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May 1, 2001

Dr. Joseph Troester, Research Hydrologist
Department of the Interior
United States Geological Survey
651 Federal Drive, Suite 400-15
Guaynabo, Puerto Rico 00965-5703

Dear Dr. Troester,

Enclosed you will find a copy of our report entitled Nitrate Contamination in Puerto Rico's Ground and Surface Waters. The report was composed at the United States Geological Survey during the period of March 12 through May 1, 2001. Preliminary work was done on the Worcester Polytechnic Institute campus in Worcester, Massachusetts to prepare for our arrival to Puerto Rico. Copies of our report are also being submitted to Professors Lew Yan Voon and Vernon-Gerstenfeld for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We thank you and the other employees of the USGS for the time and effort to support our project.

Sincerely,

Charles W. Gamache Jr.

Kevin D. Jorczak

Alonna M. Schienda

Alonna M. Schienda

Nitrate Contamination in Eastern Puerto Rico's Ground and Surface Waters and Its Sources

Report Submitted to:

Susan Vernon-Gerstenfeld
Lok C. Lew Yan Voon
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By

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In Cooperation With

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U.S. Department of the Interior
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May 2, 2001

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of the U.S. Geological Survey or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Abstract

Wells in Puerto Rico have experienced elevated nitrate concentrations in recent years. Our group, along with the help of the U.S. Geological Survey, conducted water sampling in eastern Puerto Rico to determine nitrate concentrations in ground and surface water. Sampling in El Yunque, the rainforest, was used to determine natural nitrate concentrations. Samples taken outside of the rainforest were compared to El Yunque to determine how different land usages change nitrate concentrations. We found that none of the areas sampled during our study contained nitrate concentrations over the Environmental Protection Agency's limit of 10 mg/L of nitrate as nitrogen in drinking water. We recommend further sampling.

Authorship

This statement acknowledges that all the members of the USGS project team participated equally in the following report. All members of the project team researched and wrote the literature review along with the methodology. Each member of the group helped to form the data analysis and conclusions that enabled the team to form recommendations for the USGS.

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Special Thanks to:

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EXECUTIVE SUMMARY

The purpose of this study was to determine if nitrate contamination in waterways was a widespread problem across eastern Puerto Rico, and if so, the occurrence of health problems associated with this contaminant. Previous studies conducted by the United States Geological Survey in 1996 and 1999 have shown high nitrate concentrations were occurring in some areas of Puerto Rico, such as the Manatí-Vega Baja area west of metropolitan San Juan.

The United States Environmental Protection Agency (EPA) has placed a limit of 10 mg of nitrate per liter of drinking water. This was done because nitrate is known to be detrimental to the health of children who consume water above this level. Infants younger than six months can experience a condition known as methemoglobinemia. The nitrites deprive the blood of oxygen, and this can lead to suffocation in the child. This condition does not affect adults because adults easily excrete nitrates in the urine.

Although adults do not experience methemoglobinemia, they can experience negative health effects from nitrates. One condition is known as acute nitrate poisoning and results from ingesting grams of nitrates. More recently, studies have shown that ingesting nitrates at levels below the EPA limit may lead to a type of cancer known as non-Hodgkin's lymphoma.

Agriculture and the use of inorganic nitrogen-based fertilizers are the largest external source. Past studies have shown that intense agriculture can lead to nitrate concentrations above the EPA limit. Other sources such as industries, sewage and septic systems, and landfills can also have an effect on nitrate concentrations.

During this study, thirty-six sites were sampled, and a total of forty-nine water samples were collected in March and April of 2001. Data was collected from the rainforest, throughout eastern Puerto Rico, and from the aforementioned Manatí-Vega Baja area. The rainforest samples were used as the standard for the rest of the samples because human interaction in the rainforest is minimal, so concentrations found there are naturally occurring.

Of the forty-nine samples that were analyzed, only two were close to the EPA's limit of 10 mg/l. Both of these samples were from the Manatí-Vega Baja area and had nitrate concentrations of 6.5 and 6.6 mg/L. This is due to the intense pineapple agriculture occurring near the wells in Manatí and Vega Baja. Nitrogen from the fertilizer is broken down and leached into the wells in the area. The next highest concentration found during the study was 1.1 mg/l, far below the concentrations observed in the Manatí-Vega Baja area.

Although we contacted many local agencies to obtain data on the occurrences of methemoglobinemia and non-Hodgkin's lymphoma for the island, we were told that the data for the island is recorded only according contaminant levels and not according to occurrences of specific health conditions. This made it impossible to determine if high nitrate levels in the Manatí-Vega Baja area have had negative effects on the health of the population in that area.

Since nitrate concentrations across eastern Puerto Rico were well below the EPA limit of 10 mg/l, excluding Manatí-Vega Baja, our project team determined that nitrate contamination is not a widespread problem across eastern Puerto Rico. We recommended that nitrate concentrations be monitored in the future in order to ensure that the nitrate concentrations stay within a safe level. We also recommended that health data be recorded according to occurrence of specific health conditions so that future researchers can attempt to determine a causal relationship between nitrate concentrations observed in the field and health conditions of the population in the area.

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CHAPTER 1. INTRODUCTION

Nitrate contamination is a problem affecting many waterways. Although the sources of this contamination vary from one site to another, correlations can be drawn to determine the source of the pollutant at any given site. Nitrates in ground and surface water pose problems to both the environment and to the health of young infants and possibly adults. The U. S. Geological Survey (USGS) asked us to determine the concentration of nitrate in the streams and rivers of the eastern part of Puerto Rico, to determine if nitrate contamination is a problem for public health, to correlate the levels of nitrates with land use data for the area, and to determine the sources.

Nitrates have many sources. They can come from naturally occurring sources such as biodegrading waste and plants, but nitrate contamination most often occurs because of human factors. Agriculture, especially the use of nitrogen-based fertilizers, is a large contributor to contamination of ground and surface waters. The leakage of septic tanks and sewers is often a problem on the local level.

The U.S. Environmental Protection Agency (EPA) has placed a limit of 10 milligrams per liter of nitrate as nitrogen of drinking water because nitrates pose both health and environmental risks. Nitrates cause problems in the environment by removing oxygen from the water. This would make it difficult for a variety of aquatic life, both plants and animals, to survive. If infants ingest water contaminated by nitrates, they may experience what is known as methemoglobinemia. This condition results in reduced oxygen in the blood stream and may lead to suffocation. Nitrogen can also be broken down in the human body to form N-nitroso compounds. Some N-nitroso compounds have been shown to be carcinogenic (Van Leeuwen, 2000). To date there is not enough data to associate large nitrate intake with cancer, so the limit of the EPA is set for the prevention of methemoglobinemia (Van Leeuwen, 2000).

As mentioned above, the USGS asked us to test the waters in the local rivers and to correlate the results with land use data. We obtained samples from various points along the rivers and streams, and these samples were analyzed on site and in the lab. In order to relate this data to land usage, we contacted the Department of Natural and Environmental Resources. The land usage data showed us what industrial and agricultural activities were taking place near the sampling areas. Based on the land usage surrounding the rivers, we determined the possible sources of the nitrates. We also examined the social implications of high concentrations of nitrates in drinking water and the social implications of reducing this contaminant.

The project results may be of interest to the U.S. Geological Survey, other environmental agencies, and to those people who are, either directly or indirectly, responsible for the contamination. Once the source of the contamination is known, a system can be devised to clean the water. If the water were treated, it could provide more freshwater for the drinking supply in Puerto Rico. This study might also help other geographic areas with nitrate pollution to determine the best way to solve their contamination problem.

An Interactive Qualifying Project (IQP) is a project that brings together both social and technological aspects in the area of scientific research. The IQP allows the students to work in a professional environment and to understand the social implications of their research. This project fulfills the requirements of an IQP by using technology to determine nitrate concentrations and to understand its sources, and it also incorporates the social aspect by determining health and environmental risks posed to the people of Puerto Rico.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

To understand nitrates and how they contaminate water, one must first understand the hydrological cycle, the properties of nitrates, and the various sources of contamination. In this chapter we discuss the hydrological cycle, environment, and how seasonal changes affect the level of nitrate pollution. Our report also covers such topics as the contributing factors to nitrate pollution. Among these factors are industrial processes, waste disposal, and agricultural production. It is important to understand the interaction between groundwater and streams and how sediment in streams and rivers can carry pollutants, because pollution of one invariably leads to pollution of the other. Various sampling methods can be used to determine the concentration of nitrates in rivers and streams. Therefore, we discuss these methods of collection along with the equipment used in the process. Nitrates also pose risks to the health of humans and to the environment. We discuss these various risks along with ways to prevent them.

2.2 Hydrological Cycle

The water found on the Earth was produced during the planet's formation. The earth's water supply stays at a constant volume because water cannot escape the earth's atmosphere. Water on the earth is constantly going through the hydrological cycle, which is also known as the water cycle. The hydrological cycle starts with the evaporation of water from the earth's surface. Evaporation takes place when the sun heats water from lakes, streams, rivers, and oceans. The heated water is then converted to water vapor. The water vapor forms clouds in the atmosphere. When the clouds are saturated and can no longer hold any more water, rain is formed. When precipitation hits the ground, it can either soak into the ground or create runoffs. Runoffs flow back into rivers, streams, or lakes; the hydrologic cycle is then started again.

The water that is absorbed by the ground is called groundwater. Groundwater seeps into the spaces or pores between rock formations and soil granules (Freeze & Cherry, 1979). The amount of groundwater and the type of and distribution of the pores determines the location of water table. Wet climates or areas surrounded by water bodies have higher water tables. Groundwater feeds many lakes and rivers as it flows underground, and when reaching the surface, the hydrological cycle is repeated.

Ninety-four percent of the water located on the earth is contained in the oceans. The remaining 6 percent is found in groundwater, lakes, glaciers, streams, rivers and other salt-water bodies (Freeze & Cherry, 1979). Since salt water is toxic for human consumption, less than 4 percent of the water on earth is usable by humans. If we exclude the arctic glaciers, only 3.5 percent of the world's fresh water is located in rivers, lakes, streams, and swamps, 1.5 percent is soil moisture and 95 percent of the fresh water is groundwater (Freeze & Cherry, 1979).

2.3 General Nitrate Information

The earth's atmosphere is made up of 78 percent nitrogen, the inert gas N_2. The National Research Council (NRC, 1978) stated that close to 1 percent or less of all the nitrogen found in the soil is in the form of nitrate, NO_3^-. The nitrate ion is reactive in soil, and this small percentage can transform rapidly into other forms of nitrogen.

External sources and the environmental conditions at any one locality are the two major factors in the concentration of nitrates.

2.3.1. Solubility of nitrates

If water such as rainfall or groundwater is present, nitrogen occurs most often as nitrate. This is because the organic forms of nitrogen react with the water molecules and oxidize (Conde-Costas & Gómez-Gómez, 1999). Organic forms of nitrogen can also be broken down into nitrates by bacteria in the water (Camesano, interview, January 25, 2001). The nitrate molecule is very stable and is transported easily in water, withstanding a variety of conditions throughout its travel. Nitrates are easily transported within water because of the high solubility of the nitrate, which is 144,940 milligrams of NO_3-N per liter of water at room temperature (68 ° F) (Conde-Costas & Gómez-Gómez, 1999). If any is present in the soil, the nitrate dissolves in water and is transported. Average concentrations of nitrates found in water in nature range from 1 to 100 milligrams of nitrate per liter of water (Lloyd & Heathcote, 1985).

2.3.2. Nitrification

There are various natural processes that govern the concentration of nitrates in soil as well. One important process is nitrification. Nitrification is the process by which microbes convert ammonia to nitrate. There are two distinct steps to this process (Evangelou, 1998). First, bacteria known as nitrosomonas convert the ammonium ion, which can easily be obtained from ammonia reacting with water, into the nitrite ion.

1. $NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+$

In the second step, microbes known as nitrobacter convert the nitrite to nitrate.

2. $NO_2^- + \frac{1}{2}\ O_2 \rightarrow NO_3^-$ (Evangelou, 1998)

This process is the reason that ammonia in the environment poses a nitrate contamination hazard. In this process, nitrite rarely accumulates because nitrobacter use the nitrite ion to produce nitrate as fast or faster than the nitrite ion is produced (Evangelou, 1998). Production of NO_3 usually leads to increased acidity in water soil systems because of the H^+ ions produced in the first step (Evangelou, 1998).

2.4 Effect of Environment on Nitrate Concentration

As environmental conditions change, so do the concentrations of nitrates in soil. The two principal factors are temperature and soil moisture. In humid climates, rains in the fall season leach the soil, and this leaves the soil depleted of nitrates during the winter season. As the temperatures begin to rise in the spring, nitrate concentration increases within the soil. During low rainfall periods of the summer months, nitrates continue to accumulate in the soil (NRC, 1978). The cycle again repeats in the fall as rain leaches the soil of nitrates.

2.5 Sources of Nitrates

As reported by the NRC (1978), one of the largest sources of nitrogen on a global scale is biological processes. The report points out, however, that for smaller more localized regions, both activities from agriculture and industry can easily exceed the input of nitrates into the environment from natural sources. There are two basic ways of labeling these non-natural sources of nitrates: point and non-point sources. Point sources are those sources of nitrates in which the origin can be easily identified. Non-point sources originate from more than one point within a region or from an untraceable origin (Conde-Costas & Gómez-Gómez, 1999). Some of these sources, both point and non-point, are responsible for high pollution levels in a localized area. Yet, others may originate at a single source and may be responsible for high nitrate levels over much larger areas (NRC, 1978). According to the NRC (1978) report, non-point sources are the largest contributors of nitrate pollution to ground and surface waters.

Groundwater is very important to the world's freshwater supplies, but groundwater pollution is growing due to surface water pollution. According to one authority (Camesano, interview, January 28, 2001), many pollutants, including nitrates, dissolve well in water. When nitrates dissolve into water, the nitrates stay with the water rather than form deposits (Camesano, interview, January 25, 2001). The water can then seep into the ground to form groundwater and can carry the nitrates along with it. Soil does not filter out the nitrates, but instead nitrates will flow with the water. The groundwater can flow underground for several miles, resurfacing into lakes, streams or ponds.

2.5.1. Acid Rain

In industrialized areas, acid rain usually precipitates in the form of nitric acid (HNO_3) (Bunce, 1990). This compound can then break down to form nitrate. Bunce (1990) credits combustion sources as the main source of acid rain containing nitrogen oxides. The NRC report (1978) mentioned earlier, agrees with this fact according to Bunce and has stated that combustion, along with the industrial synthesis of ammonia (NH_3), are two important sources of fixed nitrogen in the environment. Nitrogen oxides are produced during combustion processes because they are readily produced in small quantities whenever air is heated. Lloyd and Heathcote (1985) also credit the oxidation of nitrogen during lightening storms as a way to produce nitrates in the atmosphere.

They also agree with Bunce that nitrogen oxides can be formed by combustion in car engines. The following chemical reactions illustrate these processes.

1. First the nitrogen reacts with oxygen in the atmosphere to create nitric oxide, when the air is heated:

   $N_2 + O_2 \rightarrow 2\ NO$.

2. In the next step, the nitric oxide is converted to nitrogen dioxide with the help of an oxidant. Since this reaction is taking place in the air, this oxidant is most often ozone, O_3:

   $NO + O_3 \rightarrow NO_2 + O_2$.

3. For the final step, the nitrogen dioxide will react with a hydroxide ion, which is easily obtained from water in the atmosphere, to form nitric acid or acid rain.

   $NO_2 + OH^- \rightarrow HNO_3$ (Bunce, 1990).

This nitric acid will then precipitate from the atmosphere as acid rain. Usually the concentrations of nitrogen dioxide in the atmosphere are relatively low, even in areas where pollution is high. Problems arise because nitric acid is easily dissolved in water. Even small concentrations of nitric acid in the atmosphere or in the acid rain can have a large effect on the pH of water. Other pollutants in higher concentrations will not affect the pH as much because they do not dissolve as readily in water (Bunce, 1990). This source of nitrate pollution to the environment is a non-point source, because once the nitrate is formed in the atmosphere it is hard to pinpoint where it originated. The primary sources of the nitrates in the atmosphere are not only the industries involved with the synthesis of ammonia but also the industries that use ammonia to produce other chemicals such as nitric acid, urea, and fertilizers. Of the ammonia manufactured each year, 75 to 80 percent is used for the production of fertilizers, but even urea and nitric acid can be used in manufacturing fertilizers (NRC, 1978). Ammonia can also have uses in the production of other acids, such as hydrocyanic acid, and in the pulp industry. The process of producing ammonia requires high temperatures, and therefore, requires large amounts of water to cool the reaction (NRC, 1978). This cooling water can absorb the ammonia, but it is then usually discharged to local streams and rivers.

2.5.2. Underground Waste Disposal

Underground waste disposal presents a threat to groundwater sources. This type of disposal takes the form of landfills, septic tanks, and deep well injections. In landfills, trash is buried underground. Ideally, when landfills are built, they are placed in a specific area where minimal groundwater is located, but groundwater is affected by changes in topography (Freeze, 1979). If the topography of the surrounding lands changes over time, groundwater could possibly flow through the old landfills.

Septic tanks pose problems because human wastewater is stored directly in the ground. When septic tanks leak, waste flows into the ground contaminating groundwater supplies. As the waste from the septic tank flows through the soil, ammonia is transformed to nitrate and continues to flow towards the groundwater (NRC, 1978). Contamination of this type is not an important source in sparsely populated areas, but in places with high population density, the tanks can produce localized pollution in groundwater (NRC, 1978).

Deep well injections are wells built to inject toxic liquid waste deep in the earth. Injection wells range from 200 to 4,000 meters deep (Freeze, 1979). Deep waste wells, are mostly located in regions of sandstone, carbonate rock, and basalt. Liquid waste is then pressurized and pumped down into the wells. The average injection pressure is about seven thousand kilo-Newtons per meter squared, which is approximately one thousand pounds per square inch (Freeze, 1979).

When waste is injected into the well, the regional groundwater pushes on the injected waste, spreading it in the direction of the water flow. As deep waste wells age, they become larger in volume due to the flow of groundwater in the area (Freeze, 1979). The groundwater and the waste within the wells gradually interact by the process of dispersion, which eventually leads to pollution. Earthquakes can also affect how fast the waste interacts with the groundwater. According to Freeze (1979), deep waste wells can also be a cause of earthquakes near fault lines.

2.5.3. Agricultural Operations

Agricultural operations, including crops and livestock, are often the source of nitrate contaminants in both surface water and groundwater (NRC, 1978). Bunce (1990) also credits agriculture as being a large source of nitrate contamination for various reasons. The principal reasons are excessive fertilizer usage, seepage of manure from livestock holdings, and leaking tanks used to hold liquid manure.

The use of inorganic fertilizers has risen dramatically since World War II. Farmers have two choices of fertilizers. They can use organic fertilizers like animal or human wastes or use chemically manufactured nitrogen fertilizers. Chemical fertilizers are used year after year to feed crops. This causes the nitrates to build within the soil.

Agricultural businesses dealing with crop production also increased the amount of pesticides and herbicides used on crops. These products keep the insects away from plants, but rainwater washes the chemicals away, polluting the groundwater and surface water. Pesticides are water-soluble making it easy for them to transport through the water system.

In some parts of the world, nitrates found in groundwater cannot be attributed to fertilizers. The cultivation of land has produced the increase in nitrates in shallow groundwater. The decay of the organic matter causes nitrates to form in the soil. The increased cultivation of the land allows oxygen and organic nitrogen to seep lower into the ground (Freeze, 1979). When water flows through the soil, the nitrate is dissolved and contaminates the local groundwater.

Since land is becoming sparse as population continues to grow, farmers are forced to cultivate their fields to their boundaries (Bunce, 1990). This means that runoff from fields, which contain the nitrates from fertilizer, will easily enter ground and surface water. There are other agricultural processes that can affect the nitrate concentrations in soil surrounding farms such as artificial drainage and irrigation (NRC, 1978). Irrigation allows for nitrates to be carried away from the site, where they eventually end up in other water systems if the water is not treated.

As world population continues to grow, the need for larger food supplies also grows. Farms are constantly trying to raise their production efficiency for both crops and livestock. This raises potential problems of nitrate contamination. The need for more efficient farms has led to many animals living in confined areas (NRC, 1978). The organic nitrogen contained in animal waste goes through a chemical reaction with oxygen before it turns into nitrate. If there are no proper facilities to store or treat the waste, the nitrate contaminates the surrounding soil where the waste is kept. Some of the nitrogen and nitrates will be removed during operations intended to clean the waste, but some may have dissolved into the soil or may have been washed away in storm runoffs (NRC, 1978).

In an interview conducted with one expert (Nowick, interview, January 22, 2001), we were told that dairy industries use nitric acid as a mineral reducer for the milk tanks. The nitric acid is used to clean the inside of the tanks. Often, not all of the nitric acid is used up in this process. After the tanks have been cleaned, the dairy farm sends the nitric acid waste to a wastewater treatment facility. Based on his experience, Professor Nowick claims that very few of these facilities have any form of nitrate removal for their wastewater. Once the water is treated, it is then released into streams and rivers with the nitrate still present (Nowick, interview, January 22, 2001).

A case study was performed in the Midwest United States, more specifically in Illinois, on how excessive agriculture can affect nitrate concentrations. In this area, the applications of fertilizer had grown steadily for twenty years in the 1960's and 1970's. This coincided with the trend of increased corn yields (NRC, 1978). During the time of increased usage, the concentrations of nitrogen and nitrate steadily climbed in the stream and rivers of this area (NRC, 1978). The fertilizer most commonly applied to the crops in this section of the U.S. was anhydrous ammonia, NH_3 (NRC, 1978). Through the process of nitrification in the soil, this ammonia can be converted into nitrate. For the case study done in Illinois, the ground and surface water contamination could have a number of sources such as animal manure, sewage, and fertilizer. Among the watersheds most closely studied, animal manures were not present in large amounts and sewage was a very localized problem (NRC, 1978). This meant that the largest contributor of nitrate contamination was fertilizer.

