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Illinois Department of
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POTENTIAL NITRATE CONTAMINATION OF GROUNDWATER IN THE ROSCOE AREA, WINNEBAGO COUNTY, ILLINOIS

by

Allen Wehrmann

Prepared for the
Winnebago County Board
and the
Illinois Department of Energy and Natural Resources

under

Contract Nos. 1-5-35324 and 1-5-39525 (ENR 20.154)

Champaign, Illinois

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This study has been financed in part under contract to Winnebago County. The contents do not necessarily reflect the views and policies of the County Board.

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ABSTRACT

Traditional tools for the evaluation of septic tank site suitability have been found to be inadequate for assessing the potential pollution of underlying groundwater in highly permeable soils. The Winnebago County Public Health Department has recently had to deal with a large number of "rural" residential homes built on permeable outwash terrace deposits along the Rock River. Located approximately 12 miles north of Rockford near the village of Roscoe, hundreds of homes have been built using individual well and septic systems for water supply and wastewater disposal.

An investigation of the groundwater flow system was undertaken to better define how surface and near-surface activities affected groundwater quality. Major emphasis was placed on nitrate quality because of its association with septic tank wastewaters and the potential harmful effects of elevated nitrates in drinking water. A mass balance model was subsequently developed to assess the long term impacts of current and future developments in the area.

Over 1100 groundwater samples and 100 water level measurements were collected to define changes in groundwater quality and flow direction. Nitrate content was found to be related to groundwater recharge, usage, wastewater effluent quantity and quality, agricultural fertilizer usage, and proximity to nitrate sources.

Because the local soils have an extremely low capacity for attenuating the nitrate load being discharged by the hundreds of septic systems located in the area, the only mechanism for reducing nitrate concentrations in the groundwater is dilution. Therefore, strict control of housing density in these sensitive areas must be used to maintain acceptable groundwater quality. The mass balance model proved to be a useful planning tool by predicting long term average nitrate concentrations for given hydrologic conditions. Modeling results indicate critical housing densities, based on the drinking water standard of 10 mg/l nitrate-nitrogen, should be limited to less than 1 home per acre in presently unplatted areas, much less than the presently allowed density of 1.5 homes per acre.

ACKNOWLEDGMENTS

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A very special thanks goes to Mr. Maichle Bacon, Director of Environmental Health at the Winnebago County Public Health Department. I am truly grateful for Mike's assistance and support throughout the project. I am also indebted to Mike's staff, including Steve Johnson, Dennis Priewe, and Frank Gulcynski for their efforts in collecting the hundreds of water samples necessary for the project. I would also like to extend appreciation to the personnel in the Health Department's Lab. Under the supervision of Maxine Pease, Ken Michaelis and Dorothy Hall spent long hours, often after a normal working day and on weekends, running analyses on the water samples we brought in. The expertise and time lent by all the WCPHD staff are greatly appreciated.

Technical expertise regarding the geology of Winnebago County were provided by John Kempton and Dick Berg of the Illinois State Geological Survey. Dick and Robb Krumm graciously took time from another project to construct the two monitoring wells built for this study.

Assistance provided by the staff at the Illinois State Water Survey include: Jim Whitney, Kenni James, Sue Bachman, Brian Kaiser, and Art Bodenschatz provided detailed chemical analyses of water and wastewater samples; John Brother and his staff, Linda Riggin, William Motherway, and Vicki Stewart prepared all the illustrations appearing in this report; Marvin Clevenger and his staff entered the chemical data into computer storage; and Kathleen Brown typed the manuscript and all revisions.

James Gibb, Thomas Naymik, and Michael Barcelona, senior members of the ISWS staff, reviewed the text and lent expertise on groundwater hydrology and chemistry. Mark Sievers, technical assistant, wrote the mass-balance program, coordinated the computer filing of the chemical data, and provided assistance on numerous field trips. My deep gratitude for his help and all the ISWS staff involved with this project.

Lastly, I wish to thank the citizens of the Roscoe area for their cooperation throughout the entire study. Special thanks to the Porters, 5647 Elevator Road, for use of a supplementary well to monitor groundwater levels, and Mr. Rod Sargeant, Principal, and the faculty of Kinnikinnick Grade School for use of the teachers' area for coordination of field activities. The overwhelming response of the local residents and businessmen revealed a deep awareness and appreciation for the future of their environment.

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INTRODUCTION

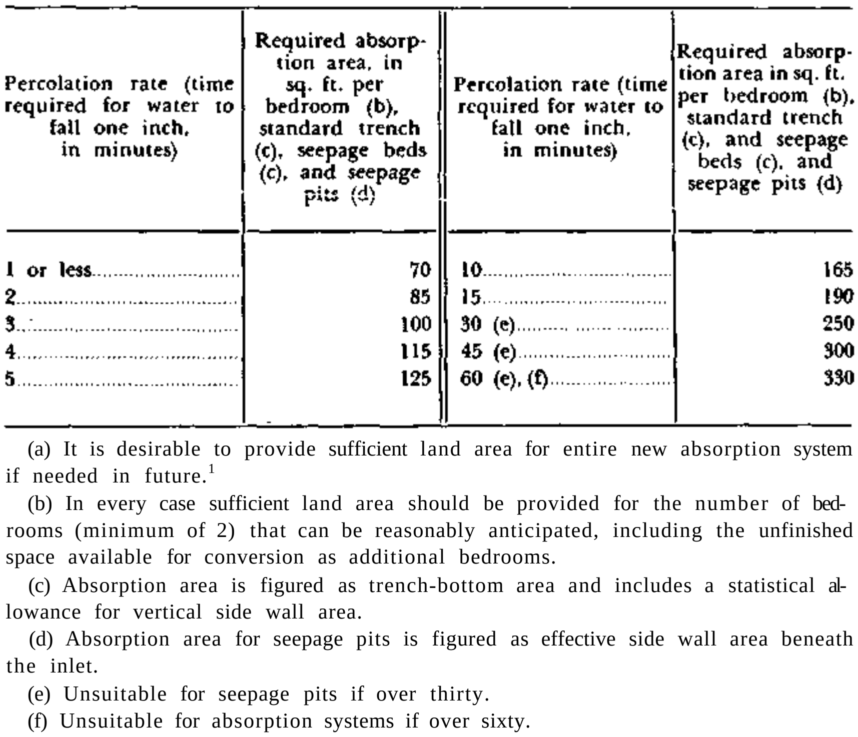
Background

Traditional tools for the evaluation of septic tank site suitability have been found to be inadequate for assessing the potential pollution of underlying groundwater, particularly in highly permeable soils. Standard septic system-leach field design has historically been based on a soil's ability to absorb wastewater effluent. The Manual of Septic-Tank Practice (1967) describes a suitable soil as one which has

> "an acceptable percolation rate, without interference from groundwater or impervious strata below the level of the absorption system. In general, two conditions must be met: 1) the percolation time should be within the range of those specified in Table 1 and 2) the maximum seasonal elevation of the groundwater table should be at least 4 feet below the bottom of the trench or seepage pit. Rock formations or other impervious strata should be at a depth greater than 4 feet below the bottom of the trench or seepage pit."

Classification of soil suitability by the U.S. Soil Conservation Service followed these criteria and Public Health Department site evaluation for septic system installation came to include a "percolation test" to define the suitability of the soil to accept water. The main concern was centered on the potential for absorption system failure, ultimately causing effluent to erupt at the ground surface or back up into the house, creating a public nuisance and health hazard from exposure to raw sewage. For these concerns, the criteria have been found to be successful.

Table 1. Absorption - area requirements for individual residences



Percolation rate (time required for water to fall one inch, in minutes)	Required absorption area, in sq. ft. per bedroom (b), standard trench (c), seepage beds (c), and seepage pits (d)	Percolation rate (time required for water to fall one inch, in minutes)	Required absorption area in sq. ft. per bedroom (b), standard trench (c), and seepage beds (c), and seepage pits (d)
1 or less	70	10	165
2	85	15	190
3	100	30 (e)	250
4	115	45 (e)	300
5	125	60 (e), (f)	330

(a) It is desirable to provide sufficient land area for entire new absorption system if needed in future.[1]

(b) In every case sufficient land area should be provided for the number of bedrooms (minimum of 2) that can be reasonably anticipated, including the unfinished space available for conversion as additional bedrooms.

(c) Absorption area is figured as trench-bottom area and includes a statistical allowance for vertical side wall area.

(d) Absorption area for seepage pits is figured as effective side wall area beneath the inlet.

(e) Unsuitable for seepage pits if over thirty.

(f) Unsuitable for absorption systems if over sixty.

Little attention was paid, however, to soils which accepted water at very fast rates. Recent scientific research (Walter et al., 1973; Dudley and Stephenson, 1973; and Starr and Sawhney, 1980) and numerous case histories (Perlmutter and Koch, 1972, Long Island; Miller, 1972, Delaware; Morrill and Toler, 1973, Massachusetts; and Spalding et al., 1982, Washington) have shown that rapid movement of wastewater through unsaturated, highly permeable soils greatly reduces treatment efficiency and in high density housing situations can lead to local and regional groundwater contamination problems. Investigators in the Delaware study went so far as to say, "The standard percolation test is not a suitable means for determination of the acceptability of a site for septic-tank effluent."

Since 1976, the private sewage disposal code for Winnebago County utilized information contained in a 1975 soil survey conducted by the Winnebago County Soil and Water Conservation District (WCSWCD). With this revised code, the Winnebago County Public Health Department (WCPHD) became one of a few such agencies to use soil survey information in their on-site sewage disposal criteria.

Included in the code is a requirement that soil borings, instead of percolation tests, be taken by WCSWCD personnel at the site of each proposed system. Because the borings penetrate depths greater than percolation tests, a much better indication of the type of geologic materials present beneath the seepage field is determined. The materials underlying the seepage field are crucial to the treatment of septic effluent.

While soil borings provide more information than percolation tests on the suitability of a site for an individual sewage system, there was still no direct method for providing information on the potential influence that numerous systems might have on groundwater quality, particularly in permeable soils. The U.S. Soil Conservation Service recognized this problem when, in 1978, all soils with percolation rates greater than 6 inches per hour, in all layers below a depth of 24 inches, were reclassified as potentially hazardous to groundwater contamination.

By this time a large number of "rural" residential homes had already been built with private well and septic systems in several sections of Winnebago County containing very permeable soils. One area of major concern was located approximately 12 miles north of Rockford near the Village of Roscoe. Located in northeastern Winnebago County, the town and surrounding subdivisions are built primarily on permeable outwash terrace deposits associated with the Rock River Valley. Subsurface materials consist of more than 200 feet of unsorted sands and gravels overlain by a thin veneer of topsoil averaging less than three feet thick. Due to the abundance of easily obtainable groundwater within the sand and gravel, all of the homes in the area have private well systems for their water supplies. However, the sand and gravel also is used to purify domestic wastes through the use of private septic systems.

The growth of housing in the Roscoe area since 1970 has been tremendous. Census data compiled by the Rockford-Winnebago County Planning Commission shows an increase of 3,386 people in Roscoe Township between 1970 and 1980, a 77.5 percent rise. This unprecedented population growth was absorbed primarily by single family residences using private well and septic systems.

Water samples collected by the WCPHD in the spring of 1979 indicated several homes in the Roscoe area exceeded the recommended drinking water standard for nitrate (10 mg/l as nitrogen). The WCPHD immediately proposed that the County Planning Commission prohibit the creation of any <u>new</u> subdivisions in the areas reclassified by the Soil Conservation Service until a more thorough investigation could be made. This proposal was not considered to create a hardship on the local housing industry because it was estimated that even at the peak building rate in existence during 1978-79, it would take 5 years to build out the lots already platted. However, local developers, contractors, and realtors did not favor a proposal that could possibly curtail their business and the proposal was never passed.

The WCPHD continued collecting water samples through 1981; results of the nitrate analyses for the years 1979-1981 appear in Table 2. For comparison purposes, those addresses which were sampled in all three years appear in parentheses after each set of complete data collected in each year. Based solely on these figures, it would appear a definite problem exists with nitrate-nitrogen (NO_3-N) concentrations rising at a rate of 1 mg/l per year. The drinking standard of 10 mg/l NO_3-N was also being approached or exceeded in some cases.

Table 2. Results of Nitrate Analyses for Samples Collected by the Winnebago County Public Health Dept. (1979-1981)

NO_3-N concentration (mg/l)	Number of Samples* Spring 1979	Spring 1980	Spring 1981
0-2	9 (8)	0 (0)	0 (0)
2-4	4 (4)	18 (6)	1 (1)
4-6	26 (21)	54 (11)	10 (10)
6-8	18 (12)	71 (19)	19 (15)
8-10	10 (8)	66 (18)	24 (22)
>10	7 (7)	19 (6)	13 (12)
Total No.	74 (60)	228 (60)	67 (60)
Mean	6.52 (6.54)	7.33 (7.82)	8.40 (8.44)
Median	5.8 (5.7)	7.6 (7.5)	8.25 (8.32)
Stan. Dev.	4.56 (4.99)	2.97 (4.37)	2.87 (3.00)

*Parentheses denote information from samples collected from the same addresses for all three years, a total of 60 homes.

Critics of this investigation noted the samples had always been collected in the spring, a time when recharge events (melting snow and rainfall) could wash pollutants, particularly nitrates, into the underlying groundwater. There was some question, also, as to the selectivity of the homes sampled. Knowing that certain areas appeared to have higher nitrate concentrations than others may have led samplers to intensify their efforts in those areas. Some samples which showed high nitrate concentrations were found to be from wells near a faulty septic system and, in another case, two improperly abandoned wells on nearby property. Lastly, the significance of the rise in nitrate concentrations over this three year period needed to be evaluated. Could a similar rise be expected every year or would a leveling of nitrate concentrations be more likely, and, if so, when? Would changes in the future development of the area help keep nitrate concentrations below the drinking standard or was the installation of a central sewer system the only alternative?

The WCPHD admitted a need for more expertise in a groundwater investigation of this nature and the Illinois State Water Survey was approached to develop a plan of study to give a better understanding of the regional groundwater system in the Roscoe area and how this system interacts with man-made influences to affect groundwater quality. The widespread use of densely located domestic septic tank-leach field systems and the potential for groundwater nitrate contamination was of particular concern. Assessments of current and future development of the area were needed so intelligent planning decisions could be made.

Scope of Study

The purpose of this investigation is to evaluate the potential effects of densely situated septic systems on the underlying groundwater quality. Major emphasis is placed on nitrate contamination because of its association with septic tank wastewaters and the potential harmful effects of elevated nitrates in drinking water.

Summarized by Miller (1980),

> "Appraisals of the potential contamination of groundwater by septic tank systems in these high density areas requires an understanding of the groundwater system into which the effluent is discharged. First, groundwater recharge areas and flow patterns should be delineated; second, the quantity of groundwater recharge must be estimated to establish the degree of natural dilution of the effluent and third, the capability of the soil system to renovate the effluent should be known. While these concepts go beyond the widely established septic system siting criteria, their institution is essential if groundwater quality is to be protected in high density septic tank areas."

Elevated concentrations of nitrate in groundwater have been linked to sources other than just septic tank effluent. Therefore, an evaluation of other nitrate sources, including agricultural and lawn fertilizers, animal feedlot runoff, and natural deposition from precipitation was made.

In addition, a conceptual model of the groundwater system, based on the data collected during the course of the study, was used to evaluate the long term effects of the various nitrate sources on groundwater quality. The model can be used as a planning tool to give guidance for the proper management of activities which could lead to groundwater quality degradation.

Study Area Description

The study area encompassed approximately 4.5 square miles in a geologically susceptible region located along the Rock River in northern Winnebago County (figure 1). The study area is bounded on the south and west by the Rock River and on the north by the center lines of Sections 19 and 20 (Township 46 North, Range 2 East) extending east to the Chicago and Northwestern Railroad. The study area boundary follows the railroad southeast to the Village of Roscoe and then follows the incorporated village limits around to at the Rock River. U.S. Route 251 generally

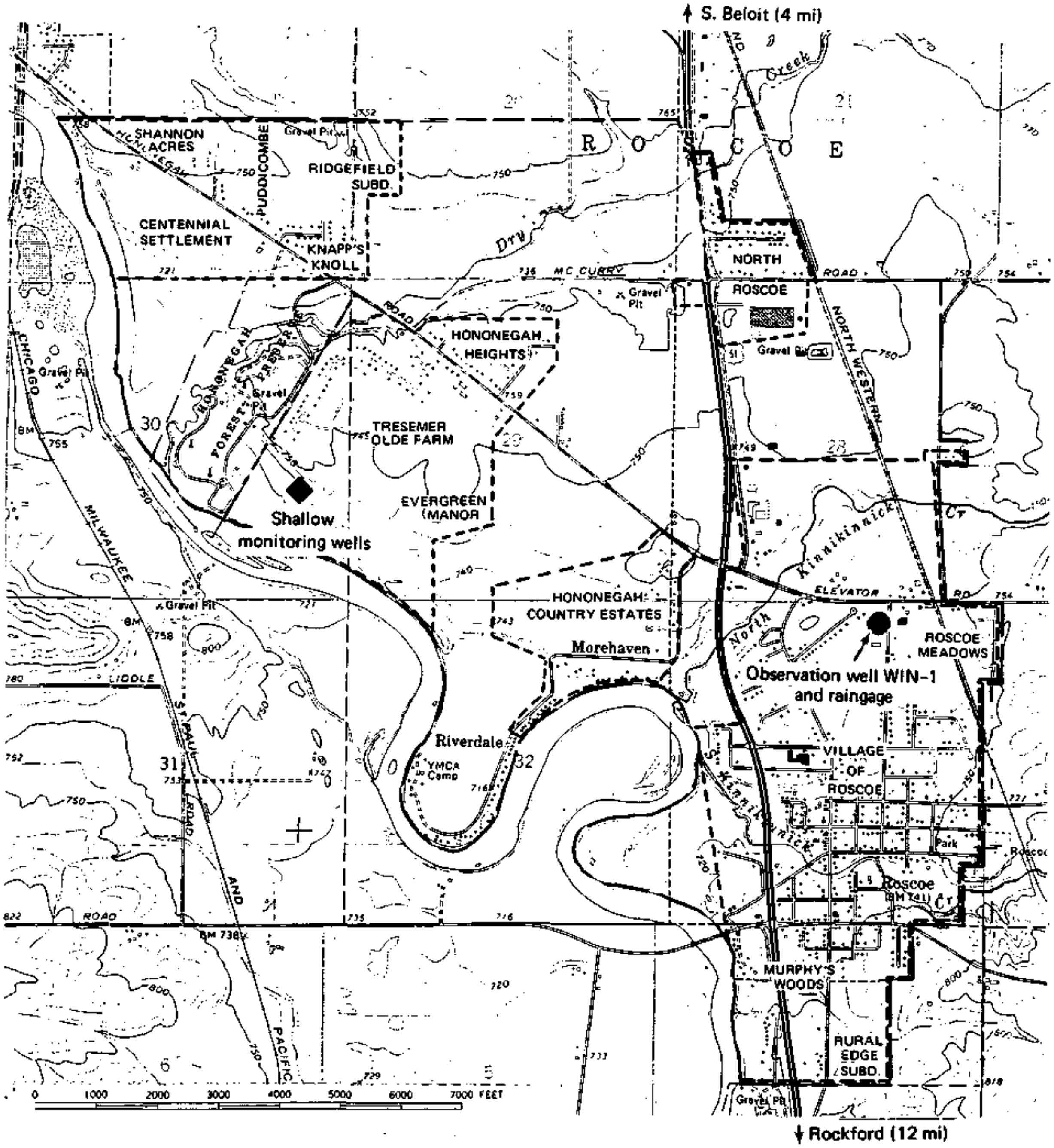


Figure 1. Rosooe study area

bisects the area into an east and west half and is the main artery connecting this area to Rockford, approximately 12 miles south.

Land surface elevations in the study area range from 760 feet above mean sea level along the north and east boundaries to less than 710 feet along the Rock River. Most of the study area is situated on a broad, flat terrace overlooking the floodplain of the Rock River. East of Roscoe, a second terrace can be seen which rises to over 800 feet. Two perennial streams, North and South Kinnikinnick Creeks, dissect the terraces as they flow to the Rock River. A third stream, Dry Run Creek, intermittently discharges to the Rock River from the north.

The study area includes industrial and agricultural settings, as well as residential subdivisions and the Village of Roscoe. No centralized water or sewer systems have been built within the area. Each home, farm, and business maintains a private, on-site water well and septic system. Early considerations to study only those subdivisions located west of Route 251 along Hononegah Road were rejected in favor of including other land use areas to help determine various land use effects on groundwater quality. The Village of Roscoe was included especially to provide data that might indicate the long-term effects of domestic septic system use on the underlying groundwater. The incorporated Roscoe area had not been sampled in previous WCPHD endeavors and this afforded a good time to do so in a comprehensive manner.

NITRATE IN THE ENVIRONMENT

The Nitrogen Cycle

Nitrogen plays a part in the life cycle of all living organisms, both plant and animal. It can be transformed biologically by bacteria as well as undergoing simpler chemical reactions. Similar to the hydrologic cycle discussed earlier, figure 2 is known as the nitrogen cycle, a pictorial display of how nitrogen occurs in nature.

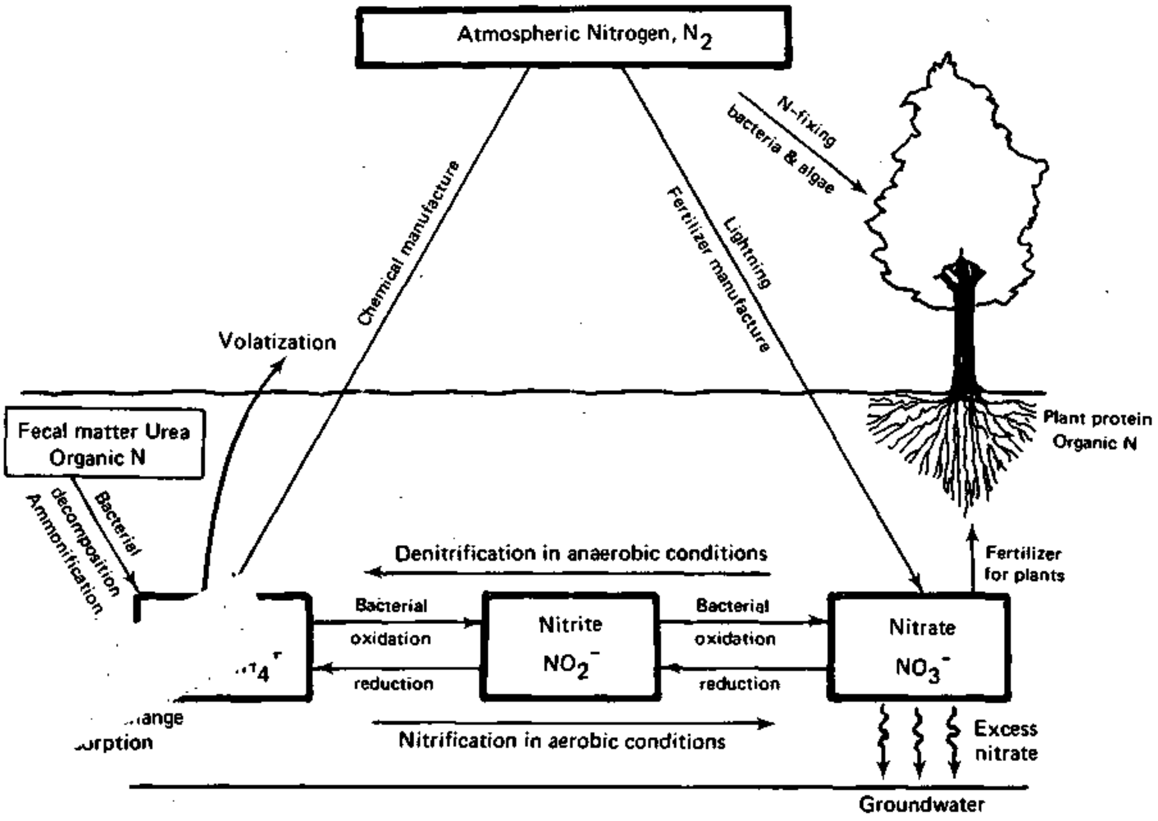
The atmosphere acts as a nitrogen reservoir from which nitrogen is removed through electrical discharge (lightning), nitrogen-fixing bacteria and algae, and by fertilizer and chemical manufacturing processes. Lightning oxidizes atmospheric nitrogen to various nitrogen oxides (NO, NO_2, N_2O). When combined with rainwater, the oxides can form HNO_3 as they fall to the earth. The nitrates, NO_3, are then available to plants and converted to proteins:

$$NO_3 + CO_2 + H_2O + \text{green plants} + \text{sunlight} = \text{protein}$$

Atmospheric nitrogen is also converted to proteins by some bacteria and algae:

$$N_2 + H_2O + \text{nitrogen-fixing bacteria and algae} + \text{sunlight} = \text{protein}$$

Humans and animals are dependent upon the consumption of plants or other animals (that feed upon plants) to provide protein. Nitrogen compounds are then incorporated as part of the protein in the body and are released back to the environment as waste products or upon death. Urine and feces contain large amounts of nitrogen resulting from the metabolic breakdown of proteins or unassimilated organic matter. Biochemical


Atmospheric Nitrogen, N_2
N-fixing bacteria & algae
Chemical manufacture
Lightning
Fertilizer manufacture
Volatization
Fecal matter Urea Organic N
Bacterial decomposition Ammonification
Plant protein Organic N
Fertilizer for plants
Denitrification in anaerobic conditions
Bacterial oxidation
reduction
Nitrite NO_2^-
Nitrate NO_3^-
ange
rption
Nitrification in aerobic conditions
Excess nitrate
Groundwater

action on nitrate by bacteria convert the nitrogen in urine to ammonium carbonate. The protein matter in feces and dead animals and plants is also converted to ammonia by bacteria. The conversion of protein-nitrogen to ammonia is often called mineralization or ammonification.

