AN ANALYSIS OF NITRATE CONCENTRATIONS IN THE GROUND-WATER OF ANTWERP TOWNSHIP, VAN BUREN COUNTY, MICHIGAN

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Private wells were tested for nitrate during the spring of 1979 throughout sections of Antwerp Township, Van Buren County, southwestern Michigan (sections 1-5, 7-22, 24-26, 28-31, 33-36). Water samples were collected from 159 private wells and analyzed for nitrate. Nitrate concentrations ranged from less than 1 mg/l NO_3-N to 14.6 mg/l NO_3-N. Seven wells were found to have nitrate concentrations equaling or exceeding the National Interim Primary Drinking Water Standard of 10 mg/l NO_3-N. Nitrate concentrations were related to age of septic system, well depth below static water level, land use, and soil type. Septic system effluent and livestock wastes were found to correlate closely with high nitrate concentration (greater than 10 mg/l NO_3-N), resulting from nitrification and leaching of wastes through highly permeable soils to the ground water. Shallow wells located at sites with older septic systems showed the highest average nitrate concentrations. Wells located on farm sites had higher nitrate concentrations. Wells that were deepest below static water level had lower nitrate concentrations. All soil types posed severe limitations for septic systems as defined by the Soil Conservation Service, with wells located in areas of Spinks Sand showing the highest nitrate concentrations.

ACKNOWLEDGEMENTS

Drillers records and septic system permits provided by the Van Buren County Health Department, soil survey information provided by the U.S. Department of Agriculture Soil Conservation Service, and air photos provided by the Van Buren County Clerk's Office form most of the data base for study of nitrate in the ground water of Antwerp Township, Van Buren County, Michigan. The author is indebted to Mr. Les Brown, Van Buren County Health Department, Hartford, Michigan and to the Van Buren County Clerk's Office, Land Deeds Division, Paw Paw, Michigan for their generous assistance. The author is particularly grateful for the guidance and assistance of advisors Dr. W. Thomas Straw and Dr. Richard Passero, without whose help this study would not have been possible.

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WESTERN MICHIGAN UNIVERSITY, M.S., 1981

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CHAPTER I

INTRODUCTION

Nitrate as a Health Hazard

Recently, much concern has been expressed about nitrate levels in ground-water supplies, particularly when these water supplies are used for domestic human consumption. Studies suggest that high nitrate intake by humans can lead to a variety of health hazards, ranging from methemoglobinemia in infants to possible cancer in adults (Bosch, et al. 1974; Tannenbaum, et al. 1969; Magee, 1972; Sen, et al. 1974; Tannenbaum, et al. 1974, 1976).

Methemoglobinemia is the condition that exists when hemoglobin, the oxygen-carrying substance in blood, is converted to methemoglobin which is unable to act as an oxygen-carrier. The condition is brought about when an oxydizing agent, such as the nitrite ion, transforms the ferrous iron in hemoglobin to ferric iron, thereby creating methemoglobin.

Comly (1945) first recognized the link between high nitrate levels in drinking water and methemoglobinemia. Subsequent studies have shown private wells to be associated with almost all cases of infant methemoglobinemia where well water was used to prepare infant formula (Gunderson, 1971; Simon, et al. 1964). In addition, Sattelmacher (1962) found that 97 per cent of infant methemoglobinemia cases were associated with drinking water conaining more than 9 mg/l NO_3-N. Under favorable conditions, nitrate is reduced to nitrite through bacteriological action in the gastrointestinal tract. The nitrite is then absorbed into the bloodstream, with subsequent methemoglobin formation.

Normally, only infants less than five months of age are affected by high levels of nitrate. Older children and adults have very acidic gastric environments (pH 1-2) which inhibit the growth of nitrate-reducing bacteria, and thus preventing nitrite formation. Infants have a more neutral gastric environment (pH 5-7) which permits bacterial growth in the stomach and nitrite is formed and absorbed into the bloodstream. Also, infant hemoglobin is more readily oxidized to methemoglobin than is adult hemoglobin. Finally in infants there is a lower activity in the blood-restoring enzyme system than in adults, so infants build up toxic levels of methemoglobin more readily than do adults.

A study done by the American Public Health Association in 1950 indicated the rarity of methemoglobinemia when nitrate levels in drinking water are less than 10 mg/l NO_3-N. Because of this relationship, the National Interim Drinking Water Standards for NO_3-N are set at a maximum allowable contaminant level (MCL) of 10 mg/l.

The direct chronic effects of nitrate on humans and animals has not been documented; most chronic toxicity is believed to result from the production of nitrite from nitrate by bacteria. Nitrate poisoning in livestock produces anorexia, dyspnea, restlessness, vasodilation, lowered blood pressure, abortion and reduced lactation (National Academy of Science, National Research Council, Panel on Nitrates). Nitrate has also been shown to interfere with the iodide trapping mechanism of the thyroid in rats (Lee, et al. 1970), but has not been observed in cattle (Jainudeen, et al. 1965) or dogs (Kelly, et al. 1974).

Of more importance is the possibility of carcinogenic N-nitroso compounds forming *in vivo* in humans. Tannenbaum, et al. (1976) demonstrated that nitrite is present in saliva, and that its concentration is dependent on the concentration of nitrate ingested. Because excess nitrite can combine with secondary amines found in food to produce nitrosamines in the stomach (Sen, et al. 1969), ingestion of high concentrations of nitrate is definitely cause for concern.

Nitrogen Cycle

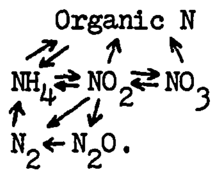
Nitrogen as the gas N_2 is inert and must be "fixed" before it can be utilized by most organisms. The largest single natural source of fixed nitrogen is terrestrial microorganisms which take the nitrogen out of the atmosphere and incorporate it in chemical compounds. Industrial processes also fix nitrogen for use in fertilizer.

In addition to N_2, three basic nitrogen compounds are involved in the nitrogen cycle, NH_4^+(ammonium), NO_2^-(nitrite), and NO_3^-(nitrate). These compounds are involved in the three processes that constitute the nitrogen cycle, nitrification, denitrification, and ammonification. In an oxidizing environment, the nitrogen compounds are progressively oxidized, with nitrate as the end product. This process, nitrification, is represented by the equation: $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$. Nitrification is carried out by two microorganisms, Nitrosomonas and Nitrobacter. Nitrosomonas converts NH_4^+ to NO_2^- and Nitrobacter converts NO_2^- to NO_3^-.

In a reducing environment, nitrogen compounds tend to denitrify with oxidized nitrogen compounds (nitrite and nitrate) being assimilated by microorganisms which convert NO_2^- and NO_3^- to gaseous N_2. Denitrification is represented by the equation: $NO_3^- \rightarrow NO_2^- \rightarrow N_2O^+ \rightarrow N_2$. In order for the microorganisms to metabolize nitrite and nitrate, organic carbon must be present in a reducing environment.

Ammonification occurs when animal and plant matter decompose, and organic nitrogen compounds are converted to NH_4^+.

A simplified nitrogen cycle can be represented by the equation:



Nitrogen in the form of NH_4^+, NO_2^-, or NO_3^- is available for use by plants and animals. Most commercial fertilizers contain nitrogen in the NH_4^+ form, because the ammonium ion is readily trapped in soil due to its positive charge. The nitrogen remains in the soil longer, and plants have more time to assimilate it than with other forms of nitrogen. Nitrate on the other hand is mobile in soils and easily leached out of the root zone of plants to the water table.

<u>Movement of Nitrate</u>

Nitrate is leached rapidly through soils, moving vertically through the unsaturated zone with little change in concentration. Upon reaching the water table, gravity ceases to be the prime force affecting nitrate movement. Instead, molecular dispersion tends to distribute nitrate in all directions, diluting the nitrate concentration. Horizontal ground-water flow tends to further inhibit downward movement of nitrate, creating instead plumes of contamination that spread down-gradient from the source (Gardner, 1965). The net result is a decrease in nitrate concentration with increasing distance from the source, and with increasing depth below static water.

Description of Study

Over the past several years, the Van Buren County Health Department has tested a number of wells throughout the County, with elevated levels (greater than 10 mg/l) of nitrate being reported for many, including wells in Antwerp Township.

Antwerp Township was chosen as the area of study because of its potential for suburban development. The predominately rural township has experienced fairly rapid growth, with development of numerous subdivisions, trailer parks, and individual private lots.

This report presents the findings of a study of the occurrence and distribution of nitrate in well water from Antwerp Township. Nitrate concentrations were correlated with well depth below static water level, distance between well and septic system, age of the septic system, depth to static water level, soil type, geologic and hydrologic characteristics of the subsurface, and land use.