In Puerto Rico, agriculture accounts for 1 percent of the Gross Domestic Product (GDP) (CIA, 2000). Industry accounts for 45 percent, and services accounts for the remaining 54 percent. The GDP is the total market value of all final goods and services produced in a country in a given year. Of the 1.3 million workers in the labor force, 3 percent are involved in agriculture (CIA, 2000). A total of 31 percent of the land in Puerto Rico is used for agricultural practices. Permanent crops account for 5 percent of the total land, and permanent pastures account for 26 percent of the total land (CIA, 2000). Some of the main agricultural products on the island are sugarcane, coffee, pineapples, plantains, and chickens. A study conducted by Carols Conde-Costas and Fernando Gómez-Gómez (1999) in the Manatí-Vega Baja area of Puerto Rico found that high nitrate levels in wells were a result of fertilizer used on the pineapple crops.

2.5.4 Other Possible Sources of Nitrates

Domestic sewage has also been known to contribute to nitrate contamination in ground and surface waters. The concentrations of the various forms of nitrogen in sewage, nitrate, urea, and ammonia, are determined most often by how much water is mixed with the wastes (NRC, 1978). Nitrate levels in sewage are usually small. Ammonia makes up the largest fraction of nitrogen in sewage, having a concentration one-half to three-fourths of the total nitrogen (NRC, 1978). The problem often is not the sewage itself but occurs when the sewage is treated. Although most of the nitrogen present is ammonia, it can be converted to nitrate by the process of nitrification. The NRC (1978) stated that from the beginning to the end of the treatment process, only around half of the nitrogen is removed. Today, there are processes that can remove nearly all the nitrate, but these processes cannot remove all forms of nitrogen present. One of these processes, denitrification, is discussed in a later section. The rest of the waste is then released into the environment as nitrate and ammonia. A case study done on the San Francisco Bay drainage basin (pop. 5 million) showed that nearly half of the nitrogen in the bay and its associated tributaries was from both agriculture and domestic sewage (NRC, 1978).

Another possible source of nitrate pollution is cemeteries and burial grounds (Santarsiero, Minelli, Cutilli, & Cappiello, 2000). Nitrates are produced during the breakdown of biological material. The gas NH_3 (ammonia) is produced when corpses are broken down. This gas can then be converted into nitrate by bacteria in the soil. The layer of soil surrounding the corpse may become saturated with the by-products of the decomposition and may lose its power of removing contaminants from the water (Santarsiero et al., 2000). This can then alter the environment around the burial site, which may lead to stagnation of water through the soil. This could mean that the water located near cemeteries might have a higher than normal concentration of nitrate. Placing the bodies in caskets may help to reduce the buildup of wastes by allowing the body to breakdown naturally inside the casket.

2.6 Groundwater and Stream Interaction

The interaction between groundwater and streams is very important to stream cycles (Winter, 1998). Streams interact with groundwater in three different ways: streams can gain water from groundwater, streams can lose water due to outflow to groundwater, or both inflow and outflow can take place within the stream (Winter, 1998).

Groundwater cannot flow into streams unless the height of the water table around the stream is higher than the surface of the stream water. The opposite has to occur in order for stream water to discharge into groundwater; the height of the stream surface has to be higher than the water table (Winter, 1998).

Two other types of streams are disconnected streams and bank storage streams. A disconnected stream has a soil buffer between the stream and the water table (Winter, 1998). In order for this to happen, the water table has to be well below the streambed. Some of the water from the stream is able to leak down to the groundwater, but this loss is minimal and is determined by the buffer length. Winter (1998) asserts that disconnected streams are not affected by groundwater pumping stations. When the groundwater is pumped out of the ground, water table decreases. The buffer zone stops the stream water from flowing into the groundwater, so pumping does not disrupt the stream's flow. If the stream is not buffered, it will lose volume to groundwater in order to neutralize the water table. Bank storage is another characteristic of streams (Winter, 1998). During heavy precipitation or heavy snowmelt, stream volume increases. If the banks of the stream do not overflow, the extra water is stored in storage banks. The storage banks are located above the water table and can be found on both sides of the stream. Water stored within the banks flows back into the stream within days or weeks. If the water rises over the stream banks and floods the surrounding areas, it could take days, weeks, or even years for the water to flow back into the stream due to the complex flow of groundwater (Winter, 1998).

2.7 Sediment Involvement in Contamination

Sediment is soil washed into rivers, streams, lakes and ponds by runoff waters. Pollutants from urban activities, agricultural activities, industrial waste and solid waste disposals are often trapped in sediments. Sediments usually contain heavy metals, pesticides, iron oxides, and carbonates (Demars, 1995). When a contaminant is trapped within the sediment, the pollutant can stay within that sediment for long periods of time. The source of the contaminants may not be present, but the contaminant will still be present in the water because the sediment remains contaminated (Demars, 1995).

Polluted sediment is very hard to clean up because the contamination can be easily spread into the water. Dredging the sediment is one way to remove the pollution (Demars, 1995). Sediment is removed from the bottom of the body of water by a dredging tool. The tool is dragged across the desired area, collecting the contaminated sediment. Dredged materials needed to be disposed of properly so the contamination within the sediment does not spread. During the dredging process, sediment can be stirred and the contamination can be spread into the water (Demars, 1995). An alternative to dredging is isolating a contaminated area. This allows the site to cleanse itself naturally over time (Demars, 1995).

2.8 Field Sampling Program

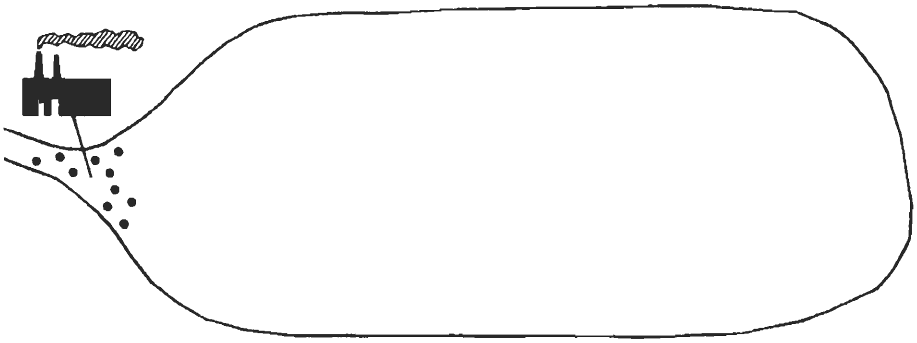
Water sampling is not a simple task. Mark E. Byrnes (1994) mentions a three-step process for ground water sampling called the Data Quality Objectives, which is also known as the DQO. To implement step one, the researcher first finds historical data about the sample site. The researcher uses the data to learn sampling equipment used, sample storage methods, sample shipment methods and age of historical data.

The historical data can help to identify contaminates addressed during the new study. The researcher can either decide to continue the old study or see if the region is being affected by different pollution. The data from the old study can also help the researcher make a model of the sampling area. The model generated will graphically show the researcher the location of the source, path and drain of the sampling water body (Byrnes, 1994).

Step two involves defining the data types that will be collected during the sampling (Byrnes, 1994). Groundwater, surface water and sediment sampling are three different data types that can be collected during a sampling. When the data types have been defined, the researcher has to identify the data quality needed for the study. Data quality is an important decision the researcher needs to make. Data can be analyzed onsite by portable devices, giving the sampler instant results, but this is not as accurate as laboratory results. If the researcher needs instantaneous data results, labs cannot be used because it can take from one to seven days to obtain the results from the lab (Byrnes, 1994). Groundwater is harder to sample than surface water. This can result in lower quantity of samples. Depending on a project's budget, it might be feasible to have a laboratory review groundwater samples. Due to the large quantity of surface water samples, it might be more feasible to use a hand held device.

When the data types and quality have been established, the researcher needs to determine the sample quantity and the sampling technique. Three different sampling techniques are biased sampling, systematic sampling and random sampling (Byrnes, 1994). Biased sampling is based on information collected from a previous study. This method uses known contaminated sites and takes new samples from these sites (Fig. 2.1). The data collected can then be compared to previous data to see the progress of the site.

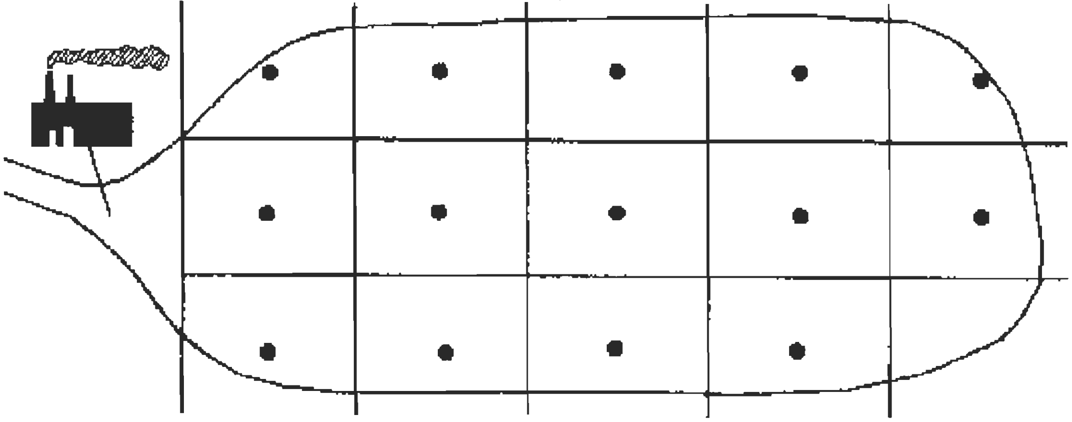
Figure 2.1 Biased Sampling Method



Source: Lecomte, Paul. (1999). Polluted Sites Remediation of Soils and Groundwater. Brookfield: A.A. Balkema Publishers, 1999.

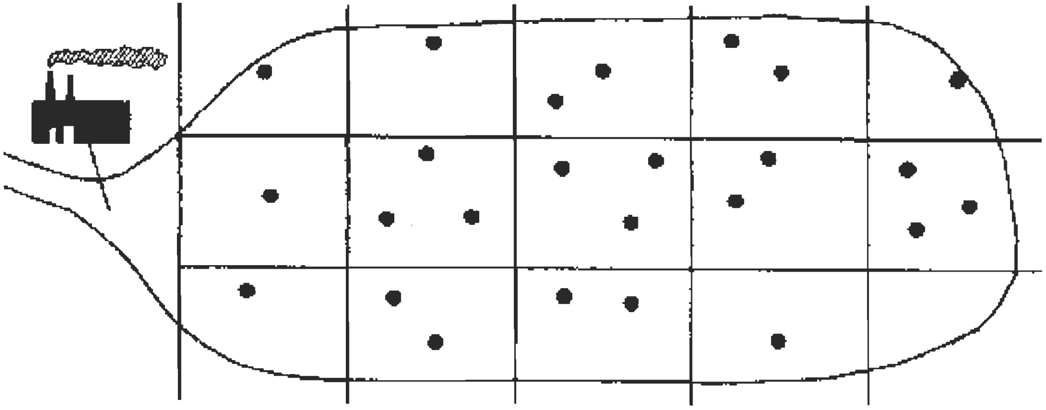
In order to do a random sample or a systematic sample, a grid has to be created on the area of study. Systematic sampling takes a sample on each grid intersection, and random sampling is done by randomly selecting points on the grid, Figure 2.2 and 2.3 respectively (Byrnes, 1994). Once the grid has been produced and the sampling method is defined the research team can move on to step three.

Figure 2.2 Systematic Sampling Method



SOURCE: Lecomte, Paul. (1999). Polluted Sites Remediation of Soils and Groundwater. Brookfield: A.A. Balkema Publishers, 1999.

Figure 2.3 Random Sampling Method



Adapted: Lecomte, Paul. (1999). Polluted Sites Remediation of Soils and Groundwater. Brookfield: A.A. Balkema Publishers, 1999.

Step three involves three different methods to obtain samples. The three different ways to obtain samples are grab sampling, composite, and integrated sampling. These three methods can use random sampling, systematic sampling, or biased sampling to determine sampling sites.

Composite samples can be taken throughout the entire site and later consolidated into one big sample. The sample can then be brought to the lab for analysis. The results from this method will give the average pollution of the site. This technique is not used often because it is only used to find the general state of a site. It does not give concentrations at specific points.

The integrated sampling technique is the most commonly used. Integrated sampling is usually done over time. A researcher doing an integrated sampling study would take samples at equal intervals of time (Byrnes, 1994). For example, researchers could take a sample every day for seven weeks to do their integrated study. Varying the depth of samples instead of time can also be considered integrated sampling.

Grab sampling is another way to collect samples. Each sample is collected and placed in its own Teflon, plastic, or stainless steel container. This method is used mostly for toxic or radiation studies (Byrnes, 1994). If the researcher is conducting a study on metal concentrations, Teflon containers should be used. If stainless steel containers are used, steel from the container could be dissolved into the water making the sample invalid.

2.8.1 Water Sampling

Water sampling should always start in the most downstream position and work upstream. Otherwise, the person taking the samples could stir up contaminants, affecting the water downstream (Byrnes, 1994). If the researcher physically needs to enter the water, the sample should always be taken on the side upstream from the researcher. This is done so the sample is not contaminated.

Before sampling, the researcher should be familiar with the local land use. If the land research points to a certain area that could be causing pollution, the sampling should be done upstream and downstream in relation to the site. This will allow the researcher to understand if this site is contributing to the pollution problem (Byrnes, 1994). Groundwater sources should also be tested because groundwater may be dissolving polluted material from the site (Byrnes, 1994). If a lake or pond is near or in the sampling area, the ponds inflow and outflow should be tested. If the inflow is clean and the outflow contains pollution, the researcher has a better chance of finding the pollution's source.

2.8.2 Equipment

Surface water sampling can be done with a variety of tools and methods. A few of the simple methods are the Bottle Submersion Method, Dipper Method, Extendable Bottle Method and Extendible Tube Method (Byrnes, 1994). These four different techniques are easy to use and can be used for all sampling methods described earlier.

The Bottle Sampling Method is the easiest to implement (Byrnes, 1994). A bottle is placed on a telescoping rod, the rod is then lowered to just below the water surface. This allows the water to flow into the bottle, collecting the sample. The Dipper Method involves lowering a stainless steal dipper below the water surface. The contents of the dipper have to be placed into a sample jar (Byrnes, 1994).

The Extendable Bottle Method uses a glass bottle attached to a telescope rod. The bottle can be lowered to any depth between zero and five feet below the water surface (Byrnes, 1994). When the desired depth is reached, the operator can break the bottle seal and allow water to flow into the bottle (Byrnes, 1994). The water from the bottle then is transferred to a sampling bottle. The method using the Extendable Tube is similar to the Extendable Bottle; however in this method a tube is lowered into the water. The tube has a check valve that opens when the desired depth is reached.

2.8.3 Nitrate Testing Methods

Nitrates are difficult to detect when they are dissolved in water (Greenburg, 1985). It is difficult to determine the concentration because nitrates can be easily confused with dissolved organic matter. Three different techniques have been developed to determine nitrate concentrations. The ultraviolet spectrophotometric screening method, nitrate electrode screening method, and the cadmium reduction method (Greenburg, 1985).

The spectrophotometer produces ultraviolet light with a wavelength of 220 nanometers and 275 nanometers. Both the organic matter and nitrate molecules absorb the 220-nanometer wavelength (Greenburg, 1985). Only the nitrate absorbs the longer wavelength. The machine is then able to measure the nitrate by subtracting the concentration of absorbent at 275 from that at 220. This procedure should only be used if the water contains a low concentration of organic matter (Greenburg, 1985).

Nitrate electrode screening uses charged electrodes to separate the nitrate from the water. Electrodes are wires charged by a power supply. When the correct voltage is applied across the two electrodes, the negatively charged nitrate is attracted to the positive electrode (Greenburg, 1985).

The cadmium reduction method is used to take the nitrate within the sample and convert it to nitrite. The water sample is passed through a coil that contains cadmium molecules and the molecules convert the nitrates to nitrites. The nitrite then reacts with sulfanilamide to produce a salt (Van Loon, 1982). The salt then reacts with an acid in the solution to form an amber colored solution. The darker the solution, the more nitrate that was present in the solution.

2.9 Nitrate Health Risks

In some areas of the world, water is not something that is beneficial to drink. Instead it is actually harmful. Polluted drinking water can have serious health risks for many people, especially infants. This is due to the suspended and dissolved materials present within the drinking water. One of these materials that pose a threat is nitrate. The most common sources of ingestion of nitrate are drinking water, vegetables such as spinach, celery, lettuce, radishes, and beets, and for infants, drinking water used in baby formula (NRC, 1978). Nitrates indirectly lead to health problems. The actual nitrate ion is not threatening to the body; it is when it is reduced to the nitrite ion that it becomes dangerous. This is done by a reducing bacterium, *Escheriscia coli (E. coli),* which is located in the intestines (Bunce, 1990).

When older children and adults ingest nitrate, the stomach absorbs the nitrate before it can be reduced. After being absorbed into the blood stream, the nitrate is rapidly excreted in urine because nitrates that are not reduced pose no threat to the hemoglobin. Nitrate can be reduced to nitrite in the saliva, but only 5 percent of the total nitrate is reduced (Levallois et al., 2000). This small amount is not enough to do any harm in adults and older children. There are times, however, when nitrates do create a problem for adults. This occurs after there is a short exposure to a large amount of nitrate, resulting in a rapid response to the nitrates. This is known as acute nitrate poisoning (NRC, 1978). Nitrate poisoning causes gastroenteritis, inflammation of the stomach and the intestine, which is accompanied by abdominal pain, blood in the urine and stool, and faintness. Poisoning is usually a result of ingesting large amounts of nitrates. Therefore, it is very uncommon (NRC, 1978).

The stomachs of infants for the first three months have a high pH of five or six, compared to that of children of six months and older whose digestive system has developed so that the stomach has a pH of two or three (Masters, 1998). The higher pH allows for *E. coli* to colonize higher up in the digestive tract. When the bacteria are higher up in the digestive tract, they are able to reduce nitrates before they can be absorbed (Bunce, 1990). The nitrates are reduced to nitrites and then absorbed into the blood stream. Once the nitrites enter the blood stream, they bind with hemoglobin creating a complex called methemoglobin. This condition is known as methemoglobinemia.

2.9.1 Methemoglobinemia

Nitrite ions are able to combine with hemoglobin in the blood creating methemoglobin. Methemoglobin is more likely to form than oxyhemoglobin, oxygen and hemoglobin, when nitrite ions are present. This is because hemoglobin has a higher affinity for nitrites than for oxygen. Methemoglobinemia is a condition that causes the amount of oxygen to be reduced because of reduced amounts of hemoglobin. This condition causes the tissues of the body to become oxygen deprived. Methemoglobinemia results in cyanosis, a condition in which the skin appears a bluish color due to lack of oxygen in the blood, also known as "blue baby syndrome" (Masters, 1998). Cyanosis is the first detectable sign of methemoglobinemia. Clinical symptoms of methemoglobinemia are visible at the 10 to 20 percent level; the body of the person will have a light purple-blue color and when their blood is tested it has a "chocolate brown" color (Fan, 1995). Methemoglobinemia can lead to mental retardation and even death, although death from this complication is rare (Bunce, 1998), because it is easily diagnosed and reversible with treatment (NRC, 1978). The condition results when the concentration of methemoglobin in the system of the infant reaches 10 percent or more (Van Leeuwen, 2000). The normal range is from 1 to 3 percent.

Methemoglobinemia was discovered in 1945 when the father of a one-month old infant in Iowa was brought to a doctor for cyanosis treatment. He told the doctor that he thought there was something in the water that, when mixed with to the baby's formula, created a poison and caused this condition. The well water was tested, and high nitrate concentrations were discovered (Bosch, Rosenfield, Huston, Shipman &Woodward, 1950). Following this, cases of methemoglobinemia were reported all over the United States.

A study was done between the years of 1947 and 1950 that accumulated data from the 139 cases of methemoglobinemia, which included 14 deaths, in Minnesota. The cases were evaluated based on the information that was provided for each one. This included how many days the infants were consuming baby formula mixed with contaminated water, and the month that the condition occurred. There was no major gap between when the most number of cases were reported. However, the time period between April and June had the highest number of incidences, 31 percent, and the lowest number of reported cases, 18.7 percent, occurred during the time period of January and March (Bosch, Rosenfield, Huston, Shipman &Woodward, 1950). For the 94 cases that provided the length of time the baby had been on formula combined with contaminated water, all had symptoms after two months of consumption. The shortest amount of time before symptoms developed was one day. This was because the water that was used for the formula was boiled for more than a half hour and the high nitrate concentration that was present in the water was tripled as the water evaporated. This effect resulting from boiling water was proven in a laboratory (Bosch, Rosenfield, Huston, Shipman &Woodward, 1950).

All the wells except for two were above 20 mg/L in nitrate-nitrogen concentration and the two that were not higher than 20 mg/L were between 11mg/L and 20 mg/L. Therefore, none of the concentrations were below the current EPA limit of 10 mg/L (Bosch, Rosenfield, Huston, Shipman &Woodward, 1950). This study is one of the reasons that the EPA has set the limit at 10 mg/L. The wells that supplied the water to the sick babies were examined. The wells were not constructed in the proper manner and were not in the correct location. The standards for proper location and construction of wells are determined by the Department of Health. The wells were either located near a source of animal contamination, for example a barnyard, or near a human contamination, such as septic tanks (Bosch, Rosenfield, Huston, Shipman &Woodward, 1950).

Since the report done by Bosch in 1950, 2000 cases of methemoglobinemia have been reported worldwide (Polakoff, 1997). These cases span over a fifty-year time period and include the world population of billions of people, which shows that methemoglobinemia is a rare condition.