Ammonia is oxidized by a group of naturally occurring bacteria in the soil. The Nitrosomonas group of bacteria convert ammonia to nitrate under aerobic conditions:

$$2NH_3 + 4O_2 \xrightarrow[\text{bacteria}]{} 2NO_3^- + 2H^+ + 2H_2O$$

The nitrates formed may serve as fertilizer for plants. However, nitrates formed in excess of plant requirements or released below the root zone where plants cannot reach will be leached by percolating water to the underlying groundwater system. Nitrates exist as dissolved ions and cannot be filtered by soil materials. Furthermore, the cation exchange capabilities of a soil do little to attenuate the nitrate ion.

Under anaerobic conditions, nitrites and nitrates can be reduced (denitrified) to nitrogen gas by a group of denitrifying bacteria. For this to occur, organic matter must be present for a bacterial energy source. Heavy soils containing large amounts of organic material are generally slow to drain, fostering anaerobic conditions and promoting denitrification.

Beneath the Roscoe study area, conditions are extremely good for complete conversion of ammonia to nitrate: well-drained, sandy soils with a deep water table allow ample opportunity for the aerobic nitrifying bacteria to complete the nitrification process. Septic system leach fields release water high in nitrogen content below the root zone of most lawn plants, further exacerbating the problem. Lastly, deeply percolated water high in nitrate cannot be denitrified under the anaerobic conditions of the groundwater regime because of a lack of organic matter filtered by the overlying earth materials. The only active mechanism present to reduce nitrates in this environment is the process of dilution.

Sources of Nitrate in Groundwater

The sources of nitrate contamination are numerous and well documented. These include agricultural and lawn fertilizers, feedlots, septic systems, sewage effluent percolation ponds, and industrial wastewaters (usually food processing oriented).

Hensler and Attoe (1970) found the occurrence of nitrates in the soil profile beneath agricultural land in Wisconsin was directly related to nitrogen fertilizer application and that rural wells producing high nitrate water were located near barnyards or feedlots and tapped shallow, course-textured deposits. Duke and others (1978) also found fertilization of corn crops on irrigated land in Colorado resulted in over 10 mg/l NO_3-N concentrations in groundwater. Baler and Rykbost (1976) studied the nitrate content of Long Island groundwater in relation to fertilization caused concentrations of NO_3-N to be significantly over 10 mg/l. Another study at Cornell University (Porter et aL, 1981) has shown links to the intensity of lawn fertilization and increased nitrogen levels in Long Island groundwater.

Owens (1960), researching nitrogen movement and transformations in sandy soils, reported, "The high levels of NO_3-N in the soil solution at the depths indicated and the relatively rapid movement of water through the profile of this sandy soil suggests that special caution is needed in establishing rates and times of application of both fertilizer N and irrigation water." Other factors such as the soil texture, the stage of plant growth, and the antecedent soil moisture conditions also play a large role in the amount of nitrate that reaches the groundwater.

Studies related to septic system sources revealed some very interesting facts about nitrate movement belov ground. Starr and Sawhney (1980) instrumented a 6 year old septic system with neutron probes, porous ceramic soil water sampling devices, and tensiometers to inspect the movement of carbon and nitrogen from a septic system drainfield. They concluded that nitrates derived from the nitrification of nitrogen compounds coming from a septic drainfield can move quantitatively with infiltrating rainwater to an underlying groundwater system.

Perhaps the most definitive work on nitrogen movement from septic effluent was done by Walker, Bouma, and others (1973). Five seepage beds that had been constructed in sandy soils were investigated to determine the biological transformation of nitrogen during soil percolation and to determine the movement of septic effluent into and through the groundwater around these systems. Excavation of the materials adjacent to the seepage beds revealed an impeding layer or "crust" at the boundary of the gravel filter bed and the adjacent natural soil. The crust was largely organic in nature and thought to be created by anaerobic organisms and the accumulation of larger solids carried by the effluent and filtered by the surrounding finer-grained natural material.

One major finding was a shift from ammonium in the raw septic effluent to nitrate within a few centimeters below the seepage bed It was their conclusion that above this impeding layer, anaerobic saturated conditions exist but once the water passes through the crust, unsaturated, aerobic conditions exist allowing nitrification of the ammonia to nitrate to occur. According to Walker, et al., "In all aerobic subsurface beds examined, nitrification commenced in the unsaturated zone within about 2 cm of the crust...Nitrification was apparently complete in a matter of hours, and was essentially quantitative as evidenced by the approximate similarity of the septic tank effluent total N concentration and the soil solution NO_3-N concentrations." The investigators went on to say that the only way to reduce the NO_3-N content in the percolating effluent was by denitrification - an unlikely situation in deep sandy soils (such as occurs in the Roscoe area).

Once the effluent has reached the underlying groundwater, the principal mechanism for reducing the NO_3-N concentrations is by dilution. This implies that the groundwater, often a local water supply, is actually part of the treatment system and that some distance or area is necessary over which the dilution can occur. In many areas, the density of surrounding systems may be such that the dilution mechanism from flowing groundwater is not allowed to work. Standard separation distances between well and septic system, often used to maintain a degree of safety from potential pollution sources, become meaningless because no distance will provide adequate protection.

Health Effects of Nitrates in Drinking Water

Medical reports describe the toxicity of nitrate In drinking water as caused by the bacterial conversion of nitrate to nitrite within the digestive tract (Cornblath and Hartmann, 1948; Walton, 1951). Nitrite converts hemoglobin, the oxygen-carrying component in the blood, to methemoglobin. Methemoglobin will not carry oxygen and the resulting physiological effect is oxygen deprivation. The affliction is called methemoglobinemia and is also known as "blue baby syndrome" because of the susceptibility of young infants. The characteristic symptom is a bluish tinge (cyanosis) around the lips, fingers, and toes which can eventually cover the entire body. Left untreated, the illness can be fatal.

It is generally accepted that the first reported case of human poisoning from nitrates in drinking water was presented by Comly in 1945. Two Iowa infants, each about one month old, showed the symptoms of cyanosis. A chance testing of the drinking water supply was conducted and a high nitrate content was found. Once the link between nitrates and drinking water had been made, other reports from across the United States soon followed (Chapin, 1947; Rovertson and Riddell, 1947; Cornblath and Hartmann, 1948; and Bosch et al., 1950).

The development of the disease was found to be largely confined to infants less than three months old. Winton (1971) explained several factors for the susceptibility of this age group. First, an infant's total fluid intake per body weight is approximately three times that of an adult's. Second, the gastric pH in an infant's stomach is higher than an adult's and is high enough (pH 5-7) to allow nitrate-reducing bacteria to live in the upper gastrointestinal tract where the bacteria can reduce the nitrate to nitrite before absorption into the bloodstream. Third, fetal hemoglobin, the most prevalent form of hemoglobin in the body at birth, is more susceptible to methemoglobin formation than adult hemoglobin. Fourth and finally, young babies have a decreased activity of the enzyme responsible for normal methemoglobin reduction.

According to Winton, occurrences of methemoglobinemia, then, are influenced by three basic factors: 1) total nitrate intake, involving both concentration and amount ingested; 2) the bacterial capacity to reduce nitrate to nitrite which is influenced by gastric acidity and 3) the biochemical equilibria of hemoglobin and methemoglobin in the blood. Control over any one of these three factors should reduce the incidence of the disease; the most easily controllable and probably best understood area is limiting the nitrate intake.

Bosch (1950) found infants who were breast fed did not develop methemoglobinemic symptoms until being changed to a formula containing high nitrate well water. The time period for the symptoms to develop depended on the nitrate concentration in the water, the amount of water in the formula, the amount of feeding, supplemental water feedings, the length of time the water was boiled, and possibly unknown physiological factors.

The practice of boiling the water before mixing in with an infant's formula was found to contribute to the problem. Boiling is useful for killing bacteria present in the water, formula, and bottles. However, boiling water will not remove nitrate and, in fact, will concentrate the nitrate by evaporation of the water. Bosch reported a case where the water was boiled for over 30 minutes, concentrating the original nitrate concentration of 140 mg/l NO_3-N to 410 mg/l NO_3-N.

Bosch also documented several other factors relating to the occurrence of methemoglobinemia in Minnesota. Of the 107 reported cases during the two-year period 1947-1948, 34 or 31.8 percent occurred during the quarter April-June. For the other quarters, January-March, July-September, October-December, only 18.7, 23.4 and 26.1 percent of the cases occurred, respectively. Of 139 total cases reported in Minnesota by January 1949, 125 received water from a dug well source. Only 12 wells involved were over 75 feet deep, of which 10 were dug (as opposed to drilled). Eighty three of the 139 wells were located within 50 feet of a contamination source: feedlot, cesspool, or septic system. Strong correlations with nitrate contamination appear to be depth of well, proximity of well to contamination source, well construction, and time of year.

One investigator (Parsons, 1977) has suggested the nitrate standard of 10 mg/l NO_3-N is too low. The ingestion of various foods containing high nitrates without causing methemoglobinemia was cited as one reason. Other reasons given were the lack of a reported fatality due to methemoglobinemia in the past 17 years, that people in several areas of the U.S. routinely ingest water containing 10-100 mg/l NO_3-N with no ill effects, and some indication that an "external" presence of bacteria is needed for nitrate to have a harmful effect on infants and adults.

Winton, et al.(1971) suggest the drinking standard offers "a respectable safety-factor needed to cover all reasonable situations." That no nitrate-induced fatalities have occurred recently speaks well of the standard. The knowledge gained from the reporting of case histories and their successful treatment has undoubtedly served to reduce, even obliterate, fatalities from nitrates in drinking water. Parson's implied need for an "external" presence of bacteria to induce methemoglobinemia has no scientific basis of fact. Additionally, while public water supplies are continuously chlorinated to guard against bacterial contamination, domestic water supplies are rarely chlorinated, thereby limiting the protection afforded domestic users.

Recent research also has related the occurrence of nitrates in drinking water and a potential for producing carcinogenic nitrosamines. Many N-nitroso compounds (including nitrosamines) have been found to cause cancer in animals and some epidemiological studies have correlated the concentration of nitrates in drinking water and the incidence of gastric cancer (Hill et al., 1973; Hawksworth et al., 1975; and Correa et al., 1975).

According to the National Academy of Sciences (1977),

> "The full series of reactions [for formation of carcinogenic N-nitroso compounds] has not yet been demonstrated, however, so that the problem is a prospective rather than a realized one. The possible role of nitrate in water in contrast to the role of the normally much greater ingestion in foods has also not been determined...Findings such as these are preliminary and suggestive. They provide no firm evidence of a causal link between incidence of cancer and high intake of nitrate. They do indicate a need for caution in assessment of lack of adverse health effects even at the 10 mg/l concentration level for nitrate as nitrogen and a need for continued intensive study on the metabolism and effects of nitrate in man."

GEOLOGY AND HYDROLOGY

Geology of the Roscoe Area

The geology of Winnebago County has been extensively studied and interpreted by several investigators (Hackett, 1960; Anderson, 1967; Berg et al., 1981). Beneath the study area, a deep valley has been carved into the valley surface. This valley was formed centuries ago by the erosional action of flowing water during the advance and retreat of several continental glaciers. Lying beneath the moder Rock River Valley, the bedrock valley was carved through the Galena-Platteville Dolomite to expose the underlying St. Peter Sandstone. The bedrock surface rises sharply to the east and west forming a sharp boundary to the central valley.

As the last glaciers retreated northward, glacial meltwaters washed huge amounts of debris (silt, clay, sand, gravel, and organic materials) into this valley. Much of the sediment that filled the valley in the Roscoe area is sand and gravel. These deposits are as much as 200 feet thick in the deepest portions of the now buried bedrock valley. Well-drained sand and gravel terraces formed by the cutting of the valley deposits and subsequent refilling with lesser amounts of glacial debris is topographically evident. A geological cross section through the study area is shown in figure 3 (Berg et al., 1981).

A more detailed discussion of the geology of this area can be found in the recently published Geology for Planning in Boone and Winnebago Counties by Richard Berg, et al. , Illinois State Geological Survey Contract Publication, 1981.

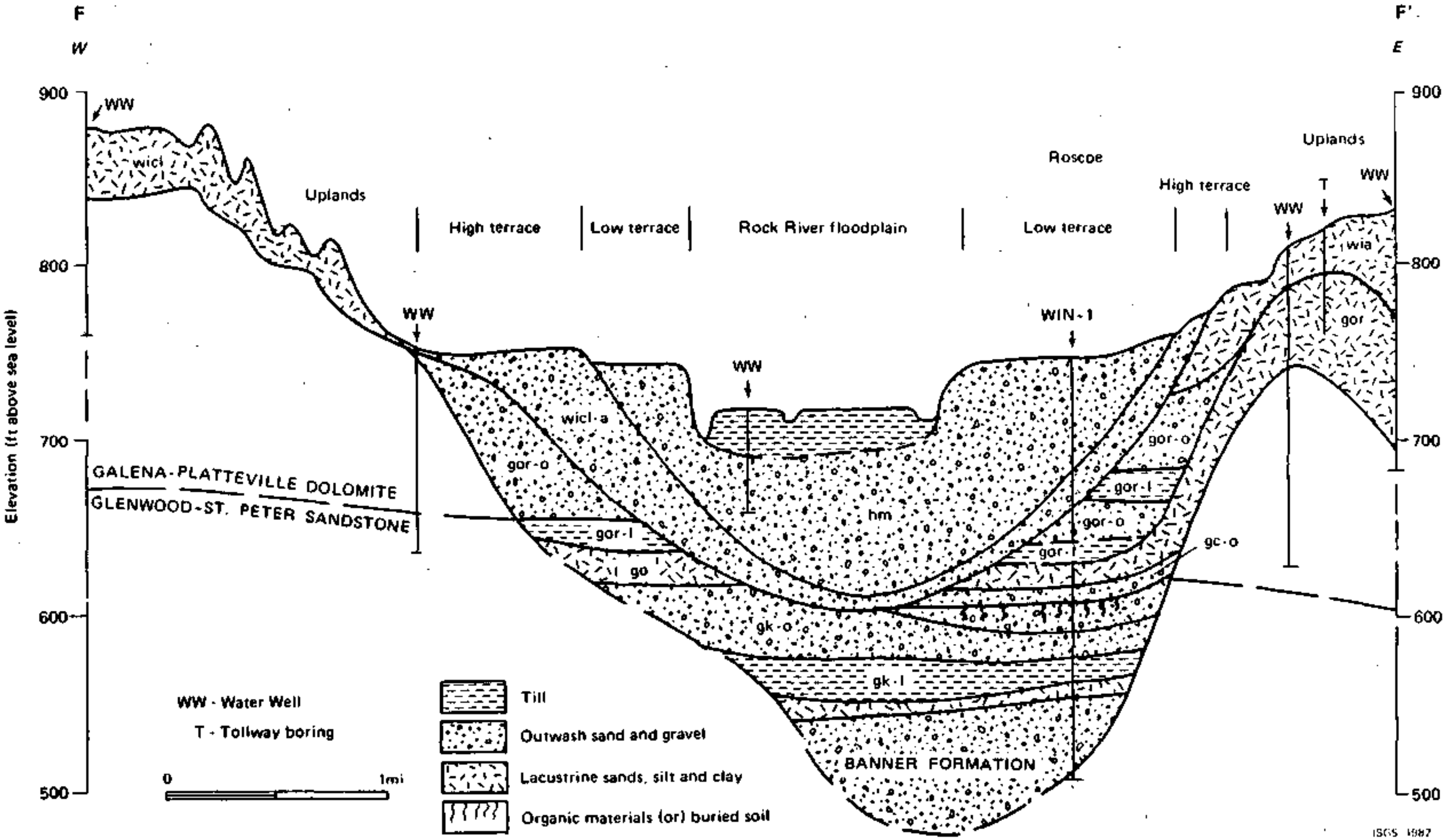


Figure 3. West to east cross section across Bock River Valley at Roscoe (from Berg, et al, 1981)

Groundwater Occurrence and Movement

Figure 4 generally illustrates the hydrologic cycle much as it would appear in the Roscoe area. Water condensed in the atmosphere falls as precipitation. Most of the water is evaporated back to the atmosphere or flows overland to local streams and rivers. A smaller portion of the water will percolate downward through the pore spaces of the soil under the influence of gravity. Here, the water is available to plant roots and can be transpired back to the atmosphere.

The amount of water which can infiltrate from a given storm is dependent upon such factors as the amount and intensity of precipitation, the slope of the land surface, the permeability of the soil (the amount of pore space open to the flow of water), the type and density of plant growth on the soil, and the amount of water present in the soil pore spaces before the storm occurs. The sandy soils around Roscoe readily accept and transmit precipitation to deeper zones.

As the water moves downward under the pull of gravity, it will reach a point where all the pore spaces are saturated. The surface of this zone of saturation is called the water table. All water below the water table is referred to as groundwater. The water table is a surface which can be approximated by the elevation of water surfaces in wells which just penetrate the saturated zone. The position of the water table will fluctuate up and down in response to rainfall recharge, evapotranspiration, and groundwater withdrawals (pumpage).

In the Roscoe area, the water table can be found at depths from 25 to 30 feet. Under natural conditions, the water table forms a surface which resembles a subdued and smoother configuration of the overlying land surface topography. The water table will be at higher elevations beneath

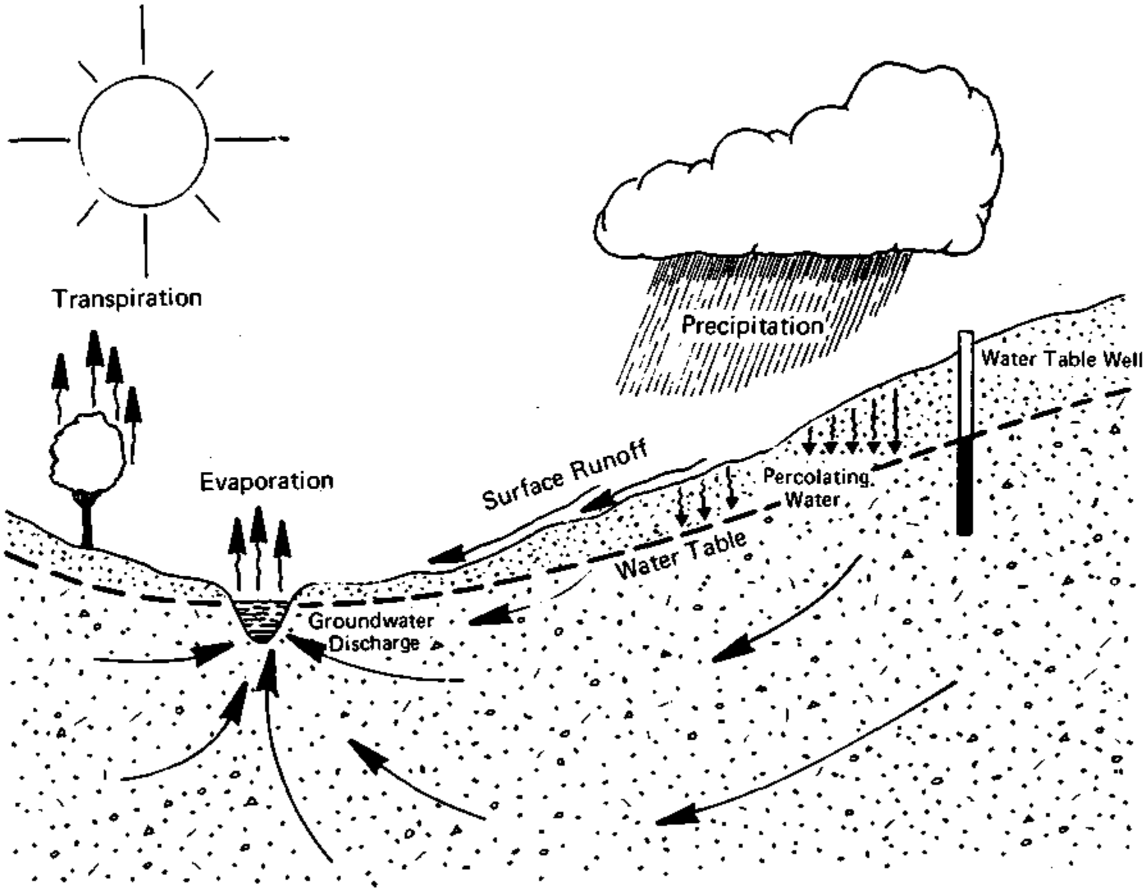


Figure 4. Generalized hydrologic cycle for the Roscoe study area

upland areas and at lower elevations in valleys. The water table intersects the ground surface along perennial streams, springs, and lakes. The intersection of the water table with the ground surface occurs in areas of groundwater discharge and marks the return of what once fell as precipitation to the surface environment.

Groundwater discharge (or runoff) can be a significant portion of the total flow of a stream or river. The flow in a perennial stream after extended periods without precipitation is due, in large part, to groundwater discharge. For some streams in Illinois, as much as 90 percent of the streamflow during dry periods is from groundwater discharge. The amount of water which discharges to a given stream is greatly dependent on the surrounding geology, topography, soil permeability, climatology, and land use.

Estimates of the magnitude of groundwater discharge have been made using streamflow hydrograph separation techniques. Because of the continuity of groundwater flow averaged over periods of time, groundwater recharge can be equated to groundwater discharge. Studies conducted at the Illinois State Water Survey (Walton, 1965 and O'Hearn, et al., 1980) for river basins similar to the area surrounding Roscoe show groundwater discharge to surface streams averages 142,000 to 237,000 gallons per day per square mile. These figures are equivalent to 3 to 5 inches of infiltrated precipitation per year (the annual precipitation for Roscoe is 33 inches).

Groundwater moves in a fashion analogous to surface water. While surface water moves downhill in response to gravity, groundwater moves "downgradient" from areas of higher potential (or pressure) to areas of lower potential. The force causing groundwater flow is directly proportional to the elevation differences of water levels in wells. A map of groundwater elevations, therefore, can be used to determine groundwater flow direction. Also, the changes in slope of the water table can give an indication of the relative rates of. groundwater movement beneath an area.