Location of Study Area

Geographic. Antwerp Township is located in east-central Van Buren County in southwestern Michigan (Figure 1). The Township is crossed by three highways: Interstate-94, Red Arrow Highway, and M-40 (Plate 1). Antwerp Township is mostly rural; however

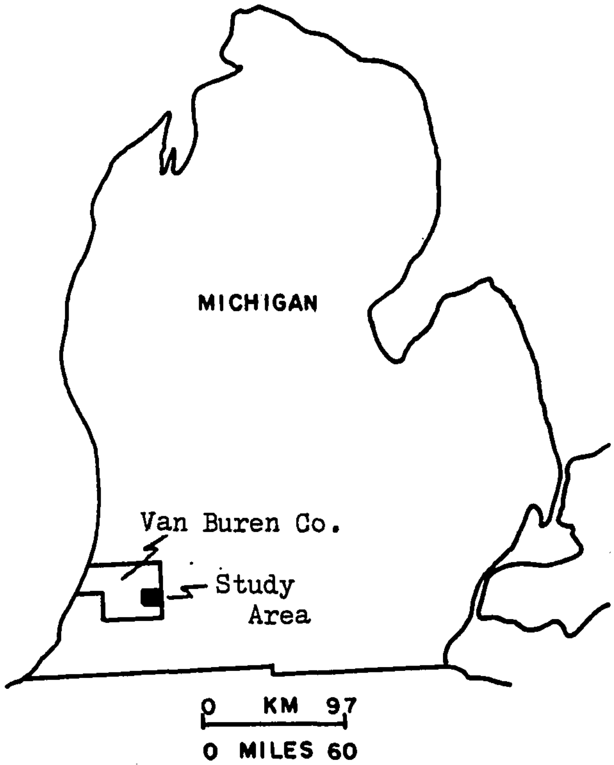


Figure 1. Location of Study Area

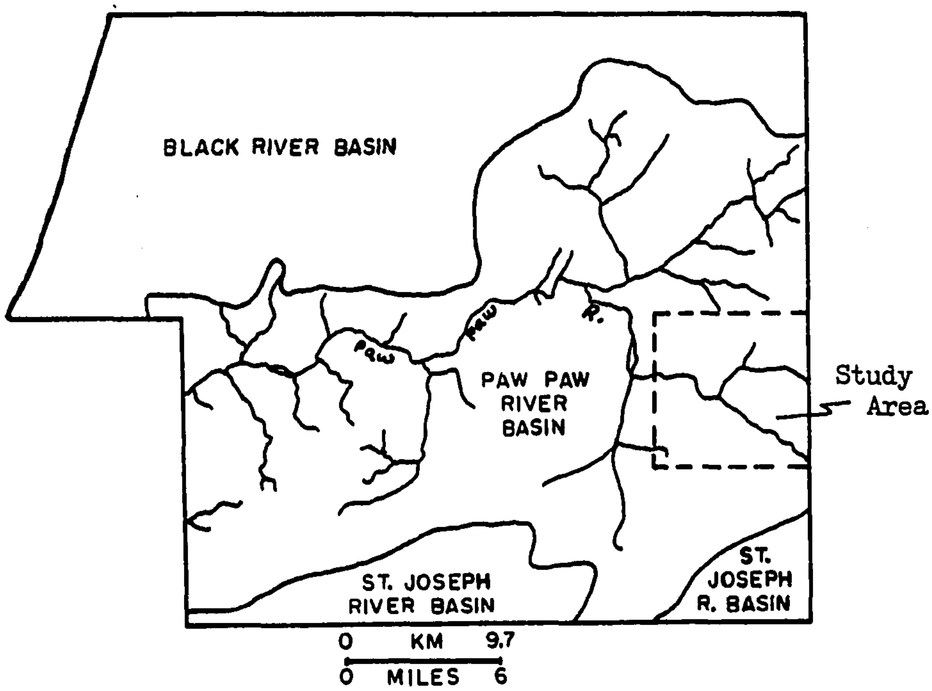


Figure 2. Van Buren County Drainage Basins

three communities, Paw Paw, Mattawan, and Lawton, lie wholly or partially within the township.

Hydrologic. Antwerp Township lies within the Paw Paw River Basin which drains westward (Figure 2). Van Buren County receives approximately 34 inches (864 mm) of precipitation annually (U.S. Weather Bureau, 1964). Abundant subsurface water supplies are found throughout the township, generally at depths of less than 50 feet (15.2 m) below the land surface, except in morainal areas where the water table may be at depths of more than 100 feet (30.5 m).

Geologic. The surface geology of Antwerp Township is a product of glaciation associated with the Lake Michigan lobe of the Wisconsinan ice sheet (Figure 3). The highest elevations are in southeastern sections of the township, along the Inner Ridge of the Kalamazoo Moraine (Plate 1). Associated with the Kalamazoo Moraine is a minor ridge represented by a series of hills which extends through sections 1, 11, 12, 15-17, 20, 29, and 30 (Figure 3). Along most of its length, this ridge is buried beneath outwash with only the backslope being unobscured (Terwilliger, 1954). Lying between the two ridges is a broad area of till plain and outwash, composed predominately of sands and gravels, with some isolated clay lenses a few feet in thickness (Terwilliger, 1954). Underlying the glacial drift, which is several hundred feet thick locally, is the Mississippian Coldwater Shale.

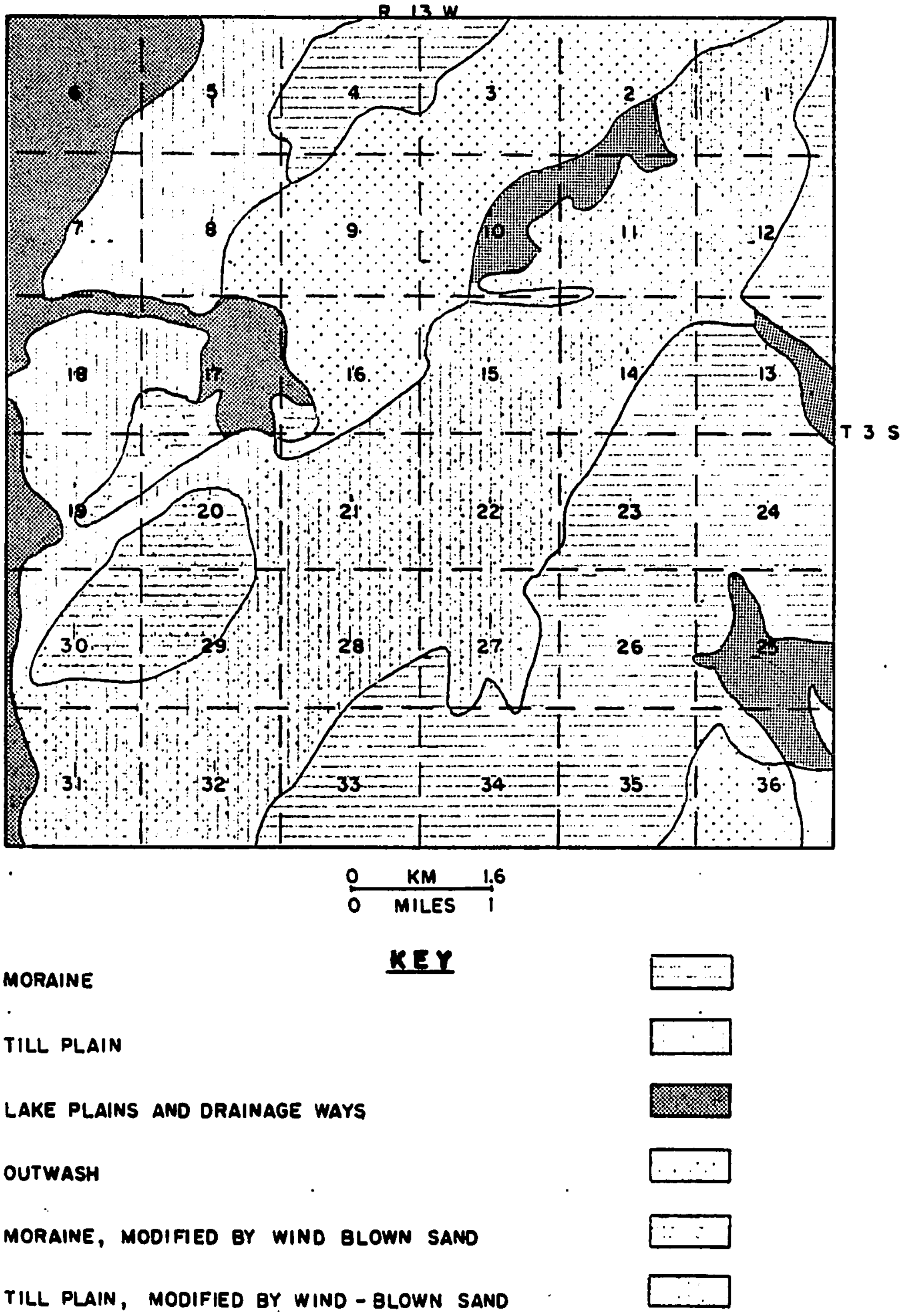


Figure 3. Surface geology of Antwerp Township, Van Buren Co., MI
(F. W. Terilliger, Geology of Van Buren County, MI, 1950)

CHAPTER II

METHODOLOGY

One hundred and fifty-nine 100 ml water samples were collected from private wells throughout Antwerp Township (Figure 4). Sampling sites were plotted on aerial photos (scale: 1" = 400') provided by the Van Buren County Clerk's Office and on a soil map composite. Elevations for each well site were obtained by plotting well sites on the 15' Marcellus Quadrangle topographic map (U.S.G.S.); accuracy was within ± 5 feet of contoured elevation.

Information related to well depth, static-water depth, distance between well and septic system, glacial lithology, and soil type for each site was taken from drillers records furnished by the Van Buren County Health Department, soil maps provided by the U.S. Department of Agriculture, Soil Conservation Service, and through conversations with property owners.

Water samples were preserved in the field with 1 ml boric acid solution per 100 ml sample and taken the same day to the lab for testing. In the lab, a preservative solution was prepared by dissolving 6.2 g of reagent grade boric acid in 100 ml of hot distilled water. The solution was used to preserve samples collected in the field from biological alteration.