2.9.2 Non-Hodgkin's lymphoma and cancer

Another health risk that may be associated with high nitrate intake is the breakdown of nitrates to from N-nitroso compounds (Van Leeuwen, 2000). This is done by gastric juices in the digestive system. Several N-nitroso compounds have been proven to be carcinogenic in animals, but not enough data exists to show a link between nitrate intake and the occurrence of cancer in humans (Van Leeuwen, 2000). Long term consumption of drinking water with a nitrate concentration of 4 mg/L or higher was associated with a higher risk of a condition known as non-Hodgkin's lymphoma (Levallois et al., 2000). Non-Hodgkin's lymphoma is a cancer that attacks the lymph system. The lymph system is a system made up of tiny tubes that carry white blood cells throughout the body. Because lymph tissue is found throughout the body, he cancer can start anywhere including the liver, bone marrow, and spleen. Health risks for adults have not been as well characterized as those for children, and because of this, consumption by adults of water with a higher concentration than the limit of 10 mg/L set by the EPA is often allowed (Levallois et al., 2000).

A study was recently done at the University of Iowa on an association between nitrates and an increased risk for bladder cancer. The study was briefly released in a press release and will be published in the May 2001 issue of the Journal of Epidemiology. A total of 21,977 women between the ages of 55 and 69 in 1986 were assessed for nitrate exposure. The women lived in 400 communities in Iowa and they consumed the same drinking water for at least 10 years. There was no individual water consumption for the women. However, the women that drank the community's water were assigned an average level of exposure to nitrate based on the nitrate data that was collected between 1955 and 1988. Based on the number of incidences of bladder cancer from the Iowa Cancer Registry, researchers found that as the nitrate levels in the water supplies increased, there was also a higher risk for bladder cancer. The study suggests that low levels of nitrate exposure, 2.46 mg/L, may increase risk of bladder cancer. Researchers suggest further studies.

2.9.3 Prevention of Health Risks

In North America, no reported cases of methemoglobinemia in infants have appeared in places with nitrate concentrations under the EPA's limit of 10 mg/L (Croen, Todoroff & Shaw, 2001). The first step in prevention is to be sure that the drinking water supplied to the public is below the EPA limit. This can be done by reducing the pollution at its source or by treating the water before it is consumed. Both methods are discussed in detail later in this report.

Another step in the process of preventing the health risks associated with nitrates is the use of antioxidants. When nitrates are broken down into nitrites by the body, the nitrogen goes through a process of oxidation. The oxidation state of the nitrogen changes from a +5 charge in nitrate to a +3 charge in nitrite. Dietary intake of antioxidants can inhibit the breakdown of nitrates to nitrites. Both vitamin C and vitamin E are well known as antioxidants (Levallois, et al., 2000). Both of these vitamins can inhibit the formation of N-nitroso compounds (Levallois, et al., 2000). This could reduce the possible risk of cancer associated with these compounds. Intake of vitamin C may also protect infants from the formation of methemoblobin in the blood (Croen, Todoroff & Shaw, 2001).

2.10 The Effect of Nitrates on Animals

Other mammals besides humans are affected by nitrate concentrations in groundwater and food. This is because mammals are not able to break nitrates down for the purpose of taking them in, digesting, and transforming them into living tissue such as amino acids. Specific mammals at risk include cows, sheep, and other cud-chewing animals. These animals have more complex stomachs causing them to have a higher susceptibility to nitrates. The nitrates are reduced to nitrites, which bind to hemoglobin, and this can be potentially harmful (Wise, 2000).

2.11 The Effect of Nitrates on Plants

Nitrates play important roles in the growth and development of plants. In plants, nitrates are considered a nutrient. Nitrates are used for synthesizing proteins and nucleic acids. Storage in the vacuole, a small fluid filled cavity in the protoplasm of a plant cell, at high concentrations can serve as an osmotic tool, creating the early expansion of leaf and stem tissues. High nitrate concentrations can also serve as a defense mechanism by making the plant toxic (Wise, 2000). This would prevent herbivores from eating the plant.

2.12 Ways to Reduce Contamination

According to the NRC (1978), there are three ways to control a given contaminant. The first is to reduce the pollution at its source. Second, one can use smart management of the contaminant by doing such things as minimizing the amount of leakage. The third is to collect the waste from the process and treat it thereby stopping the waste from being released back into the environment. There are many factor those doing the cleanup need to consider when determining what solution is the best. One important factor is cost. The solution must be one that is economically feasible. Another important factor is how relevant the solution is to a specific site. What works for one site may not always be the best solution for other sites. Practicality of the pollution control must also be considered. Some solutions may cause other problems. Removing nitrate from wastewater in an industrial process may mean the nitrogen waste is now being released into the atmosphere (NRC, 1978). All of these factors must be considered when those in charge of the cleanup decide on the proper solution to removing the contamination.

2.12.1 Agricultural Cleanup

As was outlined in this report, agriculture is one of the largest contributors on nitrate pollution. Because it is such a big contributor to nitrate contamination, many solutions have been developed to reduce this contamination. One suggestion is to allow cattle to roam on larger area of pastures (NRC, 1978). This would reduce the buildup of nitrates by eliminating the buildup of manure in a localized area. The problem with this solution is that as population continues to rise, the amount of available land continues to decrease.

Another solution is to regulate the amount of fertilizer applied to the crops (NRC, 1978). Although this would reduce the amount of nitrogen in the soil, reducing fertilizer could damage crop production. One proposed solution to this problem has farmers apply fertilizer at key times in the growing season. If the fertilizer application is greater than the amount of nitrogen the crops can use, the nitrogen will begin to build up in the soil (NRC, 1978). Chipperfield et al. (1998) agree that the leaching of nitrates increases as fertilizer application increases above the optimum level for crop production. They say that if the crops cannot use the all of the fertilizer applied, it will wash away or seep into the soil. This means that on a local scale nitrates can have an effect on groundwater quality. If farmers apply the fertilizer at the proper stages, the crops can more efficiently use it. The problem with this is that knowing when to apply the fertilizer is difficult. It can vary with both environmental conditions and depending on the year.

Using manure is another way to reduce nitrate pollution. Manure contains only 10 percent of the nitrogen that fertilizers do (NRC, 1978). It is also cheaper than chemical fertilizers in some areas that produce both crops and livestock. The problem arises in the fact that manure contains only 10 percent of the nitrogen found in fertilizer, and because of this the crops may not absorb enough nitrogen to develop properly.

Storing the runoff of wastewater from an agricultural area then treating it can be a useful solution to nitrate contamination. The topography needs to be suitable to allow for the collection of runoff, and the wastewater then needs to be collected and sent to a treatment facility. Cost would play a large part in the feasibility of this solution, since the wastewater would need to be stored and transported to a waste treatment facility.

A simulation model was used for the Kissimmee River basin in Florida to determine which methods for storage and treatment of wastewater from agricultural runoff were the most effective (NRC, 1978). The runoff was diverted into a marsh that could hold nearly 80 percent of the runoff for two days. The total nitrogen removal from nutrient and microbe removal was close to 70 percent. This solution is an example of a site-specific solution. Not all polluted areas have such natural storage and treatment facilities.

Another solution to nitrate buildup in soils is the use of nitrification inhibitors. One such nitrification inhibitor is nitrapyrin. This chemical inhibits the bacteria, nitrosomonas, which are responsible for the production of the nitrite ion in the first step of the nitrification process (NRC, 1978). Nitrapyrin has also been shown to inhibit this process for four to six weeks. Not only does it have a low toxicity, but it can also easily and rapidly degrade through environmental and biological processes (NRC, 1978).

Again, cost must be a consideration. If the chemical is to be applied to entire fields year after year, it could become expensive. Another nitrification inhibitor used is dicyandiamide (DCD). Today in agriculture, DCD is one of the most widely used inhibitors (Jain, Kumar, Kumar, Majumdar & Pathak, 2000). In a case study conducted by Jain et al. (2000), the DCD significantly reduced nitrous oxide emissions in the rice fields of India when the DCD was applied with the fertilizer.

2.12.2 Sewage Treatment

Treatment of sewage is another way to reduce high concentrations of nitrates in the environment. In the processing of sewage there are two major treatments (NRC, 1978). The first is primary treatment. This involves filtering the waste or allowing it to settle then dredging it. The other type of treatment is secondary treatment. This involves using microbes and bacteria to break down the wastes in the sewage biologically, which is a process known as denitrification. This process is discussed in greater detail in the following section. Both treatments combined remove only 30 to 40 percent of the total nitrogen (NRC, 1978). This means that after being treated, more than half of the nitrogen that enters the treatment facility will be returned to the environment. Swaddle (1990) mentions a third step in the treatment of wastewater. This tertiary treatment is used to remove a specific pollutant that the second treatment could not remove. Most often it is the removal of phosphates, but nitrates can be included if they are not removed in the second step (Swaddle, 1990).

2.12.3 Biological denitrification

The traditional methods for cleaning water such as filtration are not effective in removing the nitrate ions from water. Techniques such as ion exchange and reverse osmosis are capable of removing nitrates. Ion exchange is a process that removes a particle based on charge. When nitrate is removed from water through this process, sulfate is also removed. This produces a wastewater along with the nitrate free water that needs proper disposal (Shrimali & Singh, 2001). The process of ion exchange is expensive and not feasible for a large-scale removal. An alternative to ion exchange is reverse osmosis. This process has an advantage over ion exchange in its ability to separate and concentrate the compounds in water. This process also has a waste disposal problem and is very expensive (Shrimali & Singh, 2001). There is a need for a cost effective method of nitrate removal.

One of the processes that reduce nitrate levels is biological denitrification. This process targets the nitrate ion directly and does not alter the concentrations of the other ions present in the water being treated. The process of biological denitrification reduces the nitrate to nitrogen gas instead of ammonia. This process uses bacteria that use the oxygen bound in the nitrate ion as a terminal electron acceptor. The microorganisms used for denitrification are autotrophic, which use inorganic carbon molecules such as CO_2 for growth, and heterotrophic, which use complex organic compounds for growth such as sugars. The two denitrification processes are known as autotrophic and heterotrophic depending on which type of microorganism is used (Shrimali & Singh, 2001). The microorganisms in denitrification require specific substrates, or compounds that allow for the process to proceed. Traditionally compounds such as methanol and ethanol are the organic carbon sources that are used in the untreated contaminated water. These two compounds had a high rate of nearly 100 percent denitrification of the water (Shrimali & Singh, 2001). However, they cannot be used in the treatment of drinking water because methanol and ethanol can cause health risks. Therefore, a non-hazardous compound such as glucose or sugar must be used as a carbon source for heterotrophic denitrification. The sugar has about an 80 percent removal of nitrate from the water (Shrimali & Singh, 2001). The process of biological denitrification is a useful technique for removing nitrates from contaminated water. There are some disadvantages that come with using this process. One of these disadvantages is that since the bacteria require substrates in order to remove nitrates, these organic compounds must be added to the water (Shrimali & Singh, 2001). Another disadvantage to this process, both autotrophic and heterotrophic, is that a biomass is produced (Shrimali & Singh, 2001). This biomass consists of bacterial cells that are used in the process along with parts of the carbon sources that remain from the process. This may cause some limitations to using this process because of the post-treatment process that must be used. This post-treatment process involves filtration steps and disinfections (Shrimali & Singh, 2001). Of the various methods for removing nitrates, the process of denitrification is feasible on a large scale and is both environmentally and economically sound (Abeliovich, Ines & Soares, 1998).

2.12.4 Benefit-cost analysis of nitrate management

A benefit-cost analysis on management of nitrates was done by Yadav and Wall (1998) for the Garvin Brook Watershed of southeastern Minnesota. They had observed nitrate concentrations above the 10 mg/L limit set by the EPA. They proposed three scenarios on how the nitrate concentrations would be in the future. At the time of the study 35 percent of the wells examined were over the limit. Scenario one assumed that nitrate concentrations would remain the same in all wells. Scenario two assumed that the

35 percent of the wells above the limit remained above the limit, and that half of the wells that had concentrations between 3-10 mg/L would rise above the 10 mg/L limit. Scenario three assumed that the 35 percent above the limit would remain the same, and that all of the wells within the range of 3-10 mg/L would rise above the EPA's limit. Yadav and Wall (1998) developed a plan to deal with elevated nitrate levels. It included paying farmers seven dollars an acre to manage their fertilizer and pesticide usage. Also included was the treatment of septic tanks in the area contributing to the problem, treatment of runoff from sinkholes in the area, and the administrative and technical assistance costs of implementing this program. They calculated the amount of money the plan would save under the three different scenarios. Yadav and Walls compared the cost of implementing the plan versus the costs if nothing was done about the contamination. For all three scenarios, the cost of implementing the plan was the same. If nothing was done about the contamination and it grew worse, implementing the plan in the begining would have saved more money. The table on the following page shows the benefit-cost analysis of the BMP (Table 5.1). If conditions remained constant, the plan would pay for itself after six years. If only half of the wells were to rise above the limit, it would pay for itself in 5 years. The plan would pay for itself in four years if all of the wells were to rise above the EPA's limit.

Table 2.1 Benefit-cost Analysis of Nitrate Management

Scenario	Total Savings (in millions)	Cost of Plan (in millions)	Number of years till plan pays for itself
1	161.5	842.4	6
2	206.8	842.4	5
3	242.5	842.4	4

Adapted from: Yadav, S.N. & Wall, D.B., 1998

CHAPTER 3. METHODOLOGY

3.1 Goals

The methodology is a description of the procedure that our team followed while in Puerto Rico. The goal of our project was to determine nitrate concentrations in streams and rivers of eastern Puerto Rico, in order to understand if nitrate contamination is a problem. If we determined that eastern Puerto Rico had a problem of high nitrate concentrations, we would search for the source of the nitrates in order to suggest ways to reduce nitrate contamination and to determine the societal impact of high nitrate concentrations in the water by collecting health data for the problematic areas. The results from eastern Puerto Rico were also correlated with previous USGS studies done in the Manatí-Vega Baja area and which revealed high nitrate concentrations (Conde-Costas, C., & Gómez-Gómez, F, 1999).

3.2 Methodological Tools

The methodology we used was based on procedures discussed by Lecomte (1999) and Byrnes (1994) on how to sample water for contaminants. Our methodology closely follows the three steps discussed by both authors. Step one was to gather historical data and land data on the site being studied. Step two was to determine the sampling method and sampling tools used during the study. Step three involved analysis of the data collected and the making of recommendations.

3.3 Historical Data and Local Maps

Before arriving in Puerto Rico, we had obtained a minimal amount of relevant historical data from the rivers and streams in eastern Puerto Rico. Once we arrived, we obtained historical data that helped us determine areas that have already been studied. Areas previously studied could possibly be sampled again to see if nitrate concentrations have changed at a particular site. By analyzing the historical data, we were able to determine new sites that could possibly be contaminated by nitrates. We began by researching nitrate concentrations in rivers and streams of eastern Puerto Rico. We reviewed data from the months of February to May for the years of 1997, 1998, and 1999 in order to determine which sites had the most recent problems with nitrates.

The local road maps and topographical maps of eastern Puerto Rico we used helped us to determine where sampling could take place. Some sampling areas were not accessible due to vegetation blocking access to the sampling site. Easily accessible sites were often where a road meets or passes over a stream.

3.4 Contacts

We contacted The Department of Natural and Environmental Resources, DNER, by telephone to obtain land usage data. We found the land usage data that the DNER had was no more recent than the data from the USGS. Because of this, we used the data from the USGS. We also contacted the Center for Disease Control branch office in Puerto Rico by phone to obtain data on occurrences of methemoglobinemia and nitrate poisoning for the eastern part of Puerto Rico area. They did not have the data we were looking for, and told us to contact local emergency rooms and doctors to obtain case-by-case information, an impossible task given our relatively short stay on the island and lack of human resources for the task. Next, we contacted the San Jorge Children's Hospital to obtain the health data. We also spoke with Rafeal Mayoral, who is the Public Affairs Specialist at the Puerto Rico branch of the Environmental Protection Agency. We also conferred with Greg Cherry of the USGS, who is conducting a study of nitrate concentrations on the southern part of the island. He told us about the sources of nitrate contamination on the southern part of Puerto Rico.

3.5 Sampling Sites

After the data was collected, we began to choose sampling sites. By determining which sites had a problem in the previous years, we could then return to those sites to study the current nitrate concentrations. Sites that we chose were both upstream and downstream of potential pollution sources. This was done to determine if a particular site was contributing to the nitrate contamination. If the nitrate concentration found downstream were higher than the upstream concentration, it would make it easier for us to pinpoint the source of the nitrate. We sampled rivers and streams in El Yunque as our standard for the island for reasons that are discussed in Chapter 4. Other samples were taken throughout the eastern part of the island and compared these values with those of El Yunque.

Systematic sampling was a problem due to the inaccessibility of the target grid area. Since we often encountered this problem, we took samples in the closest accessible areas in order to represent the site it the best way possible. We found that specific sites could not be chosen before going into the field because there was often no easy access to the stream. Instead, we used a combination of biased and reconnaissance sampling to determine the sites. After consulting with Gregg Cherry, we learned that some wells in the Manatí-Vega Baja area were known to have high nitrate concentrations due to local pineapple farms. We decided to sample the wells to determine if nitrate contamination was still a problem. We also learned from consulting with Gregg Cherry that due to extensive chicken farming, high nitrate levels were found in waterways in the south of Puerto Rico. Due to time constraints on the project, we were unable to sample in these areas.

Once the sampling sites were determined, we traveled to the sites and began to sample the water. We collected forty-nine samples during the eight-week period. We attempted to sample as many sites as possible in order to get a general idea of the concentrations across the eastern half of the island. Samples were analyzed on site and in the lab to ensure accuracy among the three methods of measurement.

3.6 Sampling Equipment

The equipment we used in the field consists of a Hach field spectrophotometer, a color wheel kit, a conductivity meter and some sampling jars. The spectrophotometer is a portable device that determines the concentration of nitrates in water. The device costs $2000, and it is accurate in measuring concentrations to one decimal place. The color wheel is a simple and inexpensive method for estimating the nitrate concentration to one decimal place and is easily used in combination with the spectrophotometer. The conductivity meter was used to determine the relative amount of dissolved solids in the water. Pure water has very low conductivity. The higher the conductivity reading of a sample, the more dissolved solids the sample has. The sampling jars were used to collect and bring samples back to the laboratory for analysis.

3.7 Sampling Procedure

When we reached a sampling site, the date, time, position, and surrounding land use was recorded. After we entered the land usage data into the data book, we collected the necessary equipment from the truck. All samples collected were collected using the grab sampling method discussed in Chapter 2.

Easily accessible sites required only the gear necessary for the collection of the sample. This equipment included a plastic sample bottle to store the lab sample in, a vial to store the standard for that site, a vacuum sealed ampoule containing the reagent to analyze nitrate, and the conductivity meter.

If a site was some distance from where the vehicle was parked, all the equipment to collect and analyze the sample was taken. In addition to the above equipment, we took the portable spectrophotometer and the color wheel to the site.

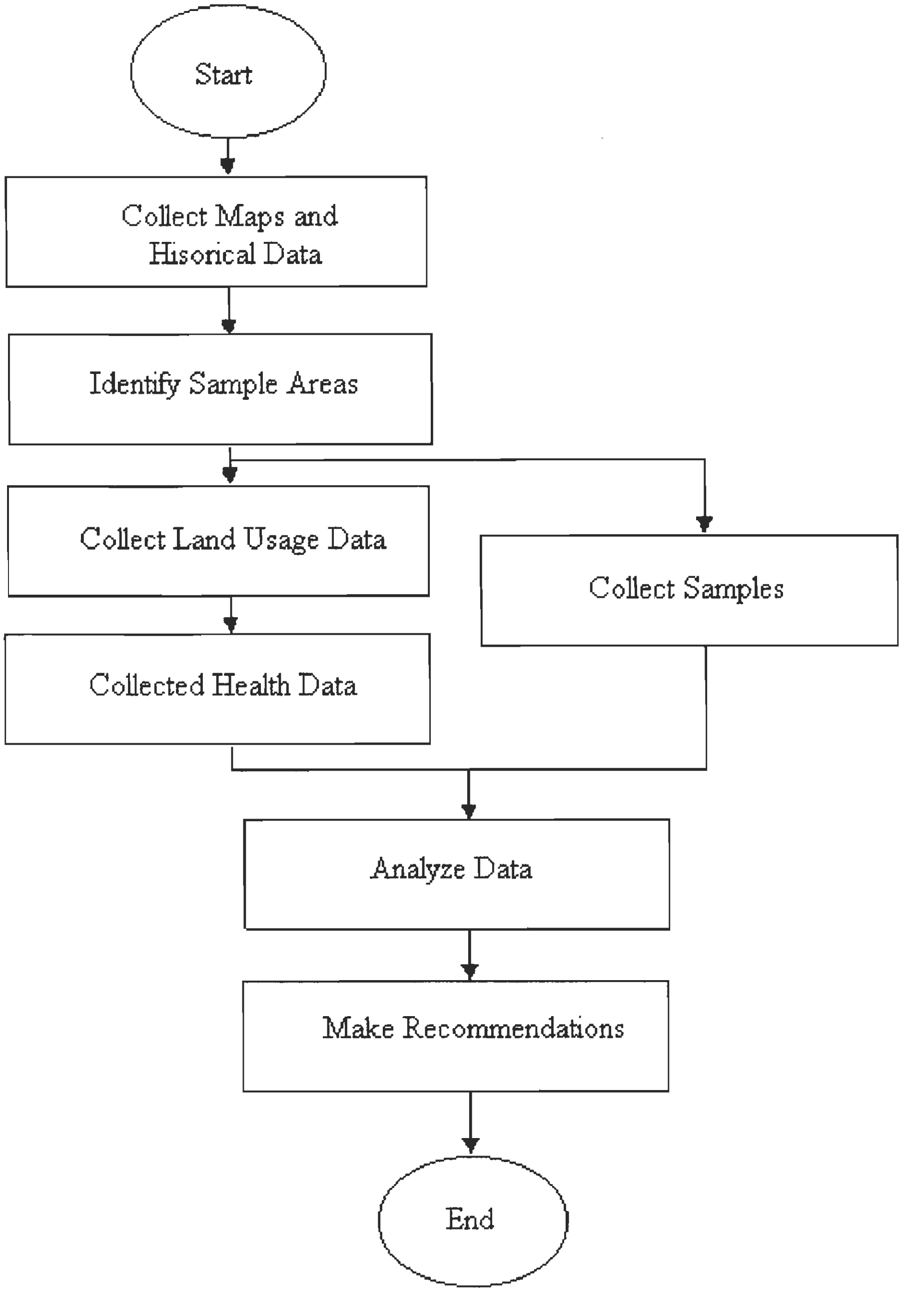
Once the samples were collected, they were put in a cooler of ice in order to preserve the sample until they could be analyzed in the lab. The samples were analyzed in the lab using the Hach spectophotometer.