Groundwater in drift deposits, such as those beneath the Roscoe area, is recharged directly by percolation of precipitation occurring in the immediate vicinity. Generally, a potential exists for groundwater in the upper deposits to move vertically downward to recharge deeper deposits. However, because of the proximity to a major regional groundwater discharge point, the Rock River, the major component of movement will be laterally toward the river. While some recharge of the deeper deposits is expected to occur within the study area, most of the recharge to those deposits occurs in areas more removed from the river. For the purposes of this investigation, only groundwater in the upper 60 to 70 feet (the depth of most wells in the study area) will be considered, keeping in mind this is only a part of a much larger system.

Geologic Susceptibility to Surface and Near-Surface Activities

As previously discussed, the materials underlying the study area are principally sands and gravels deposited centuries ago by glacial meltwaters. The relatively large pore spaces in the sand and gravel allow large amounts of water to flow, water which can easily be pumped by wells. Unfortunately, the hydraulic characteristics that make these deposits good aquifers also make them susceptible to contamination from a variety of sources. Walker (1969) identified several areas in Illinois which have a high potential for contamination from surface-derived sources based primarily on areas known to yield large amounts of groundwater from

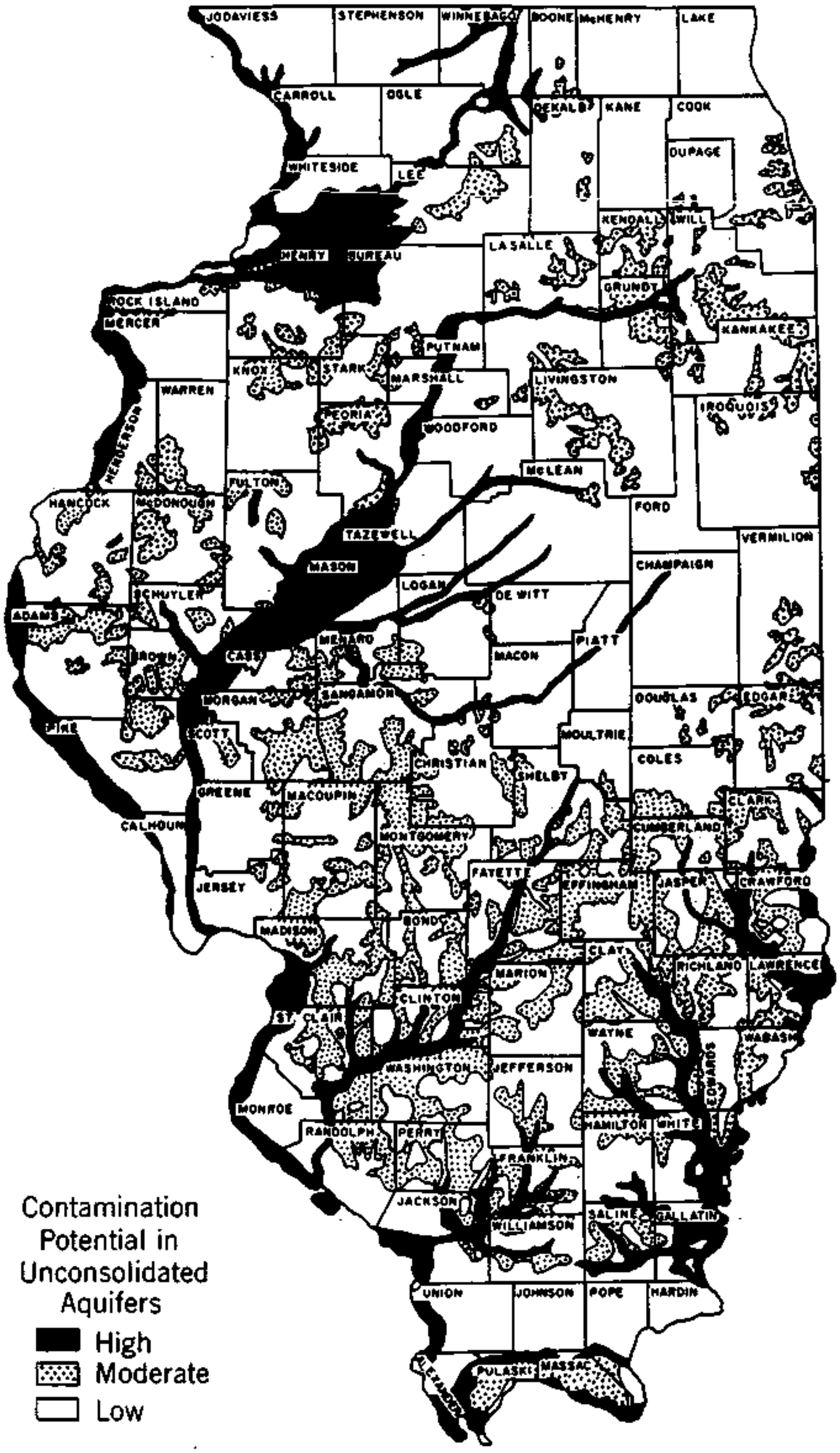


Figure 5. Unconsolidated aquifer contamination potential (from Walker, 1969)

shallow, unprotected aquifers ("unprotected" relates to the absence of overlying material of fine texture which could attenuate potential contaminants). The Rock River Valley in Winnebago County is clearly defined (figure 5). Berg et al., (1981) characterize the same area as being subject to contamination from the land burial of wastes, septic tank systems, and surface application of waste products and agricultural chemicals because of a low-cation exchange capacity, generally attributed to low clay and organic content, and high porosities and hydraulic conductivities (permeability).

METHODS AND PROCEDURES

Groundwater Flow Patterns and Recharge

Mapping groundwater flow direction and groundwater level response to precipitation events is very important in nearly any groundwater quality investigation. With this information, an idea of potential contaminant source locations and directions of movement can be determined. Surface or near surface derived pollutants, such as septic tank wastes, are washed into the groundwater system from infiltrating water. Periods when this occurs are important for evaluating water quality data.

Precise water level measurements (depth to water below ground surface) were taken at sixty wells throughout the study area during the spring and fall. Topographic level circuits were extended from known bench marks to precisely determine the ground elevation (feet above mean sea level) at each well. A groundwater elevation map was then produced by subtracting depth-to-water measurements from ground elevations. Contours of groundwater elevation define the regional flow pattern and give an indication of the relative velocities of groundwater movement through the study area.

A continuous record of groundwater levels and precipitation were measured at a site located at the north end of Roscoe (figure 1). A well originally drilled as part of a geologic investigation of Boone and Winnebago Counties by the Illinois State Geological Survey (see WIN-1, "Geology for Planning in Boone and Winnebago Counties, Illinois", ISGS Contract Report, 1981) was instrumented with a Stevens Type-F water level recorder to give a precise, continuous record of groundwater levels during the study period (March, 1982 to January, 1983). A Belfort weighing bucket recording rain gauge was placed next to the observation well to give a record of the time and amount of precipitation events. Data from these two devices were used to detect groundwater response to precipitation and recharge events. A recharge event occurs when infiltrating precipitation reaches the water table causing groundwater levels to rise.

Groundwater Sample Collection and Analysis

Over 1100 water samples were collected and analyzed during this study. Approximately 40 to 60 samples were collected on a monthly basis and 320 to 350 samples were collected during two 2-week periods in April-May and November. Analyses were conducted for nitrate-nitrogen, ammonia-nitrogen, chloride, specific conductance, and pH on nearly all samples. Methylene blue active substances (MBAS) analyses were conducted on a lesser number.

Because each residence has its own private well, outside faucets afforded an excellent means for sampling groundwater throughout almost the entire study area. Outside faucets were used whenever possible to avoid unnecessary entry of homes and because they normally deliver untreated water thereby minimizing water quality changes due to private water treatment units. After turning on a faucet, the temperature of the water was observed; the water was left running until the temperature appeared to stabilize, indicating the water from the tap was fairly fresh. Samples were collected in sterilized, 185 ml glass jars provided by the WCPHD. The samples were kept cool in insulated containers, transported within three hours to a temporary laboratory set up in a nearby school

(Kinnikinnick School) for pH measurement, and then to the WCPHD lab by the end of each day for determination of additional parameters. Samples not analyzed for nitrate on the same day as they were collected were preserved with sulfuric acid for later analysis. All water analyses were conducted by the WCPHD. Duplicate samples were collected and analyzed at the Illinois State Water Survey for approximately 10 percent of all samples.

Water samples were gathered from approximately 60 homes spread randomly throughout the study area on a monthly basis. These samples were used to give an indication of seasonal variations in groundwater quality and, in some cases depending on the timeliness of sample collection, were correlated with recent recharge events.

Water samples were collected from over 300 wells (approximately one-third of all the wells in the study area) during two 2-week periods in the spring and fall. The large number of samples gathered during these two periods were used to give "snapshot" indications of the groundwater quality and to see if spatial relationships existed across the study area. Samples collected during late April and early May also provided a basis for comparison with samples gathered from 1979 to 1981 by the WCPHD. Samples collected in the spring were expected to reflect groundwater quality influenced by recent recharge from snowmelt and rain. Samples collected in mid-November were expected to show groundwater quality after the summer dry period when little recharge to the aquifer had taken place.

Septic Effluent Sample Collection and Analysis

To evaluate the effect septic systems have on the underlying groundwater, It was necessary to determine the effluent characteristics in its raw form, before chemical transformation and dilution could alter the effluent quality. Septic effluent samples were collected from eight domestic systems.

A drain tile probe was used to locate the distribution box which > separates the septic tank effluent into each of the drain tile lines. Once located, the distribution box was uncovered with a spade and a 1/2-inch hole drilled in the top (distribution boxes are typically 2 to 3 feet across, 1 foot deep, and made of concrete 2 to 3 inches thick). A length of plastic tubing was inserted in the hole until the end was submerged; an effluent sample was then removed with a peristaltic pump. After sample collection, marine cement was used to plug the hole in the distribution box. The box was subsequently covered and the lawn sod replaced.

Effluent samples were kept cool in an insulated container for transport to the WCPHD and State Water Survey labs. Samples to be brought to the Water Survey were collected in two bottles, one containing a sulfuric acid preservative for total keldahl nitrogen, nitrate, and ammonia determinations, and one containing no preservative for chloride, sulfate, and total dissolved mineral determinations. Samples going to the WCPHD contained no preservatives and were analyzed within 24 hours of collection. The WCPHD analyzed for nitrate, nitrite, ammonia, chloride, specific conductance, and MBAS.

Shallow Monitoring Wells

Several studies have shown that surface-derived nitrate sources can create a "pool" of elevated nitrate concentrations at or near the groundwater surface (Childs et al., 1974; Duke et al., 1978; and Spalding and Exner, 1980) which travels with the migrating groundwater. Because most of the wells in the study area were drilled to 60 or 70 feet with approximately 2 feet of screened interval at the bottom, the quality of shallow groundwater was not being effectively monitored. Determination of the shallow nitrate concentrations was thought to be important enough to merit the construction of two shallow monitoring wells within a residentially developed subdivision. Permission from a local developer was granted to drill the wells on a vacant lot in the southwest corner of Olde Farm Subdivision (figure 1).

The wells were constructed with the assistance of the State Geological Survey to depths of 30 and 40 feet (figure 6). An 8-inch diameter, hollow-stem auger was used to install 2-inch diameter PVC casings and screens. To insure that the hole would not collapse and the screen could be placed at the intended depth, the well materials were preconstructed above ground and placed down the inside of the augers before the auger flights were pulled out of the hole. Sand below the water table collapsed around the screen and casing as the augers were retracted. Dry bentonite powder was then placed in the annulus to act as a seal against possible surface drainage down along the casing. Drill cuttings were subsequently used to fill the remaining annulus up to ground surface. For protection against surface disturbances, the upper 7 feet of casing was constructed with 2-inch diameter galvanized pipe with threaded galvanized caps.

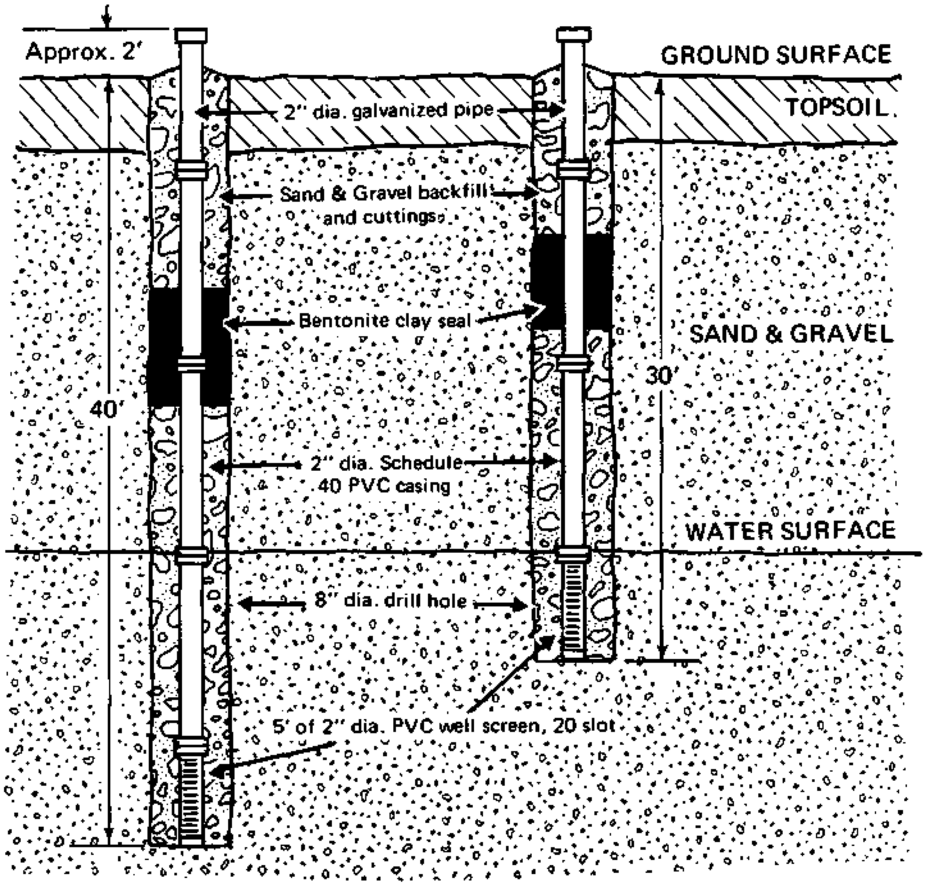


Figure 6. Shallow monitoring well construction details

Quantification of Other Nitrate Sources

Other potential sources of nitrate contamination in the study area were identified and noted. Old farmsteads and associated feedlots are potential sources because of the abundance of animal wastes. Agricultural and lawn care fertilizers also are potential nitrate sources- One local farmer reported he used 150 pounds of nitrogen, applied as anhydrous ammonia, per acre for his corn late in April. At other times, he broadcasted as much as 200 pounds of nitrogen per acre. Similarly, anomalously well-fertilized lawns stand out lush and green as a sign that, left unattended, the sandy soils of this area can only support a sparse growth of grass. Data from the National Atmospheric Deposition Program, whose central analytical lab is at the Illinois State Water Survey, revealed some nitrate is naturally present in rainfall. While not in large enough concentrations to cause a contamination problem, the nitrate in rainfall will contribute to what is considered "background" concentrations in groundwater.

Mass-Balance (Dilution) Model

Information gathered during this investigation was used to formulate a conceptual "model" of the groundwater system and the inputs to that system from the various nitrate sources. The computer model performs mass-balance computations on a conservative chemical constituent (for this study, nitrate) calculated from the known volumes and concentrations from various sources. Inputs to the model include septic tank effluent quality and quantity, housing density (which affects the volume of septic effluent), infiltrated precipitation quality and quantity, nitrate contributions to background water quality, the transmissivity or watertransmitting capability of the underlying aquifer, the cross-sectional width of a groundwater flow volume, and the longitudinal dimension of a selected groundwater flow path. The model can be used to simulate the possible effects on groundwater quality from potential housing development schemes and waste disposal alternatives.

FIELD RESULTS

Water Table Maps

Groundwater elevation or "water table" maps were prepared from observed water level data collected during the spring and fall samplings (figures 7 and 8). The water table configuration resembles the overlying land surface only in a much more subdued matter. Observed groundwater elevations during the spring ranged from a maximum of 727.67 feet MSL in the far northeast corner of the study area to less than 710.73 feet MSL at just east of the Rock River. The same locations exhibited the high and low elevations again during the fall with 724.80 and 709.85 feet MSL, respectively. Groundwater contours (points of equal elevation) indicate a drop of approximately 2.5 feet throughout the study area between spring and fall. This is substantiated by the hydrograph of groundwater levels recorded at the observation well, WIN-1 (see figure 9).

Groundwater moves perpendicularly to water surface contours. From the shape of the contours depicted in figures 7 and 8, it is apparent that groundwater movement proceeds from the surrounding uplands and terraces to the Rock River. Below areas north of Roscoe and also west of Route 251, groundwater movement is essentially to the southwest, almost perpendicular to Hononegah Road. Groundwater in this area is moving beneath the broad, gently sloping terraces of the Rock River Valley. Groundwater movement assumes a more westerly direction beneath Roscoe, moving from the valley uplands, directly toward the Rock River, essentially perpendicular to Route 251.

The water table slope beneath areas west of Route 251 was essentially the same in spring and fall, approximately 0.0018 ft/ft. The water table

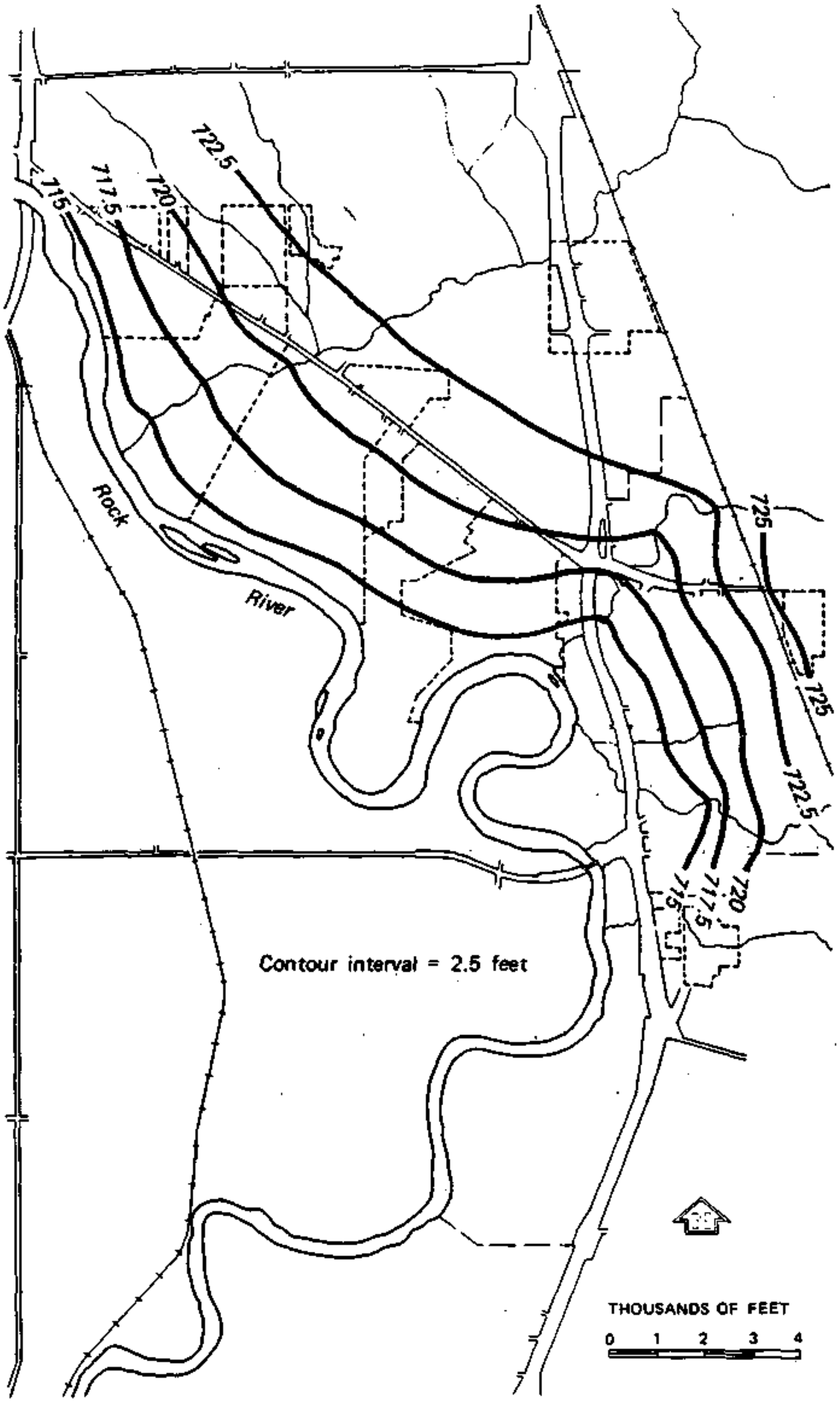


Figure 7. Shallow groundwater elevations, Spring 1982

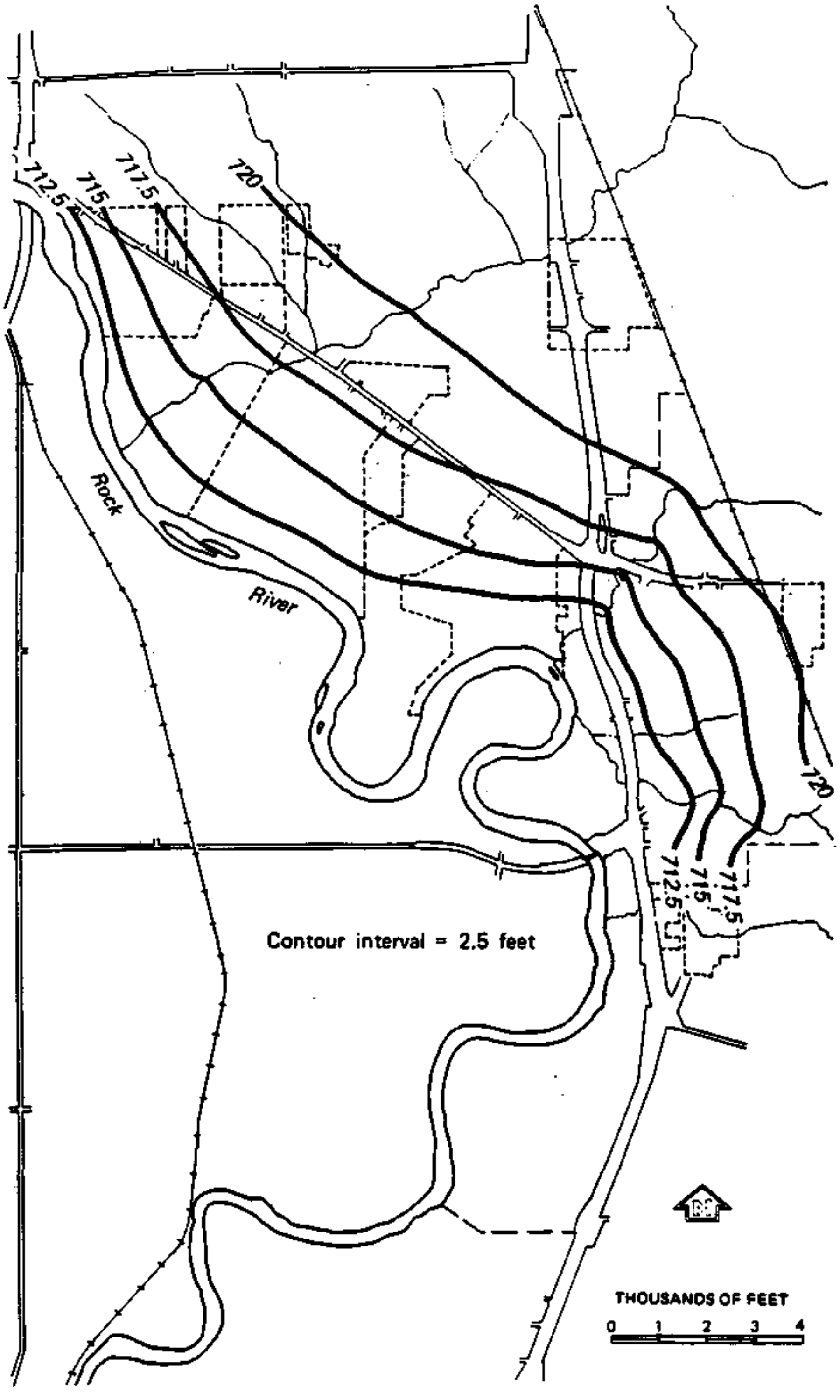


Figure 8. Shallow groundwater elevations, Fall 1982

slope beneath Roscoe during the spring was approximately 0.003 ft/ft but dropped off to 0.0022 ft/ft during the fall. The difference in slopes indicates a greater groundwater flow rate beneath Roscoe during the spring, probably as a result of groundwater flow from the valley uplands. The data also indicate there is groundwater discharge to North and South Kinnikinnick Creeks and, to a much lesser extent, to Dry Run Creek.