A model 407A Orion specific ion meter was used in conjunction with an Orion nitrate-specific ion electrode for testing of all samples. The use of the nitrate-specific ion electrode permitted rapid

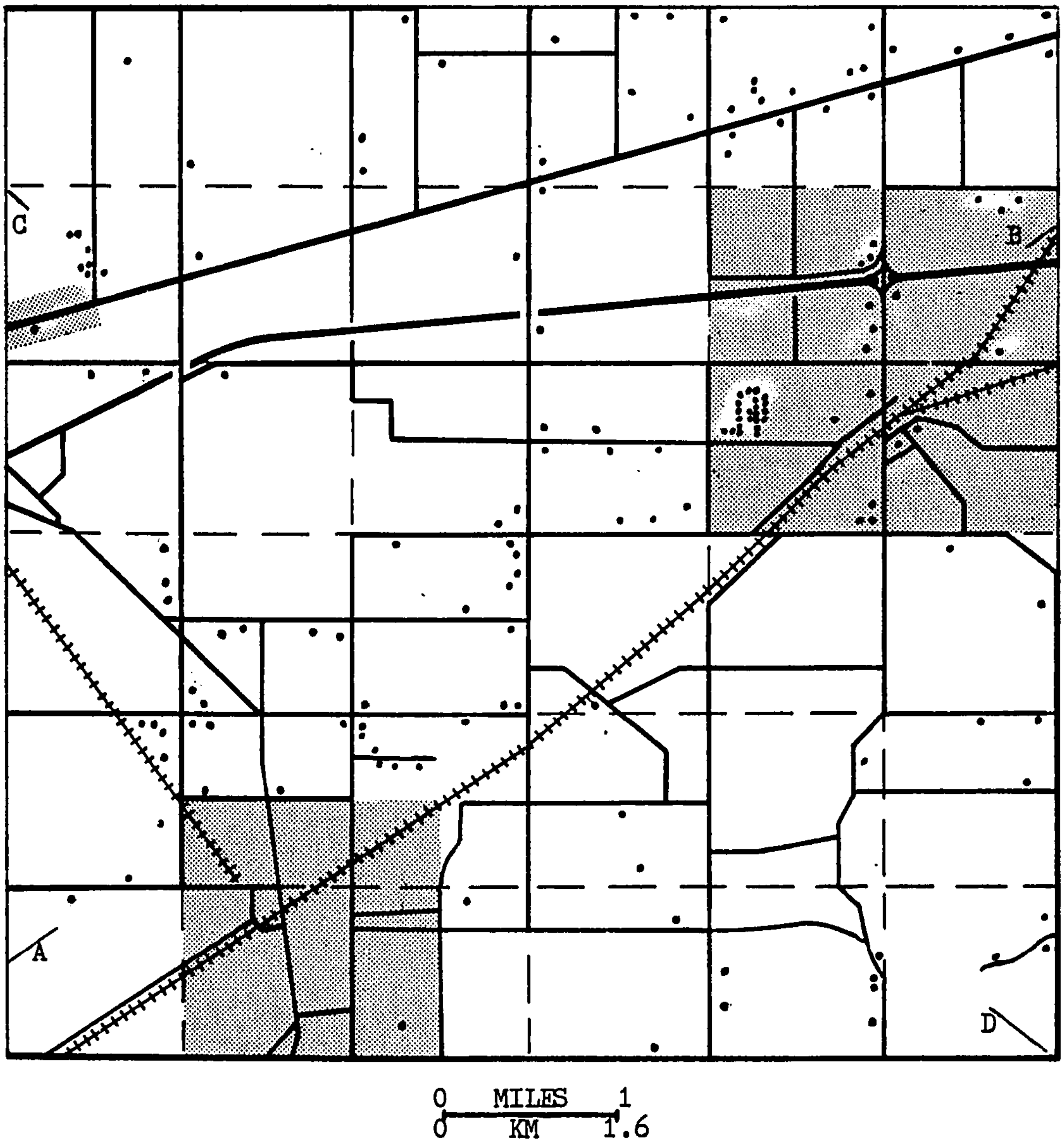


Figure 4. Location of sampling sites in Antwerp Township, Van Buren County, Michigan

testing of samples, and the accuracy of this method is comparable with extraction-distillation methods, within 0.1 mg/l (Bremmer, et al. 1968). In tests where known nitrate concentrations were measured using the ion electrode method, the recovery ranged from 99 to 101 per cent (Bremmer, et al. 1968).

A standard stock solution was prepared for calibration of the ion electrode by weighing out 7.218 g of reagent grade KNO_3 and diluting with distilled water to 1000 ml. The stock solution was then used to prepare 100 ppm, 10 ppm, and 1 ppm standard reference solutions for calibration of the ion meter before testing of each batch of samples.

An ionic strength adjustor (ISA) solution was prepared by dissolving 26.42 g of reagent grade $(NH_4)_2SO_4$ in 100 ml of distilled water. In order to provide a constant ionic background strength when using the ion electrode, 2 ml of the ISA solution was added to each 100 ml sample prior to testing.

Parametric statistical analysis was accomplished through use of the Students t-Statistic and Pearson's coefficient of correlation. Contingency tables were used for non-parametric analysis. Due to the skewed nature of the data, both types of statistical analysis were used in order to assure the greatest possible degree of accuracy. Regression curves and data transforms were used to plot lines of best fit to various groups of data. Only those wells with measurable nitrate (greater than 1 mg/l) levels were used for parametric analysis, whereas all test sites were used in non-parametric analysis.

CHAPTER III

ANALYSIS OF DATA

General Distribution of Nitrate

Nitrate concentrations in 159 samples of ground water taken throughout Antwerp Township ranged from less than 1 mg/l to 14.6 mg/l NO_3-N. The mean nitrate concentration for all wells was 3.1 mg/l NO_3-N and the median nitrate concentration was 1.8 mg/l NO_3-N. As seen in Figure 5, the distribution of nitrate concentrations is skewed to the right (low), with only 32 out of 159 wells tested having nitrate concentrations higher than 3.1 mg/l NO_3-N.

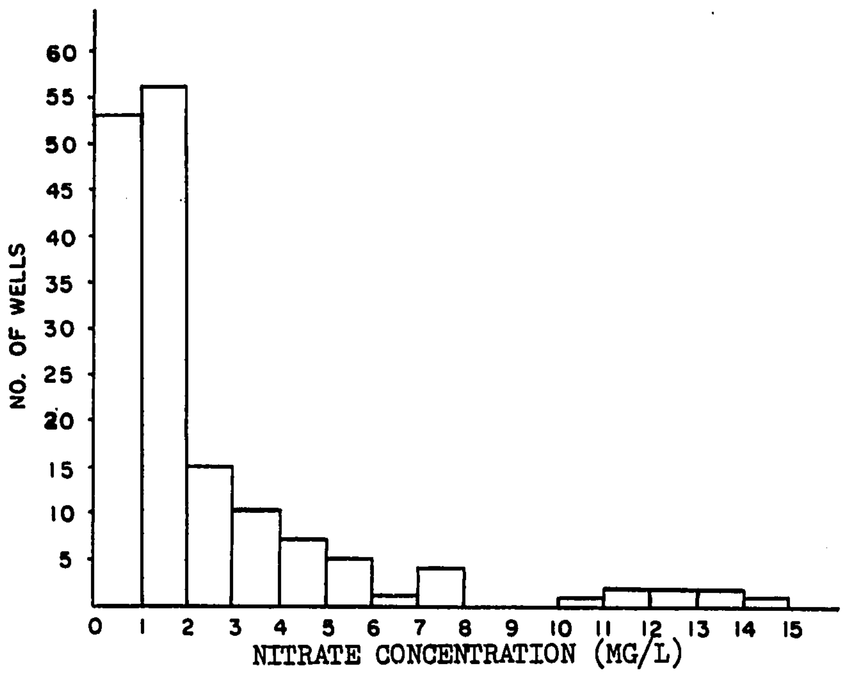


Figure 5. Distribution of Nitrate Concentrations in Antwerp Township, Van Buren County, Michigan

Nitrate levels for only 4.4 per cent of 159 wells tested contained nitrate levels equaling or exceeding the National Interim Drinking Water Standard limit of 10 mg/l NO_3-N, and 21.4 per cent contained less than 1 mg/l NO_3-N. Although the 159 sample sites were scattered throughout all sections of the township, only wells on till and outwash plains contained 10 mg/l or more nitrate. There was no incidence of elevated nitrate levels in morainal areas. On moraines, wells are deeper than on the till and outwash plains. Because of the increased depth to water greater opportunity exists for nitrate dispersion and denitrification than in till and outwash plains. Also, drillers records for Antwerp Township indicate a higher clay content in moraines compared to till and outwash plains, which are predominately sands and gravels, rendering the nitrate ion less mobile.

Soil Type in Relation to Nitrate Levels

Soil types at each sample site were identified from soil maps provided by the U.S. Department of Agriculture, Soil Conservation Service. Figure 6 shows the percentage distribution of each soil

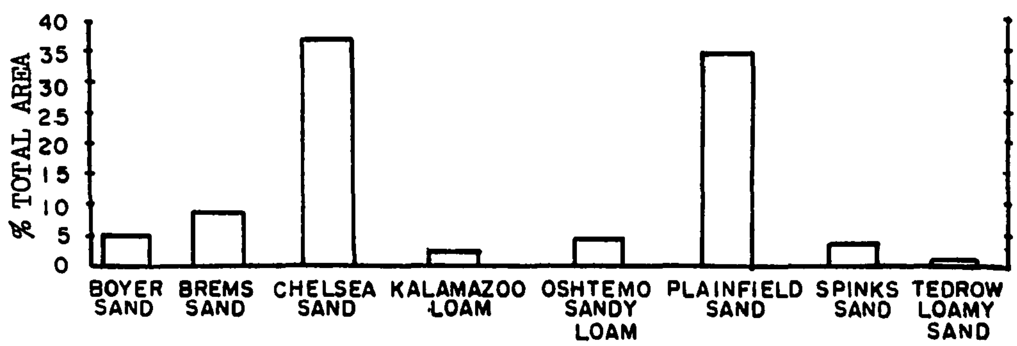


Figure 6. Percentage distribution of soils in Antwerp Township, Van Buren County, Michigan.

type considered in the study.