3.8 Analysis and Recommendations

Once the data was obtained, we began to analyze it. We looked at the land usage maps we obtained to correlate the usage with the nitrate concentrations found at the sites. We compared the land usage maps to our observations in the field to determine if the land usage data is still relevant. By matching the land usage to the concentrations, we identified what possible sources were contributing to the nitrate concentrations. After the data was analyzed, we determined what sites, if any, had problem or a potential problem of high nitrates. Once the potential sources were determined, we made recommendations based on the sites that had the highest nitrate levels, the sites that had greatest risks to health and the environment, and the sites that were easiest to clean up.

3.9 On Site Flow Chart

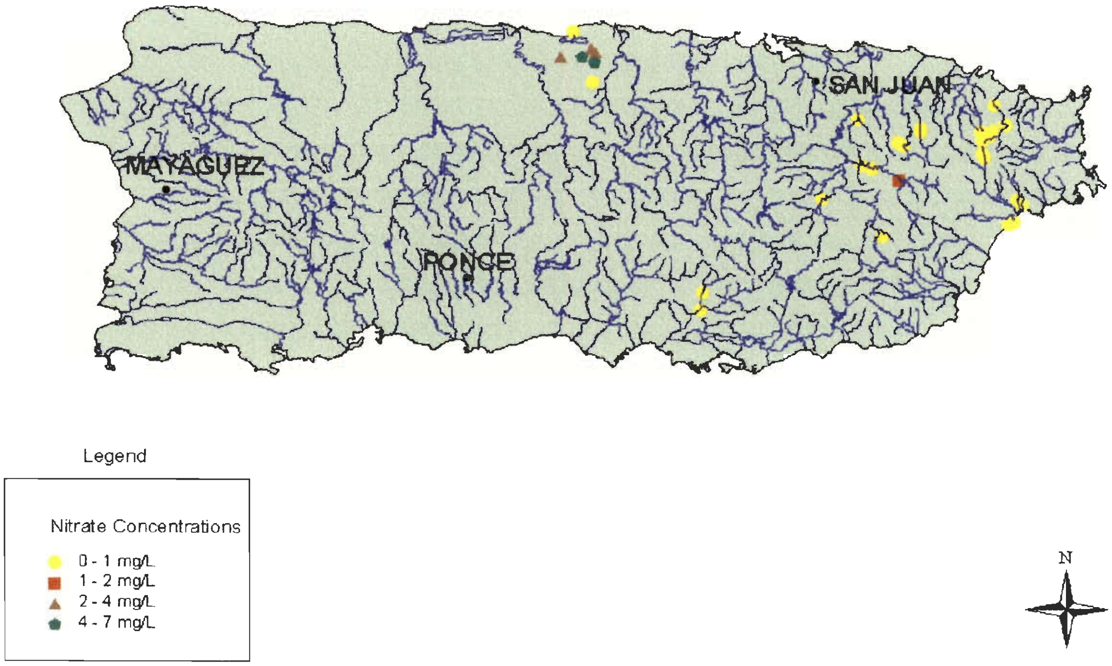
Figure 3.1 Project Flow Chart



CHAPTER 4. DATA AND ANALYSIS

Through the course of our study we surveyed thirty-six sites and collected a total of forty-nine water samples. All data we recorded during the study were tabulated and are included in Appendix C. A complete map of all sampling sites along with the concentrations we determined during the project can be seen below (Figure 4.1). Standards were used to determine how accurately the device was measuring the samples. After the error of the machine was found, we performed a linear regression analysis to adjust the numbers to their true values. The results of the linear analysis can be found in Appendix D. All numbers reported are the corrected values from the laboratory spectrophotometer.

Figure 4.1 Sampling Site Locations

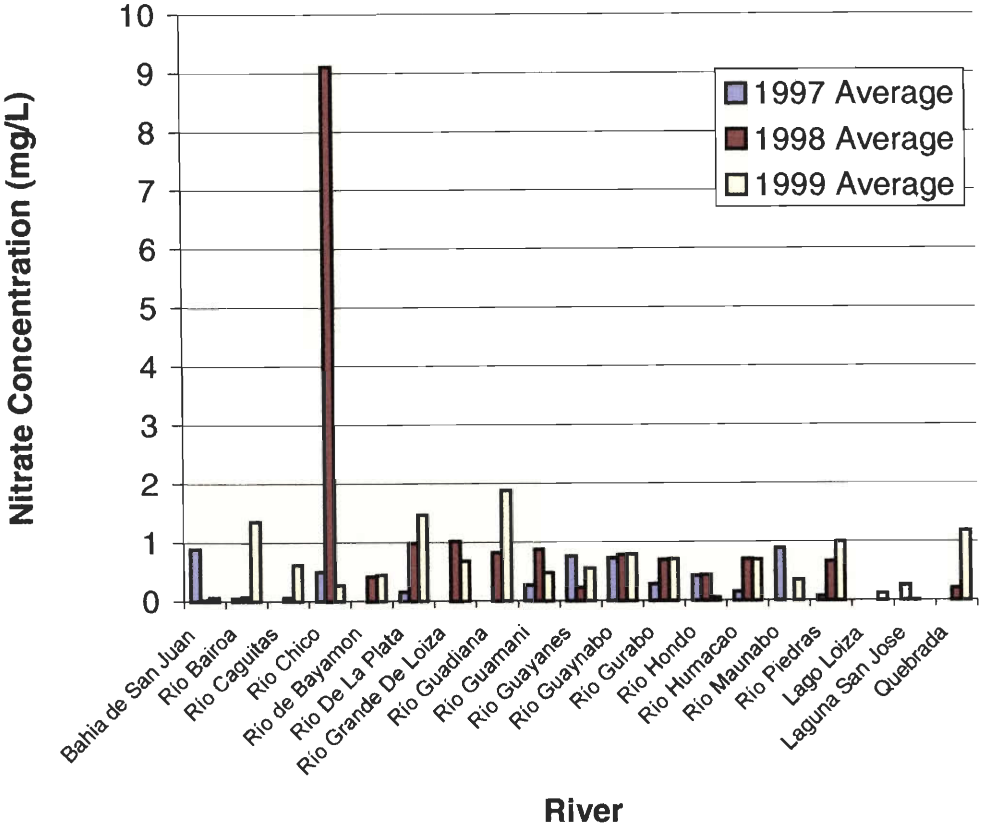


4.1 Historical Data

The U.S. Geological Survey has collected historical data on nitrate concentrations for a small fraction of the rivers and streams of Puerto Rico. The data from 1997, 1998 and 1999 show there is not a nitrate problem in most areas, but in some areas there are high levels that can cause problems. For each of these years we examined data collected between February and May to compare with the time period we conducted our study. Río Chico had the highest concentration at 9.1 mg/L in 1998, but the concentration fell to 0.27 mg/L in 1999. This drastic change may have been due to inconsistent rainfall, illegal dumping in 1998, or perhaps a conscious effort was made to clean the water of nitrates between 1998 and 1999. Figure 4.2 on the following page shows the average of the historical data from the months of February to May in the years of 1997, 1998, and 1999. All the rivers are located in the eastern half of the island. The data is available at certain rivers because the USGS monitors many rivers through gauging stations located on site. Since quarterly water-quality sampling is done on these rivers, ample data from previous years can be found for these sites.

As can be seen from the historical data, the concentrations vary widely across the island. Values taken in El Yunque remained constant during our sampling, as discussed in section 4.2. The historical data for eastern Puerto Rico, however, shows values ranging from 0.01 mg/L at Laguna San Jose to the aforementioned 9.1 mg/L at Río Chico. None of the historical data for the eastern half of the island that we located was over the EPA's limit of 10 mg/L. No values near the 4 mg/L value associated with an increased risk of Non-Hodgkin's Lymphoma were recorded during the months we researched. In general, nitrate concentrations seemed to rise slightly from 1998 to 1999. This may be due to the variations of rainfall between the two years.

Figure 4.2 Historical Data for Eastern Puerto Rico



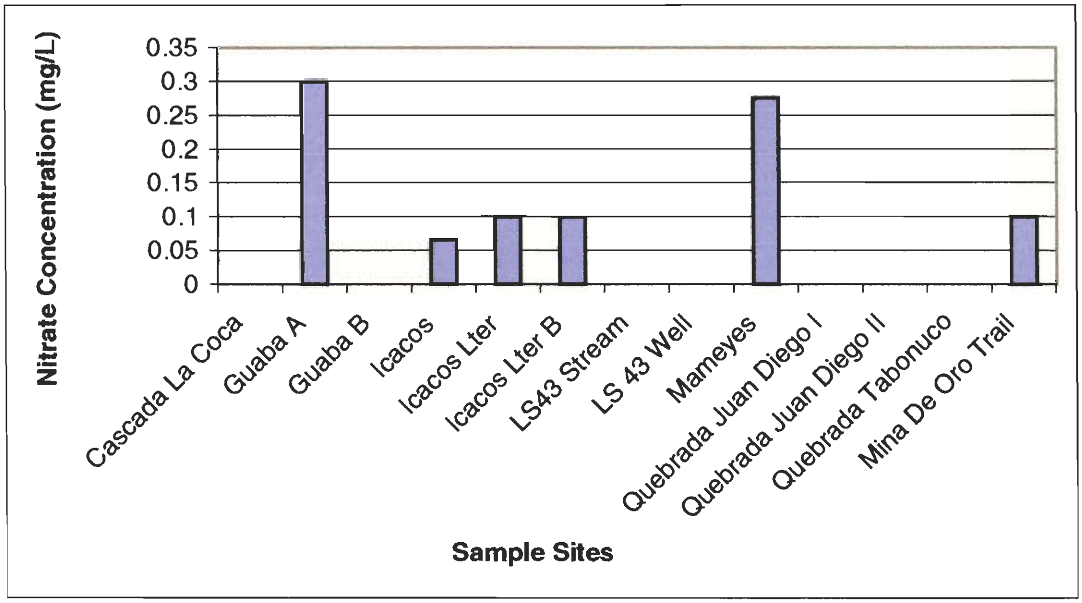
Adapted from: (USGS Water Resource Data Books, 1997, 1998, 1999)

4.2 El Yunque

In El Yunque, we sampled rivers and streams in the typical tourist areas and in areas that tourists do not frequently enter. Since we used the rainforest as the site having the minimal amount of human contact, we sampled multiple times at various sites in El Yunque to get an understanding of what natural concentrations of nitrates on the island were. The values from El Yunque were used as our baseline, or standard, to compare to the rest of the island. Thirteen sites were sampled, and a total of twenty-six samples were collected. The highest value we recorded in El Yunque was 0.5 mg/L, recorded at Río Guaba and Río Mameyes on March 26, 2001. The lowest value recorded in El Yunque was 0.0 mg/L and was found in seven of the thirteen sites sampled.

One possible reason that the concentration varied so much in Río Guaba is the heavy rainfall in the forest. Decaying vegetation produces nitrates in the soil. The nitrate is leached from the soil by the rainfall, but since rain occurs almost daily in most parts of the forest, the concentrations can vary depending on how long a specific site has gone without rain. To make up for this inconsistency we sampled multiple times at the sites. Figure 4.3 shows the average concentrations for all the sites sampled in El Yunque.

Figure 4.3 Average Nitrate Concentrations in El Yunque (2001)



Source:(Gamache, Jorczak, Schienda, 2001)

Sites without a bar above them in the graph averaged a concentration of 0.0 mg/L during sampling. The data remained consistent after the concentrations for these sites were averaged. All values fell between 0.0 and 0.5 mg/L. This provided us with a standard with which we could compare values from other parts of the island. There was no large difference between concentrations of nitrates in the tourist areas and non-tourist areas. Thus, we conclude that tourist activities had a minimal impact on the nitrate concentrations in El Yunque. Figures 4.4 and 4.5 show non-averaged data taken from both the tourist areas of El Yunque and areas that are not frequented by tourists, respectively. Each color bar represents a sample taken at that site. Sites without a bar had a concentration of 0.0 mg/L.

Figure 4.4 Tourist Area of El Yunque

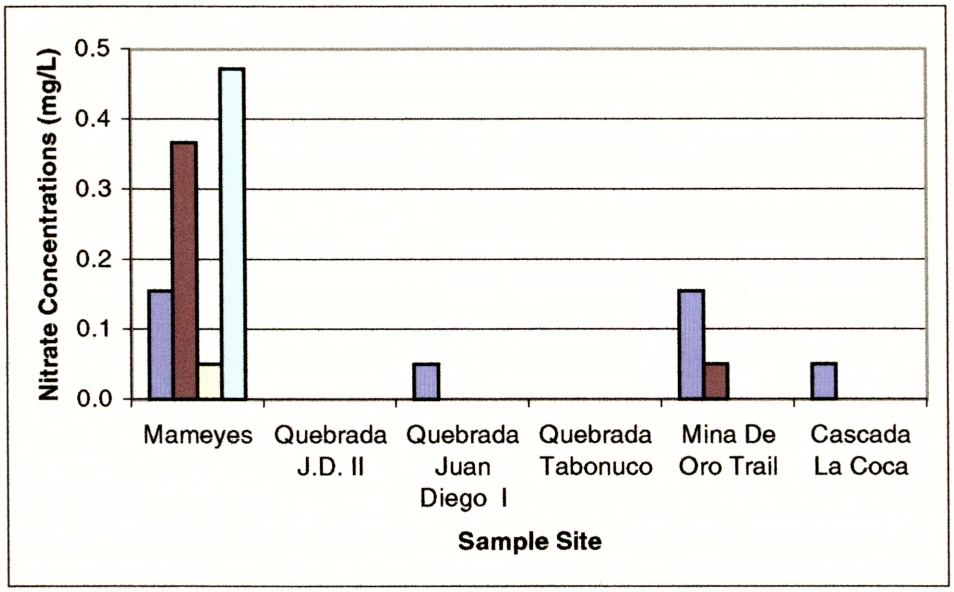
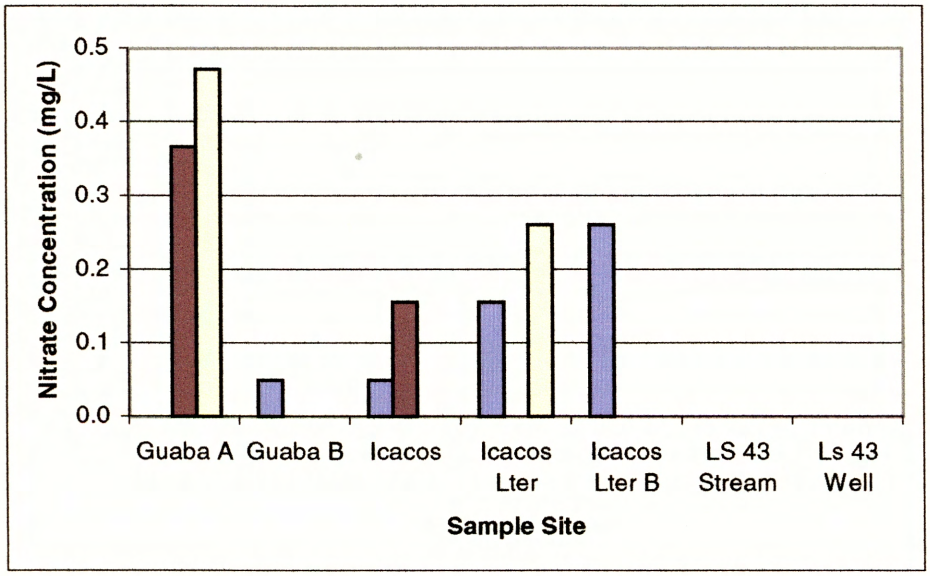


Figure 4.5 El Yunque Area Closed to Tourists



Source:(Gamache, Jorczak, Schienda, 2001)

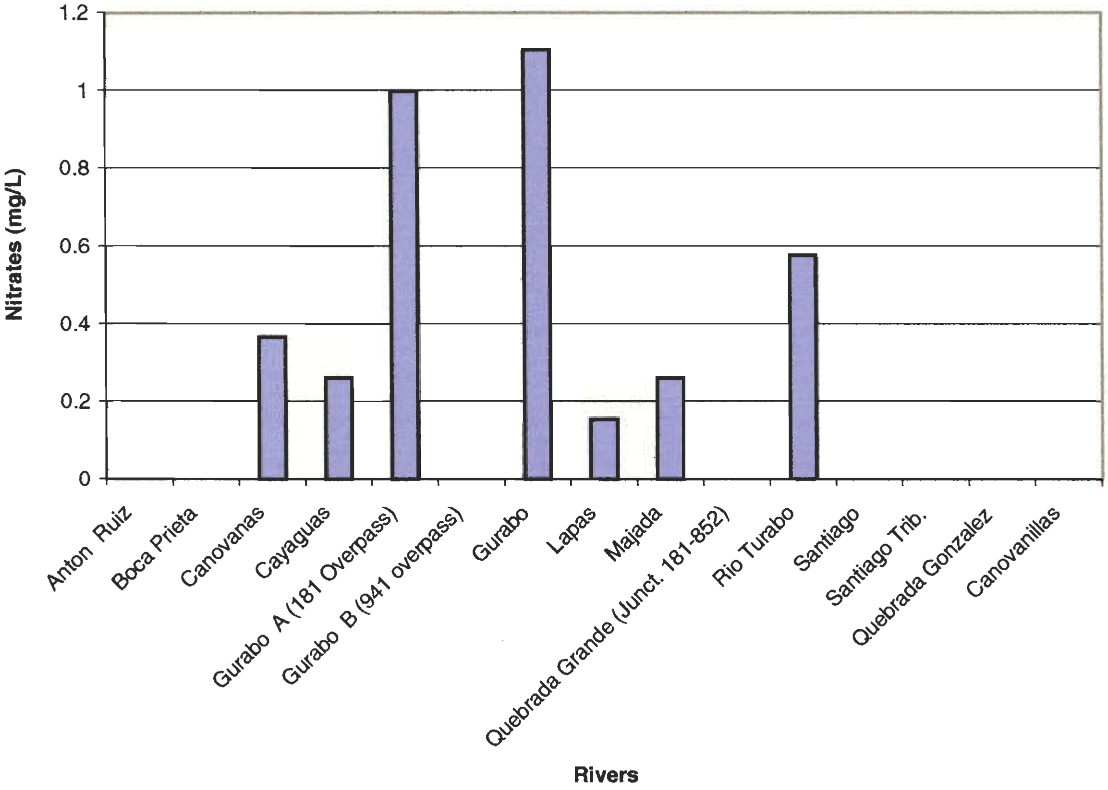
As mentioned earlier, El Yunque was used as our standard for the island, but the large amount of decaying plants has an effect on nitrate concentrations by causing natural values to be slightly off set from the values we would expect throughout the island. This does not mean that El Yunque was not a good choice as our standard. The rainforest has thick vegetation constantly decaying which can contribute to the nitrate concentration in the waterways, but the rain constantly washes the nitrates away keeping the values steady throughout the rainforest

4.3 Eastern Puerto Rico

The data for eastern Puerto Rico outside El Yunque varies more widely than the data inside El Yunque. The highest value obtained was 1.1 mg/L at Río Gurabo. The next highest concentration was 1.0 mg/L at Río Gurabo A. This site was chosen because it was upstream of a water treatment facility. Another site was sampled downstream of the facility, Gurabo B. This was done in order to determine if the water treatment facility was dumping nitrate-rich water into the river. Pastureland, livestock and farmland were also located near the sampling site. This was one reason the concentrations were higher than in other places sampled. The concentration downstream of the water treatment facility, Gurabo B, was lower with a concentration of 0.0 mg/L. The lower concentration downstream may be due to two factors. The water treatment plant may have be discharging clean water into the stream and, therefore, diluting the nitrates in the river. Small runoffs may also be flowing into Río Gurabo and diluting the nitrates.

No values we tested in the eastern part of the island approached the 4.0 mg/L possibly associated with increased NHL risk. All the data that was collected for the eastern part of the island is shown in Figure 4.6. Some values shown are lower than those for El Yunque. This may be because humans do not have a large effect on nitrate concentrations in those areas. Instead, natural sources such as decaying plant material are responsible for regulating the concentrations in the streams. Since the areas outside El Yunque have less vegetation than the rainforest, the natural concentrations are lower than those in El Yunque. Some concentrations are slightly higher than El Yunque values for reasons discussed in section 4.6. All sites without a bar represent a 0.0 mg/L concentration.

Figure 4.6 Eastern Puerto Rico Concentrations (2001)



Source:(Gamache, Jorczak, Schienda, 2001)

4.4 Bottled water

We also sampled various name brands of bottled spring water to determine nitrate concentrations. The purpose was to compare the water that people may believe is safer to drink to the groundwater. Some bottled water, such as Evian and Castle Springs, print the nitrate concentration of the water on the label, along with other dissolved materials on the label as shown in figure 4.7. The nitrate concentration in Evian bottled water is stated as being 1 mg/L.

Figure 4.7 Evian Label With Mineral Compositions

Recyclable: Check to see if facilities exist in your area.