Groundwater Quality

The effects of surface and near-surface activities on nitrates in groundwater were found to be subject to several interrelated factors. These include, but are not limited to, precipitation and groundwater recharge events, groundwater usage, wastewater effluent quantity and quality, and location of the groundwater source in relation to nitrate sources.

Variations in water usage and septic output between sampling periods can greatly affect shallow groundwater quality. The volume of water used and discharged as septic effluent in a given period is associated with the number and age of residents, their water-using habits, and the number of water-using fixtures within the home (showers, toilets, washing machine, dishwasher, and water softener). Infiltration of water from lawn sprinkling and even car washing could influence shallow groundwater quality by diluting the percolating septic effluent.

While water usage and wastewater discharge affected groundwater quality, sampling results over the period of investigation were consistent and allowed spatial and temporal relationships to be interpreted. Forty to sixty homes spaced randomly across the study area were sampled monthly to define changes in nitrate quality over time. Samples collected from

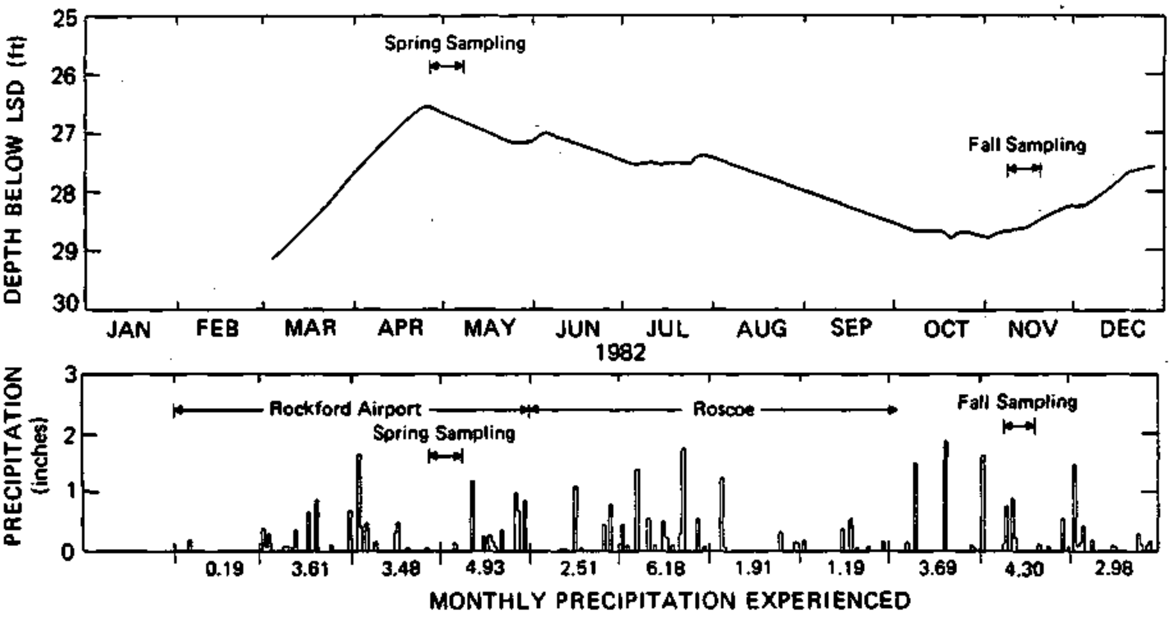


Figure 9. Groundwater hydrograph and precipitation at Observation Well WIN-1

over 300 homes in the spring and fall were used to give "snapshot" glimpses of spatial differences in nitrate quality. A discussion of the relationships in nitrate quality that were found follows.

Temporal Relationships

Table 3 presents the number of private wells with nitrate-nitrogen concentrations within the described intervals along with the mean, median, and standard deviation of the nitrate-nitrogen concentrations for each month. For comparison purposes, numbers within parentheses denote-information from wells common to all months, approximately 47. The spring sampling included only 10 wells that were used in the monthly samplings; similarly, the fall and December samplings included only 35 and 34 wells, respectively. By this time, many outside faucets had been turned off, making sampling difficult.

Average NO_3-N concentrations varied from a low of 5.76 mg/l during the spring sampling effort to 6.94 mg/l during the fall. The low value in the spring may have been affected by the small sample size (10 homes). However, it is apparent that the earlier samplings (March, Spring, May, and June) produced lower concentrations than later samplings in October, Fall, and December. Comparison of the groundwater hydrograph produced at the observation well (WIN-1), precipitation events, and nitrate concentrations at individual wells helps to explain this occurrence.

Figure 7 illustrates the groundwater level measured in Observation Well WIN-1. Below the hydrograph is a record of precipitation events measured by the rain gauge located at WIN-1. Groundwater levels rose over 2.5 feet during March and April in response to spring rains and snowmelt. While February precipitation recorded at the Rockford Airport was only

Table 3. Monthly Sampling Results for NO_3N, 1982.

NO_3N concentration (mg/l)	Number of Samples*									
	March	Spring	May	June	July	August	September	October	Fall	December
0-2	2 (1)	11 (0)	1 (1)	1 (1)	1 (1)	1 (1)	0 (0)	1 (1)	11 (0)	2 (1)
2-4	14 (9)	47 (3)	13 (11)	10 (9)	9 (8)	12 (11)	9 (9)	11 (11)	47 (7)	5 (5)
4-6	13 (11)	72 (2)	12 (11)	12 (11)	15 (14)	12 (11)	14 (12)	10 (8)	54 (7)	11 (10)
6-8	20 (12)	96 (3)	14 (9)	15 (14)	12 (10)	14 (11)	11 (11)	15 (13)	83 (6)	6 (6)
8-10	8 (8)	77 (2)	11 (10)	12 (12)	12 (11)	11 (11)	15 (13)	19 (11)	115 (9)	9 (8)
10-12	3 (3)	22 (0)	1 (1)	1 (1)	2 (2)	1 (1)	1 (1)	1 (1)	52 (5)	3 (3)
12-14	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (1)	1 (1)	1 (1)	5 (1)	2 (1)
>14	0 (0)	0 (0)	1 (1)	1 (1)	1 (1)	0 (0)	0 (0)	1 (0)	2 (0)	2 (0)
Total No. of Samples	60 (44)	326 (10)	53 (44)	52 (49)	52 (47)	52 (47)	51 (47)	59 (46)	369 (35)	40 (34)
Mean Conc. (mg/l)	5.84 (6.10)	6.53 (5.76)	6.16 (6.15)	6.26 (6.33)	6.38 (6.39)	6.20 (6.21)	6.38 (6.36)	6.87 (6.28)	7.30 (6.94)	7.30 (6.66)
Median Conc. (mg/l)	6.08 (6.40)	6.85 (5.88)	6.23 (5.84)	6.18 (6.18)	6.35 (6.34)	6.27 (6.20)	6.46 (6.46)	6.88 (6.33)	7.72 (6.94)	6.76 (6.64)
Stan. Dev.	2.52 (2.66)	2.53 (2.30)	2.69 (2.80)	2.55 (2.58)	2.59 (2.65)	2.47 (2.55)	2.45 (2.46)	2.96 (2.55)	2.76 (2.82)	3.77 (2.79)

*Parentheses denote the number of samples collected from addresses common to all months, a total of approximately 47 homes. These addresses are not comparable with WCPHD samplings (1979-1981) because of the expanded study area which included the town of Roscce. Occasionally, homes common to the monthly samplings could not be sampled, especially in Fall-December, when outside faucets were turned off.

0.19 inches (1.10 inches below normal), the 6 inches of snow reported on the ground at the beginning of the month had melted by February 22, indicating a good potential for snowmelt recharge. Increased evaporation rates and water requirements for plant growth and transpiration during the summer months reduced the availability of water for infiltration and caused water levels to decline starting early May. Late May rains and an unusually wet July (1.91 inches above normal) reduced or even reversed the falling water level trend but the groundwater level recession returned during the extremely dry months of August and September. During those two months, groundwater levels continued to fall even though several rains occurred. Heavy rains from October through December, combined with lower evaporation rates and decreased plant needs, caused groundwater levels to recover through the end of the year.

The groundwater level recorded at the end of December was already above the water levels recorded during the previous March. Frozen ground during January and February, 1982 prohibited infiltration and caused the groundwater level to be quite low when the water level recorder began operation early in March, 1982. The extremely mild weather experienced during the late fall and winter of 1982-83 allowed rain (which normally would have fallen as snow on frozen ground) to infiltrate and cause groundwater levels to rise.

Figure 10a displays NO_3-N concentrations at three selected addresses. Nitrate concentrations at these locations are typical of most of the wells sampled. A period of stable to slightly increased NO_3-N concentrations through July is followed by a dip in NO_3-N in August and September. NO_3-N concentrations rise again through the end of the investigation period.

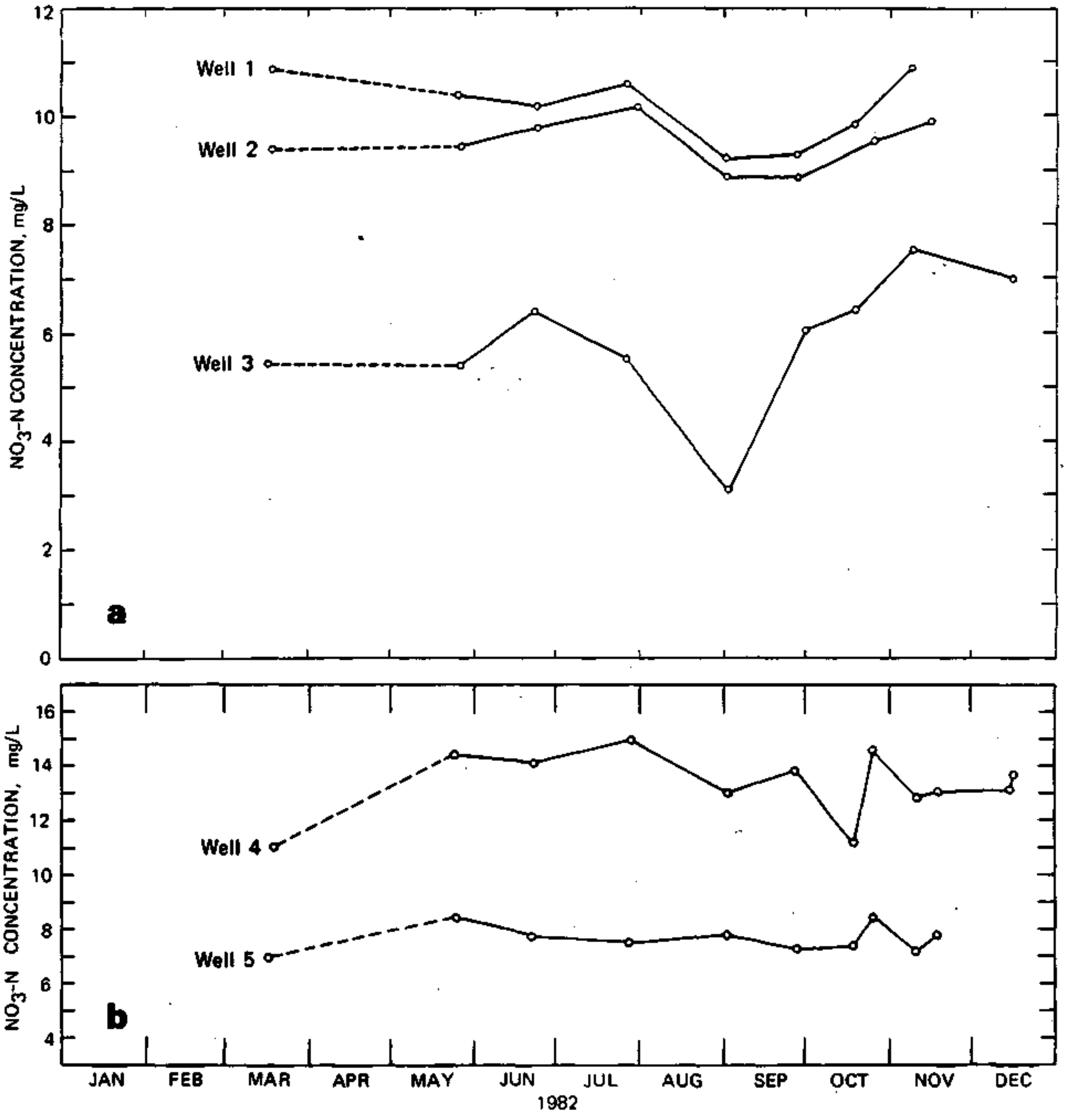


Figure 10. Nitrate-nitrogen concentrations at 5 selected locations

The NO_3-N concentrations were fairly stable during the period May through July because rainfall percolating through the overlying materials kept a constant source of NO_3-N moving downward. As recharge decreased through August and September, the downward movement of NO_3-N was likewise reduced and NO_3-N concentrations in the water decreased. When recharge increased again in the fall, NO_3-N was flushed out of the overlying, unsaturated materials into the groundwater system causing NO_3-N concentrations in the water to rise.

As further evidence of this relationship, two residential wells sampled twice within a one-week period showed marked increases in NO_3-N levels after a heavy rain. NO_3-N concentrations at the two locations were 7.42 and 11.21 mg/l, respectively on October 18 (Wells 4 and 5, figure 10b). On October 20, 1.87 inches of rain was recorded at the rain gauge. Subsequent sampling of Wells 4 and 5 on October 25 produced concentrations of 8.50 and 14.63 mg/l NO_3-N, respectively. Similar results were experienced between November 10 and 18 in the same wells with jumps in NO_3-N from 7.19 to 7.80 mg/l and from 12.85 to 13.05 mg/l. Over one inch of rain fell between those two dates.

The time of year and the occurrence of similar results at other addresses discounts effects from fertilizer application. The flushing of septic effluent to the groundwater system by recharge from heavy rains appears most likely.

Because of the regular occurrence of NO_3-N concentrations over 10 mg/l at Well 4, an effort was made to sample several homes in that area. The results of November 18 sampling are shown in figure 11. The highest NO_3-N concentration, 19.0 mg/l, was found at Well 6, two homes

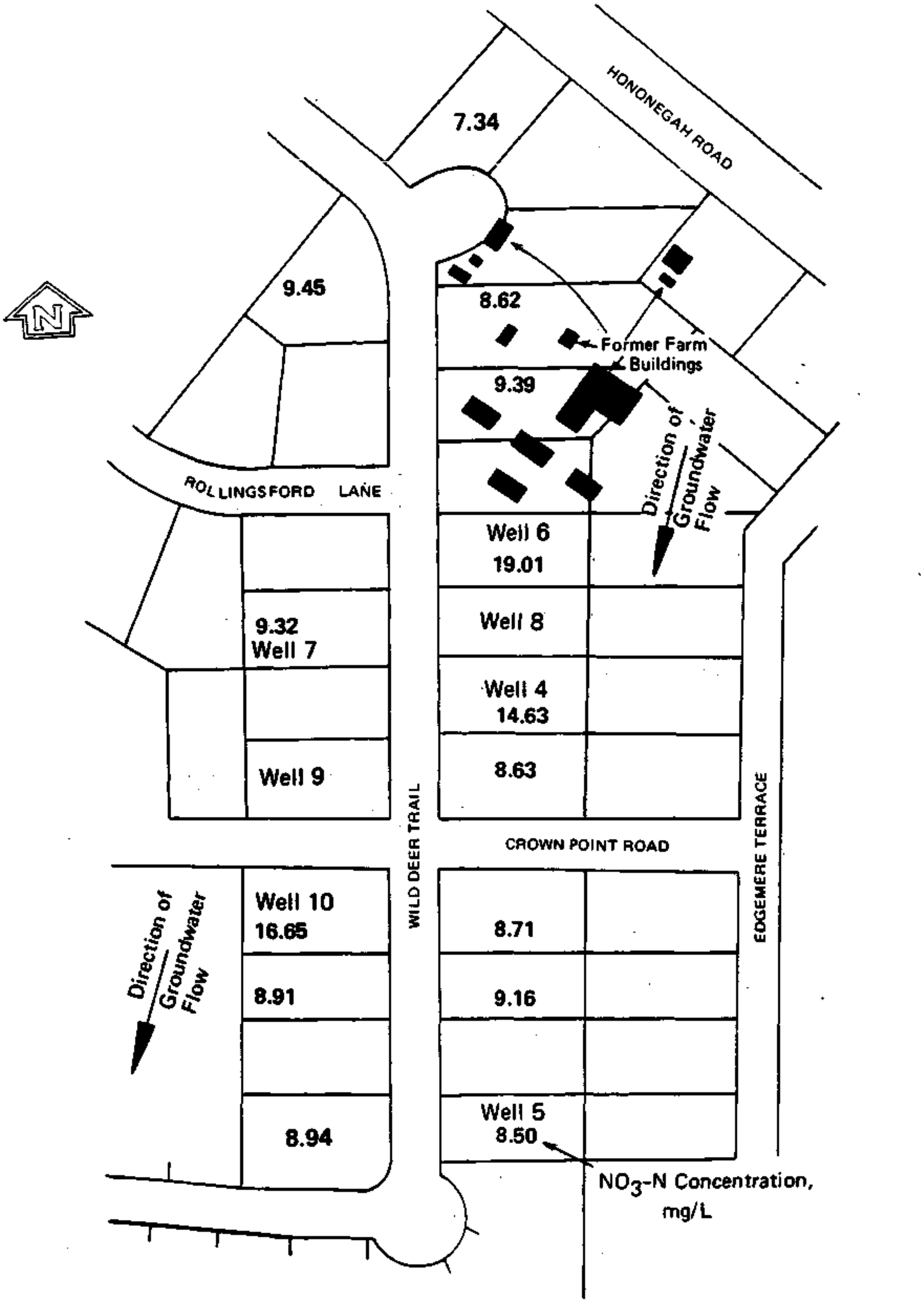


Figure 11. Nitrate-nitrogen concentrations along Wild Deer Trail on October 25, 1982

upgradient of Well 4. This concentration was the highest found during the entire investigation.

Previous sampling by the WCPHD during 1979-1981 showed similarly high results. NO3-N results for those three years and for October and December, 1982 are shown below. The wells are listed from upgradient to downgradient location (refer to figure 11).

Well Location No. (figure 10b & 11)	1979	1980	1981	Oct. 1982	Dec. 1982
Well 6	34.6	28.6	20.0	19.0	17.8
Well 7	16.7	9.5	10.7	9.3	--
Well 8	10.0	16.6	15.8	--	--
Well 4	--	--	--	14.6	13.7
Well 9	9.9	25.2	18.9	--	17.3
Well 10	--	--	--	16.6	13.7

After noting elevated nitrate levels in this area, an effort was made in 1980 by a local driller and concerned citizens to find possible contamination sources. Two improperly abandoned wells from an old farmstead were found in the two lots immediately upgradient of Well 6. The wells were 4 inches in diameter and approximately 50 feet deep. The well closest to Well 6 was within 3 1/2 feet of a septic field line. This well could have acted as a direct connection between the high nitrate water from the septic effluent and the underlying groundwater, the drinking water supply.

Evidence of reductions in nitrate concentrations after plugging of the wells in the summer of 1980 can be seen. The appearance of a nitrate "wave" or plume with elevated nitrate concentrations appearing at downgradient wells in succeeding years is also apparent. If the major source of contamination was just upgradient from Well 6, it appears the peak of the wave (plume) may have moved as far as Well 9 between 1979 and 1980 with elevated concentrations still evident on the tail side of the contamination plume. Reductions in the peak concentration are due to dilution. Rises in NO_3-N concentrations after the peak had passed could be due to a contribution from other sources, particularly septic system discharges which occur between the primary source and the sampling points. It also appears from this data that contribution of nitrate above what has been seen in other locations is still present in this area.

During the period of investigation, nitrate concentrations were higher in the fall than in the spring. Even though groundwater levels in the spring were high in the spring, reflecting spring recharge, the sampling was conducted during a fairly dry period (figure 9). Groundwater levels had peaked and were on the decline. The fall sampling, on the other hand, was conducted during a wet period when groundwater levels were starting to rise.

It is apparent that nitrate concentrations in the drinking water supplies are significantly affected by recent groundwater recharge events. Nitrate concentrations are highest when heavy rains follow a dry period. Nitrate levels were often found to exceed 10 mg/l (as nitrogen) shortly after a rain. The nitrates are stored in the pore spaces of the unsaturated sandy soils during dry periods and released to the groundwater system after a period of recharge. The stored nitrates move downward as a front pushed ahead of the infiltrating precipitation. Nitrate concentrations will decrease as recharge continues because of dilution with the infiltrating precipitation and the underlying groundwater.

Spatial Relationships

Results of nitrate determinations from the spring and fall sampling efforts were plotted on maps to determine if nitrate concentrations across the study area were appreciably different. A color coding system for 2 mg/l NO_3-N intervals was used to make spatial patterns more evident. The most recognizable feature on these maps was that nitrate concentrations in the Village of Roscoe were much lower than in the surrounding subdivisions. Figure 12 shows the average NO_3-N concentrations by generalized subdivisions computed from data collected during the fall. The average fall NO_3-N concentration within Roscoe was 4.76 mg/l; the lowest average outside Roscoe was 7.30 mg/l NO_3-N in the Tresemer-Olde Farm area. Table 4 contains the average NO_3-N concentrations by month and generalized subdivision. NO_3-N concentrations within Roscoe were less than 5 mg/l for the period of investigation, whereas surrounding subdivisions often averaged over 6 mg/l and sometimes as high as 9 mg/l.

It had originally been thought the higher nitrate values would be found in the older portions of Roscoe as the result of long-term effects of densely placed septic systems. A review of information gathered during the study and impressions made during visits to the area present a combination of factors that would cause lower nitrate levels to appear in Roscoe.