The Soil Conservation Service considers soils to have severe limitations for septic drainage fields if the permeability exceeds 2 inches per hour. The rapid permeability does not allow for adequate renovation of septic effluent and nearby shallow wells are susceptible to contamination.

All soils considered in the study have severe limitations for septic drainage fields as defined by the Soil Conservation Service, as permeabilities of all soils range from 2 inches/hour to greater than 20 inches/hour (Table 1). Wells located on Spinks Sand had a significantly higher average nitrate level than wells in any other soil type (90% confidence level).

TABLE 1

Analysis of Soil Type in Relation to Nitrate Concentrations

Soil Type	Percentage Clay	Permeability (inches/hr.)	n	Mean NO_3-N	SD
Boyer Sand	5 - 50%	2 - 20	6	2.9	2.6
Brems Sand	5 - 25%	more than 20	9	2.3	2.1
Chelsea Sand	5 - 19%	6 - 20	37	2.8	2.9
Kalamazoo Loam	0 - 55%	2 - 20	3	3.2	1.8
Oshtemo Sandy Loam	0 - 45%	2 - 20	5	1.9	1.2
Plainfield Sand	1 - 4%	6 - 20	35	3.1	2.6
Spinks Sand	5 - 30%	6 - 20	4	10.1*	4.6
Tedrow Loamy Sand	3 - 40%	6 - 20	1	2.8	---

* Significantly higher than rest of values at 90% confidence.

There was no significant difference in nitrate concentrations from wells located on other soils.

Land Use in Relation to Observed Nitrate Concentrations

Land use in Antwerp Township was divided into four categories: (1) dense residential areas consisting of subdivisions, trailer parks, and village residences; (2) sparse residential areas consisting of relatevely isolated residences; (3) business areas consisting of commercial buildings, government buildings, schools and churches; and (4) crop or livestock farms. The distribution of wells and nitrate concentrations with regard to land use is presented in Table 2.

TABLE 2

Distribution of Nitrate With Respect to Land Use

Nitrate Range	Land Use				Totals
	Dense	Sparse	Business	Farm	
0- 1.9 mg/l	50	48	7	4	109
2- 3.9 mg/l	8	14	3	0	25
4- 5.9 mg/l	7	4	1	0	12
6- 7.9 mg/l	2	2	1	0	5
8- 9.9 mg/l	0	0	0	0	0
10-11.9 mg/l	2	1	0	0	3
12-13.9 mg/l	0	0	0	2	2
14-15.9 mg/l	2	0	0	0	2
Total n	71	69	12	6	158
Mean NO_3	3.2 mg/l	2.6 mg/l	3.1 mg/l	9.1 mg/l	
S.D.	3.2 mg/l	2.0 mg/l	2.0 mg/l	6.8 mg/l	

Statistical analysis of 159 water samples indicates that, at a 90% confidence level, there is a correlation between land use and nitrate concentrations (Table 3). Farm wells have a significantly higher average nitrate level than residential or business wells while no significant difference (90% confidence) exists between mean nitrate levels for sparse residential, dense residential, and business wells (Table 3).

TABLE 3

X^2 Values and t-Statistics With Regard to Land Use

	Dense	Sparse	Farm	Business
Dense		1.09^{NS}	-2.90***	0.00^{NS}
Sparse	4.80^{NS}		-4.60***	$.81^{NS}$
Farm	25.50***	24.80***		2.42***
Business	3.24^{NS}	1.40^{NS}	6.50**	

t-Statistics
χ^2

NS = Not significant at .90.
** .05 probability.
*** .01 probability.

Depth to Static Water With Respect to Observed Nitrate Concentrations

Data was gathered from drillers records for 156 sample sites. Distribution of nitrate concentrations with regard to depth to static water level is presented in Table 4. Depth to static water ranged from 3 feet (0.9 m) to 160 feet (48.8 m), with a mean depth of 27 feet (8.2 m), a median depth of 20 feet (6.1 m), and a standard deviation of 22.7 feet (6.9 m). A linear regression curve fit to the data has the following equation: $y = 1.7 + .08x - .0006x^2$, with

TABLE 4

Distribution of NO_3 With Respect to Depth to Static Water Level

Nitrate Range	Depth to Static Water (no. wells) 0-19 ft.	20-160 ft.
0- 1.9 mg/l	61	48
2- 3.9 mg/l	10	14
4- 5.9 mg/l	2	9
6- 7.9 mg/l	1	4
8- 9.9 mg/l	0	0
10-11.9 mg/l	1	2
12-13.9 mg/l	0	2
14-15.9 mg/l	1	1
Total n	76	80
Mean NO_3 [a]	2.7 mg/l	3.5 mg/l
S.D.[a]	2.6 mg/l	10.8 mg/l

[a] Values are based on samples with measurable nitrate (greater than 1 mg/l NO_3-N).

a correlation coefficient of r = .250 (Figure 7).

Statistical analysis of sample nitrate concentrations in relation to selected factors, presented in Table 5, indicates a significant correlation between observed nitrate levels and the depth to static water, with nitrate concentrations increasing as static water depth increases. However, none of the four wells with static water levels deeper than 70 feet (21.3 m) has nitrate concentrations in excess of 1.4 mg/l NO_3-N.

A plot of the regression curve (Figure 7) shows an increase in nitrate as static water depth increases up to 64 feet (19.5 m), then a decrease for static water depths greater than 64 feet.

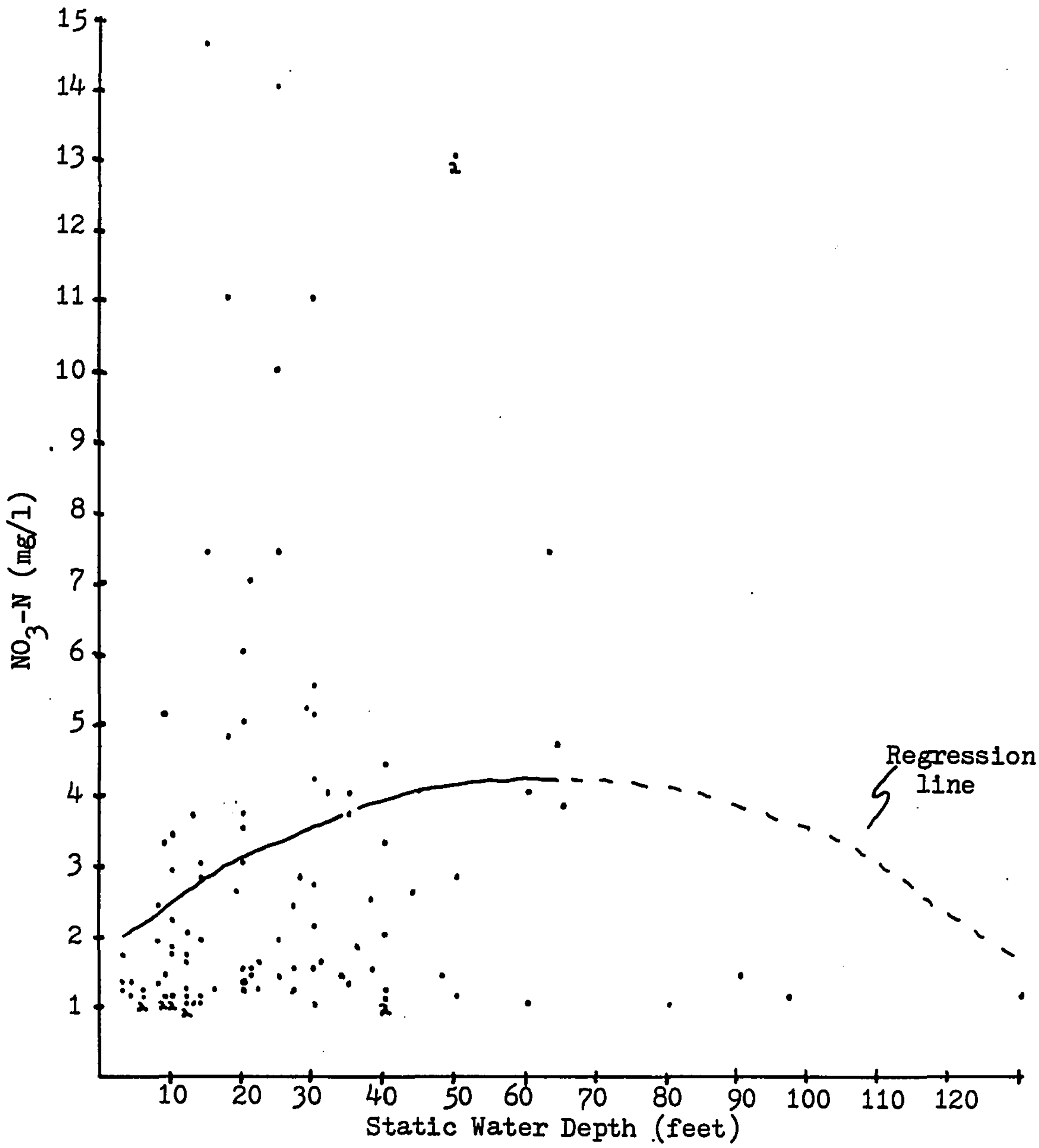


Figure 7. Static water depth in relation to observed nitrate.

The distribution has a kurtosis of 13.78 and a skewness of 2.72.

TABLE 5

Analysis of Selected Factors in Relation to Nitrate Concentrations in Antwerp Township

	Contingency Analysis		Students t-Statistic		Correlation Coefficient
Factor	n [a]	χ^2 [b]	n [c]	$\bar{X}_1 - \bar{X}_2$	r
Static Water Depth	156	11.85 *	104	-1.62 *	.25 ***
Well Depth Below Static Water	156	15.75 ***	104	2.63 ***	.25 ***
Clay Thickness	110	1.63 NS	67	- .48 NS	.08 NS
Distance Between Well and Septic	133	13.87 ***	87	1.03 NS	.06 NS
Septic System Age	154	10.82 *	104	- .81 NS	.40 ***

[a] All samples.