PETE

Mineral Composition in mg/liter

Calcium	78	Bicarbonates	357
Magnesium	24	Sulphates	10
Silica	14	Chlorides	4
Neutrally balanced pH = 7.2		Nitrates (N)	1

Dissolved solids @ 180°C: 309 p.p.m. (mg/l)

CA CASH REFUND
NV: AC-51-05011
CT # 23 • ME 5¢ DEP
NYSHD Cert No I-011

evian®
Natural Spring Water

Nutrition Facts
Serving Size 8 fl oz (240 ml)
Servings about 4

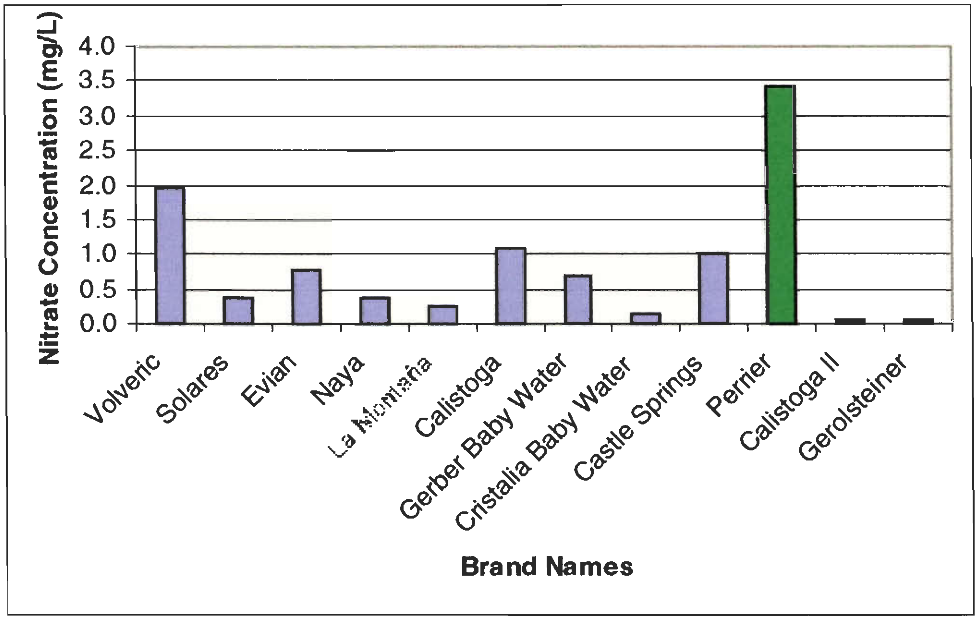
Amount Per Serving	
Calories 0	
	% Daily Value*
Total Fat 0g	0%
Sodium Less than 5mg	0%
Total Carbohydrate 0g	0%
Protein 0g	

SODIUM FREE
BOTTLED BY S.A. EVIAN CO.
AT EVIAN 74500 FRANCE.
A COMPANY OF
THE DANONE GROUP
DANONE
SOURCE: CACHAT SPRING,
EVIAN FRANCE
PRODUCT OF FRANCE
For information call:
1-800-633-3363

Although this label does give the concentrations of various minerals, it does not say how they determined the concentrations of these chemicals. Also, the label does not tell how the water was treated before it was bottled.

With the lab spectrophotometer, we determined the concentration of nitrates in Evian was 0.8 mg/L. The highest concentration we found in bottled water was in Perrier sparkling water. It had a nitrate concentration of 3.5 mg/L. In the 12 brands of water we sampled, nitrate concentrations ranged from 3.5 mg/L in Perrier to 0.0 mg/L in the sparkling water of Calistoga and Gerolsteiner. The chart below shows the concentrations for all the bottled water we tested. The green bars represent the sparkling water, and the blue bars are the bottled spring water.

Figure 4.8 Bottled Water Nitrate Concentrations



Source:(Gamache, Jorczak, Schienda, 2001)

The two local bottled waters that we tested, La Montaña and Cristalia Baby Water, had relatively low concentrations of nitrates with values of 0.3 and 0.2 mg/L, respectively. These were the two lowest concentrations for all of the non-sparkling water we tested. Perrier's value is close to the value of the 4 mg/L possibly associated with an increased risk of non-Hodgkin's Lymphoma, but further bottles should be tested in order to determine if there is a problem with nitrates in Perrier. Since we tested only one bottle from each of the name brands, it is impossible to draw conclusions about specific name brands. Instead, we tested bottled water to compare the values observed with bottled water to those values we found in eastern Puerto Rico.

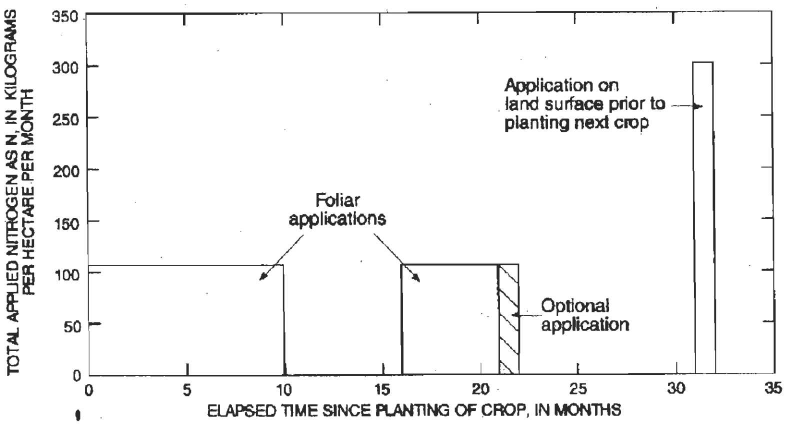
4.5 Manatí-Vega Baja Area

Previous studies have been done on the wells of the Manatí and Vega Baja, which are areas west of metropolitan San Juan. These wells have shown high concentrations of nitrates in the past. Three wells in the area were shut down due to nitrate concentrations over the EPA's limit of 10 mg/L in the three years previous to our study. For this reason, we decided to sample wells and streams located in the area. Drinking water for the Manatí and Vega Baja area comes from the upper limestone aquifer, which flows from south to north. The limestone aquifer provides the Vega Baja and Manatí with 37,000 cubic meters of water per day for residential use and 4,900 cubic meters per day for industrial use, 70 percent of the water Manatí and Vega Baja use (Conde-Costas & Gomez-Gomez, 1999).

4.5.1 Pineapple Fertilizer

The principal fertilizer used for the pineapples is urea, $CO(NH_2)_2$. Urea is applied every 15 to 30 days during the crops cycle. The concentration of the fertilizer is between 9,200 to 18,380 mg/L of nitrogen (See Chapter 2 for the breakdown of urea to nitrate) and is applied 3 times over the 31.5-month crop cycle. Over this time it was estimated that 1,890 to 2,100 kilograms of nitrogen was applied to each hectare of land. This amount of fertilization would represent 760 kilograms of nitrogen per hectare per year. Figure 4.9 on the following page shows the fertilization cycle.

Figure 4.9 Pineapple Fertilization One Crop Cycle



Source: (Conde-Costas & Gomez-Gomez, 1999)

4.5.2 Nitrogen Load

A large percentage of the people living in the Vega Baja and Manatí area live in rural communities using septic systems. In order to determine the amount of nitrate produced by a rural community some additional data is needed. The average person excretes about 17 grams of nitrogen each day. In the Manatí area 4,160 cubic meters of water per day was supplied to 5,852 households each producing a wastewater discharge of about 0.71 cubic meters per day. Using the data above, Carlos Conde-Costas and Fernando Gómez-Gómez (1999) were able to calculate that each rural community in the Manatí area was capable of producing 85 mg/L of nitrogen per hectare of land. They also found that each community could produce an annual load of 200 kilograms of nitrogen per year. The calculated amount of nitrogen that would reach the aquifer would be 27 mg/L. The nitrogen reaching the aquifer is much lower than the figure predicted because nitrates are diluted with recharge waters.

The pineapple fields produce about four times as much nitrogen as rural un-sewered communities. By looking at figure 4.9, the lowest levels of fertilization take place during the first 10 months and during the 16th to the 22nd month. Using this amount of fertilizer as the average amount placed down per year, it is found that 400 to 690 kilograms of nitrogen per hectare crop cycle will be applied to the field. If we include the fertilizer needed to pre-treat the land for new crops the nitrogen concentration increases to 1,200 to 1,490 kilograms per hectare per year. Using this figure, Conde-Costas and Gómez-Gómez were able to calculate the minimum amount of nitrate applied to the 600 hectare of pineapple fields. The minimum amount of nitrate as nitrogen was calculated to be 246,000 kilograms of nitrate per year. During the study the maximum amount of nitrate was calculated to be 283,000 kilograms of nitrate per year.

Using the data from both the rural communities and the pineapple fields, Conde-Costas and Gómez-Gómez were able to calculate the expected nitrate concentration produced from the two systems to be 17 mg/L. This assumes that all of the nitrate enters the aquifer and that the groundwater flow is constant. Since less nitrate is entering the aquifer and the groundwater flow is not constant, nitrate concentrations would vary from the number that Conde-Costas and Gómez-Gómez predicted.

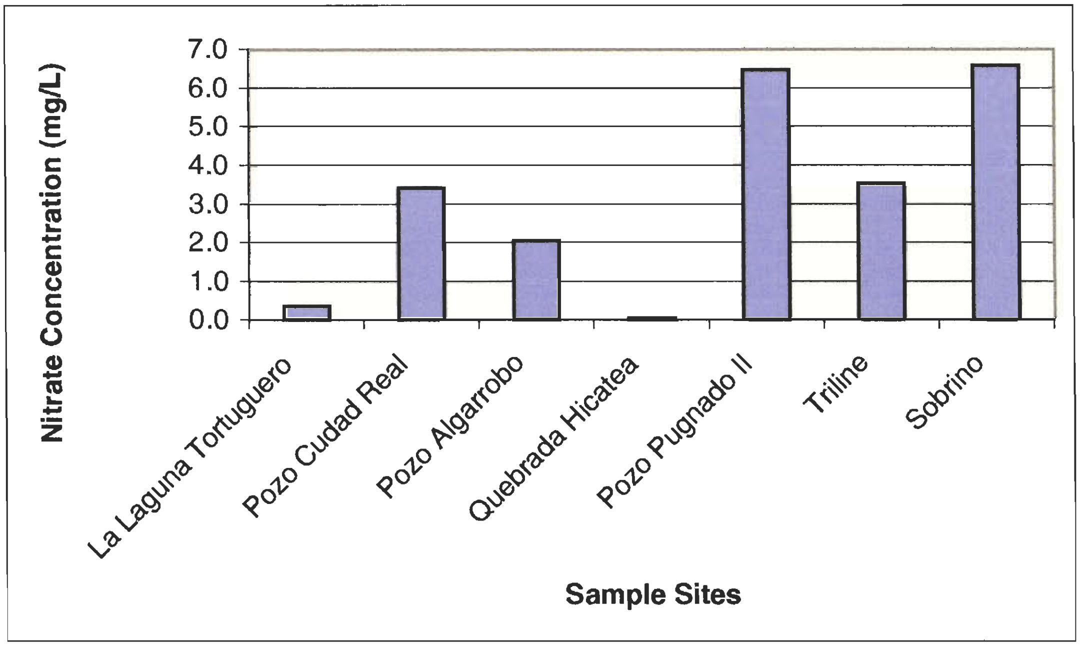
4.5.3 Storm Runoff

During the study conducted by Conde-Costas and Gómez-Gómez, two sampling sites were chosen to determine nitrate concentrations from storm runoffs. While doing the study they found that the pineapple fields produced 85 percent of the nitrogen from runoffs. The runoff from the pineapple fields had a 45 times higher concentration of nitrates than the urban runoff. The average amount of nitrate found within the runoff in urban communities was found to be 0.2 mg/L. The pineapple field's average concentration was 9.0 mg/L.

4.5.4 Current Nitrate Concentrations

During our study of the Manatí-Vega Baja area, concentrations in two wells were still high. The nitrate concentrations at these wells were 6.5 and 6.6 mg/L. Figure 4.10 below shows the nitrate concentrations we recorded in the area.

Figure 4.10 Nitrate Concentrations in Manatí-Vega Baja



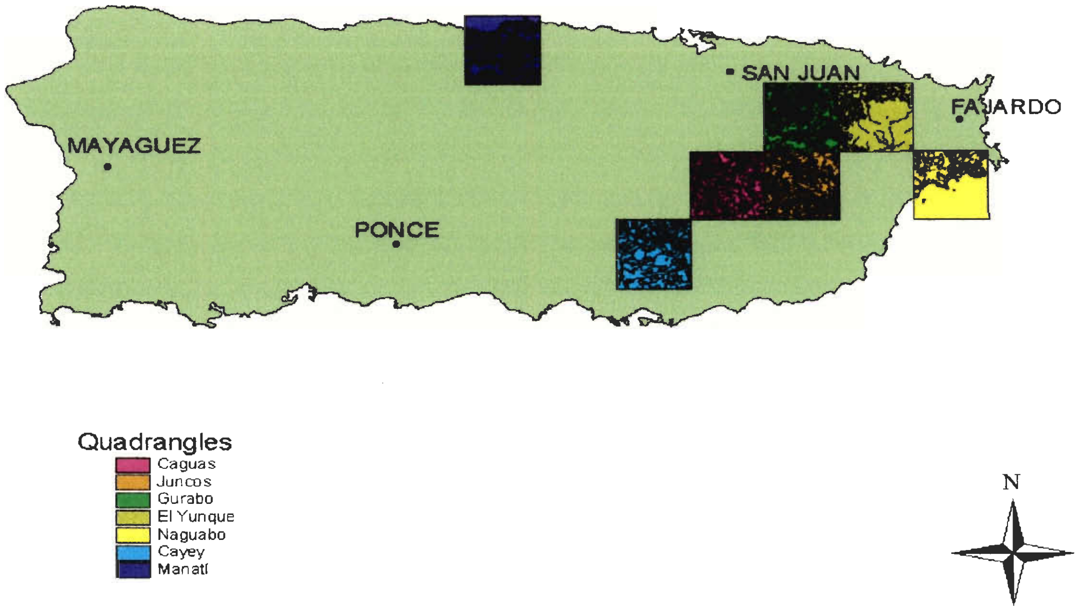
Source: (Gamache, Jorczak, Schienda, 2001)

The two lowest concentrations of nitrates were in the streams La Laguna Tortuguero and Quebrada Hicatea, with concentrations of 0.4 and 0.0 mg/L, respectively. A detailed analysis of the reasons for the higher concentrations we found is given in Section 4.6.

4.6 Land Usage Data

In order to determine the source of the nitrates in the areas we sampled, we need to relate the concentrations to land usage maps. Figure 4.11 shows a map of all the areas we sampled. In total, seven quadrangles, areas, were sampled. The map below shows these seven quadrangle. The sections that follow the map are a breakdown of each quadrangle.

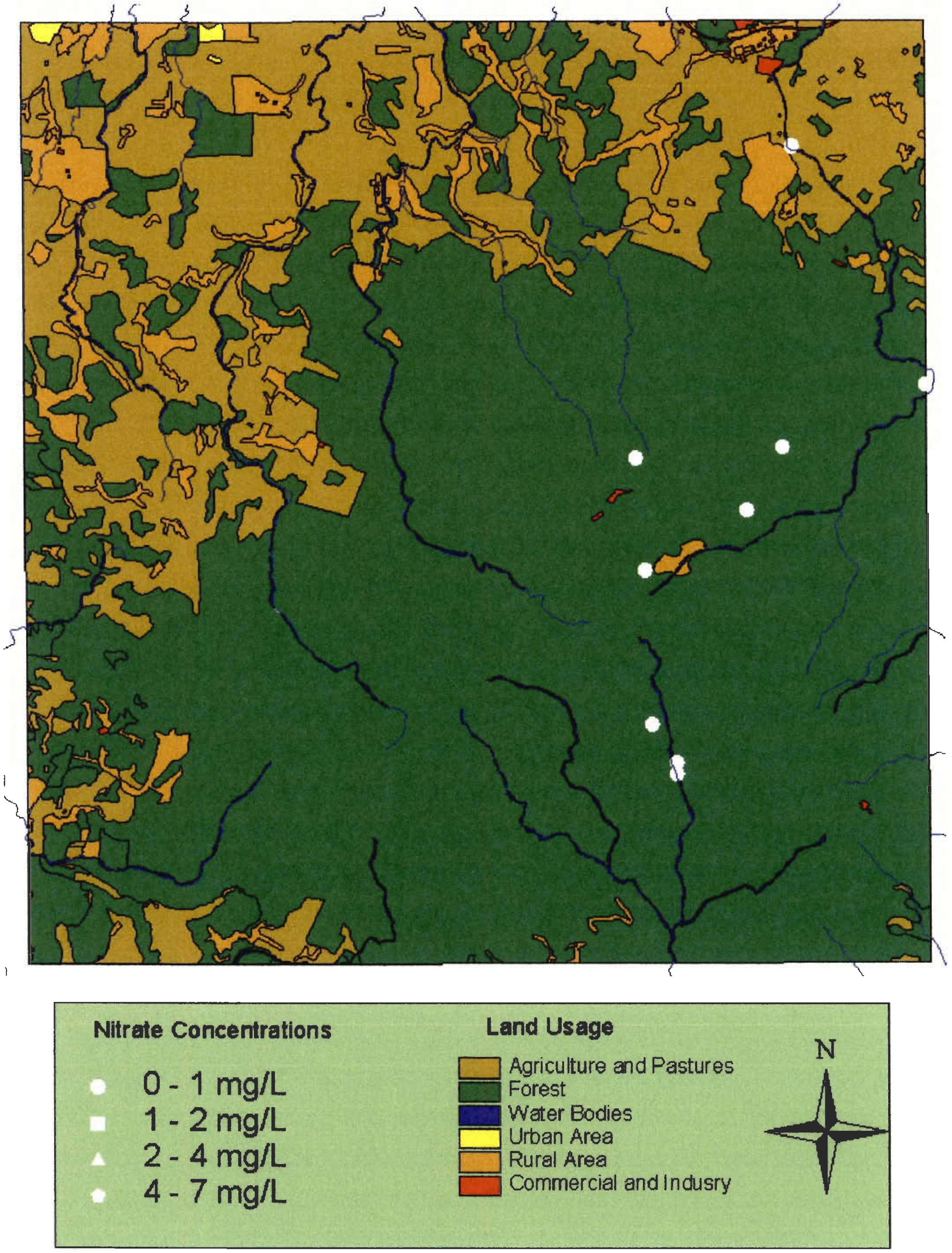
Figure 4.11 Breakdown of Sampling Areas



4.6.1 El Yunque Land Usage

El Yunque's land is very different from any other areas sampled during our project, because of the dense vegetation and climate. We sampled within the Caribbean National Forest because it is relatively untouched by humans in most areas. Since the land is untouched, we were able to sample for natural nitrate concentrations. Also, by sampling El Yunque we were able to determine if tourists and locals affect nitrate concentrations within the forest. Figure 4.12 shows the land usage within El Yunque.

Figure 4.12 El Yunque Land Usage



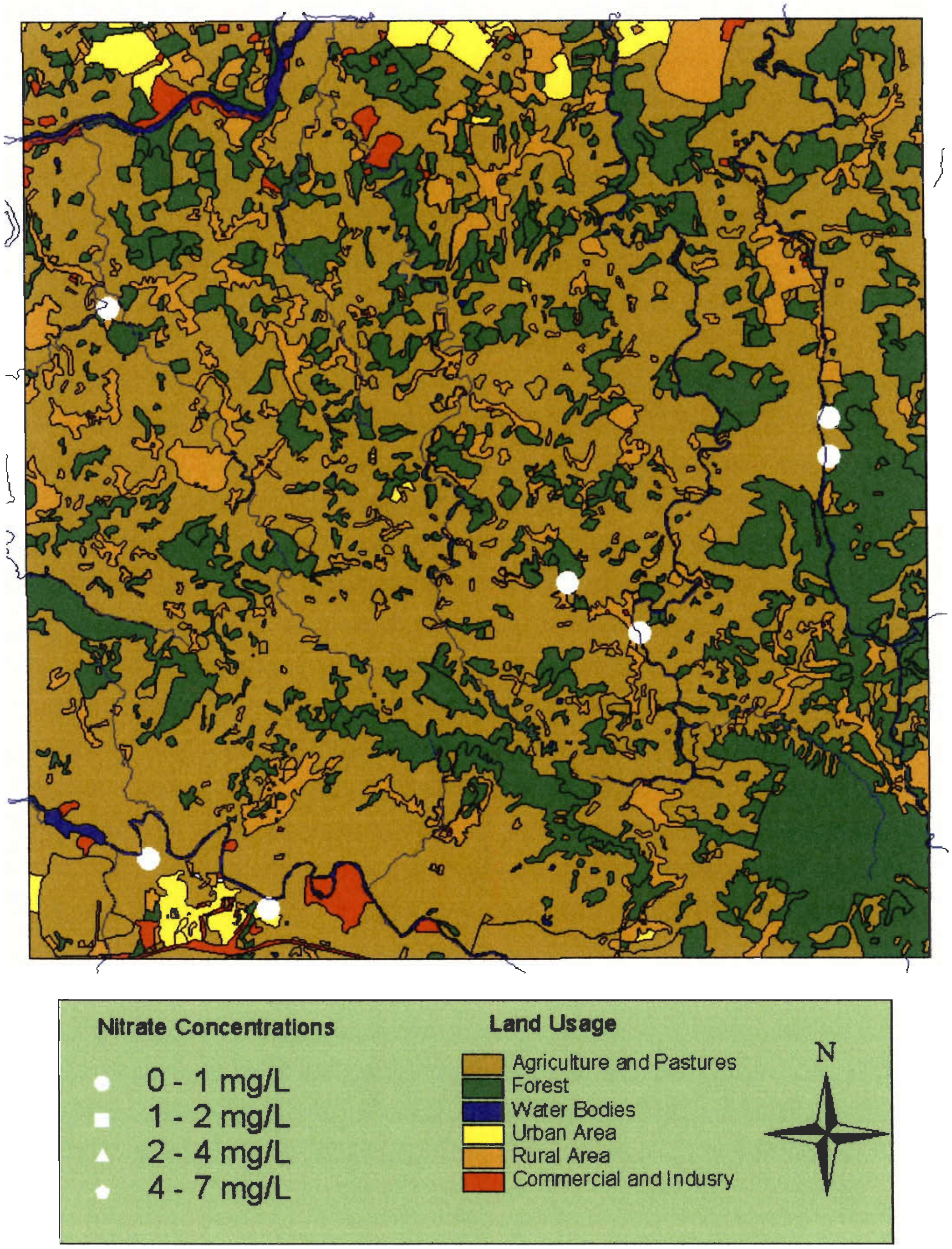
Each white circle in figure 4.12 shows where a sample was taken and the concentration we determined for that site. The map shows that the nitrate concentrations within El Yunque were between the ranges of 0.0 to 0.6 mg/L. The points found in the southern part of the map are areas not frequented by tourists. Samples taken in the northern section on the map were taken in tourist areas. As shown in the map, the tourist areas have the same nitrate concentrations as the areas that are untouched by humans because the nitrate concentrations are constant throughout the forest. The highest concentration found in El Yunque was found at Río Mamayes, 0.6 mg/L. This point is the western most point shown in figure 4.12. The sample site at Río Mamayes is often used for swimming and cookouts. This is one reason why we observed higher nitrates in this area. We also sampled an area to the north of the Caribbean National Forest, which was also Río Mamayes. We found that the nitrate concentration observed downstream, the northern point, was lower than the nitrate concentration within the Caribbean National Forest. The area sampled downstream is located in an area with rural towns and heavy pasturelands. The nitrate concentration in this area could have been lower because of storm runoffs from the road that runs parallel to the river.