The most apparent differences between Roscoe and areas north and west of town are the groundwater flow direction and rate (refer to figure 7 or 8). Groundwater beneath areas north and west of Roscoe is moving essentially southwest, perpendicular to the Rock River. The slope of the water table beneath this area is quite flat, averaging only 0.0018 ft/ft, for a rate of movement of approximately 1 ft/day. Water moving beneath

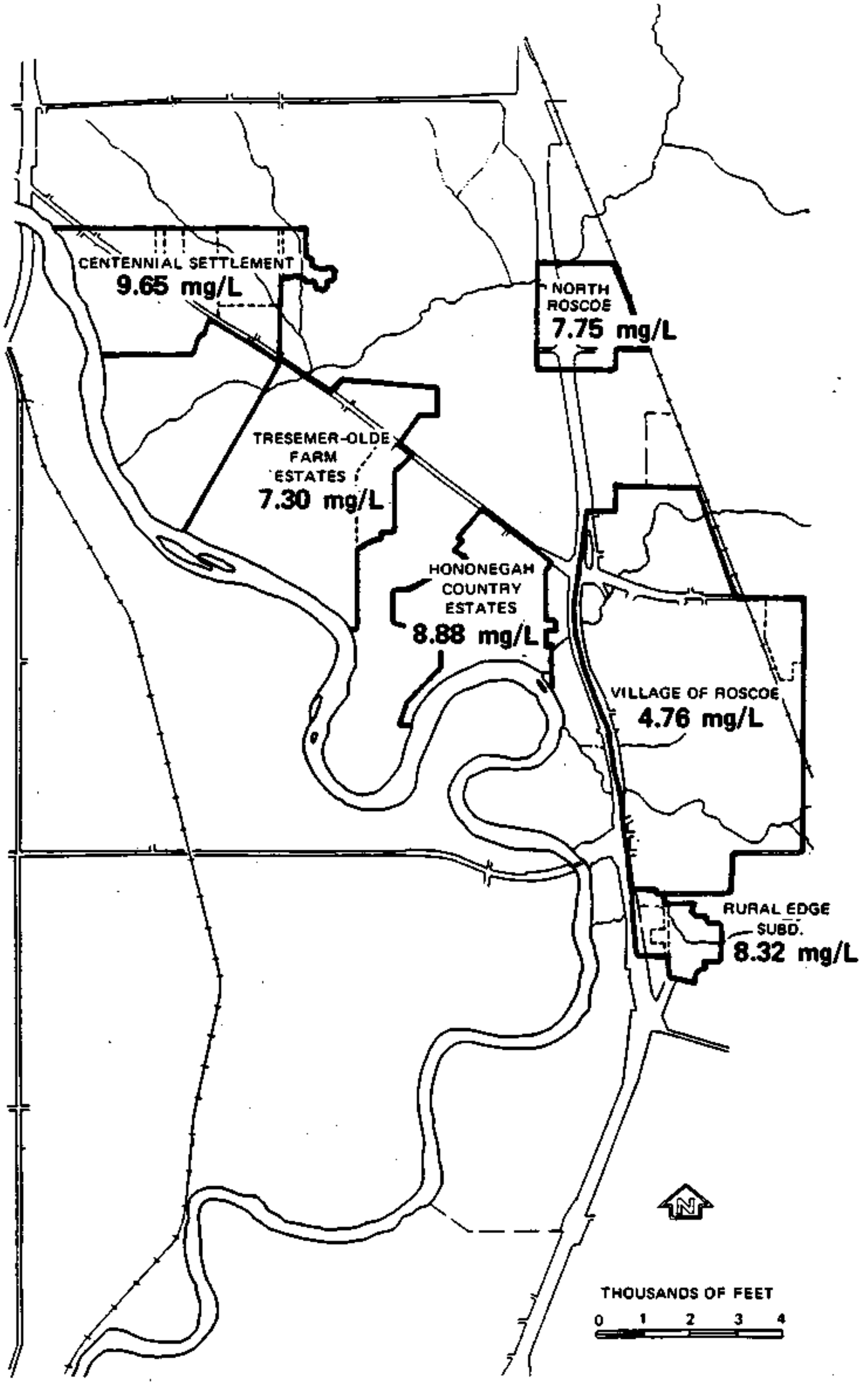


Figure 12. Average nitrate-nitrogen concentrations by generalized subdivision, Fall 1982

Table 4. Average water quality by subdivision

		SC	CL	NO3-N	NH4-N
CENTENNIAL SETTLEMENT AREA	MARCH	527. (8)	41. (8)	8.23 (8)	.02 (8)
	SPRING	565. (60)	56. (54)	8.72 (60)	.36 (60)
	MAY	527. (9)	48. (9)	8.10 (9)	.06 (9)
	JUNE	505. (8)	29. (8)	8.60 (8)	.05 (8)
	JULY	553. (8)	29. (7)	8.24 (7)	.08 (7)
	AUGUST	530. (8)	27. (8)	7.42 (8)	.09 (8)
	SEPTEMBER	481. (7)	29. (7)	8.30 (7)	.03 (7)
	OCTOBER	516. (7)	25. (7)	8.40 (7)	.06 (7)
	FALL	527. (75)	33. (75)	9.65 (75)	.07 (75)
	DECEMBER	491. (5)	34. (5)	9.04 (5)	.04 (5)
TRESEMER-OLDE FARM AREA	MARCH	537. (14)	48. (14)	5.81 (14)	.04 (14)
	SPRING	581. (106)	69. (57)	6.49 (106)	.39 (76)
	MAY	513. (12)	46. (12)	6.62 (12)	.12 (12)
	JUNE	560. (11)	47. (11)	6.56 (11)	.06 (11)
	JULY	588. (12)	43. (11)	6.35 (11)	.09 (11)
	AUGUST	575. (13)	39. (13)	6.44 (13)	.10 (13)
	SEPTEMBER	502. (11)	44. (11)	6.68 (11)	.02 (11)
	OCTOBER	528. (10)	34. (10)	6.91 (10)	.03 (10)
	FALL	548. (121)	46. (120)	7.30 (121)	.06 (120)
	DECEMBER	522. (10)	42. (10)	6.25 (10)	.11 (10)
HONONEGAH COUNTRY EST.	MARCH	540. (6)	51. (6)	7.32 (6)	.04 (6)
	SPRING	620. (36)	64. (19)	8.67 (37)	.48 (33)
	MAY	540. (7)	49. (7)	8.59 (7)	.08 (7)
	JUNE	550. (8)	38. (8)	8.24 (8)	.06 (8)
	JULY	579. (7)	39. (7)	8.41 (7)	.13 (7)
	AUGUST	580. (6)	40. (6)	7.58 (6)	.12 (6)
	SEPTEMBER	508. (6)	38. (6)	8.18 (6)	.02 (6)
	OCTOBER	548. (20)	44. (20)	9.64 (20)	.10 (20)
	FALL	585. (57)	46. (57)	8.88 (57)	.08 (57)
	DECEMBER	553. (8)	50. (8)	12.41 (8)	.04 (8)
N. ROSCOE AREA	MARCH	546. (8)	68. (8)	7.05 (8)	.03 (8)
	SPRING	609. (15)	48. (15)	7.08 (15)	.54 (15)
	MAY	620. (6)	54. (6)	6.20 (6)	.10 (6)
	JUNE	599. (9)	44. (9)	6.63 (9)	.05 (9)
	JULY	647. (6)	49. (6)	7.19 (6)	.12 (6)
	AUGUST	594. (7)	48. (7)	6.94 (7)	.13 (7)
	SEPTEMBER	570. (7)	49. (7)	6.88 (7)	.07 (7)
	OCTOBER	563. (7)	46. (7)	6.63 (7)	.22 (7)
	FALL	554. (14)	48. (14)	7.75 (14)	.03 (14)
	DECEMBER	547. (7)	59. (7)	7.19 (7)	.12 (7)
ROSCOE	MARCH	551. (19)	52. (19)	4.17 (18)	.05 (19)
	SPRING	651. (120)	52. (117)	4.31 (117)	.63 (116)
	MAY	628. (16)	52. (16)	3.96 (16)	.52 (16)
	JUNE	604. (17)	44. (17)	4.54 (17)	.06 (17)
	JULY	614. (16)	34. (16)	4.92 (16)	.09 (16)
	AUGUST	626. (15)	46. (15)	4.76 (15)	.12 (15)
	SEPTEMBER	554. (15)	42. (15)	4.88 (15)	.05 (15)
	OCTOBER	557. (15)	35. (15)	4.81 (15)	.13 (15)
	FALL	550. (101)	48. (101)	4.76 (101)	.04 (101)
	DECEMBER	525. (11)	45. (11)	4.84 (11)	.05 (11)
RURAL EDGE AREA	MARCH	558. (2)	63. (2)	6.01 (2)	.02 (2)
	SPRING	655. (11)	53. (11)	8.37 (11)	.68 (11)
	MAY	610. (2)	38. (2)	5.57 (2)	.21 (2)
	JUNE	545. (2)	25. (2)	6.18 (2)	.11 (2)
	JULY	570. (3)	25. (2)	6.91 (2)	.14 (2)
	AUGUST	575. (2)	30. (2)	7.08 (2)	.16 (2)
	SEPTEMBER	525. (2)	38. (2)	6.61 (2)	.01 (2)
	OCTOBER	565. (2)	28. (2)	6.46 (2)	.25 (2)
	FALL	544. (11)	47. (11)	8.32 (11)	.03 (11)
	DECEMBER	470. (1)	65. (1)	6.86 (1)	.05 (1)
OUTLIERS	MARCH	427. (3)	38. (3)	5.68 (3)	.09 (3)
	SPRING	597. (3)	53. (3)	9.59 (3)	.48 (3)
	MAY	560. (3)	37. (3)	2.97 (3)	.06 (3)
	JUNE	527. (3)	27. (3)	3.19 (3)	.15 (3)
	JULY	583. (3)	28. (3)	3.34 (3)	.11 (3)
	AUGUST	550. (3)	30. (3)	3.16 (3)	.11 (3)
	SEPTEMBER	510. (3)	32. (3)	3.39 (3)	.06 (3)
	OCTOBER	507. (3)	27. (3)	2.67 (3)	.12 (3)
	FALL	497. (5)	37. (5)	5.76 (5)	.06 (5)
	DECEMBER	458. (2)	45. (2)	3.34 (2)	.14 (2)

UNITS OF SPECIFIC CONDUCTANCE ARE MICROMHOS PER CENTIMETER
UNITS OF OTHER CONSTITUENTS ARE MILLIGRAMS PER LITER
NUMBERS IN PARENTHESIS ARE TOTAL SAMPLES USED IN COMPUTING EACH MEAN VALUE
TRACE VALUES OF NH4-N ARE EVALUATED AS 0.005 MG/L WHEN AVERAGING

this area has no chance to discharge to surface waters until it reaches the Rock River. Therefore, as groundwater moves downgradient, it will accumulate nitrate from contributing activities until discharge occurs at the Rock River.

On the other hand, groundwater beneath the Village of Roscoe is moving westerly from the uplands east of Roscoe to the now southward bound Rock River. The water table gradient is greater, 0.002 to 0.003 ft/ft, and the rate of movement is greater, approximately 2 ft/day or more. The presence of North and South Kinnikinnick Creeks is also significant. These perennial streams are shallow groundwater discharge areas allowing nitrates to be flushed out of the groundwater system. In this manner, nitrates will not accumulate to the extent that they might in the surrounding subdivisions. The till uplands east of Roscoe may also play a part by reducing nitrates before they are introduced to groundwater upgradient of Roscoe.

Another factor that may have influenced nitrate quality differences is wastewater discharge flow and quality. As mentioned earlier, the amount and quality of wastewater produced in a home is directly related to the number and type of water-using fixtures in the residence, their frequency of use, and the age and number of people living in the residence. While no quantitative demographic breakdowns for Roscoe and the surrounding subdivisions were made, a few general observations were noted. First, the population of the downtown Roscoe area (as delimited on figure 1) appears to be older. Young married couples with children tend to populate the subdivisions built up around Roscoe. Second, because the families are younger, the subdivisions tend to be more densely populated (more children, more people per residence). Third, older populations generally use less water—fewer dishes, less bathing, fewer clothes to wash.

Therefore, less wastewater is being introduced to the groundwater system in the older sections of Roscoe and, once introduced, movement to surface waters is more rapid than beneath the surrounding subdivisions. Data from areas within Roscoe support this hypothesis. For example, newer areas within Roscoe, where younger families have purchased homes (along Ada, Donald, Fry, and Kelmor Drives and south along Bitterroot Road and Flatwillow and Rural Edge Drives), show consistently higher nitrate concentrations than the older sections of town.

To further illustrate differences due to wastewater discharges, water collected at Wells 11 and 12 show markedly different NO_3-N concentrations (Figure 13a) even though they are located within two blocks of each other. Well 11 is a much newer home and might be expected to exhibit lower nitrates. However, concentrations at Well 12 ranged between 2 and 4 mg/l while concentrations at Well 11 were between 8 and 9 mg/l. Differences such as this may be related in part to household water and wastewater usage and in part to proximity to other nitrate sources.

NO_3-N concentrations generally ranged from 1 mg/l to over 10 mg/l depending on the location of the well sampled. Figure 13 illustrates the range of NO_3-N concentrations that were found across the study area. In some instances, NO_3-N concentrations can be related to their geographic location. For example, Well 15 (figure 13b) is situated at the far northeast corner of Roscoe, in a fairly new subdivision bordering existing farmland. Similarly, Well 14 is a rural residence about 1/2 mile north of Well 15. Well 20 (figure 13b) exhibited even lower NO_3-N concentrations and is located in an area that, although developed for some time, is not

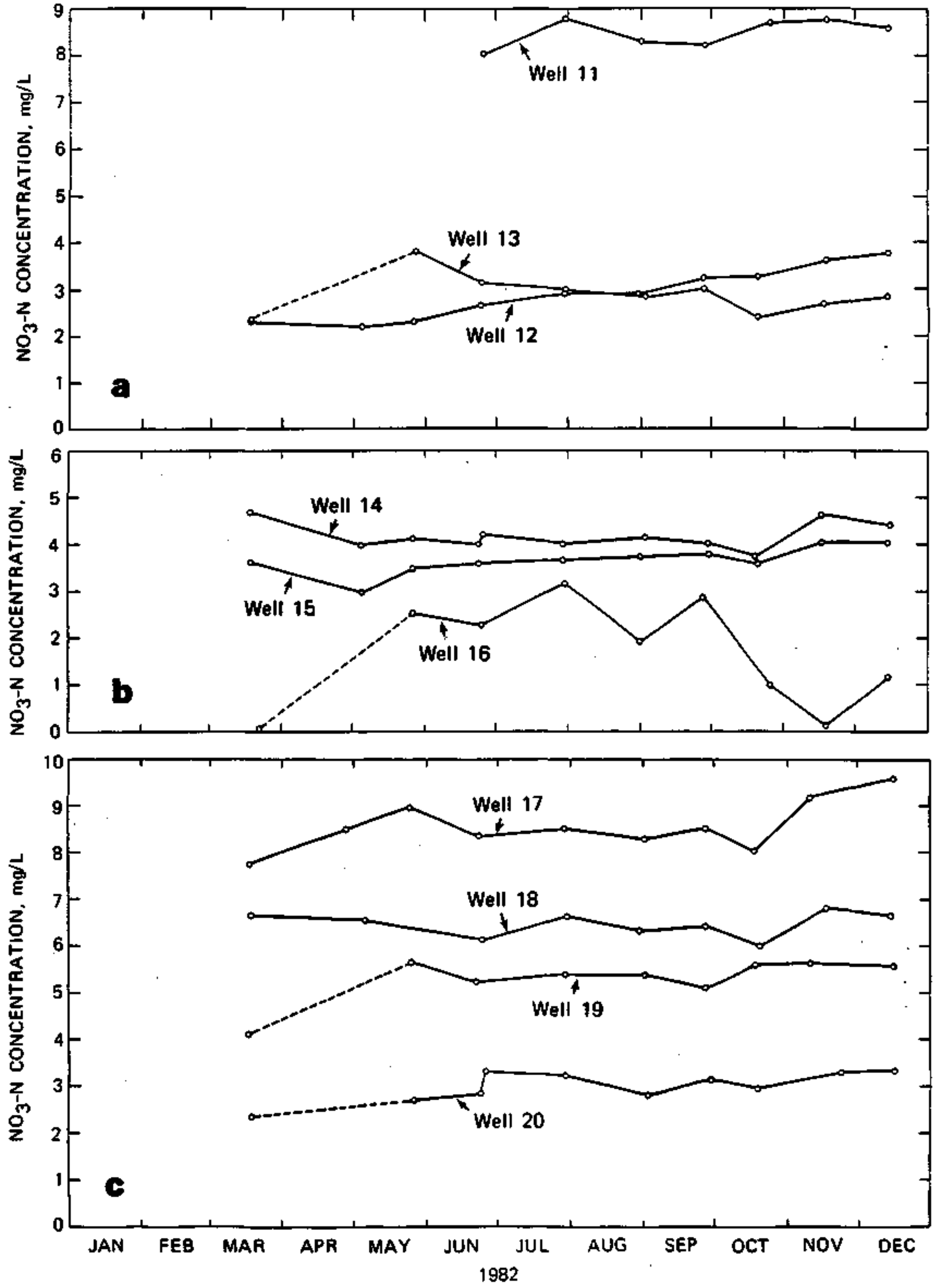


Figure 13. Nitrate-nitrogen concentrations at 10 selected locations

densely housed. Well 16, located southeast of the study area in the Kieselburg Forest Preserve (figure 13b), showed wide variations in NO_3-N concentrations with very little correlation to recharge events. NO_3-N concentrations ranged from as low as 0.10 mg/l in March to 3.2 mg/l in July. The low concentrations might be attributable to low water usage, allowing nitrates to "pool" at the groundwater surface and not mix due to cyclic pumpage. The range of NO_3-N concentrations that appear at the other locations shown are most probably due to their proximity to nitrate sources. Most of the wells depicted are situated within subdivisions and are surrounded by septic and fertilizer sources.

Data collected during this study reveals an interesting dilemma: what should be considered a "background" NO_3-N concentration, where a well taps a portion of the aquifer not influenced by nitrate sources? It is the general impression from this investigation, there is no such place within the study area. Agricultural fertilizer use and/or septic systems have been too wide spread for any well tapping the sand and gravel to be unaffected. For the purposes of this study, background concentrations will be considered to be from wells fairly removed from dense housing and ranges from approximately 2 to 4 mg/l. This "background" concentration is assumed to include the influence of agricultural sources and infiltrating precipitation.

Vertical Relationships

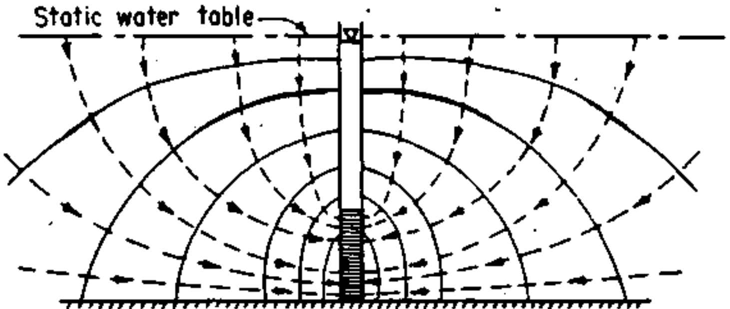
Sampling data generated during this investigation were primarily used to detect changes in nitrate concentrations with time and location. Investigations in other areas (Childs, et al., 1974; Duke, et al., 1978; and Spalding and Exner, 1980) have shown that surface-derived nitrate sources can create a "pool" of elevated nitrate concentrations at or near the groundwater surface. Because most of the wells within the study area tap the aquifer at 60 to 70 feet (30 to 40 feet below the water table), it was felt water samples collected from shallower depths may show higher nitrate concentrations. Vertical changes in water quality would indicate the degree of mixing that is occurring beneath the study area and would be very important in determining the consequences of future development of the area.

Two wells were constructed at depths of 30 and 40 feet (see figures 1 and 6 for well location and construction details) to determine if the vertical changes in groundwater quality are significant. The wells also can be part of a monitoring scheme to assess the long-term effects of rural residential subdivisions on the environment.

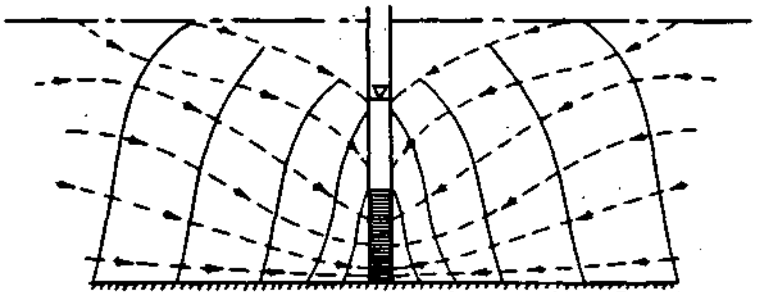
Analytical results from samples collected in November and December are shown in table 5. It can be seen that dissolved constituent concentrations (including nitrate) do decrease with depth. Nitrate concentrations, while noticeably different between 30 and 40 feet, are not drastically different from concentrations experienced in nearby deeper wells (see the average for Tresemer-Olde Farm wells, Table 4).

Table 5. Shallow Monitoring Well Water Quality

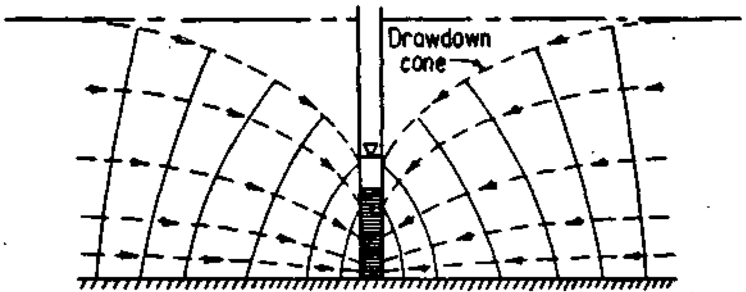
	30' Monitoring Well		40' Monitoring Well	
Parameter	11-11-82	12-15-82	11-11-82	12-15-82
NO_3-N	8.61	10.2	7.21	8.2
Cl	53.4	90.	18.0	30
SO_4	53.4	--	38.3	--
NH_4-N	--	0.56	--	0.47



A. Initial stage in pumping a free aquifer. Most water follows a path with a high vertical component from the water table to the screen.



B. Intermediate stage in pumping a free aquifer. Radial component of flow becomes more pronounced but contribution from drawdown cone in immediate vicinity of well is still important.



C. Approximate steady state stage in pumping a free aquifer. Profile of cone of depression is established. Nearly all water originating near outer edge of area of influence and stable primarily radial flow pattern established.

Figure 14. Development of flow distribution about a discharging well in a free aquifer (from U.S. Dept. of Interior, 1981)

The reason for the similarity in groundwater quality with depth is illustrated in figure 14. When a well is pumped under water table conditions (meaning the groundwater surface is at atmospheric pressure such as exists beneath the study area), the initial path the groundwater follows has a high vertical component of flow. Therefore, a large portion of the water discharged during the initial stages of pumping is derived from near the groundwater surface (the water table) where nitrate concentrations are greater. With the large number of wells situated throughout the study area, shallow and deep groundwater will be mixed quite effectively.

Nitrate Source Quantification

To determine the effects of various nitrate sources on the groundwater system, efforts were made to quantify the volumes and concentrations of nitrate being contributed by each source. The following is a discussion of the major sources of nitrate in the Roscoe area: agricultural and lawn fertilizers, precipitation recharge, and septic system discharges. Infiltration of water from feedlot sources was not found to be a major nitrate source. No areas were detected where a nitrate plume could be attributed to a known past or present feedlot. For example, homes built near the Olde Farm entrance, where a large barn still exists, show no significantly higher nitrate concentrations than homes removed from this potential source.

Agricultural and Lawn Fertilizers

Direct measurement of agricultural and lawn fertilizer contributions was not undertaken for several reasons: 1) drilling shallow wells in agricultural fields and lawns where fertilizers had been applied was felt to be too expensive and had not been budgeted, 2) the placement of wells on established lawns was considered unacceptable to homeowners, 3) a large amount of data already existed in the scientific literature on leaching of fertilizer nitrates, and 4) an estimate of agricultural contribution could be found upon examination of wells in subdivisions bounded by agriculturally used fields and removed from the influence of other sources.

As previously discussed, the literature clearly agrees that variations in the loss of nitrate to crops through leaching below the root zone depends on the type of crop being grown, the soil type, the time of fertilizer application, the amount of application, the antecedent soil moisture conditions, and the intensity and duration of rainfall or irrigation following fertilizer application. As might be expected, individual investigations yielded widely different nitrate concentrations depending on the effects of the previously mentioned factors (see table 6 for results from several investigations).

Buildup of nitrate concentrations from repeated applications of fertilizer from one growing season to the next is a very real possibility. However, our data suggests that large buildups have not occurred - plant uptake approaches the 80 percent range (although, that is not likely to occur every year). For example, crop rotation with less fertilization of beans than corn, would help reduce NO_3-N concentrations. Also, downward regional groundwater flow will carry some nitrate deeper, below the intake of local wells.

Lawn fertilizer applications at the generally recommended 2 to 4 pounds nitrogen per 1000 square feet (87 to 174 pounds/acre) could also result in a contribution of nitrate to the groundwater. Contributions from lawn fertilizers over large areas are much less likely than from agriculturally applied fertilizers. Variations in fertilizer application and the amount of lawn sprinkling or natural rainfall after application will affect the amount of nitrate that will leach.