[b] Chi Squared value based on data groupings presented in Tables 4, and 6-9.

[c] Samples with measurable nitrate (greater than 1 mg/l NO_3-N).

$\bar{X}_1$ = mean for all samples below factor median.

$\bar{X}_2$ = mean for all samples above factor median.

NS = not significant.

* .90 significance.

** .95 significance.

*** .98 significance.

Depth of Well Below Static Water in Relation to Nitrate Concentration

Sampled wells ranged from 10 feet (3 m) to 212 feet (64.6 m) below static water level, with a mean of 34.9 feet (10.6 m), a median of 31 feet (9.4 m), and a standard deviation of 26.4 feet (8 m).

Distribution of nitrate concentrations with regard to well depth is presented in Table 6. The distribution is highly skewed to the right and peaked, with a skewness of 4.34 and kurtosis of 26.42. A regression curve has the following equation: $y = 5.34 - .09x + .0004x^2$, with a correlation coefficient of $r = .254$. A plot of the data points and regression curve (Figure 8) shows a distinct downward trend in nitrate concentrations as well depth increases.

Statistical analysis of well depth below static water in relation to nitrate concentrations (Table 5) indicates a significant degree of correlation between well depth below static water and nitrate concentrations in Antwerp Township, with nitrate concen-

TABLE 6

Distribution of NO_3 With Respect to Well Depth Below Static Water

NO_3 Range (mg/l)	Well Depth (no. wells)	
	0-30 ft.	31-202 ft.
0- 1.9	46	61
2- 3.9	14	10
4- 5.9	6	6
6- 7.9	5	0
8- 9.9	0	0
10-11.9	4	0
12-13.9	2	0
14-15.9	2	0
Total n	78	77
Mean NO_3 [a]	3.7 mg/l	2.2 mg/l
S.D. [a]	3.6 mg/l	1.2 mg/l

[a] All samples with measurable nitrate (greater than 1 mg/l NO_3-N).

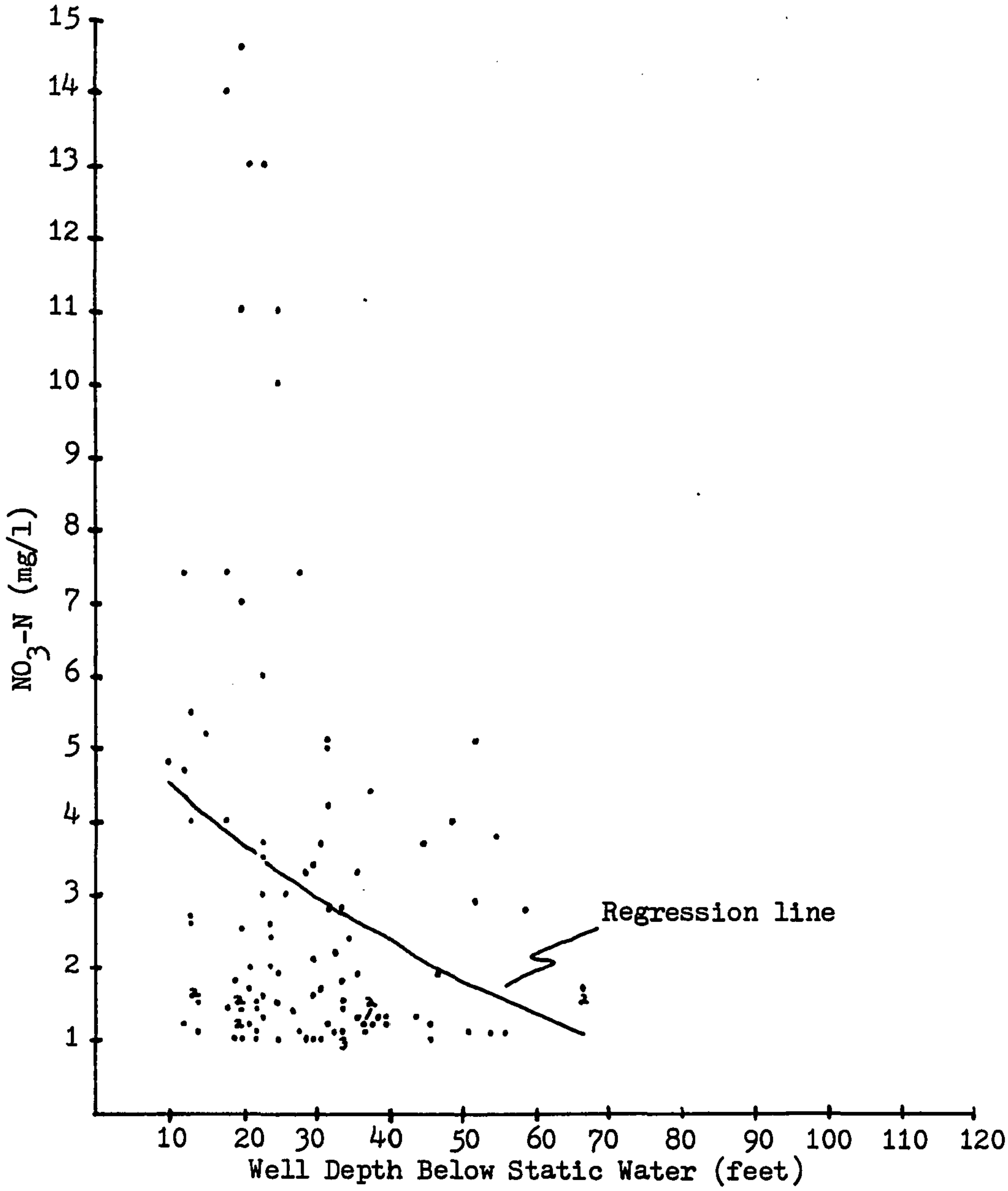


Figure 8. Well depth below static water in relation to nitrate.

trations decreasing as well depth below static water increases.

Thickness of Clay in Subsurface in Relation to Nitrate Concentration

Total thickness of clay in the subsurface for 110 well sites ranged from 0 feet (0 m) to 78 feet (23.8 m), with a mean thickness of 5.4 feet (1.6 m), a median of 0 feet (0 m) and a standard deviation of 12.2 feet (3.7 m). Only 44 wells (40 percent) were in areas where clay was present in the subsurface, the dominant subsurface material being sand and gravel. Clay barriers throughout Antwerp Township consist of lenses of clay and silt, with the thickest lenses being found in morainal areas (Figure 9).

TABLE 7

Distribution of Nitrate in Relation to Subsurface Clay

NO_3 Class (mg/l)	No. of Wells	
	No Clay	Clay
0- 1.9	46	30
2- 3.9	9	9
4- 5.9	7	3
6- 7.9	3	1
8- 9.9	0	0
10-11.9	0	0
12-13.9	0	0
14-15.9	1	1
Total n	66	44
Mean NO_3 [a]	2.83 mg/l	3.18 mg/l
S.D.[a]	2.42 mg/l	2.79 mg/l

[a] All samples with measurable nitrate (greater than 1 mg/l NO_3-N).

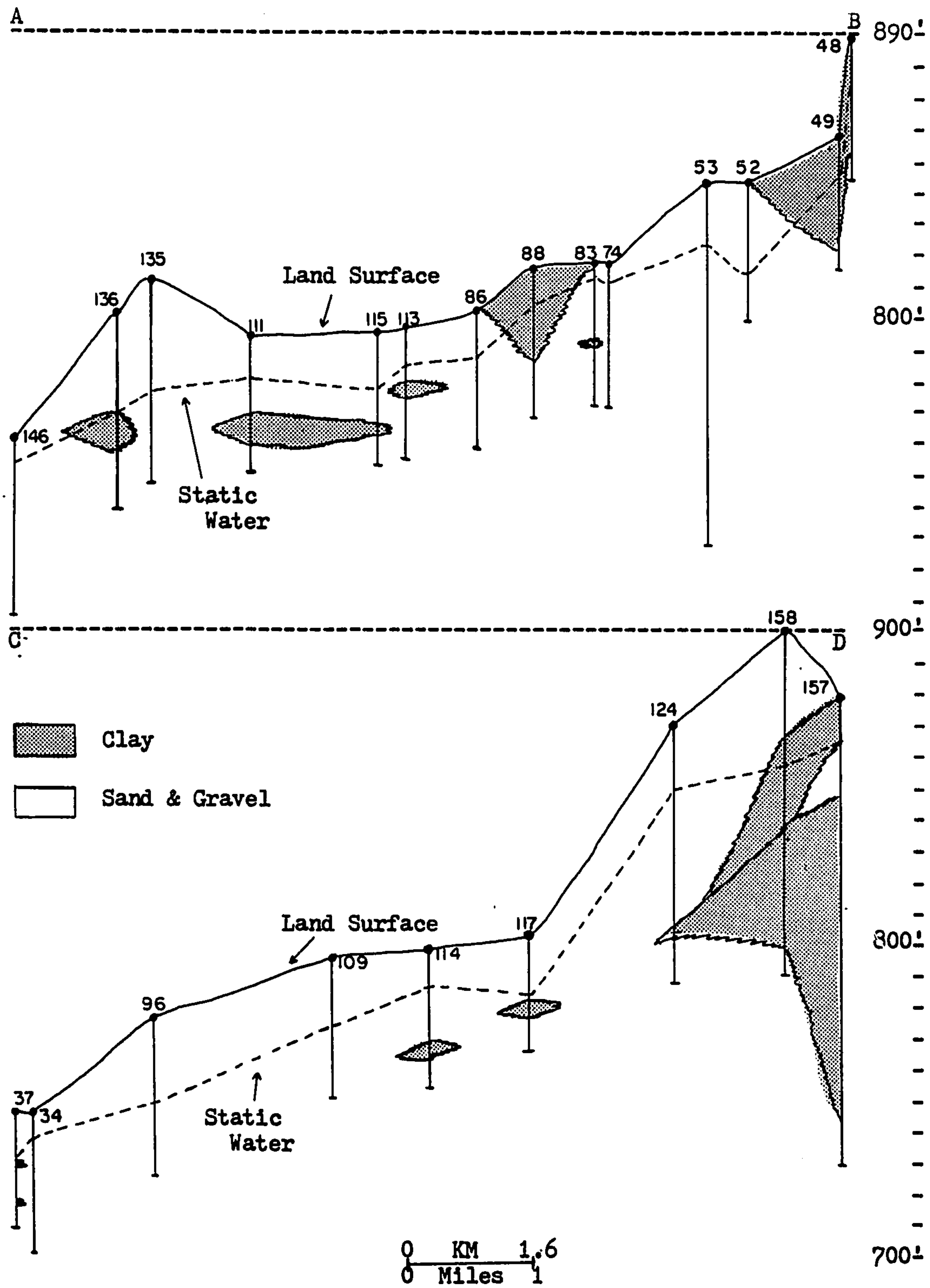


Figure 9. SW-NE and NW-SE cross sections of glacial drift (see Fig. 4).