4.6.2 Gurabo Land Usage

The map in figure 4.13 shows the land usage for the Gurabo area. The figure also shows the sites we sampled within the area. The Gurabo area has a wide range of land usage. The samples we analyzed were located near all the different land usages in the area, allowing us see how each land usage effect nitrate concentrations.

The highest concentration was found in the southwest corner of the map and was 1.0 mg/L. Located in this region is a sewage treatment plant. We took a sample upstream from the sewage treatment plant and downstream of the sewage treatment plant. The downstream point turned out to have a lower nitrate concentration, 0.0 mg/L, than the upstream sample site. This would lead us to believe that the sewage treatment plant is releasing water that dilutes the nitrate concentration in the river.

Figure 4.13 Gurabo Land Usage



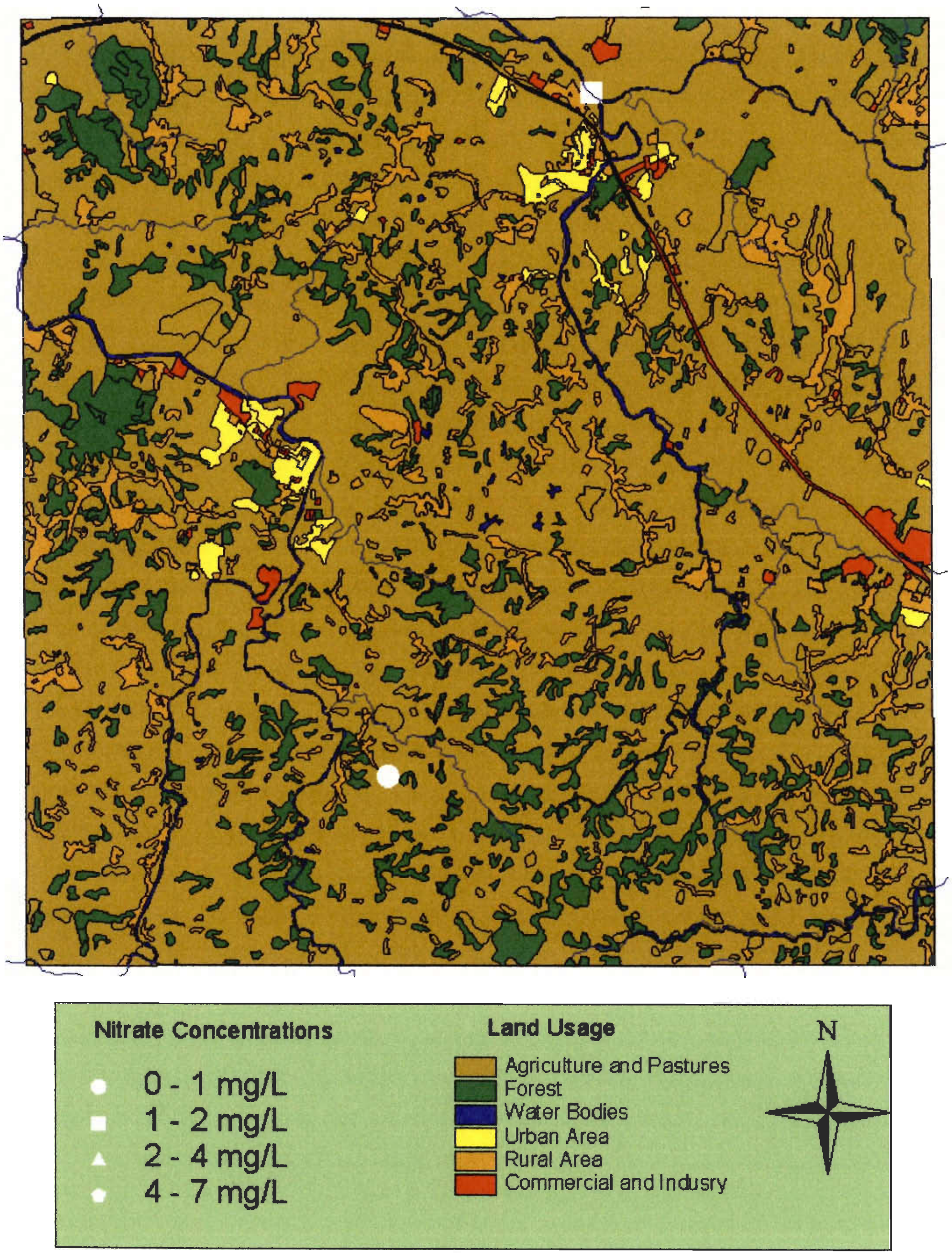
The rest of the nitrate concentrations were found to be low ranging from 0.0 to 0.4 mg/L. The nitrate concentration found in the eastern half were two sites with nitrate concentrations of 0.4 mg/L. These two sites were between pastureland and forest, so we could be finding higher nitrate concentrations in this area due to pasturelands in the area and natural nitrification. Rural communities are also located in this area, and local sewage and septic systems could have contributed to the higher levels.

4.6.3 Juncos Land Usage

Two samples where taken in the Juncos quadrangle. The higher nitrate concentration was found in the northern part of the quadrangle as shown in figure 4.14. The sample was taken at Río Gurabo near a mixture of rural community, pasture land, and commercial land usage. The nitrate concentration at this site was found to be 1.1 mg/L. The nitrates could be leaching from the rural community located directly west of the sample site. The nitrates could also be leaching from the pasturelands surrounding the area.

Río Cayaguas was sampled in the southern part of the quadrangle and had a very low nitrate concentration of 0.1 mg/L. The stream is located near rural communities and pastureland. Nitrates concentrations may have been low because it was the dry season, and the nitrates were not being leached from the soil due to lack of precipitation.

Figure 4.14 Juncos Land Usage



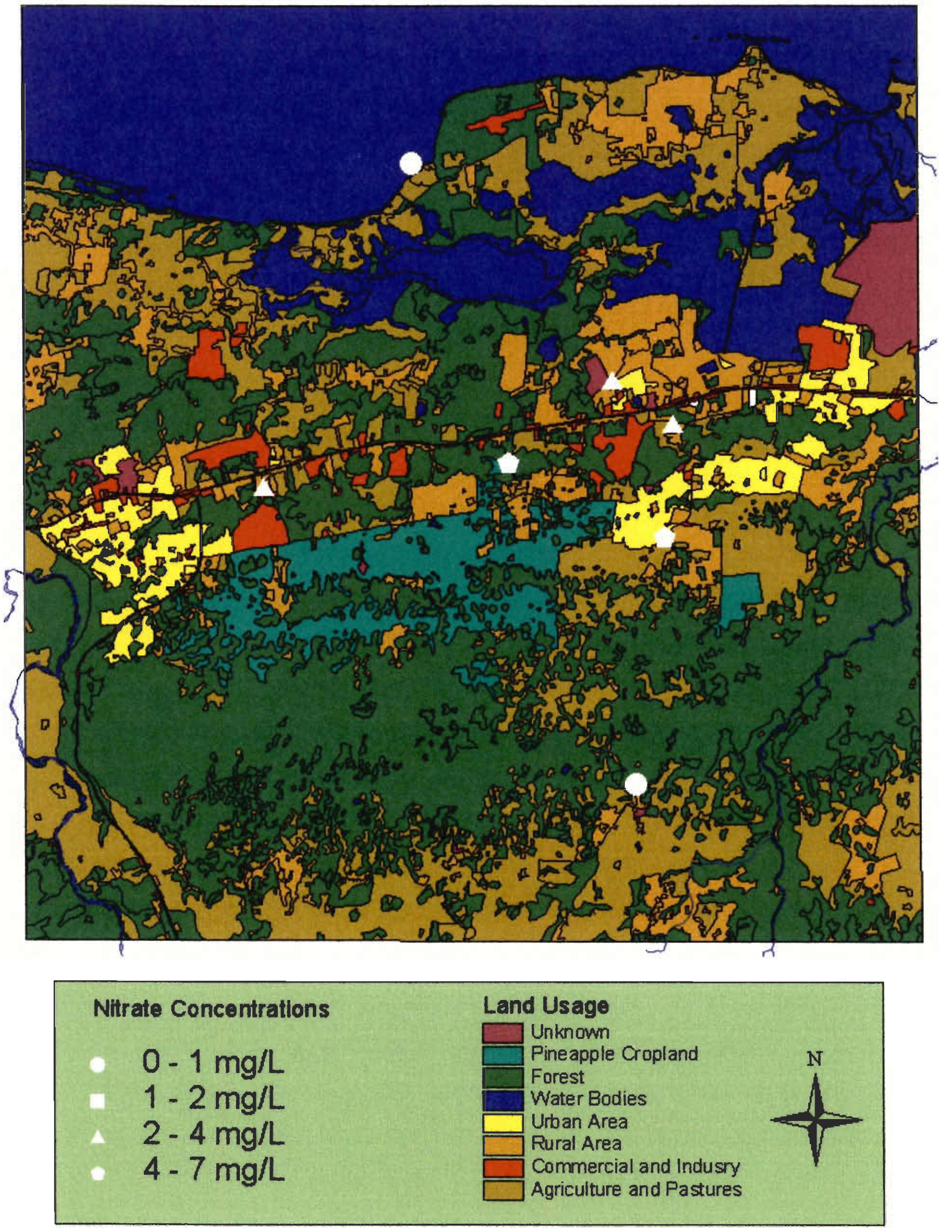
4.6.4 Manatí Land Usage

The Manatí and Vega Baja area had the highest nitrate concentrations found during the study. Figure 4.15 Shows the Manatí Vega Baja land usage. While in the area, we sampled two streams and five wells. The Quebrada Hicatea located in the southern part of the map contained 0.0 mg/L of nitrate. La Laguna Tortuguero, located in the northern part of the map, flows from the lake into the ocean and was found to have a nitrate concentration of 0.4 mg/L.

As stated above, the other five sites sampled were groundwater wells. The wells sampled in this area were north of the pineapple crops, where the water in this area flows from the south to north. Because the water flows in this direction, it brings the nitrates from the pineapple fields in the south to the wells in the north. Two of the wells sampled were directly north of the pineapple fields while the other three wells were located to the east of the larger pineapple fields. The wells to the east of the pineapples had a lower nitrate concentration than the wells directly north of the large pineapple fields.

The three wells in the area had nitrate readings ranging from 3.5 to 6.6 mg/L. With most of the nitrate pollution coming from the pineapple fields, but as mentioned in this chapter, rural communities in the area also contribute to the nitrate pollution. The site located directly to the east of the pineapple fields is next to both a large rural community and agriculture fields. Since the land usage map from for this area was last updated in 1987, the pineapple plantations could have expanded into the agriculture land in this area. The two wells that had the highest nitrate concentrations are located directly to the north of the pineapple fields. One of the wells, Pozo Sobrino, is located twenty feet from a pineapple field and contained the highest nitrate level found in the study. The nitrate concentration found in Pozo Sobrino was 6.6 mg/L. The other well, Pozo Pugnado II, is located near rural communities and commercial land and had a nitrate concentration of 6.5 mg/L.

Figure 4.15 Manatí Land Usage

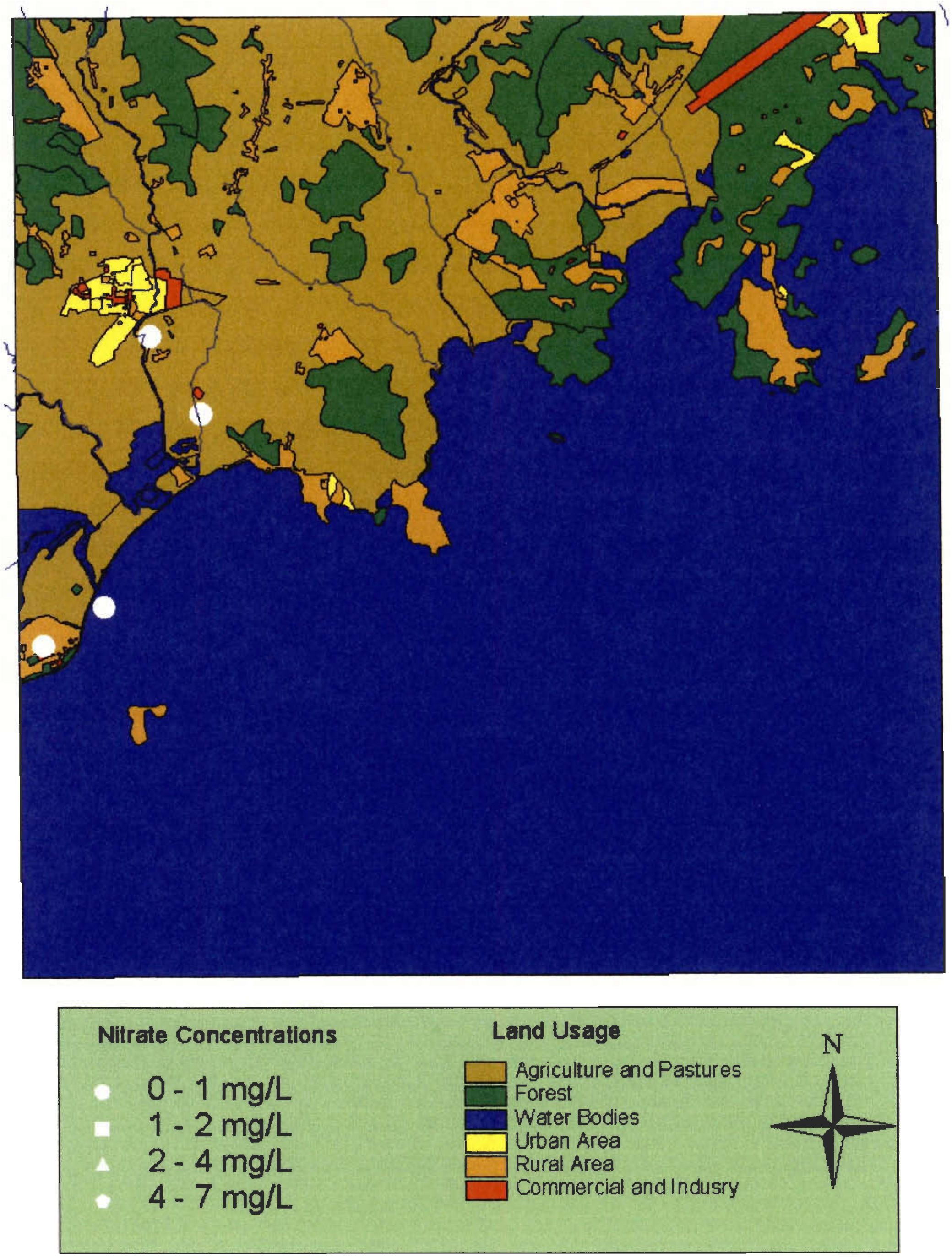


4.6.5 Naguabo Land Usage

Four samples were taken in the Naguabo area with each of the samples having a nitrate concentration of 0.1 mg/L or below, which can be seen in figure 4.16 on the following page. The Naguabo area has similar land usage to other areas sampled, except it is close to the coast.

Coastal areas have a higher water table because of there close proximity to the ocean. With costal areas having a higher water table, nitrates that are leached from the soil sink to the water table. The nitrates are diluted into the seawater and can be taken out to sea with the tides.

Figure 4.16 Naguabo Land Usage

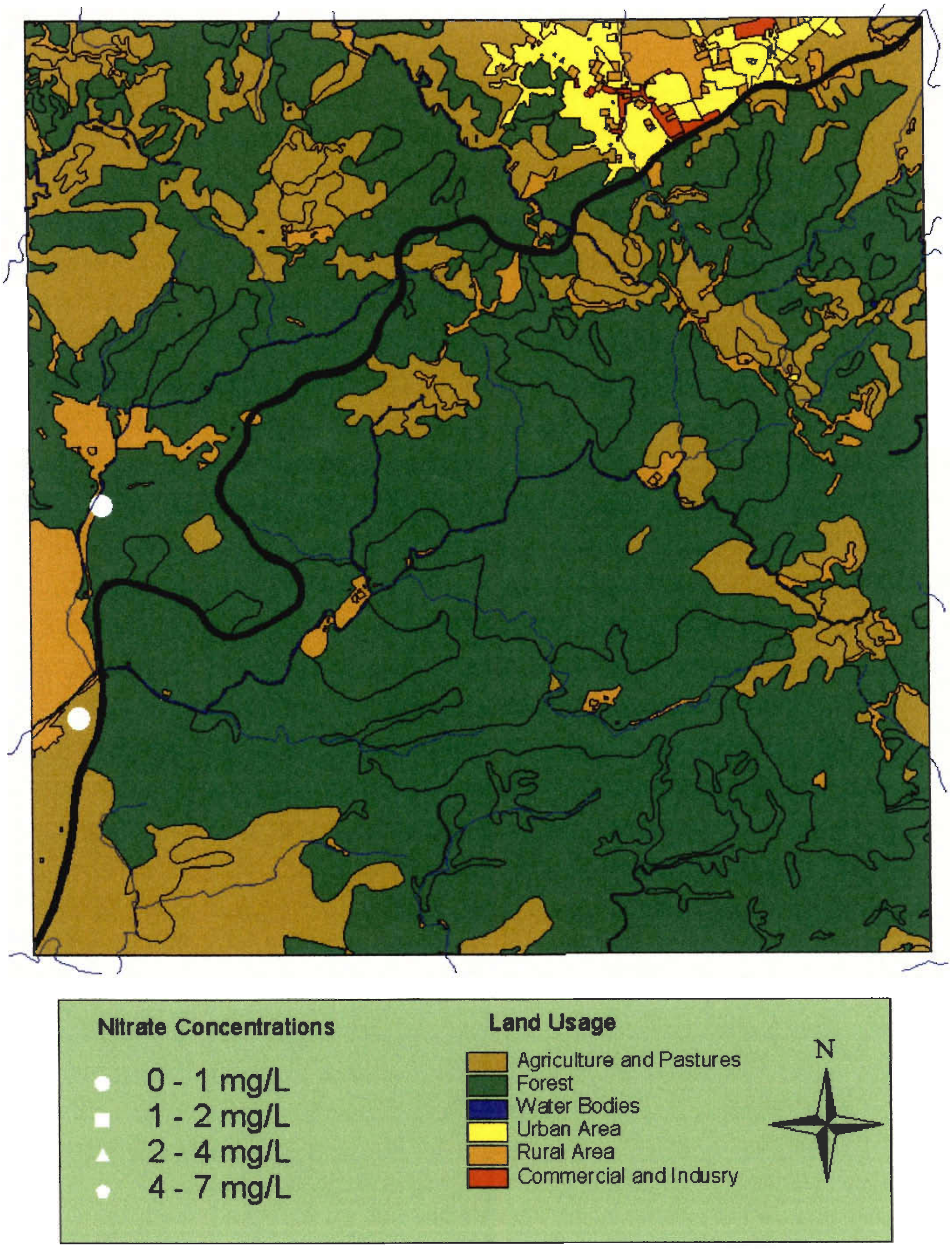


4.6.6 Cayey Land Usage

Two samples were taken within the Cayey Quadrangle. Río Majada was sampled and is the southern most point on the map, and Río Lapas is the northern point sampled. The map of Cayey can be found in figure 4.17 on the following page. Cayey was very dry when we visited each sample site, and water flow in both rivers was low. The sample at Río Majada was taken downstream of a construction site and was also located next to pasturelands. The nitrate levels could have been low because nitrates could be built up in the soil and have not been leached by rain for some time. It also seemed that construction done within the stream bed was not effecting nitrate concentrations.

Lack of rain in the area could have also lowered nitrate concentrations in Río Lapas. One observation we noticed while sampling Río Lapas was its extensive algae growth. When algae is found within the stream it can be an indication of elevated nitrate concentrations, but this was not the case. The algae growth could be caused by the presence of other nutrients in the water.