Based on the information gathered during this investigation, nitrate contributions from agricultural sources appear to be from 2 to 4 mg/l nitrate-nitrogen. These concentrations were found in wells bordering subdivisions or in rural locations removed from the influence of densely placed septic systems.

Precipitation Recharge

Precipitation often contains some nitrate. Lightning changes large amounts of atmospheric nitrogen to nitrogen oxides. When combined with rainwater, these compounds form HNO_3 which falls to the earth. Nitrate concentrations in excess of plant requirements will percolate through the soil zone beyond the reach of plants' roots to the groundwater system.

Analyses of rain samples collected by the Illinois State Water Survey as part of the National Atmospheric Deposition Program revealed that rainwater in northern Illinois contains small amounts of nitrate. Samples collected between May, 1981 and April, 1982 in DeKalb, Illinois (40 miles southeast of the study area) contained as much as 2.4 mg/l NO_3-N and 3.0 mg/l NH_4-N. Average NO_3-N and NH_4-N concentrations were approximately 0.6 mg/l for each constituent. Assuming the NH4-N is completely converted to NO_3-N in the aerobic soil conditions present within the study area, an average of 1.2 mg/l NO_3-N could be percolating through the soil zone. During periods of groundwater recharge, water is

Table 6. Agriculturally Derived Nitrate Concentrations in Groundwater

Investigator	Location	NO_3N beneath site (mg/l)	Crop grown	Fertilizer Applied (lbs/acre)	Irrigated	Comments
Robbins & Carter (1980)	Idaho	3.2 (average)	alfalfa	data not available	Yes	Loamy soils, crops rotated
Exner & Spalding (1979)	Holt County, Nebraska	8 (average)	corn	data not available	Yes	Nebraska studies: 40-50 yrs. of crop production with heavy irrigation on loamy-sandy soils, little crop rotation; regional county-wide investigations
Spalding, et al (1979)	Merrick County, Nebraska	10-30	corn	75-300	Yes	
Duke, Smika, Heermann (1978)	Colorado	4-50	corn likely	0-210	Yes	Lower NO_3N concentrations with depth; sandy soils
Baier & Rykbost (1976)	Long Island, New York	6-21	turf grass (lawn)	up to 350	Sometimes	Outwash sand and gravel
		8-23	potatoes	125-310	Not detailed	

percolating past the root zone. Losses of nitrogen by plant uptake and volatization will be minimal during these periods. Therefore, precipitation recharging the groundwater system may contain approximately 1.0 mg/l NO_3-N.

The amount of precipitation that infiltrates into the ground fluctuates seasonally and annually. A large portion of annual precipitation is transpired and evaporated back to the atmosphere; only a small portion of precipitated water actually infiltrates to the groundwater system. Estimates of groundwater recharge have been made by determining the groundwater contribution (base flow) to surface streams.

A recent investigation completed by the Illinois State Water Survey (O'Hearn and Gibb, 1980) estimated the groundwater contribution to streamflow for 78 drainage basins in Illinois. Because large rivers (basins > 1000 square miles) were not investigated, the Rock River at Roscoe was not included in this study. Average baseflow values for the Kishwaukee River at Belvidere were estimated to be 13, 3.7, and 1.3 inches/year for flows equaled or exceeded 10, 50, and 90 percent of the time, respectively. A summary of the mean base flows calculated for northwestern Illinois is shown in table 7.

Walton (1965) estimated groundwater discharges for near normal, above average, and below average precipitation years. Relations between the latitudes of stream basins and frequencies of occurrence of streamflows corresponding to groundwater discharges during years of near, above, and below normal precipitation were used to estimate annual groundwater discharges to the Rock River at Rockton. Computed discharges were 8, 5.3, and 3.8 inches/yr for above, near, and below normal precipitation years.

Table 7. Summary of Average Regional Base Flow Characteristics (from O'Hearn & Gibb, 1980, Region B)

Flow Duration*	Median baseflow cfs/mi^2	Recharge Rate gpd/mi^2	Basin Recharge in/yr
Q_{10}	0.67	433000	9.1
Q_{50}	0.22	142000	3.0
Q_{90}	0.13	84000	1.8

*where Q_p is the flow equaled or exceeded p percent of the time.

For the purposes of this study, rainfall recharge was assumed to equal groundwater discharge. Recharge was estimated to be 3, 5, and 9 inches/year for below, near, and above normal precipitation years, respectively. These figures convert to 142,000; 238,000; and 428,000 gallons per day per square mile (gpd/mi^2). Data collected by the National Atmospheric Deposition Program suggest this water may contain 1 mg/l NO_3-N.

Septic Effluent

Samples of septic tank effluent were collected from eight systems during early September (table 8). Variations in domestic septic effluents are attributable to the number and type of water-using fixtures in the residence, their frequency of use, and the age and number of people living in the home. Individual activities may be separated into three major groups: 1) garbage disposal wastes, 2) toilet wastes, and 3) sink, basin, and appliance wastes. The number of residents and water-using fixtues present in the homes sampled appear in table 9.

Ammonia-nitrogen (NH_4-N) was the major nitrogen containing component ranging from 17.9 to 46.2 mg/l. Organic nitrogen components

Table 8. Septic Effluent Quality

Sample	Wastewater Quality Parameters								
	NH_4-N	Org N	NO_3+NO_2-N	Total-N	Cl	SO_4	TDM	Spec. cond.	MBAS
1	20.2	4.6	0.25	25.0	30	22	576	—	3.96
2*	31.1	6.1	0.36	37.6	320	43	1069	1550	2.48
3*	17.9	7.3	0.47	25.7	690	140	1762	—	>4.0
4	30.7	6.5	0.61	37.8	51	12	539	920	>4.0
5*	34.2	6.9	0.41	41.5	51	19	699	1000	2.96
6	46.2	6.1	0.36	52.7	65	33	615	1220	1.92
7*	19.8	5.4	0.36	25.6	700	44	1882	3000	>4.0
8*	42.3	7.7	0.72	50.7	68	35	761	1240	>4.0

Values reported in mg/l

*Water softeners reported in the home.

Table 9. Resident Water-Using Characteristics

Factor	Sample* 2	3	4	5	6	7	8
No. of residents							
Adults	2	3	2	2	2	2	2
Children (age)	1 (14 mon)	0	2 (5,10yr)	3 (7,7,11yr)	0	0	3 (2,6,10yr)
No. of water-using fixtures							
Toilets	3	3	2	2	2	1	2
Bathtubs	1	1	1	2	1	1	2
Showers	2	1	1	2	1	1	2
Basins or tubs	3	5	3	2	1	1	3
Clotheswasher	1	1	1	1	1	1	1
Dishwasher	0	1	0	1	1	1	0
Kitchen sink	1	2	1	1	1	1	2
Garbage disposal	0	1	0	0	0	0	0
Water softener	1	1	0	1	0	1	1

*Results not available for sample 1.

account for nearly all of the remaining nitrogen varying from 4.6 to 7.7 mg/l. The presence of nitrate and nitrite-nitrogen (NO_3 and NO_2-N) was nearly negligible at concentrations less than 1.0 mg/l (0.25 to 0.72 mg/l).

The relative abundance of ammonia is a result of the breakdown of protein-containing wastes within the septic tank. Once leaving the leach field drain system, the effluent can be expected to nitrify completely to the nitrate form before reaching the groundwater system. Nitrate-nitrogen contributions from the drain systems can be assumed to equal the total nitrogen concentrations of the septic effluent, from 25 to 52.7 mg/l. These concentrations compare favorably with other investigations shown in table 10.

Chlorides also are often used as pollution indicators from septic systems because they are contained in human urine and are not altered by biological processes. Like nitrates, chlorides are not adsorbed by soil particles. Chloride concentrations in the septic effluent samples ranged from 30 to 700 mg/l. Concentrations between 320 and 700 mg/l are the result of water softener regeneration and backwash. Homes with water softeners that did not have high chlorides in their septic tank effluents may be related to frequency of backwash and sampling period or that the treatment units are commercially regenerated and no brine solution enters the septic system. A good correlation occurs with chloride content and total dissolved minerals (and specific conductance). However, little correlation can be made with chloride and total nitrogen concentrations. This is further exemplified by the drinking water samples gathered throughout the course of this investigation. Inspection of well water

Table 10. Septic Effluent Quality Reported by Various Investigators

Investigator	NH_4-N	Org N	NO_3+NC_2-N	Total N	Cl	ABS
Robeck et al (1964)	22	5.4	0.12	27.5	75	8.7
Hickey & Duncan (1966)	37	3.4	trace	40.4		3.4
Popkin & Bendixen (1968)	24.6	5.6	0.21	30.4		MBAS=9.7
Thomas & Bendixen (1969)	25.4	7.9	<0.1	33.3	95	
Walker et al (1973)	66.3	13.7		80	105	
Viraraghavan & Warnock (1976)	97		0.026	97.1	53	
Whelan & Titamnis (1981)	63-201 109 ave.		0.01-0.03	74-237 125.4 ave.		
Starr & Sawhney (1979)				102		
USEPA (1980)*	6-18		<1	35-100		
This study	30.3	6.3	0.44	37.0		MBAS=2.83
Mean concentrations	51.4	7.0	0.16	63.7		6.2

*Based on results from five investigators, Laak (1975), Bennett, et al. (1975), Siegrist et al. (1976), Ligman, et al. (1974), and Jones (1974). Not used in calculations of mean values.

sample analyses showed little correlation between chloride and nitrate concentrations.

Methylene blue active substances (MBAS) are synthetic organic molecules, many of which are commonly used in commercial detergents. The presence of elevated MBAS in a groundwater source drinking supply should be a good indication of contamination related to household wastewater, i.e., septic effluent. MBAS concentrations in the septic effluent samples ranged from 1.92 to over 4.0 mg/l. These results compare favorably with work done by other investigators looking at alkylbenzene sulfonates (ABS), a standard surfactant. The presence of MBAS in drinking water samples at concentrations from 0.1 to 0.6 mg/l indicates the likelihood of a household wastewater source.

To determine the mass of nitrate entering the groundwater system from wastewater sources, the quantity or flow of wastewater being discharged through the septic systems must be considered. Flow estimates include per capita water usage, the average number of people occupying a residence, and the number of residences per unit area.

The scope of this investigation did not allow metering of local wastewater flows; however, a DSEPA survey (Otis et al., 1980) of several other investigations found,

> "The average daily wastewater flow from a typical residential dwelling is approximately 45 gallons per capita per day (gpcd). While the average daily flow experienced at one residence compared to that of another can vary considerably, it is typically no greater than 60 gpcd and seldom exceeds 75 gpcd."

A summary of residential wastewater flows from other studies appears in table 11.

1980 U.S. Census data for portions of Roscoe and Rockton Townships (Tracts 39.02, 40.01, and 40.02) revealed 13,521 people were living in

Table 11. Summary of Average Daily Residential Wastewater Flows (from USEPA Design Manual, 1980)

Investigator	Number of residences	Duration of study (months)	Wastewater Flow Study average (gpcd)	Wastewater Flow Range of individual residence averages (gpcd)
Linaweaver, et al. (1967)	22		49	36-66
Anderson and Watson (1967)	18	4	44	18-69
Watson, et al. (1967)	3	2-12	53	25-65
Cohen and Wallman (1974)	8	6	52	37.8-101.6
Laak (1975)	5	24	41.4	26.3-65.4
Bennett and Linstedt (1975)	5	0.5	44.5	31.8-82.5
Siegrist, et al. (1976)	11	1	42.6	25.4-56.9
Otis (1978)	21	12	36	8-71
Duffy, et al. (1978)	16	12	42.3	--
	Weighted average		44	

4523 dwelling units for a ratio of nearly 3 people per residence. A count of the number of lots per subdivision derived from county plat maps divided by the planimetered area of each subdivision shows the average housing density in the Roscoe area is 1.49 lots per acre. A summary of the lot count, area, and estimated 1980 population for each subdivision is presented in table 12 (population estimates were made by the Rockford-Winnebago County Planning Commission).

Table 12. Summary of Population and Lot Densities in the Roscoe Area

Subdivision	No. of lots	No. of homes built (1980)	Population* (1980)	Area (acres)	People home	Lots/acre
Centennial Settlement	128	50	150	102.9	3.0	1.24
Evergreen Manor	49	14	32	35.0	2.3	1.40
Hononegah Country Estates	178	120	360	122.0	3.0	1.46
Hononegah Heights	61	44	132	36.0	3.0	1.69
Knapp's Knoll	42	31	93	19.3	3.0	2.18
Northland Estates	62	29	87	49.2	3.0	1.26
Olde Farm	195	127	381	158.5	3.0	1.23
Puddicombe	17	13	39	11.3	3.0	1.50
Ridgefield	22	2	6	16.2	3.0	1.36
Shannon Acres	29	2	6	17.4	3.0	1.67
Treseiner	127	100	300	114.5	3.0	1.11
Village of Roscoe	224	451	1338	120.9	3.0	1.85
				Mean:	3.0	1.49

*Population estimates from Rockford-Winnebago County Planning Commission

MASS BALANCE MODEL

Conceptualization

Data indicates that the local geologic materials have a low capacity for attenuating or reducing the nitrate load being discharged by the hundreds of septic systems located within the study area. Near total nitrification of the septic effluent will occur under the aerobic conditions present in these sandy soils. Therefore, nearly all of the nitrogen in the effluent will reach the water table as nitrate. Reduction of nitrate concentrations in the septic effluent must rely on dilution with infiltrating rainfall and groundwater of lower nitrate concentration.

If dilution is considered to be a treatment process, the amount of nitrate entering the groundwater "treatment system" can be effectively controlled by the housing density. The long-term average concentration of nitrate leaving this system can be estimated through a "mass-balance" approach.

Referring to figure 15, the mass of nitrate (volume x concentration) entering an elemental volume from the various nitrate sources (septic effluent, fertilizers, and infiltrating rainfall) is divided by the volume of the combined diluents (infiltrating rainfall, septic effluent, and resident groundwater less groundwater pumpage) to give an average nitrate concentration leaving the elemental volume. The method can also be used to calculate a critical housing density by holding the diluted nitrate concentration equal to the nitrate drinking water standard (10 mg/l NO_3-N) and calculating the housing density required to stay below the standard.

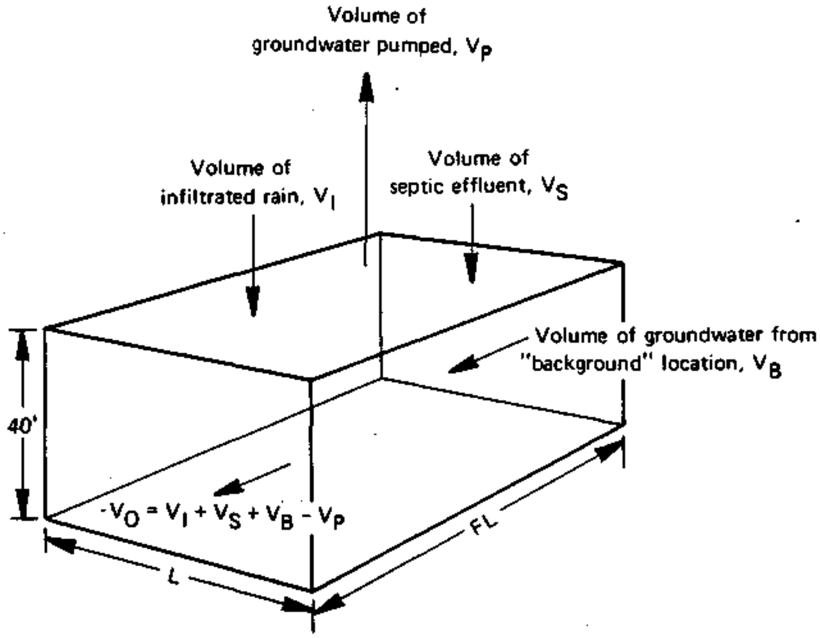


Figure 15. Mass balance control volume

A similar approach has been used by Hantzsche (1982) and. Trela (1978) for predevelopment planning in California and New Jersey. These investigators, however, used infiltrating precipitation as the sole source of dilution. Resident groundwater was not included in the dilution for three reasons: 1) Without pumpage, complete mixing of infiltrating rainwater and groundwater does not naturally occur. Rainwater tends to push the groundwater downward ahead of it, leaving the nitrate contamination pooled at the groundwater surface. 2) Little specific, regional groundwater flow information was available for their investigations. 3) Degradation of groundwater quality was considered untenable. For example, the New Jersey Department of Environmental Protection set a standard of 2.0 mg/l NO_3-N for groundwater quality. Because the areas were undeveloped and pristine, steps were being taken to maintain natural conditions.

For this investigation, groundwater quality degradation from present development has already occurred. Short of installation of sanitary sewers or alternative waste disposal systems, little can be done to reverse this situation. The groundwater system is truly a part of the dilution process and must be handled as such for future planning considerations. The groundwater flow information gathered during this investigation allows reasonable assumptions to be made about the amount of groundwater that is available for dilution. From the shallow monitoring well data, it appears pumpage from the large number of private wells has created a good mix of groundwater with depth, enough to merit using the depth of groundwater present from the water table to the intake level of local wells (about 40 feet) as the dilution volume. The peaks in nitrate levels observed in wells shortly after heavy rains support the Idea that there is rapid downward movement of groundwater.

Antececent moisture conditions and the timing and size of groundwater recharge events are only a few of the factors that will affect the amount of nitrates released to the underlying groundwater. Because the interrelationships between factors such as these are so complex, no simple method can be used to quantify nitrate contributions to the groundwater from a particular recharge event. By assuming the nitrates discharged by all sources will not be stored in the unsaturated zone and will reach the water table, the mass-balance approach offers a simplification that provides estimates for long-term average conditions.

Derivation

The following equation often is used to calculate the concentration of a known volume of solution after it has been diluted from a smaller, more concentrated volume:

$$V_1 \; C_1 = V_2 \; C_2 \qquad (1)$$

$$C_2 = \frac{V_1 \; C_1}{V_2} \qquad (2)$$

where,

V_1 = original volume

C_1 = original concentration in V_1

V_2 = final volume produced by adding water to V_1; $V_2 \geq V_1$

C_2 = final concentration of solute in V_2 diluted from C_1

Similarly, if two solutions of different concentrations are combined, the final concentration of the combined solutions can be found as follows:

$$V_1\ C_1 + V_2\ C_2 = (V_1 + V_2)\ C_3 \qquad (3)$$

$$C_3 = \frac{V_1\ C_1 + V_2\ C_2}{V_1 + V_2} \qquad (4)$$

where,

V_1 and V_2 = original volumes to be mixed

C_1 and C_2 = concentrations in v_1 and v_2, respectively

C_3 = concentration of combined volumes.

Equations 1-4 are known as "mass-balance" equations because the total of the masses (volumes x concentrations) of a constituent contained in separate solutions will remain the same after the solutions are combined. A modification of equation 3 was used to simulate the natural interaction between septic system discharges, rainfall infiltration, and groundwater. The equation and defined terms appear below; figure 15 portrays the volumes of flow from each of the nitrate sources and sinks used in equation 5.

$$v_b\ c_b + v_i\ c_i + v_s\ c_s - v_p\ c_p = (v_b + v_i + v_s - v_p)\ c_o \qquad (5)$$

where,

V_b = volume of flow of groundwater entering the elemental volume from an upgradient or "background" area

C_b = concentration of nitrate-nitrogen contained in the groundwater entering the elemental volume

V_i = volume of infiltrating precipitation entering the elemental volume

C_i = concentration of nitrate-nitrogen contained in the infiltrating water

V_s = volume of septic effluent entering the elemental volume

C_s = concentration of nitrate-nitrogen contained in the septic effluent

V_p = volume of groundwater pumped by wells within the elemental volume

C_p = concentration of nitrate-nitrogen contained in the pumped groundwater

C = diluted concentration of nitrate-nitrogen coming out of the elemental volume

The volumes from each nitrate source can be further defined as:

$$V_b = T\ I\ L \tag{6}$$

where,

T = aquifer transmissivity, in gpd/ft

I = hydraulic gradient or slope of water table, in ft/ft

L = width of the elemental volume perpendicular to groundwater flow, in ft

$$V_i = (74.39)\ R_i\ A \tag{7}$$

where,

R_i = rate of infiltrating precipitation, in in/yr

A = surface area of the elemental volume, in acres

74.39 = factor to convert in-ac/yr to gpd

$$V_s = P\ H\ Q_p\ A \tag{8}$$

where,

P = number of people per household

H = lot density, in homes/acre

Q_p = wastewater flow per person, in gpcd

A = surface area of the elemental volumes, in acres

$$A = L \quad FL/43560 \tag{9}$$

where,

L = width of the elemental flow volume perpendicular to groundwater flow, in ft

FL = length of the elemental flow volume parallel to groundwater flow or flow path length, in ft

43560 = factor to convert square feet to acres

Additionally, an assumption was made that the amount of groundwater pumped by wells within the elemental volume was equal to the volume of septic effluent entering the elemental volume, or $V_p = V_s$. This assumption is reasonable because most residential water-use is nonconsumptive. A further assumption was made that the concentration of nitrate-nitrogen contained in the pumped groundwaer, C_p, was equal to the average of the background groundwater concentration and the diluted groundwater concentration, or $C_p = (C_b + C_0)/2$.

Combining these terms, equation 5 can be rewritten as:

$$(T\ I\ L)C_b + (74.39)\ A\ R_i\ C_i + P\ H\ Q_p\ A\ C_s - (P\ H\ Q_p\ A)\left(\frac{C_b+C_o}{2}\right) = C_o\ [T\ I\ L + (74.39)\ A\ R_i] \tag{10}$$

Two terms are of particular concern, 1) the concentration leaving the elemental volume, C_0, and 2) the critical housing density, H, based on setting C_o equal to the drinking water standard of 10 mg/l NO_3-N. Equation 10 can be rearranged to solve for each of these terms:

$$C_o = \frac{(74.39)\ R_i\ A\ C_i + P\ H\ Q_p\ A\ C_s + (T\ I\ L - P\ H\ Q_p\ A/2)\ C_b}{T\ I\ L + (74.39)\ R_i\ A + P\ H\ Q_p A/2} \tag{11}$$

and

$$H = \frac{T\ I\ L(10-C_b) + (74.39)R_i\ A(10-C_i)}{P\ Q_p\ A\ [C_s-(C_b+10)/2]} \qquad (12)$$

Equation 6 is a mathematical expression of Darcy's formula for groundwater flow through a saturated, porous medium. The quantity of flow, in gallons per day, is expressed as the product of the aquifer transmissivity, the slope of the water table, and the width of a cross section through the groundwater flow path. Further, the transmissivity is the product of the hydraulic conductivity (permeability) of the porous medium and the thickness of the aquifer or flow system. Simply stated, the transmissivity is a measure of the amount of water an aquifer will yield per unit area and is a function of the number, size, and degree of interconnection of the pore spaces within the aquifer. A summary of the range of hydraulic conductivity values that can be expected for different geologic materials appears in table 13. For this study, a hydraulic conductivity equal to 1500 gal/day/ft was used; only the upper 40 feet of saturated material was considered to be involved in the dilution process.

It should be noted that equations 6 through 8 actually express flow rates, in gallons per day, not volumes. To obtain volumes from each equation, time factors should be introduced. However, the time factor cancels out in equations 11 and 12. Similarly, the cross-sectional flow width, L, appears in all terms and changes in magnitude will not affect the outcome.