The distribution of subsurface clay in relation to observed nitrate is shown in Table 7, based on data collected from drillers records. The distribution is highly skewed to the right and peaked, with a skewness of 4.34 and a kurtosis of 17.39. A regression curve fit to the data has the following equation: $y = 2.88 + .06x - .00x^2$, with a correlation coefficient of $r = .076$.

A plot of the regression curve (Figure 10) shows an apparent drop in nitrate levels as subsurface clay thickness exceeds 14 feet (4.3 m). However, statistical analysis indicates that there is no significant relationship between the presence (or lack) of clay in the subsurface and nitrate concentrations on a regional basis (Table 5).

<u>Distance Between Well And Septic System in Relation to Nitrate Concentrations</u>

Distances between well and septic system were obtained from well records for each test site and ranged from 10 feet (3 m) to 500 feet (152.4 m), with a mean of 69.2 feet (21.1 m), a median of 60 feet (18.3 m), and a standard deviation of 27.2 feet (8.3 m). The distribution of distances between well and septic system in relation to observed nitrate is presented in Table 8. The distribution is highly skewed and peaked, with a skewness of 106.75 and a kurtosis of 6.84.

A regression curve fit to the data has the following equation: $y = 5.49 - .06x + .0003x^2$, with a correlation coefficient of $r = .06$. A plot of the regression curve (Figure 11) shows a decrease in nitrate concentrations as the distance between well and septic system

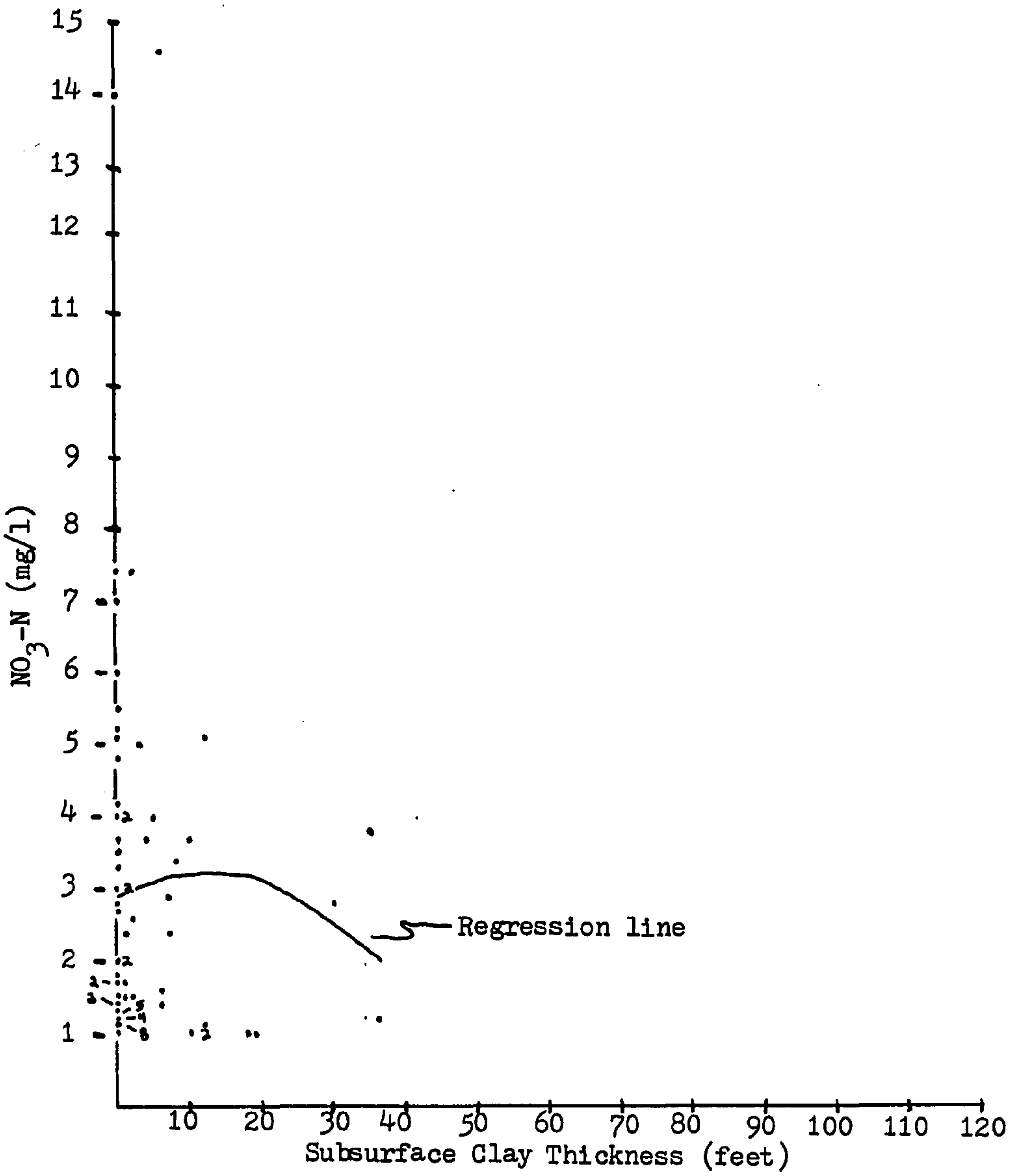


Figure 10. Subsurface clay thickness in relation to nitrate.

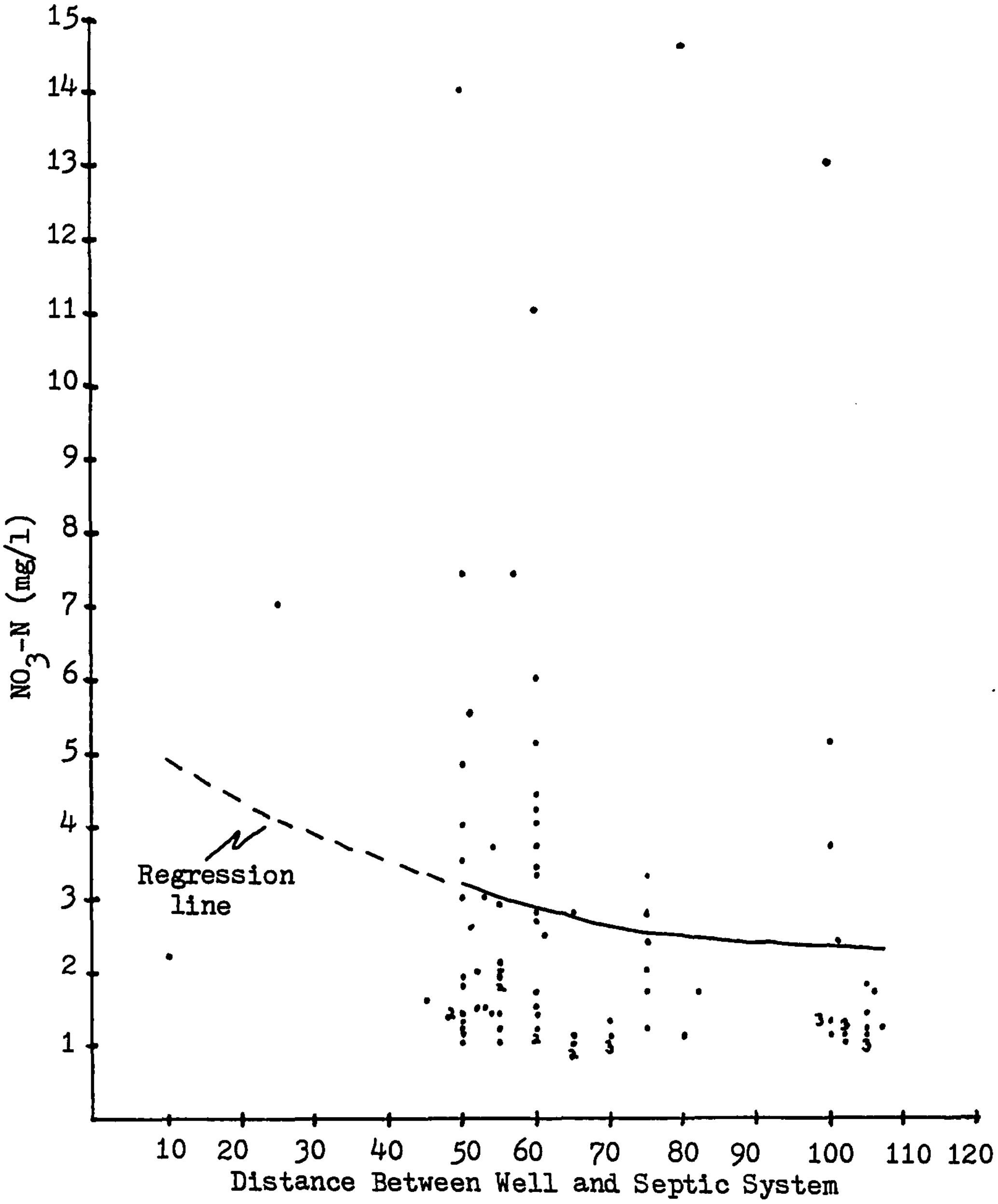


Figure 11. Distance between well and septic system in relation to nitrate concentrations.

increases, leveling off for distances greater than 90 feet (27.4 m). Contingency analysis confirms this trend. There is a significant relationship between nitrate concentrations and the distance between well and septic system (Table 5). T-statistic analysis indicates no significant relationship between well/septic distance and observed nitrate, but the highly skewed nature of the sampling distribution reduces the validity of this particular statistical test.