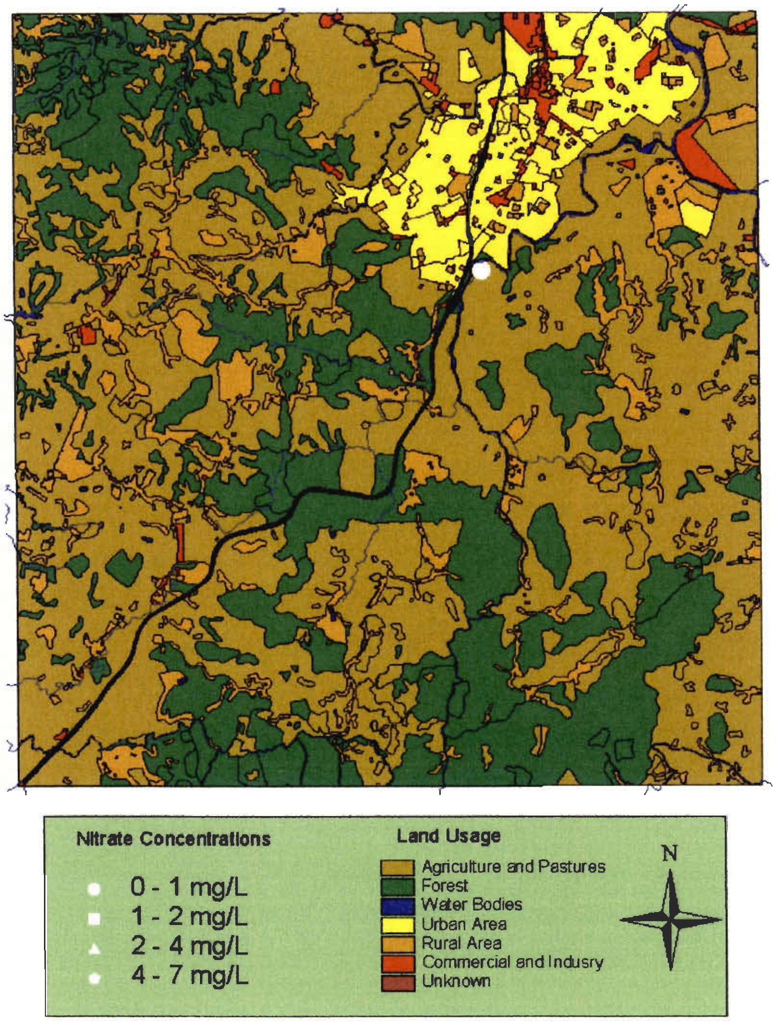
Figure 4.17 Cayey Land Usage



4.6.7 Caguas Land Usage

One sample was taken in the Caguas quadrangle and can be seen in figure 4.18. The nitrate concentration found at Río Turabo was 0.6 mg/L. The sample was taken near heavy urban development and farmland. Nitrate concentrations from this area could be caused from local homeowners' using fertilizer within their gardens or lawns. Nitrates may also be leaching from the pasturelands located near the site.

Figure 4.18 Caguas Land Usage



4.6.8 Land Usage Summary

By looking at land usage maps for the areas we sampled, we were able to show how the land usage used affected nitrate concentrations. Agriculture and pastureland seem to have a minimal effect on nitrate concentrations. In the Manatí area, the land usage maps shows how the pineapple agriculture is affecting the nitrate concentrations in wells to the north and east. Overall, concentrations are low across the areas we sampled, but changes in land usage did have a small effect on nitrate concentrations.

4.7 Increased Agriculture on the island

On March 12, 2001, an article was published in the San Juan Star on how Governor Calderón and the Puerto Rico Department of Agriculture, are intending to encourage agriculture in Puerto Rico. The goal of the legislation is to decrease the amount of food imported into Puerto Rico. The legislation also gives supermarkets and local business incentives to buy local goods.

Currently in Puerto Rico there are 40,000 local farmers across the island (Vazquez, 2001). Agriculture on the island represents one percent of the gross national product. This year the farming industry is projected to earn 685 million dollars (Vazquez, 2001). Dairy farming industry leads the sector with a value of 193 million dollars (Vazquez, 2001). Table 4.1 below shows the value for the top ten agricultural sectors in Puerto Rico.

Table 4.1 Top Ten Agricultural Sectors in Puerto Rico

Sector	Value Millons
Dairy	193.0
Poultry	103.1
Plantains	59.9
Beef and Veal	30.8
Vegtables and Legumes	30.5
Ornamental Plants	30.0
Coffee	26.7
Pork	22.8
Bananas	22.8
Fish and Seafood	21.0
Rest of Sector	144.4
Total	685.4

Source: San Juan Star March 12, 2001

The governor's plan would increase the amount of farmland, which would also increase the number of jobs on the island by approximately 20,000 over four years. The Secretary of State, Fernando Mercado, would like to achieve an overall 20 percent increase in agricultural production (Vazquez, 2001). If we assume a 20 percent increase financially, there would be a $137 million increase in revenue. This would give a total of $822 million in revenue. This increased revenue would need to be compared with the costs associated with possible risks of increased agriculture. Through the increased use of fertilizers on the crops and the increased number of animals on the farms depositing more waste in a concentrated area, there could be an increase in the nitrate concentration in the ground. The increased level of nitrates in the ground will then be leached into the water, potentially causing contamination.

4.8 Health Data

As we stated in Chapter 3, we contacted three agencies to obtain records on the occurrences of methemoglobinemia in Puerto Rico. None of the agencies had the data that we were seeking. Both the EPA and the San Jorge Children's Hospital told us that the records were kept according to contaminants and not according to health problems. Because the data was kept in this manner, we were unable to determine the number of occurrences of methemoglobinemia on the island. This made it difficult to relate the high levels of nitrates we found in the Manatí-Vega Baja area to problems that these levels may have caused (as discussed in Chapter 2).

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

Data presented in Chapter 4 shows that nitrate contamination is not a widespread problem across the eastern half of Puerto Rico. Problems are occurring on very localized areas such as those that have intense agriculture and in places that have deficient sewage and septic systems. Minimal health data exists for the occurrences of either methemoglobinemia or non-Hodgkin's lymphoma, but elevated concentrations of nitrates in the Manatí-Vega Baja area may have caused problems in the past, or they may lead to problems in the future. Nitrate concentrations should continue to be monitored in the future to ensure they stay within safe levels.

The data for eastern Puerto Rico showed relatively low concentrations of nitrates during the six weeks in which we sampled. The variance in concentrations were due to factors such as topography of the area surrounding the sampling site, land usage surrounding the sampling area, and amount of rainfall the area received before we sampled.

Of the sites that were located near agricultural and pasture areas, none showed a large increase in nitrate concentrations. This may be due to a lack of rain, since all sampling was done during the dry season. Another reason the concentrations were low may be that the farmers in some areas are careful about how much nitrogen-based fertilizer they are putting on their crops. If they were regulating their fertilizer usage and putting fertilizer down only during key periods, the concentrations of nitrates would be kept low.

The wells in the Manatí-Vega Baja area were shown to have relatively high concentrations of nitrates compared to the rest of the island. The elevated concentrations can be traced to the pineapple fields, septic tanks, and sewage systems in the area. Although none of the concentrations were over the EPA's limit of 10 mg/L, the concentrations in this area were much higher than those of eastern Puerto Rico. The wells are used as a public drinking supply and have had a history of high nitrate concentrations (Conde-Costas & Gomez-Gomez, 1999). Nitrate concentrations in the wells have the potential to rise above the limit set by the EPA due to the fertilizer usage in the area. If farmers continue to use the amount of fertilizer they are using now, the area will continue to experience elevated nitrate concentrations.

5.1 Recommendation One–Second Study

Our first recommendation is that another sampling take place during the beginning of the rainy season. This is when nitrates will begin to leach from the soils, which would mean the highest concentrations of nitrates would be observed. To ensure that nitrate levels are not a problem for eastern Puerto Rico, it is important to determine the highest concentrations of the year. Although the concentrations we observed were well below the EPA's limit of 10 mg/L and below the 4 mg/L that may be associated with a risk of non-Hodgkin's lymphoma, these concentrations may rise during the rainy season.

5.2 Recommendation Two-Monitor Concentrations

Our second recommendation is to continue to monitor nitrate concentrations in the future. If the governor's plan is successful, the 20 percent rise in agriculture may lead to higher nitrate concentrations in local streams and rivers. This may lead to a higher incidence of methemoglobinemia in young children. Although health data is not recorded by illness on the island, the increased agriculture could have an effect on the number of cases of this condition in future years.

5.3 Recommendation Three-Record Health Data

This leads to our third recommendation that health conditions be recorded according to illness. Statistics on the occurrence of many conditions, not only methemoglobinemia, are very important for a variety of reasons. They help to show what types of problems are occurring on the island, where these problems are taking place, how many people a problem may be affecting, and the demographics of who a problem is affecting. If the data were kept properly, it would then be easier for researchers to determine the best method to solve a specific health problem or to determine causal relationships between water quality and illness.

5.4 Recommendation Four-Regulating Fertilizer

One recommendation for controlling nitrate concentration for the Manatí-Vega Baja area is the plan discussed by Yadav and Wall (See Chapter 2 for the benefit-cost analysis). Paying the farmers to control their fertilizer usage may reduce nitrate concentrations in the wells and prevent or reduce incidence of methemoglobinemia and/or non-Hodgkin's lymphoma. It is difficult to determine costs for this area since accurate health records are not kept. If accurate health records were available for the occurrence of methemoglobinemaia and non-Hodgkin's lymphoma, the cost of treating those affected could be weighed against the cost of paying the farmers to regulate fertilizer usage in order to determine what method or methods would be cost-effective in the reduction of nitrates.

5.5 Recommendation Five-Update Land Usage Data

Another problem we encountered was trying to obtain up to date land usage maps. The current land usage maps for the island are from the years of 1977 and 1987. Over the past fourteen years, however, the land usage on the island has changed as the economy has shifted from agriculture to industry. In order to pinpoint the sources of nitrates and other contaminants, it is necessary to have accurate land usage information. The Department of Geography at the University of Puerto Rico (UPR) at Río Piedras has begun work on updating the land usage maps for Puerto Rico. We recommend that the USGS work in conjunction with UPR to ensure that these maps are completed.

APPENDIX A – UNITED STATES GEOLOGICAL SURVEY

On March 3, 1879, the United States Geological Survey (USGS) was established as part of the Department of the Interior. The USGS was created to classify public lands, examine geological structure, mineral resources and products of the national domain. The first project the USGS took on was the classification of public lands. The agency studied the land in sections of the US to determine the location of mineral resources within these public lands.

Today, the USGS is the world leader in natural science research. The organization provides the nation with reliable data that helps the USGS to understand and describe the geology of the Earth, minimizes casualties and property damage due to natural disasters, provides clean drinking water, and manages natural resources and improves the quality of life. In the future, the USGS plans to extend their programs and capabilities, to continue to be the leader in natural science research and to provide leadership to resolve complex problems.

The national headquarters of the United States Geological Survey is located in Reston, Virginia. The agency contains four major divisions. They are cartography, geology, hydrology and biology. These four departments employ 8,600 scientific, technical, clerical, and administrative personnel.

For the fiscal year of 2001, the total budget for the USGS was 895.4 million dollars. This money was split among the four divisions, as seen in figure A.1.

Chip Groat, who is the director, and Kathryn Clement, who is the deputy director, head the organization. The Puerto Rico office falls into the eastern region, which is headed by Bonnie McGregor. The entire breakdown of the USGS is shown in figure A.2.

The Caribbean District of the USGS is located in Guaynabo, Puerto Rico. The office employs 80 people, and the District Chief is Dr. Matthew C. Larsen. In Puerto Rico, the Geological Survey is responsible for maintaining the quality of the water supply by operating gauging stations and reservoir stations to gather data on surface and ground water quantity and quality. This data is collected and is used to determine quality, quantity, and location of Puerto Rico's water resources. Since the island has a high rate of natural disaster occurrences, such as hurricanes and earthquakes, the USGS is also attempting to improve ways of providing the public with clean, safe drinking water.

In accordance with the goals of the USGS in Puerto Rico, our project focuses on providing data on the pollution of streams and the source of this pollution. Through our efforts, the USGS will be able to find ways of improving water quality for the citizens of Puerto Rico.

Figure A.1 USGS 2000 Budget Breakdown

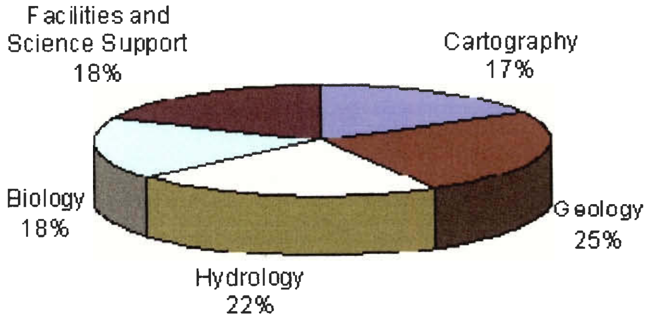
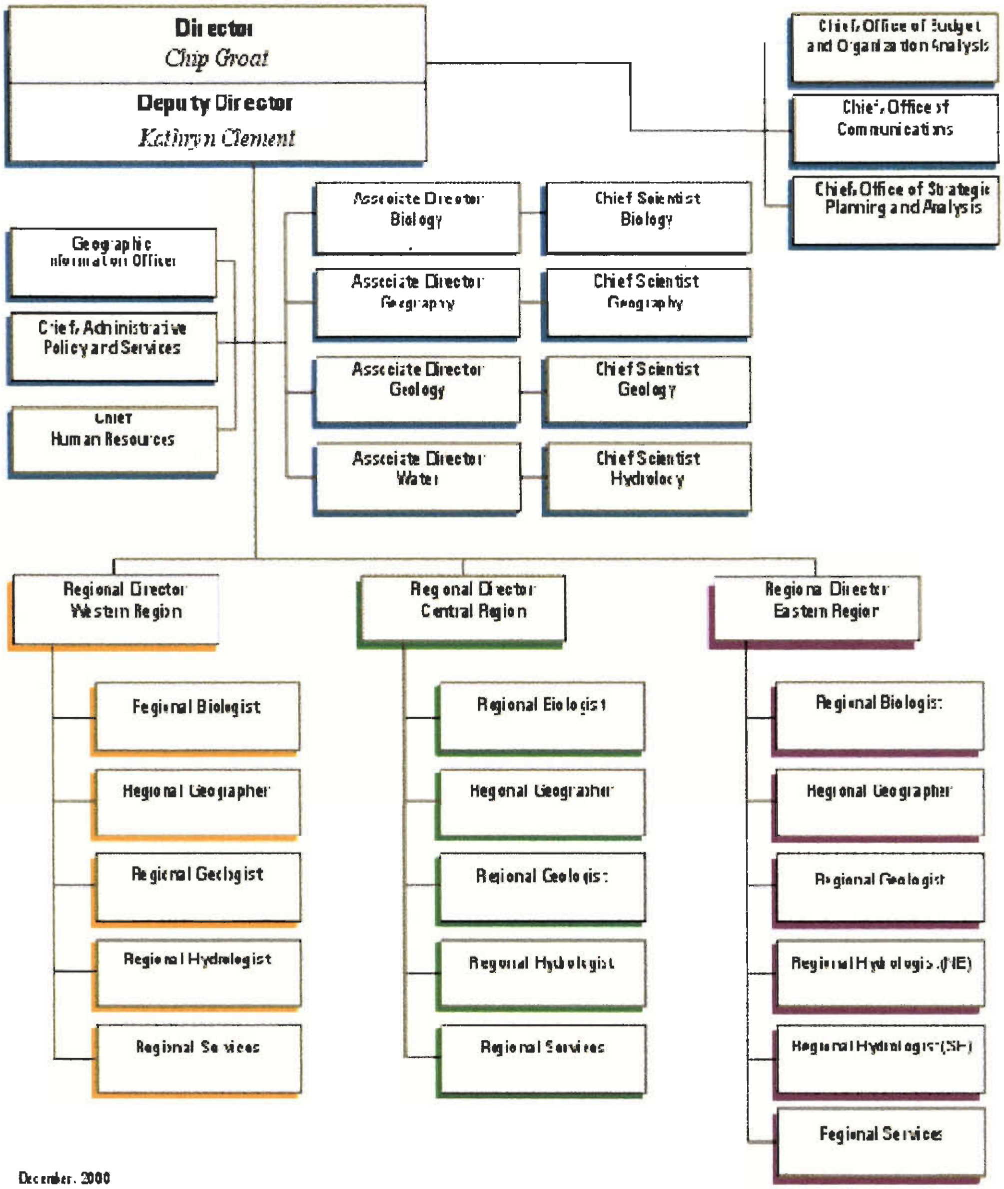


Figure A.2 USGS Personnel Breakdown



December, 2000

Source: www.USGS.gov

APPENDIX B- GLOSSARY

Autotroph - An organism capable of synthesizing its own food from inorganic substances, using light or chemical energy. Green plants, algae, and certain bacteria are autotrophs.

Basalt - A hard, dense, dark volcanic rock having a glassy appearance.

Carcinogenic- A cancer-causing substance or agent.

Carbonate Rock – A rock composed of calcium carbonate or other carbonates.

E. Coli - A bacillus *(Escherichia coli)* normally found in the human gastrointestinal tract and existing as numerous strains.

Groundwater - Water beneath the earth's surface, often between saturated soil and rock, that supplies wells and springs.

Heterotroph - An organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.

Historical Data – previous data collected on the site being studied.

Hydrophobic - Repelling, tending not to combine with, or incapable of dissolving in water.

Leach - To remove soluble or other constituents from water by the action of a percolating liquid.

Nitroso- A prefix (also used adjectively) designating the group or radical NO, called the nitroso group, or its compounds.

Nitrosomonas – soil bacteria responsible for the first step in the nitrification process.

Nitrobacter – soil bacteria responsible for second step of nitrification.

Non-Hodgkin's Lymphoma- A group of lymphomas which differ in important ways from Hodgkin's disease and are classified according to the microscopic appearance of the cancer cells. The disease is classified as either low grade (slowly growing), intermediate grade or high grade (rapidly growing) and may be treated in a variety of ways depending on the exact diagnosis. Previously called lymphosarcoma.

pH – a measure of the acidity of a liquid.

Protoplasm - The complex, semifluid, translucent substance that constitutes the living matter of plant and animal cells and manifests the essential life functions of a cell. Composed of proteins, fats, and other molecules suspended in water, it includes the nucleus and cytoplasm.

Runoff - Rainfall not absorbed by soil.

Sandstone - A sedimentary rock formed by the consolidation and compaction of sand and held together by a natural cement, such as silica.

Urea - A water soluble chemical $CO(NH_2)_2$, found in urine of mammals and other organisms.

Vacuole - A small cavity in the cytoplasm of a cell, bound by a single membrane and containing water, food, or metabolic waste.

Watershed - A ridge of high land dividing two areas that are drained by different river systems.

APPENDIX C - COLLECTED DATA

Sampling Site Locations

Table C.1 El Yunque Locations

Name	Date	Time	Position
Cascada La Coca	3/26/01	1:00 PM	N 18 19.1 W 65 46.2
Guaba A	4/2/01	11:20 AM	N 18 16.9 W 65 47.3
Guaba A	3/15/01	12:30 PM	N 18 16.9 W 65 47.3
Guaba A	3/27/01	11:00 AM	N 18 16.9 W 65 47.3
Guaba B	3/15/01	1:00 PM	Same as Gurabo A
Guaba B	3/27/01	11:15 AM	Same as Gurabo A
Icacos	3/15/01	11:25 AM	N 18 16.5 W 65 47.1
Icacos	3/27/01	1:15 PM	N 18 16.5 W 65 47.1
Icacos	4/2/01	2:15 PM	N 18 16.5 W 65 47.1
Icacos LTER	3/15/01	11:39 AM	N 18 16.6 W 65 47.1
Icacos LTER	4/2/01	2:30 PM	N 18 16.6 W 65 47.1
Icacos LTER	3/27/01	N/A	N 18 16.6 W 65 47.1
Icacos Lter B	3/15/01	11:56 AM	70 feet from Icacos
Icacos Lter B	4/2/01	2:45 PM	70 feet from Icacos
Icacos Lter B	3/27/01	N/A	70 feet from Icacos
LS 43 Stream	4/2/01	10:30 AM	Rio Guabo (coord.)
Ls 43 Well	4/2/01	10:10 AM	Same as LS 43 Stream
Mameyes	3/15/01	9:30 AM	N 18 19.6 W 65 45.0
Mameyes	3/26/01	9:10 AM	N 18 21.9 W 65 46.2
Mameyes	4/4/01	9:30 AM	N 18 21.9 W 65 46.2
Mameyes	3/27/01	9:00 AM	N 18 19.6 W 65 45.0
Quebrada Juan Diego II	3/26/01	12:15 PM	30 feet from Q.J.D. I
Quebrada Juan Diego I	3/26/01	12:15 PM	N 18 18.6 W 65 46.5
Quebrada Tabonuco	3/26/01	9:30 AM	N 18 21.5 W 65 46.1
Mina De Oro Trail	3/26/01	10:45 AM	N 18 19.017 W 65 47.421
Mina De Oro Trail	3/26/01	11:05 AM	N 18 18.139 W 65 47.357

Table C.2 Eastern Puerto Rico Location

Name	Date	Time	Position
Santiago Trib.	3/21/01	12:00 PM	N 18 11.9 W 65 43.5
Anton Ruiz	3/21/01	10:30 AM	N 18 10.4 W 65 44.3
Boca Prieta	3/21/01	10:00 AM	N 18 10.1 W 65 44.8
Canovanas	4/4/01	12:35 PM	N 18 19.0 W 65 53.3
Cayaguas	4/4/01	3:10 PM	N 18 09.0 W 65 57.0
Gurabo A (181 Overpass)	3/20/01	9:15 AM	N18 15.4 W 65 58.0
Gurabo B (941 overpass)	3/20/01	9:45 AM	N 18 15.8 W 65 59.0
Lapas	4/3/01	11:09 AM	N18 03.6 W 66 14.4
Majada	4/3/01	11:37 AM	N 18 01.9 W 66 14.6
Quebrada Grande (Junct. 181-852)	3/20/01	11:00 AM	N 18 20.2 W 65 59.3
Santiago	3/21/01	11:25 AM	N 18 12.5 W 65 43.9
Rio Turabo	4/3/01	12:00 PM	N 18 12.5 W 66 02.8
Rio Gurabo	4/6/01	10:00 AM	N 18 14.4 W 65 55.3
Quebrada Gonzalez	4/6/01	N/A	N 18 17.6 W 54.9
Rio Canovanillas	4/6/01	N/A	N 18 18.0 W 65 55.5
Rio Canovanas	4/6/01	N/A	N 18 19.3 W 65 53.3