Table 13. Representative Hydraulic Conductivities for Selected Geologic Materials (from Dudley, et al, 1973)

Material	Hydraulic Conductivity, gal/day/ft^2
Clay, silt, till	1-100
Sand	
Very fine	100 - 300
Fine-medium	300 - 400
Medium	400 - 600
Medium coarse	600 - 800
Coarse	800 - 900
Very coarse	900 - 1000
Sand and gravel	1000 - 2000
Gravel	2000 and up

Because the time element is left out, solutions to equations 11 and 12 must be considered to represent long-term average conditions. As the length of the groundwater flow path (FL) increases, the actual time taken for groundwater to move through an elemental flow volume becomes very long (at 3 ft/day, it would take nearly 5 years to move one mile). Therefore, over long flow paths (greater than 1/2 to 3/4 mile) the assumption of instantaneous mixing of all the water used in the dilution process becomes strained. It was found that nitrate concentrations leaving the longer elemental flow volumes were less than what was calculated by compounding shorter flow volume concentrations (using the concentration leaving an upgradient flow volume as the background concentration for the following downgradient flow volume). To overcome this averaging effect, the mass-balance model was modified to iterate over increments of 1/4-mile flow path length. In this manner, nitrate concentrations exiting an incremental upgradient flow volume were successively used as the back-

Table 14. Summary of Input Values for Variables in NO_3-N Mass-Balance Model

Variable Name	Value Used	Comments
Groundwater Conditions		
Transmissivity, T	60,000 gal/day/ft	Produced most realistic results. K=60,000/40 ft= 1500 gal/day/ft^2. Very reasonable number for hydraulic conductivity, see Table 13.
Hydraulic Gradient, I	0.0018 ft/ft	Slope west of Rt.251, see figures 7 & 8
Cross-sectional flow width, L	any value	Change in flow width produces no change in output
Flow path length, FL	1/2 to 1 mile	Depending on subdivision, length varies. Most often less than 1 mile.
$N0_3$-N Concentration in Groundwater, C_b	3.0 mg/1	Average value of observed "background" concentrations observed, 2-4 mg/1.
Septic Effluent Conditions		
Housing Density, H	1.5 homes/acre	Calculated from maps, see Table 12
Residents per home, P	3.0 people/home	From 1980 census data, see Table 12
Wastewater Discharge, Q_p	45 gal/person/day	From USEPA Design Manual, Otis et al., (1980) See Table 11
$N0_3$-N Concentration in Effluent, C_s	40 mg/1	Average value from this investigation, See Table 10.
Precipitation Recharge Conditions		
Recharge Amount, R_i	5 in/yr, average 3 in/yr, low 9 in/yr, high	Values calculated from previous investigations, Walton (1965) and O'Hearn & Gibb (1980)
$N0_3$-N in Recharge, C_i	1.0 mg/1	From Nat'l. Atmos. Deposition Program data at DeKalb, IL.

ground concentrations entering an incremental downgradient flow volume until the area of interest was exited.

Transient peaks in nitrate concentrations, such as those found after rainfall events, cannot be predicted using these equations. Assumptions must be made concerning average outputs of wastewater quantity and nitrate concentration, rainfall infiltration, and aquifer hydraulic properties. Localized changes in any of these "input" variables will obviously change the outcome.

The model is a simplification of a real world situation which, at best, can only produce results as accurate as the input information. The more generalized the information used to simulate certain conditions, the more generalized the result. Results from this model represent average long-term conditions. When applied to nitrate concentrations, the term "average" implies that actual concentrations are above and below that concentration.

Despite seasonal predictive shortcomings, equations 11 and 12 produced very useful information. Variables representing different hydrologic and demographic situations can be entered to inspect the effect they would have on the outcome of nitrate concentrations and critical housing densities. As shown later, even though changes in each input variable caused changes in the results, definite conclusions regarding the effects of present and future developments in the Roscoe area are possible.

Input

Values for the model input variables were selected from information gathered during this study. The variables and the values that best reproduced observed conditions are summarized in Table 14.

Because the contribution of agricultural fertilizers was not directly measured, the effect of fertilizers was incorporated into the background concentration, C_b present in the groundwater used to dilute the septic effluent. Nitrate concentrations in wells removed from densely placed septic systems ranged from 2 to 4 mg/l NO_3-N. The effects of using different background nitrate concentrations were investigated (see Results section, figures 18 and 19); a background level of 3 mg/l NO_3-N satisfactorily represented present conditions.

An aquifer transmissivity of 60,000 gal/day/ft was used to represent the groundwater flow characteristics of the upper 40 feet of aquifer. Water table slopes were 0.0018 ft/ft beneath areas west of Rt. 251 and 0.002 to 0.003 ft/ft beneath Roscoe. The volume of groundwater discharge used to dilute the septic effluent will change depending on the cross-sectional width, L, chosen. Groundwater for dilution through a 1/2-mile cross section would average approximately 206 ,000 gal/day beneath areas west of Rt. 251 and 317,000 gal/day beneath Roscoe.

Housing densities and population statistics (Table 12) show an average of 1.5 homes/acre and 3 people/home. Total nitrogen concentrations found in septic effluent by various investigators (Table 10) ranged from 27 mg/l to over 100 mg/l; the average of the eight effluent samples collected during this study was 37 mg/l. Using the results from this study, if all the nitrogen is converted to nitrate in the soil, approximately 40 mg/l NO_3-N is potentially present in the drain field effluent. At an average discharge of 45 gal/person/day, approximately 25 lbs N/acre/year are being introduced to the groundwater system.

From previous investigations conducted at the Illinois State Water Survey, estimates of 3 in./yr, 5 in./yr, and 9 in/yr were used for groundwater recharge from precipitation during low, average, and high precipitation years, respectively. Therefore, approximately 220, 370, and 670 gal/day/acre in those years are helping to dilute the septic effluent in the underlying groundwater. Infiltrating rainwater was assumed to contain 1.0 mg/l NO_3-N.

Results

Figures 16 through 22 portray the results of using various hydrologic and demographic conditions in the mass-balance equations. The figures show an increase in nitrate concentrations as the length of flow path increases. This outcome reflects the buildup of nitrates that will occur as groundwater flows from an upgradient area to a point of discharge. Nitrate concentrations and critical housing densities were plotted against flow path length for different hydrologic conditions. In this manner, the sensitivity of the dilution process to present and future conditions can be seen.

Figures 16 and 17 show the effects of changes in aquifer transmissivity, T. Note that these graphs were made using the average hydrologic conditions outlined in Table 14. As the aquifer becomes more transmissive, more water will flow through a given area, diluting the septic effluent. Similarly, the greater the dilution effects, the more housing an area can sustain.

Plots also were made to show the effects of reducing the septic load to 20 mg/l NO_3-N. Such waste load reductions might be achieved through an alternative wastewater treatment system where a denitrification step is introduced to the system before the effluent is discharged to the seepage field (Laak, et al, 1981). Systems such as this are still in the experimental stage and have not been used widely.

For the geohydrologic conditions present in the Roscoe area, a transmissivity of 60,000 gal/day/ft produced results closest to those observed in the field. For example, Tresemer-Olde Farm and Centennial Settlement Subdivisions are approximately 3/4 to 1 mile long in the direction of groundwater flow. Average concentrations for those subdivisions ranged from 5.81 to 7.30 mg/l NO_3-N and from 7.42 to 9.65 mg/l NO_3-N, respectively (Table 4). For flow path lengths from 3/4 to 1 mile and a transmissivity of 60,000 gal/day/ft the model predicted NO_3-N concentrations will range from 7.3 to 8.4 mg/l NO_3-N (figure 16). Considering the potential variability in each of the input variables, the results are close to the observed concentrations. Concentrations in Hononegah Country Estates could not be closely matched because of the unusually high concentrations found along Wild Deer Trail which are possible remnants from two improperly abandoned wells.

A change in slope from 0.0018 ft/ft to 0.003 ft/ft did not reduce nitrate concentrations to the levels detected in Roscoe. This confirms that a greater groundwater discharge is not solely responsible for creating lower nitrate concentrations beneath Roscoe. A nitrate loading smaller than 25 lbs N/acre/yr, on the order of 15 lbs N/acre/yr, produced results comparable to observed conditions. More also needs to be known about how North and South Kinnikinnick Creeks might help to reduce nitrate concentrations in the groundwater.

Figures 18 and 19 portray nitrate concentrations and critical housing densities for changes in background nitrate concentration, C_b. These figures describe the effect agricultural fertilizers might have on downgradient concentrations produced after diluting the septic effluent.

The wide range of nitrate concentrations displayed in figure 18 indicate background nitrate can have a significant effect on the nitrate levels found in groundwater beneath a subdivided area. Under present conditions, with a background concentration of 3 mg/l NO_3-N, the final nitrate concentration, C_o, is shown to stay below 10 mg/l NO_3-N until the flow path exceeds 1.5 miles. For this reason, it is believed that at the present development level of homes in the study area, average nitrate concentrations should remain below drinking water standards. Transient peaks over 10 mg/l NO_3-N have already been observed, however, indicating the averaging effect this model has. Also, it should be noted that even with no fertilizer contribution ($C_b = 0.0$ mg/l), diluted concentrations in the groundwater would exceed 6 mg/l NO_3-N and peaks over 10 mg/l may still be experienced. Figure 19 shows that no matter what the background nitrate contribution is, developed areas exceeding 3/4-mile in the direction of groundwater flow must be subdivided at less than 3 homes/acre.

Figure 20 illustrates the effect of different housing densities on long-term nitrate concentrations. Solid lines represent conditions when the background nitrate concentration is zero (no fertilizer or upgradient septic contributions). Dashed lines represent the present condition with background concentrations at 3 mg/l NO_3-N. With a 3 mg/l NO_3-N background concentration, densities of 2 and 3 homes/acre will clearly exceed the drinking standard at flow path lengths of less than one mile. Densities of 1 to 1.5 homes/acre are necessary to maintain nitrate concentrations below 10 mg/l NO_3-N.

The effects of different recharge rates are presented in figures 21 and 22. The diluting effects from increased rainfall infiltration can be seen clearly. Because low infiltration reduces dilution, below average infiltration conditions are critical for planning considerations. Even though the observed period of no recharge from August to October produced lower nitrate levels because the septic effluent was not being flushed downward, extended dry periods (6 months or longer) should cause increased nitrate levels as the septic effluent drains naturally. Nitrate concentrations in the groundwater might be expected to more nearly approach concentrations shown for zero recharge in figure 21. Critical housing densities would then follow the lower limitation depicted in figure 22. Even if the septic effluent loading could be reduced to 20 mg/l NO_3-N (dashed lines, figure 22), critical housing densities must be kept below 5 homes/acre and, as will be described, subdivisions to be built upgradient of presently developed areas must discharge less than 10 mg/l NO_3-N so as not to cause downgradient areas to exceed the drinking water standard.

To further explain this concept and to explore possible future consequences of housing developments, assume the triangular area bounded by Hononegah Road, Route 251, and McCurry Road is' to be subdivided for housing. The longest flow path within this area is approximately 3/4 mile (extending from the corner of McCurry Road and Route 251 to Hononegah Road in a southwesterly direction). If the housing density is maintained at 1.5 homes/acre, the diluted concentration in the groundwater leaving this area would be expected to contain approximately 7.5 mg/l NO_3-N (figure 18, FL = 0.75 mile, C_b = 3.0 mg/l). This concentration is now the background concentration, C_b that will be entering the downgradient subdivision. If the downgradient subdivision is 3/4-mile long in the direction of groundwater flow (similar to Evergreen Manor Subdivision), then the nitrate concentration in the groundwater exiting this subdivision can be expected to be very close to 10 mg/l NO_3-N (figure 18, FL = 0.75 mile, Cb = 7.5 mg/l). Figure 18 was also prepared using average recharge conditions (5 in/yr). A low recharge year boosts average nitrate levels even higher.

If the density is decreased to 1 home/acre, the average nitrate concentration leaving the upgradient subdivision would be approximately 6 mg/l NO_3-N (figure 20, FL = 0.75 mile, C_b - 3.0 mg/l). The nitrate concentration expected in the downgradient subdivision would now be approximately 9 mg/l NO_3-N (figure 18, FL - 0.75 mile, C_b = 6 mg/l) for average recharge conditions. Again, low recharge years may put average concentrations over 10 mg/l NO_3-N. Compounding this problem, the subdivided area northeast of the McCurry Road-Route 251 intersection has produced groundwater nitrate concentrations around 7 mg/l (see Table 4, North Roscoe Area). This 7 mg/l concentration serves as the background concentration in the groundwater entering the Route 251-McCurry Road-Hononegah Road area. The mass balance model indicates that for average infiltration conditions (5 in/yr) and a background concentration of 7 mg/l NO_3-N, the housing density must be severely limited so enough dilution can occur before the groundwater enters the presently developed areas south of Hononegah Road. With a housing density of 0.5 home/acre in the undeveloped portions north of Hononegah Road, average concentrations will just reach 10 mg/l NO_3-N in areas south of Hononegah Road. Again, if recharge does not occur for an extended period of time, average nitrate concentrations may exceed 10 mg/l.

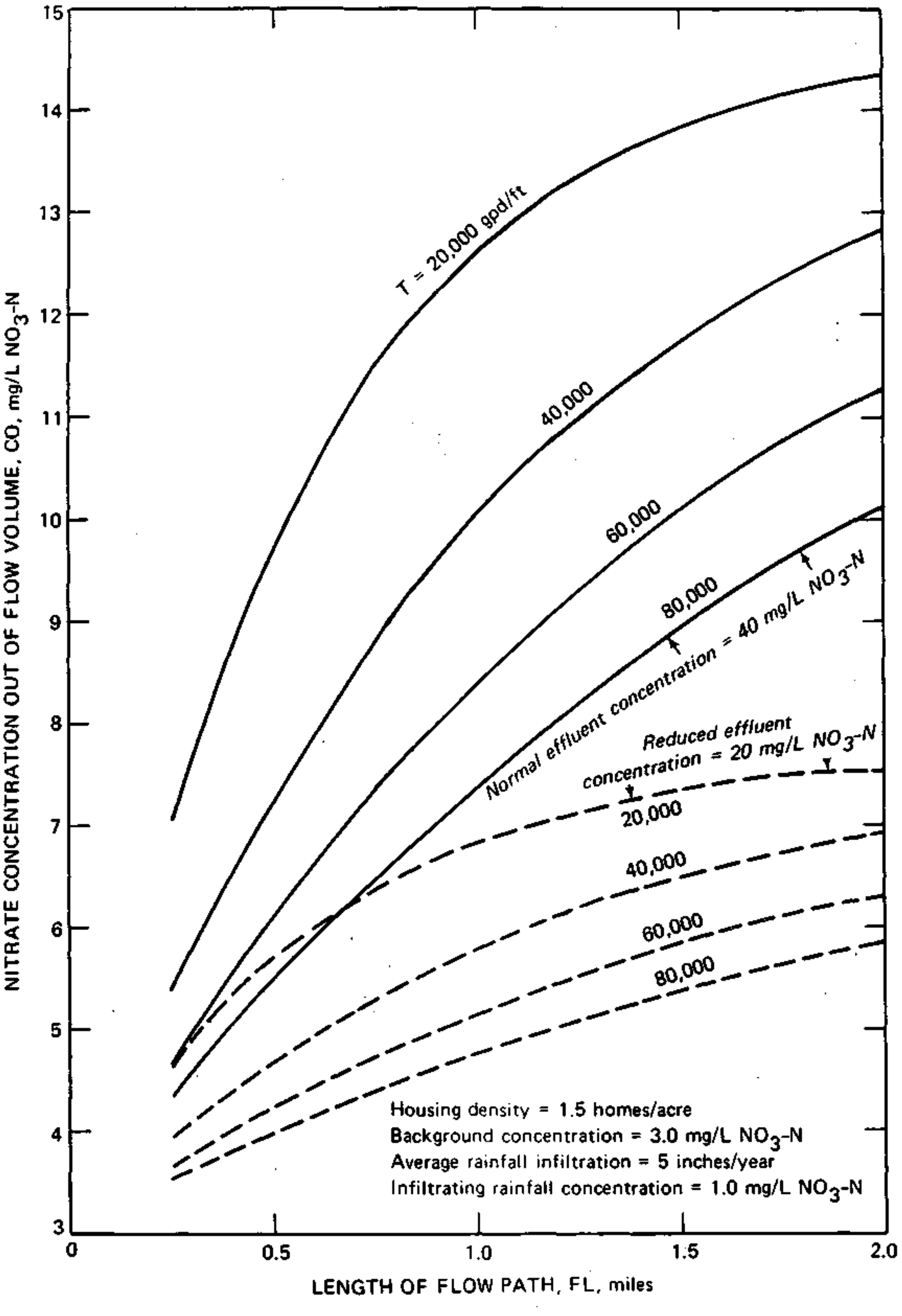


Figure 16. Long term nitrate concentration vs. length of flow path for different values of transmissivity

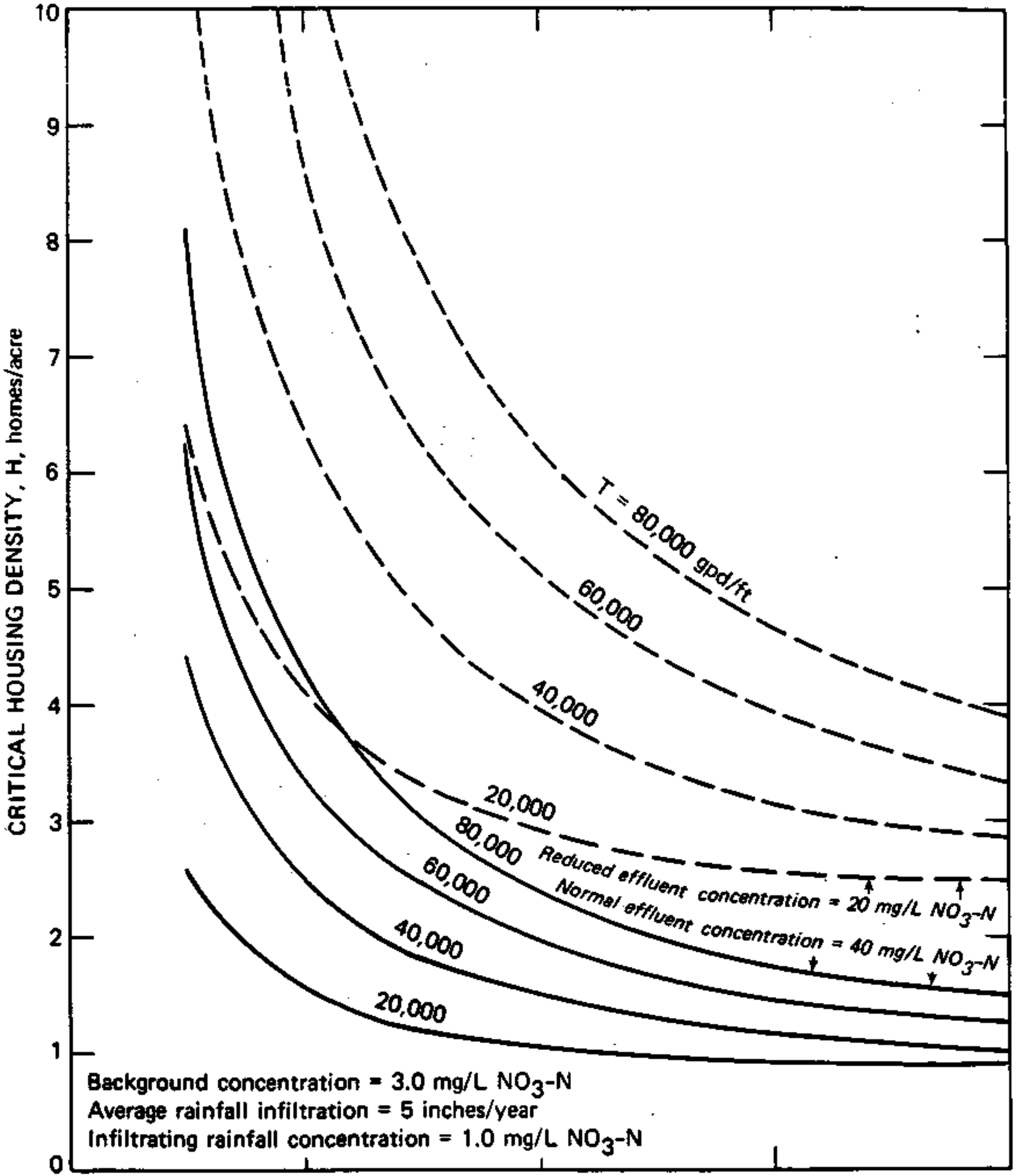


Figure 17. Critical housing density vs. length of flow path for different values of transmissivity

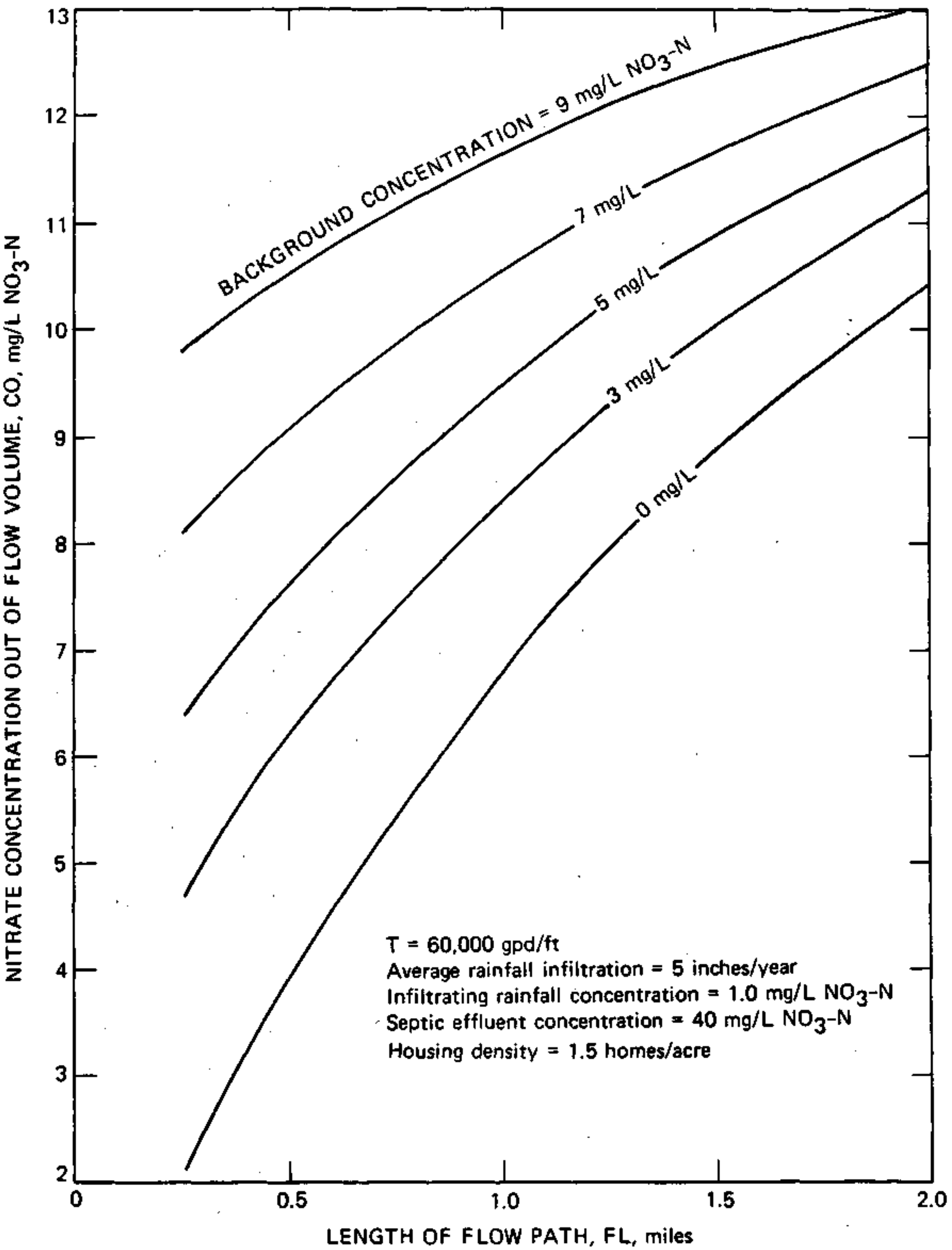


Figure 18. Long term nitrate concentration vs. length of flow path for different values of background nitrate concentrations