TABLE 8

Distribution of Nitrate in Relation to Distance Between Well and Septic System

NO_3 Range (mg/l)	No. Wells	
	0-60 ft.	61-107 ft.
0- 1.9	42	53
2- 3.9	15	8
4- 5.9	7	1
6- 7.9	4	0
8- 9.9	0	0
10-11.9	1	0
12-13.9	0	1
14-15.9	1	1
Total n	70	64
Mean NO_3 [a]	3.14 mg/l	2.31 mg/l
S.D. [a]	2.56 mg/l	2.85 mg/l

[a] Based on samples with measurable nitrate (greater than 1 mg/l NO_3).

Septic System Age in Relation to Nitrate Concentrations

Septic system ages were determined from septic system permits and ranged from 1.2 years to 12.4 years in age, with a mean of 6.2

years, a median of 6.1 years, and a standard deviation of 10.3 years. The distribution of septic system ages with respect to nitrate concentrations is shown in Table 9. The distribution is near-normal and slightly peaked with a skewness of .40 and a kurtosis of 2.59.

A regression curve fit to the data has the following equation: $y = 5.5 - 1.15x + .11x^2$, with a correlation coefficient of $r = .369$. A plot of the regression curve (Figure 12) shows a downward trend in nitrate levels as septic system age increases, up to about 6 years of age. Beyond this point, nitrate concentrations rise sharply as septic system age increases.

TABLE 9

Distribution of Septic System Ages in Relation to Nitrate Concentrations

NO_3 Range (mg/l)	No. wells	
	0-6.0 years	6.1-12.4 years
0- 1.9	51	55
2- 3.9	14	10
4- 5.9	6	6
6- 7.9	5	0
8- 9.9	0	0
10-11.9	0	3
12-13.9	0	2
14-15.9	1	1
Total n	77	77
Mean NO_3 [a]	2.86 mg/l	3.33 mg/l
S.D. [a]	2.40 mg/l	3.48 mg/l

[a] Based on samples with measurable nitrate (greater than 1 mg/l NO_3).

Contingency analysis confirms that there is a significant relationship between septic system age and observed nitrate concen-

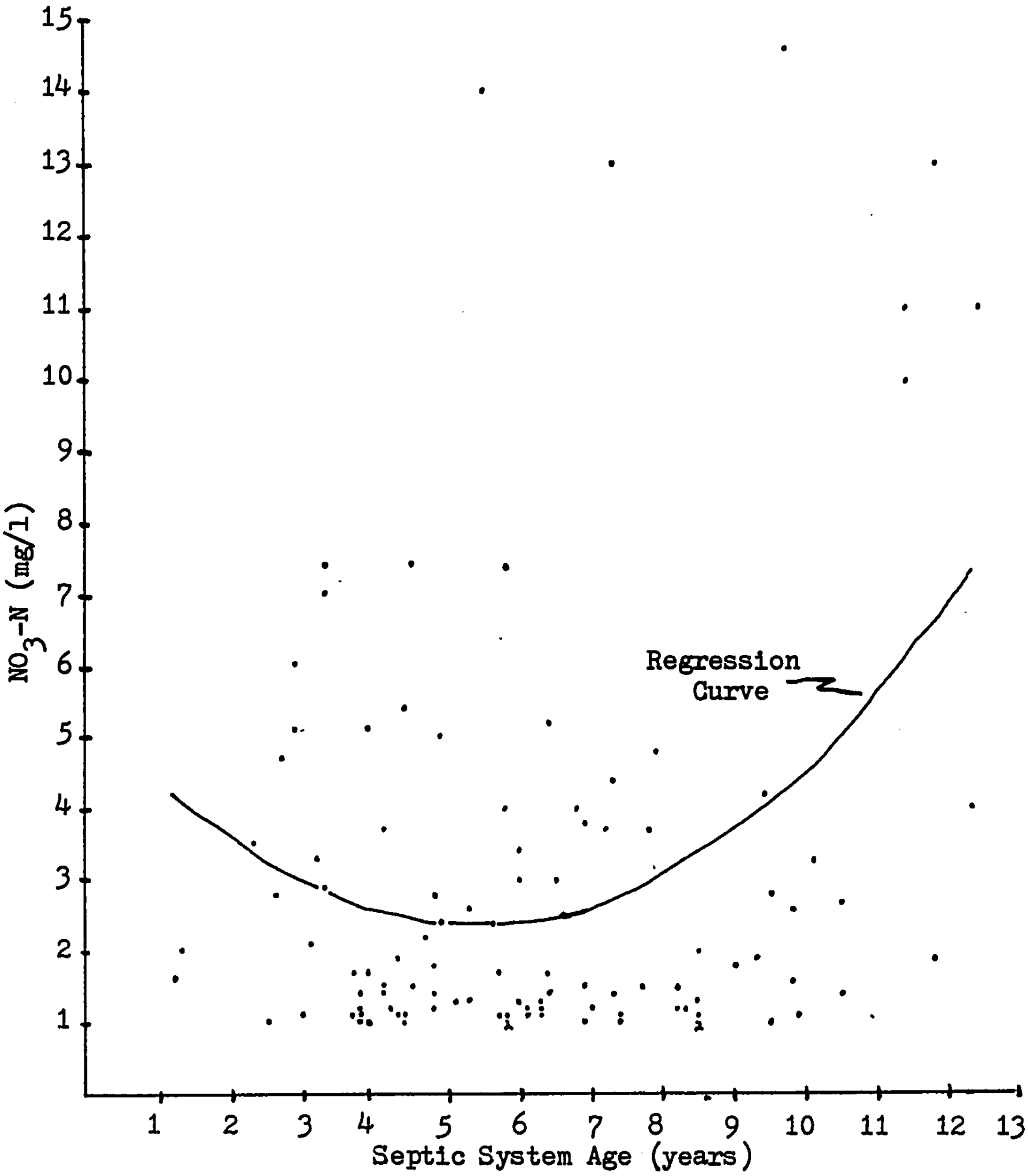


Figure 12. Septic system age in relation to observed nitrate.

trations. T-statistic analysis, on the other hand, fails to establish any relationship between septic system age and observed nitrate. The regression curve reaches a minimum for a septic system age of 6 years, and then increases (Figure 12). All t-Statistic analyses considered nitrate values on either side of the median value for whatever factor was being evaluated. For septic system age, nitrate values averaged out the same either side of the median. However, comparing nitrate concentrations above and below a septic system age of 7 years, which is a break point where nitrate concentrations increase sharply, there is a significant (.90 confidence) increase in nitrate levels as septic system age increases. Contingency analysis also supports the hypothesis that septic system age is related to observed nitrate concentrations.

Overall, there seems to be a relationship between septic system age and observed nitrate concentrations, particularly for septic system ages greater than 7 years.

CHAPTER IV

INTERPRETATION OF DATA

Information regarding several possible sources of nitrate contamination of ground-water supplies in Antwerp Township was gathered from field observations and through conversations with property owners. They include animal wastes from farmyards, crop fertilizers, lawn and garden fertilizers, and septic system effluent.

The lack of wells containing excessive nitrate concentrations (greater than 1 mg/l NO_3-N) indicates that ground-water contamination by nitrate is not a widespread problem, but rather a localized problem with several individual nitrate sources affecting small areas.

A study done by Walker, et al. (1973) indicates that septic system effluent can be a major contributor of nitrate to the ground water. Similarly, studies by Baier and Rykbost (1976) and Singh and Sekhon (1976) indicate that high concentrations of nitrate derived from fertilizers and animal wastes can be leached down to the water table.

Lawn and garden fertilizer can be eliminated as a major contributor of nitrate to the ground water in Antwerp Township. Few people in the township reported fertilizing their lawns or gardens, and the wells of those that did failed to show elevated levels of nitrate in the ground water.

The following factors were found to be significant in relation to observed nitrate levels in Antwerp Township: (1) land use; (2) well depth below static water level; (3) distance between well and septic system; and (4) septic system age.

As a group, farm wells had significantly higher nitrate concentration than did other wells (Table 1). Two of the farm wells tested had nitrate concentrations in excess of 10 mg/l NO_3-N. At one of these two sites, large quantities of animal waste from cattle was present adjacent to the house. The second farm site used fall-applied manure to fertilize crops. No farms were irrigated. Both farm sites with elevated nitrate levels (greater than 10 mg/l NO_3-N) had wells less than 25 feet below static water level. This factor increases the risk of nitrate contamination as wells closer to the water table experience less renovation. Thus, it appears likely that manure contributed substantially to the elevated nitrate levels found at the two farm sites.