Table C.3 Manatí-Vega Baja Locations

Name	Date	Time	Position
La Lunguna Tortuguero	4/10/01	N/A	N 18 28 44 W 66 26 44
Pozo Cudad Real	4/10/01	N/A	N 18 27 00 W 66 25 04
Pozo Algarrobo	4/10/01	N/A	N 18 26 39 W 66 24 34
Quebrada Hicatea	4/10/01	N/A	N 18 23 45 W 66 24 53
Pozo Pugnado II	4/10/01	N/A	N 18 25 44 W 66 24 38
Triline	4/10/01	N/A	N 18 26 08 W 66 27 59
Sobrino	4/10/01	N/A	N 18 26 19 W 66 25 57

Nitrate Concentration Data

Table C.4 Historical Data

Name	Position	1997 Concentrations (mg/L)	1998 Concentrations (mg/L)	1999 Concentrations (mg/L)
Quebrada	N18 23 W 65 58	0.26	0.2	1.18
Rio Guamani	N/A	N/A	0.88	0.48
Rio Caguitas	N 18 15 W 66 01	0.05	0.067	0.62
Rio Bairoa	N 18 15 W 66 02	0.89	0.074	1.36
Rio Gurabo	N 18 15 W 65 59	0.73	0.691	0.71
Lago Loiza	N 18 19 W 66 01	0.07	N/A	0.12
Rio Grande De Loiza	N 18 21 W 66 00	0.16	1.16	0.884
Rio Espiritu	N 18 21 W 65 48	N/A	N/A	N/A
Rio Humacao	N 18 08 W 65 49	0.42	0.7	0.69
Rio Guayanes	N 18 03 W 65 54	0.265	N/A	0.55
Rio Guayanes	N 18 03 W 65 49	N/A	0.222	N/A
Rio Maunabo	N 18 00 W 65 54	0.15	N/A	0.35
Rio Chico	N 17 59 W 66 00	0	9.11	0.27
Rio Hondo	N 18 26 W 66 09	0.28	0.436	0.057
Rio de Bayamon	N 18 14 W 66 08	0.5	0.53	N/A
Rio Guaynabo	N 18 22 W 66 07	0.76	0.78	0.796
Rio de Bayamon	N 18 24 W 66 04	N/A	0.324	0.444
Rio Piedras	N 18 22 W 66 03	N/A	0.51	1.07
Rio Piedras	N 18 24 W 66 04	0.89	0.81	0.918
Laguna San Jose	N 18 25 W 66 02	0	0.01	N/A
Bahia de San Juan	N 18 26 W 66 05	N/A	0.022	0.061
Rio De La Plata	N 18 03 W 66 05	N/A	1.57	2.26
Rio De La Plata	N 18 44 W 66 12	N/A	N/A	1.38
Rio Guadiana	N 18 18 W 66 13	N/A	0.828	1.88
Rio De La Plata	N 18 24 W 66 15	N/A	0.414	0.77

Table C.5 El Yunque Data

Name	Lab Spect. (mg/L)	Field Spect. (mg/L)	Color Wheel (mg/L)
Cascada La Coca	0.0	0.7	0.6
Guaba A	0.0	1.0	1.8
Guaba A	0.4	0.7	0.7
Guaba A	0.5	0.3	1.1
Guaba B	0.0	0.0	0.1
Guaba B	0.0	0.0	0.5
Icacos	0.0	0.2	0.5
Icacos	0.2	0.2	0.9
Icacos	0.0	0.7	1.4
Icacos Lter	0.2	0.8	0.5
Icacos Lter	0.0	0.8	1.1
Icacos Lter	0.3	0.0	1.4
Icacos Lter B	0.3	0.0	0.0
Icacos Lter B	0.0	0.2	1.4
Icacos Lter B	0.0	1.6	2.3
LS 43 Stream	0.0	0.6	1.7
Ls 43 Well	0.0	0.2	1.0
Mameyes	0.2	0.0	0.6
Mameyes	0.4	0.3	0.5
Mameyes	0.0	0.0	0.9
Mameyes	0.5	0.9	0.9
Quebrada J.D. II	0.0	1.1	0.5
Quebrada Juan Diego I	0.0	0.4	0.2
Quebrada Tabonuco	0.0	0.0	0.6
Mina De Oro Trail	0.2	0.2	0.5
Mina De Oro Trail	0.0	0.3	0.2

Table C.6 Eastern Puerto Rico Data

Name	**Lab Spect. (mg/L)**	**Field Spect. (mg/L)**	**Color Wheel (mg/L)**
Santiago Trib.	0.0	0.0	0.1
Anton Ruiz	0.0	0.0	0.7
Boca Prieta	0.0	0.0	0.9
Canovanas	0.4	0.1	1.1
Cayaguas	0.3	0.0	1.4
Gurabo A (181 Overpass)	1.0	0.5	1.8
Gurabo B (941 overpass)	0.0	0.0	0.9
Lapas	0.2	N/A	1.3
Majada	0.3	N/A	1.4
Quebrada Grande (Junct. 181-852)	0.0	0.2	0.5
Santiago	0.0	-0.1	0.5
Rio Turabo	0.6	N/A	N/A
Rio Gurabo	1.1	1.1	2.2
Quebrada Gonzalez	0.0	N/A	1.1
Rio Canovanillas	0.0	0.0	0.9
Rio Canovanas	0.4	N/A	0.5

Table C.7 Manatí-Vega Baja Data

Name	**Lab Spect. (mg/L)**	**Field Spect. (mg/L)**	**Color Wheel (mg/L)**
La Lunguna Tortuguero	0.4	N/A	0.5
Pozo Cudad Real	3.4	4.5	6.6
Pozo Algarrobo	2.1	3.0	3.7
Quebrada Hicatea	0.0	0.1	0.5
Pozo Pugnado II	6.5	7.8	7.9
Triline	3.5	4.8	5.3
Sobrino	6.6	9.4	9.6

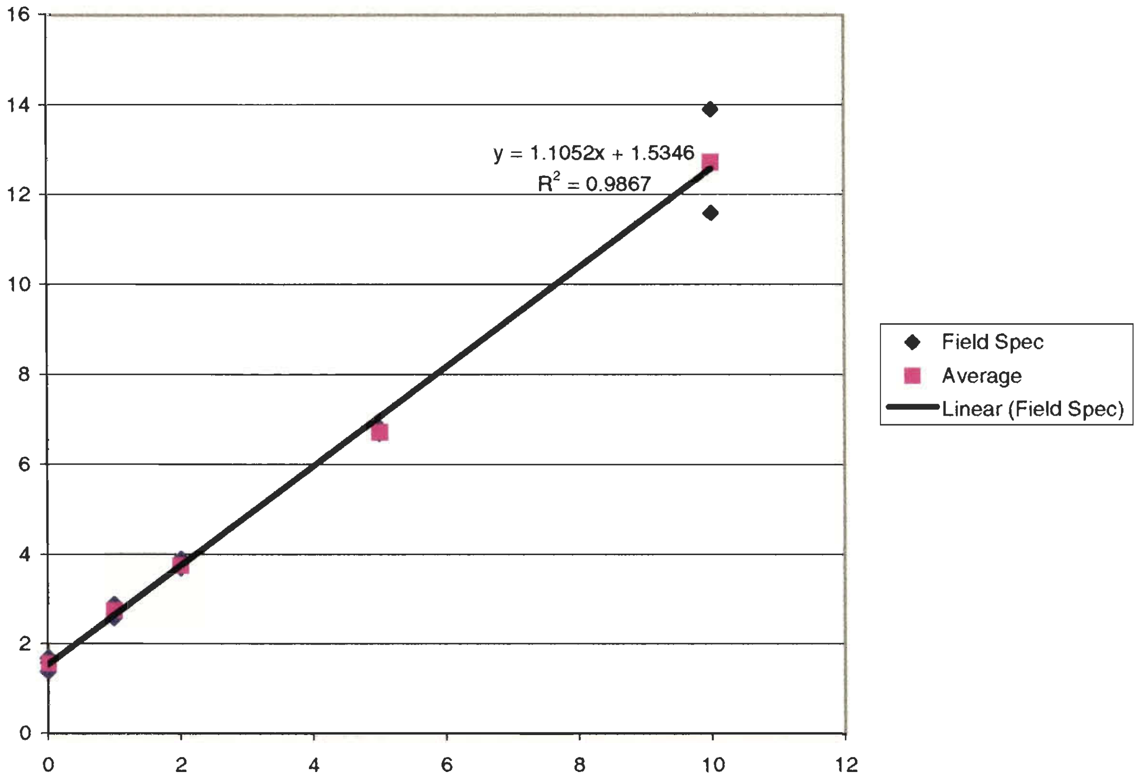
Table C.7 Bottled Water Data

Brand Name	Concentration
Volveric	1.9
Solares	0.4
Evian	0.8
Naya	0.4
La Montaña	0.3
Calistoga	1.1
Gerber Baby Water	0.7
Cristalia Baby Water	0.2
Castle Springs	1.0
Perrier	3.4
Calistoga II	0.0
Gerolsteiner	0.0

APPENDIX D – LINEAR REGRESSION ANALYSIS

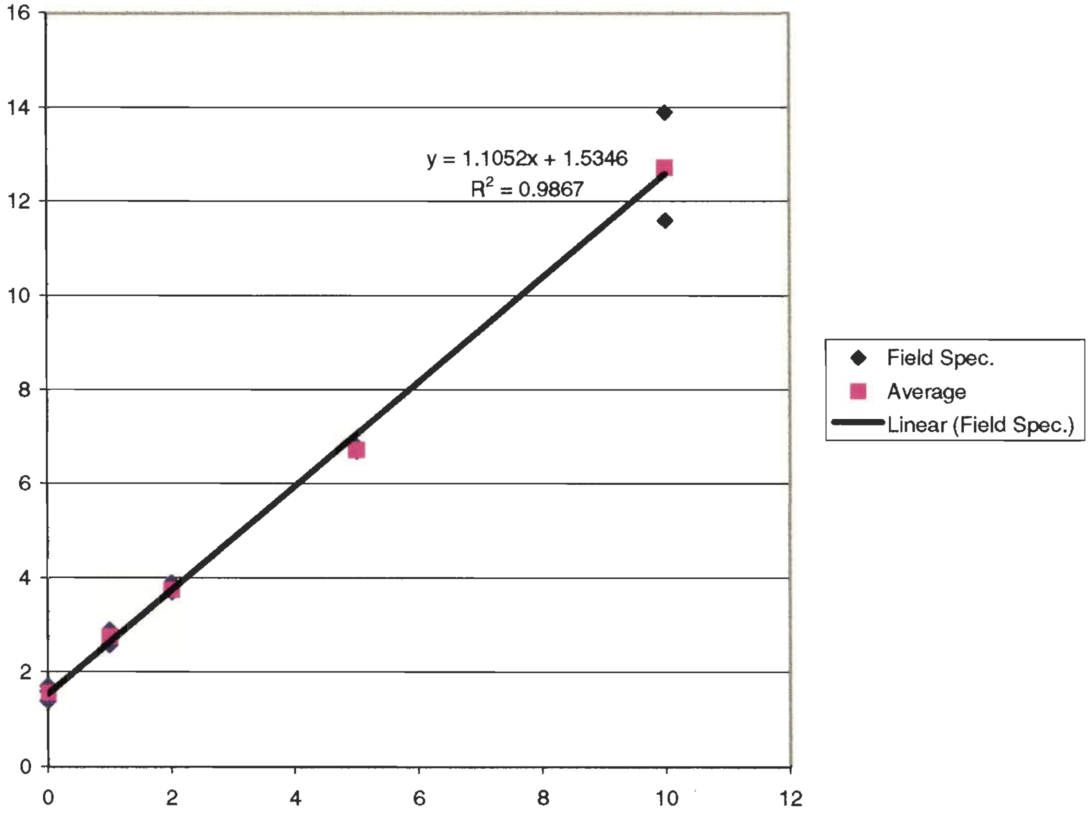
Below are the three graphs we used to perform a linear regression analysis on the three machines used to measure nitrate concentrations. We plotted the observed reading versus the actual concentration of five standards. We then used Excel to determine a best fit line for the points. Once the line was drawn by Excel, we determined the equation for the line in the form $y = mx + b$, m being the slope of the line and b being the value where the line crosses the y axis. We then corrected all values taken during the study by substituting the value the machine gave us into the equation above. This value was substituted for y and we then solved for x. This gave us the actual concentration of the sample. On the following pages are the three Excel graphs for the three machines with the equations on them (Figures D.1, D.2, D.3). The R^2 value shown below the equation on each chart represents how close the points are to forming a straight line. The closer the R^2 value is to one, the closer the points are to forming a straight line.

Figure D.1 Linear Regression graph: Lab Spectrophotometer



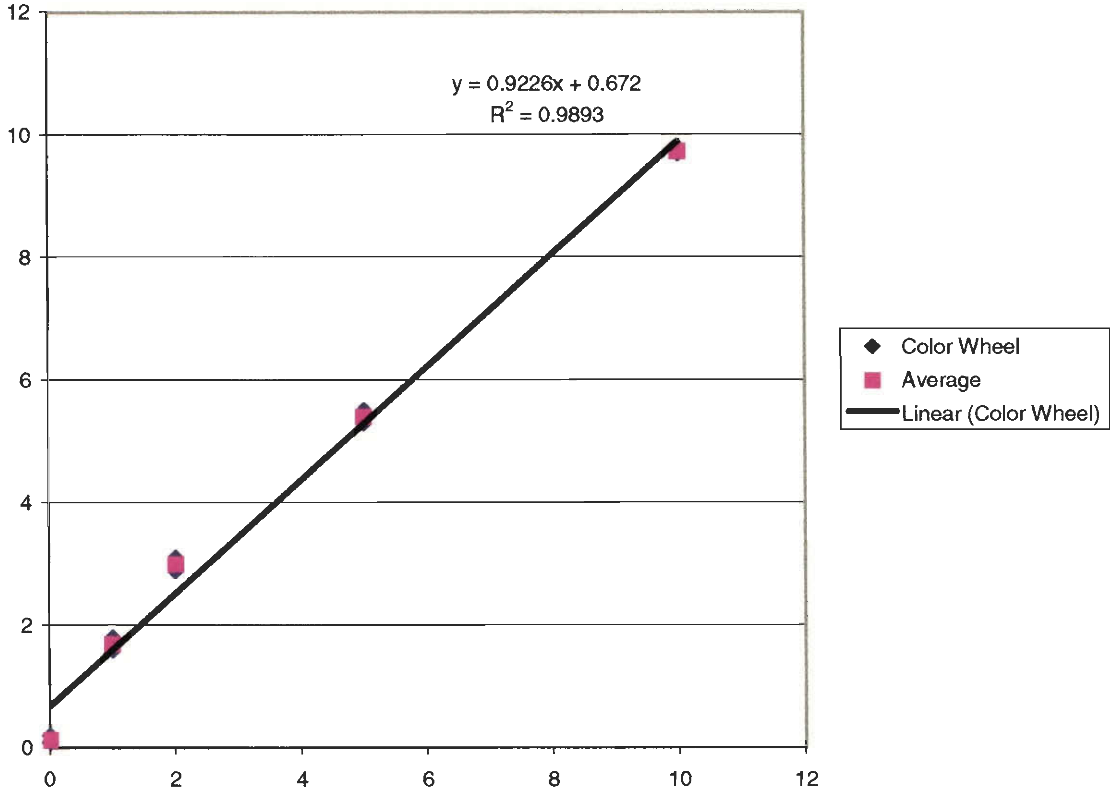
Source: (Gamache, Jorczak, Schienda, 2001)

Figure D.2 Linear Regression Graph: Field Spectrophotometer



Source: (Gamache, Jorczak, Schienda, 2001)

Figure D.3 Linear Regression Graph: Color Wheel



Source: (Gamache, Jorczak, Schienda, 2001)

References

Abeliovich, A., Ines, M. & Soares, M., (1998, December). Wheat straw as a substitute for Denitrification. Water Research, 32, 12, pg. 3790-3794. Retrieved February 17, 2001, from the World Wide Web: http://www.sciencedirect.com.

Bosch H., Rosenfield A., Huston R., Shipman H. & Woodward F. (February, 1950). Methemoglobinemia and Minnesota well supplies. Journal of the American Water Works Association, 42, pp. 161-170.

Bunce, N. J. (1990). Environmental chemistry. Winnipeg: Wuerz Publishing Ltd.

Byrnes, M. E. (1994). Field sampling Methods for Remedial Investigations. Boca Raton: Lewis Publishers.

Chipperfield, K., Zelarth, B.J., Hii, B. Liebscher, H., Rul, J.W., Grove, G. & Szeto, S.Y., (1998, June 15). Agricultural land use practices and nitrate contamination in the Abbotsford Aquifer, British Columbia, Canada. Agriculture, Ecosystems & Environment, 69, 2, pg. 99-112. Retrieved February 17, 2001, from the World Wide Web: http://www.sciencedirect.com.

Central Intelligence Agency (CIA). (2000, January 1). The World Fact Book. Retrieved April 2, 2001, from the World Wide Web: http://www.cia.gov/cia/publications/factbook/geos/rq.html#Econ.

Conde-Costas, C., & Gómez-Gómez, F. (1999). Assessment of nitrate contamination of the upper aquifer in the Manatí-Vega Baja area, Puerto Rico (Water-Resources Investigations report 99-4040). San Juan: U.S. Department of Interior, U.S. Geological Survey.

Croen, L.A., Todoroff, K. & Shaw G.M. (2001). Maternal exposure to nitrate from drinking water and diet and risk for neural tube defects. American Journal of Epidemiology, 153, 4, pg. 325-331. Retrieved March 22, 2001, from the World Wide Web: http://www.sciencedirect.com.

Daniel, D. E., & Trautwein S. J. (Ed.). (1994) Hydraulic Conductivity and waste Contaminant transport in Soil. Philadelphia: ASTM.

Demars, K. R., Richardson G. N., & Yong R. N., (ed.). (1995) Dredging, remediation, and Containment of Contaminated Sediments. Philadelphia: ASTM.

Evangelou, V. P., (1998). Environmental Soil and Water Chemistry. New York: John Wiley & Sins.

Fan, Anna M. & Steinburg, Valerie E. (1995). Health Implications of Nitrate and Nitrite

Freeze, A. R., & Cherry J. A. (1979). Groundwater. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Jain, M.C., Kumar, S., Kumar, U., Majumdar, D. & Pathak, H., (2000, November). Reducing nitrous oxide emissions from an irrigated rice field of north India with nitrification inhibitors. Agriculture, Ecosystems & Environment, 81, 3, pg 163-169. Retrieved February 17, 2001, from the World Wide Web: http://www.sciencedirect.com.

Lecomte, Paul. (1999). Polluted Sites Remediation of Soils and Groundwater. Brookfield: A.A. Balkema Publishers, 1999.

Levallois, P., Ayotte, P., Van Maanen, J.M.S., Desrosiers, T., Gingras, S., Dallinga, J.W., Vermeer, I.T.M., Zee, J., Poirier, G., (November, 2000). Excretion of volatile nitrosamines in a rural population in relation to food and drinking water consumption. Food and Chemical Toxicology 38, 11, pg 1013-1019. Retrieved March 19, 2001 from the World Wide Web: http://www.sciencedirect.com.

Lloyd, J. W., & Heathcote, J. A., (1985). Natural Inorganic Hydrochemistry in Relation to Groundwater: An Introduction. Oxford: Clarendon Press.

Masters, G. (1998). Introduction to Environmental Engineering and Science. (pp. 177). Prentice Hall: Simon & Schuster/ A Viacom Company.

National Research Council. (1978). Nitrates: an environmental assessment. Washington, D.C.: The National Research Council.

Polakoff, Judy (December, 1997). Public Health Goals for Nitrate and Nitrite in Drinking Water. Pesticide and Environmental Toxicology Section. Office of Environmental Health Hazard Assessment. California Environmental Protection Agency.

Powledge, Fred. (1982). Water. Toronto: McGraw-Hill Ryerson Ltd.

Rice, Rip G.(Ed.). (1985). Safe Drinking Water- The Impact of Chemicals on a Limited Recourse. (pp. 2, 13). Michigan: Lewis Publishers.

Santarsiero, A., Minelli, L., Cutilli, D. & Cappiello, G., (December 2000). Hygienic aspects related to burial. Michrochemical Journal 67,1-3, pg 135-139. Retrieved March 19, 2001 from the World Wide Web: http://www.sciencedirect.com.

Shrimali, M. & Singh, K.P., (2001). New methods of nitrate removal from water. Environmental Pollution 112, pg 351-359. Retrieved March 29, 2001 from the World Wide Web: http://www.sciencedirect.com.

Swaddle, J.W. (1990) Applied Inorganic Chemistry. Calgary: The University of Calgary Press.

Van Leeuwen, F.X.R. (2000, April 1). Safe drinking water the toxicologists approach. Food and Chemical Toxicology 38, Supplement 1, pg S51-S58. Retrieved March 19, 2001, from the World Wide Web: http://www.sciencedirect.com.

Vazquez, M.K. (March 12, 2001) Plowing ahead: Agriculture Department sets out to save Puerto Rico growers and sow the seeds of a farming renaissance. The San Juan Star. pp 32-34

Winterm, T. C., Harvey, J. D & Franke, O. L. (1998) Groundwater and Surface Water A Single Resource. U.S. Geological Survey Circular 1139 (1998).

Wise, Donald L., Trantolo, Debra J., Cichon, Edward J., Inyang, Hilary I., & Strottmeister, Ulrich. (ed.). Bioremediation of Contaminated Soils. New York: Marcel Dekker, Inc.

Yadav, S.N., & Wall, D.B, (1998) Benefit-cost analysis of best management practices Implemented to control nitrate contamination. Water Resource Research, 34, 3, pp 497-504

List of Interviews

Camesano, T., Ph.D. Environmental Engineering. Professor of Chemical Engineering, Worcester Polytech., Interviewed January 25, 2000.

Nowick, H. Professor of Chemical Engineering, Worcester Polytech., Interviewed January 25, 2000.

Guerrin, P., Water Resource Coordinator, Worcester D.P.W., Interviewed February 14, 2000.