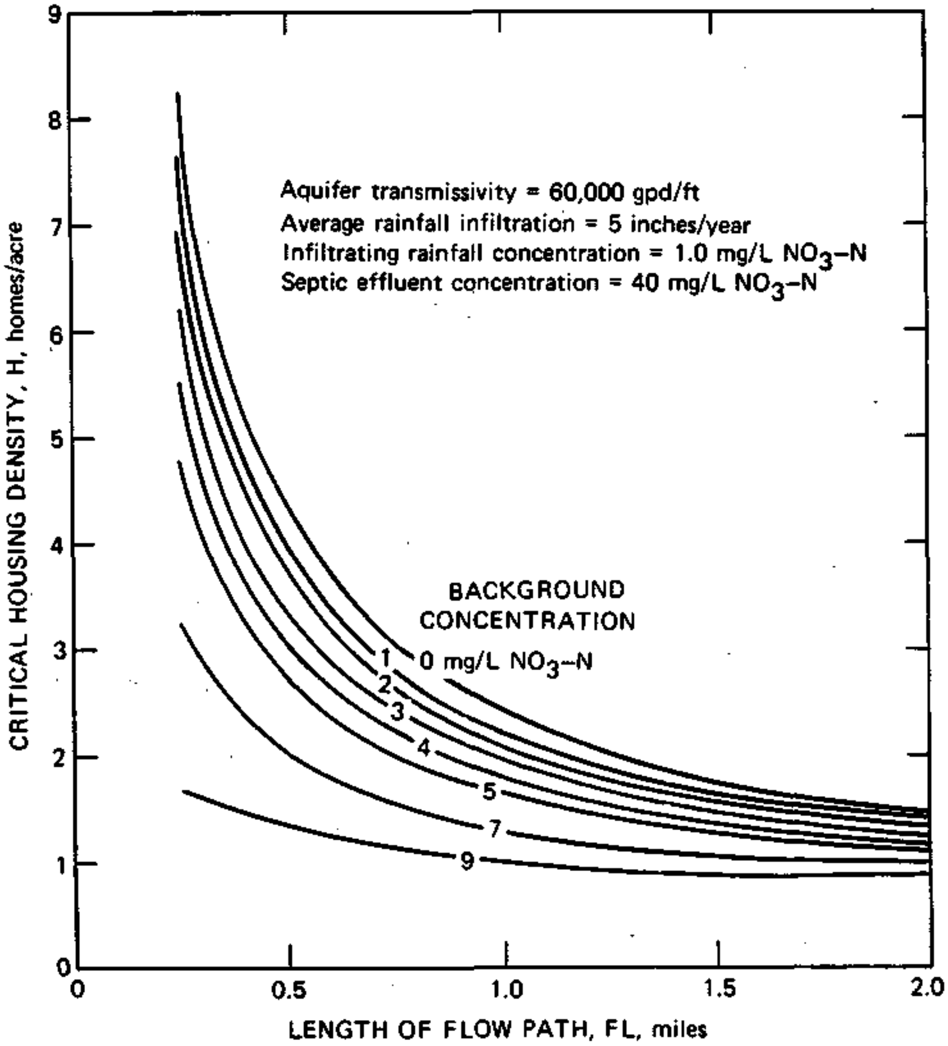


Figure 19. Critical housing density vs. length of flow path for different values of background nitrate concentrations

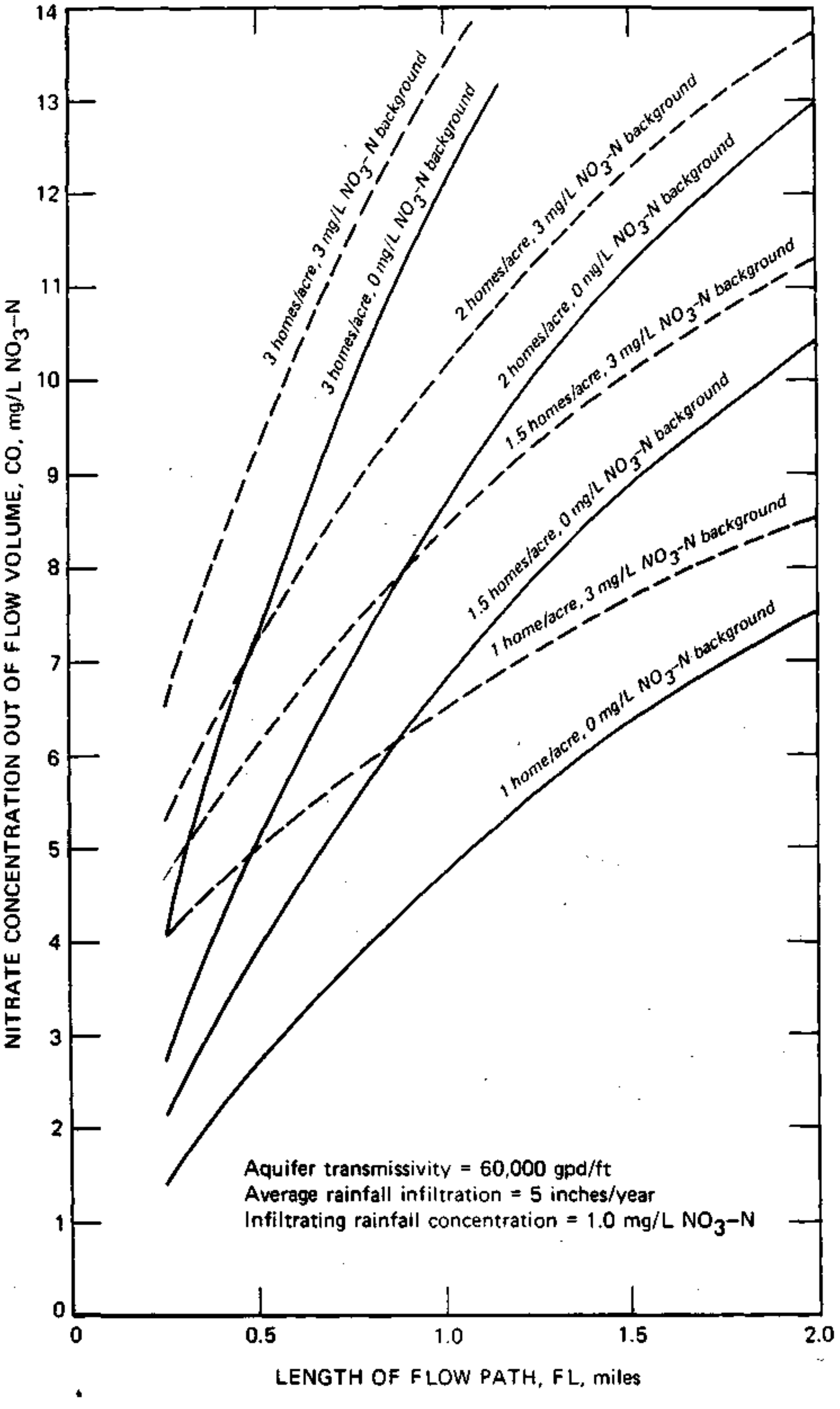


Figure 20. Long term nitrate concentration vs. length of flow path for different housing densities and background nitrate concentrations

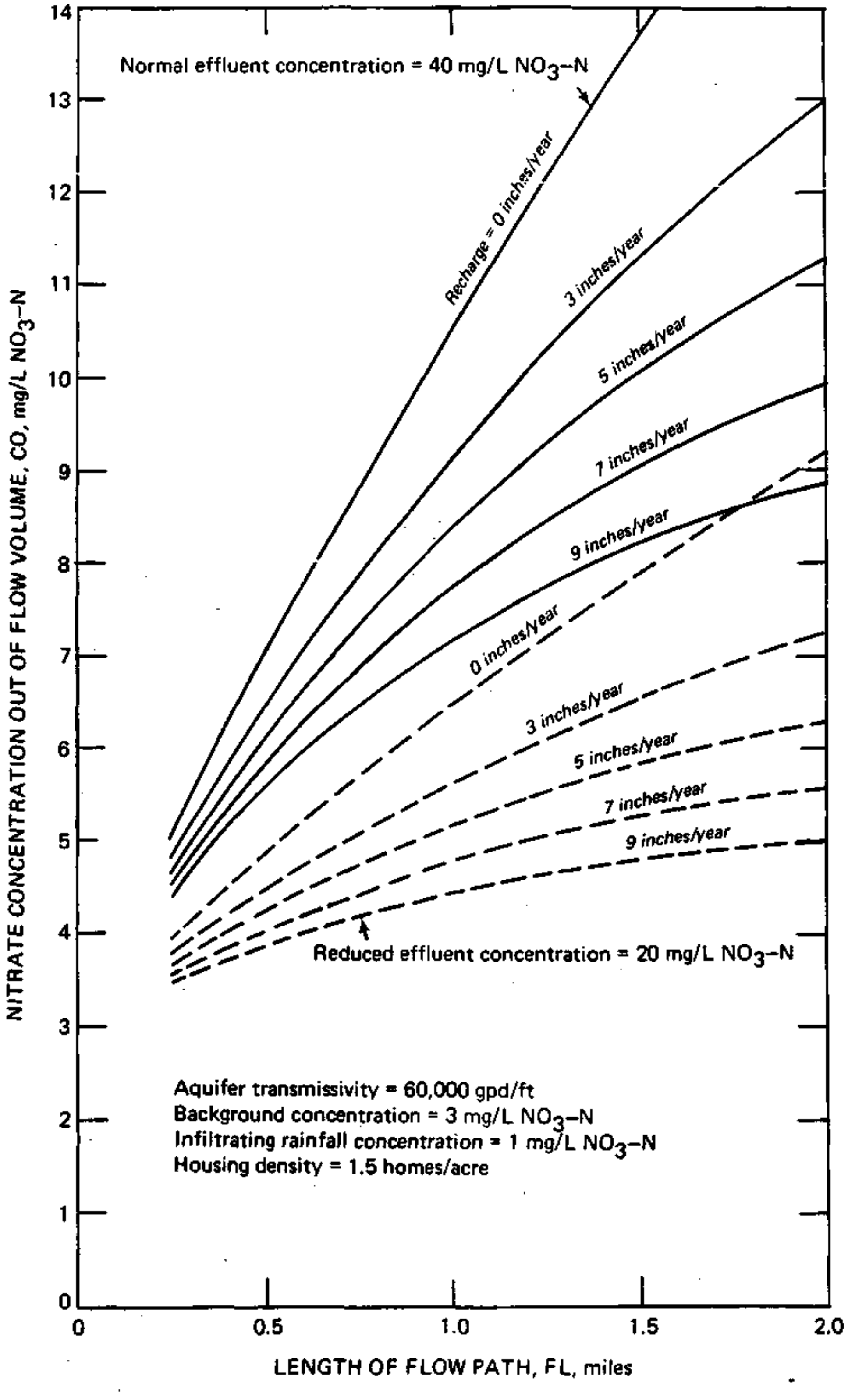


Figure 21. Long term nitrate concentration vs. length of flow path for different groundwater recharge conditions

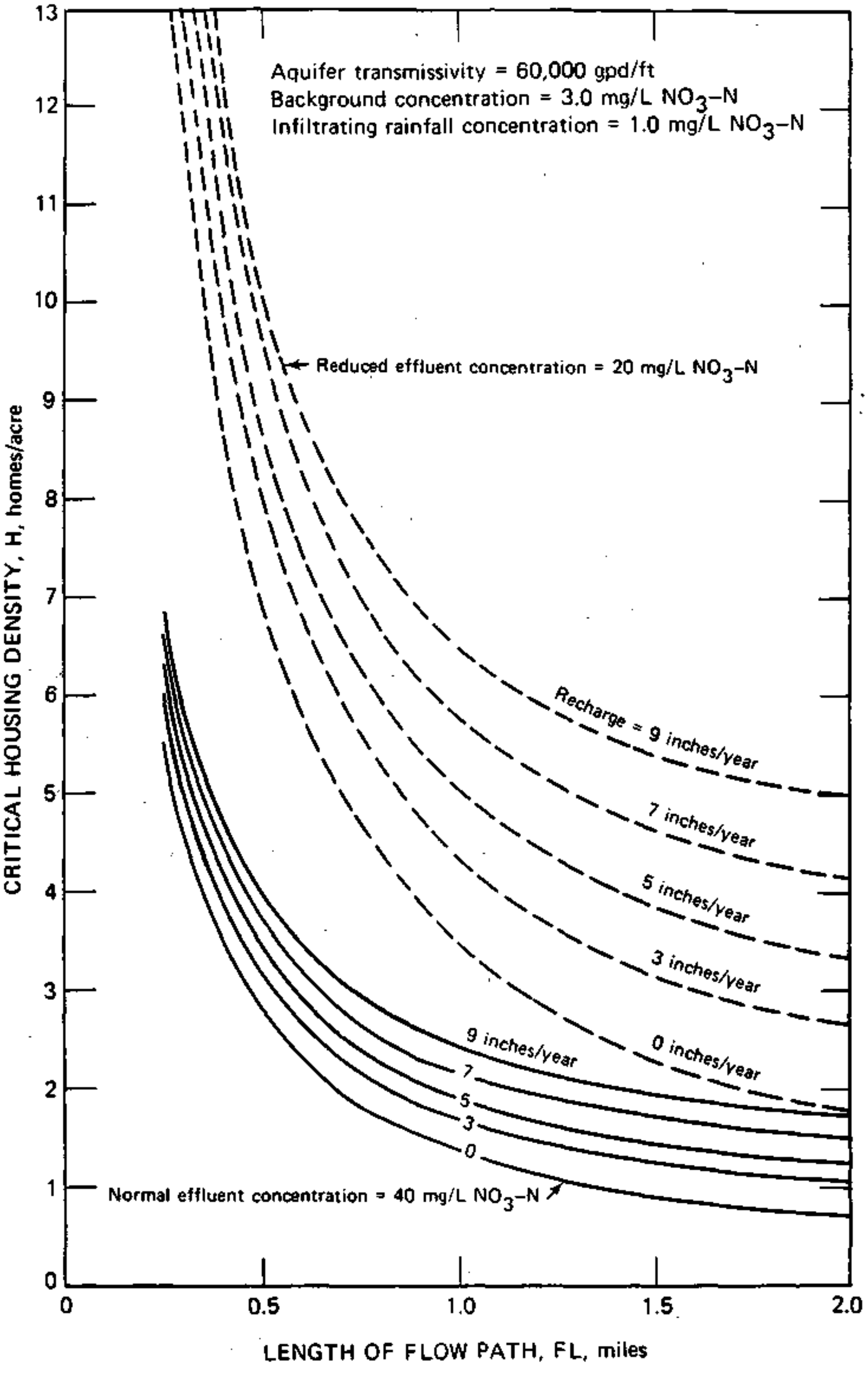


Figure 22. Critical housing density vs. length of flow path for different groundwater recharge conditions

CONCLUSIONS AND RECOMMENDATIONS

Standard percolation tests in the Roscoe study area have demonstrated the ability of the local geologic materials to transmit water readily. Unfortunately, these materials have generally poor nitrate treatment capabilities. The biological conditions in the subsurface greatly favor the formation of nitrate which is not attenuated by the subsurface sand and gravel. Once in the groundwater system, nitrate concentrations can only be reduced by dilution.

No general trends in nitrate concentrations were found during the course of this project. Rather, nitrate concentrations were found to vary in response to recharge events and to the proximity and strength of nitrate sources. These results do not discount the trend observed by the WCPHD during the years 1979-1981. Those findings were probably a result of the housing boom experienced just prior to and during their investigation.

By the time this study began in early 1982, the housing industry had come to a standstill. This circumstance gave groundwater quality conditions time to equilibrate and allowed better interpretation of the gathered data. The WCPHD findings actually confirm the findings of this investigation-controlled development of on-site wastewater disposal systems must take place if the presently developed areas are to remain unaffected.

Because of the historical use of agricultural fertilizers and septic systems throughout the area, no well was found to be totally unaffected by nitrate. Perhaps the least affected samples were collected from a well in Kieselburg Forest Preserve, approximately 1.5 miles south of the study area. Removed from sources of contamination, nitrate concentrations were always less than 3 mg/l. Other wells located in outlying areas contained from 2 to 4 mg/l NO_3-N.

Concentrations in Roscoe and surrounding subdivisions, where septic tank-leach field systems number in the hundreds, generally averaged over 6 rag/1 NO_3-N with some residences exceeding 10 mg/l JO3-N. One sample contained 19 mg/l NO_3-N and is probably the result of an improperly abandoned well located nearby. Because nitrate levels in this one area have remained so high after the well was plugged, it is likely another pollution source in the area exists. Further investigation is warranted.

Nitrate concentrations beneath Roscoe were much less than concentrations beneath surrounding subdivisions. Greater groundwater flow beneath Roscoe and rapid groundwater discharge to North and South Kinnikinnick Creeks appears to be partly responsible. A generally older population with potentially fewer occupants per home may also help to produce lower nitrate concentrations beneath Roscoe. With a less dense, older population, wastewater discharges should be smaller and the contribution of nitrate to the groundwater system should be similarly reduced. In support of this hypothesis, areas within Roscoe which contain apparently younger populations exhibit higher nitrate levels.

This points to a potential problem for the future of Roscoe. Should the population characteristics of Roscoe change, becoming younger with more inhabitants per home, groundwater quality can be expected to become more like that experienced in areas west of Route 251. Development of areas upgradient of Roscoe, particularly the sandy terrace areas northeast of town, will also tax the dilution capability of the groundwater, contributing to groundwater quality degradation.

Groundwater nitrate concentrations varied greatly in response to recharge events. Nitrate concentrations would rise sharply after a recharge event, often over 10 mg/l, and gradually decline to ambient levels after several days. It had been suspected that nitrate levels would be higher during the spring as infiltrating rainfall and snowmelt washed suspended septic effluent out of the unsaturated zone into the underlying groundwater. However, water samples collected during late April and early May contained less nitrate than samples collected during mid-November.

The cause can be related to the relatively dry period extending through the spring sampling effort as compared to the heavy rains experienced during the fall sampling effort. Even though groundwater levels were approximately 2.5 feet higher in the spring than in the fall, groundwater levels were on a downward trend indicating a lack of recent recharge. Groundwater levels were on an upward trend during the fall sampling indicating recent infiltration.

Samples collected monthly at selected homes illustrated this variation in nitrate concentrations very clearly. Nitrate levels were fairly stable when sufficient infiltrating rainfall kept a constant source of nitrate moving downward. As recharge decreased, the downward movement of nitrate decreased, and nitrate concentrations in the water decreased. Increases in recharge flushed nitrate out of the overlying, unsaturated materials into the groundwater system, causing nitrate concentrations to rise temporarily.

Increased rainfall infiltration, while causing temporary rises in groundwater nitrate levels, actually enhances the dilution process. Infiltrating water will cause nitrate levels to rise but after several days, mixing of the septic effluent, rainwater, and groundwater will cause nitrate levels to be reduced. The more rainwater that has infiltrated, the more dilation is possible. Extended dry periods (6 months or longer) will allow septic effluent to drain by gravity at "full strength" to the groundwater system, producing nitrate concentrations that would be much more critical.

These findings along with data relating to nitrate source concentrations and local hydrologic conditions were incorporated into a mass-balance or dilution model. The model was developed on the assumption that complete mixing of septic effluent, rainfall recharge, and groundwater to a depth of 40 feet below the water table (the depth of most local well intakes) takes place. Through this approach, expected long-term nitrate quality and critical housing densities were investigated.

Modelling results show that sewering of the present developments should not be necessary. Additionally, the Evergreen Manor area located south of Hononegah Road between Tresemer-Olde Farm Subdivision and Hononegah Country Estates should be able to sustain housing densities comparable to the presently developed subdivisions (1-1.5 homes/acre). Groundwater flowing through the Evergreen Manor area will not impinge on other subdivisions before discharging to the Rock River, therefore the subdivisions east and west of Evergreen Manor will not be affected.

Serious impacts will result if similar development with on-site wastewater disposal systems is continued north of Hononegah Road, east and north of Hononegah Heights, and east of Knapp's Knoll on the north side of McCurry Road. In order to allow proper diLution of septic effluent so downgradient homes are not adversely affected, housing densities in these areas should be no greater than 0.5 home/acre. Even at this density, average long-term nitrate concentration in downgradient subdivisions will approach 10 mg/l NO_3-N; therefore, several homes can be expected to be over 10 mg/l. Model results suggest that any sandy areas throughout Winnebago County, susceptible to nitrate contamination, should be closely supervised when on-site wastewater systems are contemplated.

Sewering to transport wastewaters to a centralized treatment plant would eliminate introduction of septic effluent to the drinking water supply. From the data gathered, sewering does not appear to be necessary under the present conditions. If 2 acre lots are not economically viable for the remaining undeveloped areas north of Hononegah Road, sewering may become more attractive.

Future homes might more reasonably incorporate a denitrification step in the basic septic system-leach field design already being used. Several full scale units have been built in Connecticut and found to reduce nitrate loads more than SO percent. With these units, future housing in areas upgradient of presently built-up areas could follow present densities (1-1.5 homes/acre). More investigation is needed to determine the applicability of these units to the Roscoe area.

Reducing the nitrate load to the groundwater system may not safely allow higher housing densities. Efforts to reduce the nitrate load may not affect other potential pollutants such as chloride and MBAS. Elevations in these two constituents have been noted in the data collected during this study.

Systems which do not incorporate a denitrification step will not reduce the nitrate load. These would include all types of mound, evapotranspiration and aerated systems which were developed specifically for soils with poor absorption capabilities. Cluster systems used to accomodate several homes or apartments will only serve to concentrate leach field effluent in one area and will greatly affect homes on downgradient flow paths. Water conservation practices, while reducing the amount of water discharged as septic effluent, will cause the discharge of higher concentrations of nitrate which will need to be diluted by other sources of water.

This study indicates that groundwater quality, especially nitrate content, has been impaired by several of man's activities. Major nitrate sources within the study area were identified as fertilizers and septic tank - leach field wastewater disposal systems. The widespread use of domestic septic systems is of particular concern. Modelling of the dilution process supplied by groundwater flowing beneath the area, indicates present development is approaching the natural dilution capability of the groundwater system. Further development with on-site wastewater disposal systems upgradient of presently developed areas along the Rock River must be carefully engineered to keep nitrate concentrations within standard drinking water guidelines.

Finally, this study has left some areas open for further investigation:

1. Monitoring of groundwater quality should begin now in areas where on-site disposal systems do not presently exist or have not affected. Monitoring in these areas will give baseline data which could not be gathered during this study and will give a much clearer indication of the effect these systems are having on the underlying groundwater.
2. Monitoring of vertical, spatial, and temporal relationships should be continued. Vertical changes in groundwater quality

were monitored at only one location throughout the study area. Further monitoring of vertical relationships, including groundwater below the depth of local wells, would give more information on the groundwater dilution process.

3. Monitoring of nitrate levels and flow in North and South Kinnikinnick Creeks will give a much better idea of the potential flushing effect these two creeks have. Monitoring during extended dry periods is extremely important because most of the flow in the creeks during these periods would be groundwater discharge. This data may help to better explain why nitrate concentrations in Roscoe are less than in the surrounding subdivisions.
4. Recent techniques in nitrogen isotope analysis have been used to distinguish between animal (human) waste and fertilizer sources (Gormly and Spalding, 1979). Such techniques may be useful for determining a more accurate assessment of the contribution fertilizers make to the nitrate concentrations found in the groundwater.
5. The Water Survey has been working on a new field method for determining the hydraulic conductivity of highly permeable deposits. This technique was developed for use on small diameter wells (2 in. I.D.) such as the wells drilled for monitoring the shallow groundwater. Use of this method at those wells and any wells drilled in the future would greatly help refine the estimates used for aquifer transmissivity in the mass balance model.

6. Alternative modes of on-site wastewater disposal must be more thoroughly investigated and demonstrated. A denitrification step, not incorporated in the present septic systems, is necessary to reduce the nitrate concentrations being discharged to the groundwater system. Installation, operation, and monitoring of several denitrification systems will give information on the applicability of these systems to the sandy regions of not only the Roscoe area but the entire county. Cooperation between developers, septic and well contractors, homeowners, and the County Health Department will further enhance the future of the groundwater resources of Winnebago County.

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