Because seven wells in Antwerp Township were found to contain elevated nitrate levels, and only two of these seven well sites were farm wells, other factors were responsible for observed nitrate concentrations at the other five well sites. Aside from farm wells, other types of land use had no statistically significant effect on nitrate concentrations, due perhaps to the relatively isolated nature of most residences in the study area. The majority of dense residential areas are relatively new, and it is perhaps too soon for these areas to show a significant impact on ground-water quality. It is interesting to note that even though there is no statistically significant difference in nitrate levels between dense residential areas and other land uses, the average nitrate concentration for dense residential areas was numerically higher than all other areas except farms.

As mentioned earlier, depth to static water appeared to be a significant factor with nitrate concentrations increasing as static water depth increased (Figure 7). Closer investigation revealed that at well sites where the static water level was close to the surface, well depths were well below static water level; Michigan codes require that a well be at least 25 feet in depth. However, as depth to static water increased, the distance between static water level and well screen decreased as wells tended to remain at shallow depths. Because nitrate tends to remain concentrated in upper levels of an aquifer (Gardner, 1965), wells drilled to depths close to static water levels are more susceptible to nitrate contamination than wells drilled deeper into the aquifer. The apparent relationship between static water depth and nitrate concentration becomes instead a relationship between the depth of a well below static water level and nitrate concentration. Beyond static water depths of 64 feet, there were insufficient data points to make any valid inferences, so the regression curve is extrapolated as a broken line (Figure 7).

Well depth below static water was the most significant factor in relation to nitrate concentrations (Table 5), with nitrate decreasing as well depth below static water level increased (Figure 8). Any nitrate present would tend to remain concentrated in the upper portions of the aquifer, and not mix downward to any great depth.

The distance between well and septic system was also a highly significant factor (Table 5), with nitrate concentrations decreasing as distance increased. This trend is expected as dilution and lateral dispersion of nitrate would have the effect of lowering nitrate concentrations with increasing distance away from the source.

Although there is no statistical significance in subsurface clay thickness in relation to nitrate concentrations, a regression curve shows a decrease in nitrate concentrations as subsurface clay thickness increases (Figure 10). The lack of a significant relationship between clay thickness and nitrate concentrations is probably due to the nature of the glacial sediments. Clay is found primarily as lenses of varying extent (Figure 9), and not as a continuous layer throughout the township. As such, the clay does not act as a barrier to nitrate movement to any great extent.

Septic system age was statistically significant in relation to nitrate concentrations, with nitrate concentrations increasing as septic system age increased past 6 years (Figure 12). There were also relatively high nitrate concentrations for very young septic system ages, decreasing as septic system age increased to about 5.5 years. It is possible that the disruption of the soil system involved in installing a drainage field allowed large amounts of nitrate to be leached to the ground water until the system stabilized. For older systems, it is possible that the soil surrounding a septic system has become saturated with nitrate and that greater amounts are being leached to the ground water. If the amount of nitrate being added to the ground water exceeds the capacity of renovation through dispersion and dilution, an increase in nitrate concentrations is to be expected.

The combination of significant factors, coupled with the fact that all soils encountered in the study have severe limitations for septic systems due to their high permeabilities, indicates that septic system effluent is the major cause of observed nitrate contamination of ground-water supplies in Antwerp Township.

CHAPTER V

CONCLUSIONS

Available evidence shows that nitrate contamination of ground water is not widespread in Antwerp Township. Of 159 wells tested throughout the township, 34 contained less than 1 mg/l nitrate and only 7 well sites had nitrate concentrations in excess of the Interim Drinking Water Standard of 10 mg/l nitrate.

Wells with elevated nitrate levels (greater than 10 mg/l NO_3-N) were scattered throughout the township with nitrate originating from several sources affecting small areas. Significant factors relating to nitrate occurence in Antwerp Township are: (1) soil type; (2) land use; (3) well depth below static water; (4) the distance between well and septic system; and (5) septic system age. All soils in the township have severe limitations for septic systems, as defined by the U.S. Department of Agriculture, Soil Conservation Service, due to high permeabilities. Wells located on Spinks Sand showed significantly higher nitrate concentrations than wells located on other soils. However, only four well sites were located on Spinks Sand so the statistical significance is suspect. It is coincidental that two Spinks Sand sites were also farm sites, with large quantities of animal waste present. Land use was a significant factor with farm wells having significantly higher nitrate concentrations than other types of land use. Dense residential areas, though not statistically significant, had a numerically higher nitrate mean than all other land use areas, excluding farms. As well depths below static water increased, nitrate concentrations decreased, due to increased dilution and dispersion of nitrate. As the distance between well and septic system increased, nitrate concentrations decreased, again due to increased renovation of septic system derived nitrate. As septic system age increased past 7 years, nitrate concentrations increased, due perhaps to accumulated loading of nitrate into the ground water exceeding its capacity for renovation.

Elevated concentrations of nitrate (greater than 10 mg/l NO_3-N) were found on till and outwash plains, with no incidence of elevated nitrate concentrations in morainal areas. Morainal areas in Antwerp Township have a higher percentage of clay in the subsurface as shown by drillers records, than do till and outwash plains, which acts as a barrier to nitrate movement towards the water table. Well sites in morainal areas were also deeper than those on the plains due to the increased depth to the water table. The thicker zone of aeration provides added renovation before effluent reaches the water table.

Elevated nitrate concentrations found in seven wells appear to be the result of nitrates derived from septic system effluent being leached to the ground water, and from nitrate derived from animal wastes in farm areas.

Although nitrate from dense residential septic systems is not presently a problem, continuing development of higher densities using shallower wells in areas of higher water table in the township could lead to significantly higher levels of nitrate in ground water.

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APPENDIX

The following pages contain information on each well containing greater than 10 mg/l NO_3-N in Antwerp Township. Locations of sample sites are shown in Figure 4 and Plate 1. Nitrate values for all wells are shown in Plate 1.

Well Site 14:

Location: SW-SE-SW, Section 2.

Elevation: 832 feet.

Land Use: dense residential.

NO_3-N: 11 ppm NO_3-N.

Soil classification: 3B; severe limitations for septic systems (S.C.S.)

Soil permeability: greater than 6 inches per hour (S.C.S.).

Depth to static water: 30 feet.

Depth of well below static water: 20 feet.

Distance between well and septic system: unknown.

Age of septic system: 11 years, 5 months.

Glacial drift:

	Thickness	Depth
sand/clay	40'	40'
water/sand	10'	50'

NO_3: 14.6 ppm NO_3-N.

Soil classification: 2B; severe limitations - septic systems(S.C.S.).

Soil permeability: 6 inches per hour (S.C.S.).

Depth to static water: 15 feet.

Depth of well below static water: 20 feet.

Distance between well and septic system: 80 feet.

Age of septic system: 9 years, 8 months.

Glacial drift:

	Thickness	Depth
sand	14	14
red clay	4	18
fine sand	10	28
clay	2	30
water sand	5	35

Well Site 39:

Location: SE-SW-NW, Section 8.

Elevation: 782 feet.

Land Use: farm.

NO_3: 13 ppm NO_3-N.

Soil classification: 12A; severe limitations - septic systems (S.C.S.).

Soil permeability: 6 inches per hour (S.C.S.).

Depth to static water: 50 feet.

Depth of well below static water: 23 feet.

Distance between well and septic system: unknown.

Age of septic system: 11 years, 10 months.

Glacial drift: Thickness Depth

Well Site 15:

Location: SW-SE-SW, Section 2.

Elevation: 831 feet.

Land Use: dense residential.

NO_3: 10 mg/l NO_3-N.

Soil classification: 3B; severe limitations for septic systems (S.C.S.).

Soil permeability: greater than 6 inches per hour (S.C.S.).

Depth to static water: 25 feet.

Depth of well below static water: 25 feet.

Distance between well and septic system: unknown.

Age of septic system: 11 years, 5 months.

Glacial drift:	Thickness	Depth
hard sand and clay	40	40
water sand	10	50

Well Site 27:

Location: SW-NW-SW, Section 4.

Elevation: 800 feet.

Land Use: farm.

NO_3-N: 13 mg/l NO_3-N.

Soil Classification: 12B; severe limitations for septic systems (S.C.S.).

Soil permeability: greater than 6 inches per hour (S.C.S.).

Depth to static water: 50 feet.

Depth of well below static water: 21 feet.

Distance between well and septic system: 100 feet.

Age of septic system: 7 years, 4 months.

Glacial drift:	Thickness	Depth
gravel and hard-pan	53	53
clay/sand	2	55
sand	6	61
sand and tan clay	3	64
medium sand	6	70
blue clay		71

Well Site 30:

Location: SW-SW-SW, Section 5.

Elevation: 765 feet.

Land use: sparse residential.

NO_3: 11 mg/l NO_3-N.

Soil classification: 12A; severe limitations for septic systems (S.C.S.).

Soil permeability: greater than 6 inches per hour (S.C.S.).

Depth to static water: 18 feet.

Depth of well below static water: 25 feet.

Distance between well and septic system: 60 feet.

Age of septic system: 12 years, 5 months.

Glacial drift:	Thickness	Depth
clay/sand	37	37
gravel	8	43

Well Site 37:

Location: NE-SE-NW, Section 7.

Elevation: 750 feet.

Land use: dense residential.

Glacial drift:	Thickness	Depth
sand and gravel	18	18
silty sand and brown clay	47	65
coarse sand	8	73

Well Site 130:

Location: NE-SE-NW, Section 28.

Elevation: 805 feet.

Land use: dense residential.

NO_3: 14 mg/l NO_3-N.

Soil classification: 9B; severe limitations for septic systems (S.C.S.).

Soil permeability: greater than 6 inches per hour (S.C.S.).

Depth to static water: 25 feet.

Depth of well below static water: 18 feet.

Distance between well and septic system: 50 feet.

Age of septic system: 5 years, 6 months.

Glacial drift:	Thickness	Depth
sand	25	25
water sand	18	43

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