Nepal Drinking Water Quality Assessment: Nitrates and Ammonia

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ABSTRACT

The objective of this study was to assess the contamination from nitrates and ammonia of drinking water in Nepal. The data was collected and analyzed in Nepal from groundwater and surface water sources for four weeks in January of 2000.

Nitrate contamination in Nepal is much more prevalent at shallow depths due to anthropogenic sources. Nineteen percent of the wells sampled shallower than 50 feet were contaminated with nitrates above the World Health Organization (WHO) limit of 10 mg/L NO_3^- -N. There were no wells deeper than 100 feet that were contaminated with nitrates above the WHO guidelines. Ammonia contamination is minimal in shallow wells. However, high ammonia concentrations exist deep in the aquifers due to the geologic depositions of peat and lignite beds.

Nitrate contamination in Nepal is more common in urban areas than in rural agricultural regions. The average concentration of nitrates from urban drinking water sources is 3.9 mg/L NO_3^- -N. However, the average concentration in rural areas is only 1.2 mg/L NO_3^- - N. There are many urban anthropogenic sources of nitrate contamination in Nepal such as poorly designed septic systems and inadequate containment and treatment of sewage. The primary rural anthropogenic source of nitrates in groundwater is from agricultural fertilizers. The lack of rural nitrate contamination is possibly a seasonal result of reduced infiltration and surface run-off during the dry season. Both dry-season and monsoon season sampling must be performed to verify if agricultural nitrate concentrations are consistent year-round.

In addition, nitrate concentrations are relatively low in supplied and treated water sources. These sources include water that is treated at water treatment plants and supplied though piped networks to large urban centers and tube wells, most of which have only recently been installed. However, nitrate concentrations in traditional water sources were very high. Traditional water sources are those sites that have been used as drinking water sources for hundreds of years such as water spouts and hand-dug wells. The average nitrate concentration in traditional water sources was 7.6 mg/L NO_3^- -N, but the average nitrate concentrations in supplied water sources was only 1.9 mg/L NO_3^- -N.

Thesis Supervisor: Susan Murcott

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1.0 INTRODUCTION

Water is essential for life, yet even in 1998, more than one billion people in developing countries lacked access to safe drinking water. The dire effects of water pollution are readily apparent. Worldwide, an estimated 900 million people suffer from water related diarrheal illnesses, and approximately 2 million people die annually from these same diseases (World Resources Institute, 1999).

These water quality problems that plague much of the developing world also plague Nepal, a small country sandwiched between India and China. Nepal is the seventh poorest nation in the world; more than half of the Nepali population lives below the international poverty line, and the average yearly income is only US$200 (USAID, 1999). Towns and villages are expanding without proper provisions for adequate water supply protection or distribution. Rural populations are moving from the countryside to the already overcrowded urban centers. Proper waste and sewage disposal and treatment systems are non-existent, so as the population grows, pollution continues to worsen and threaten drinking water sources. Many rural villages cannot afford the costs of obtaining clean water from deep wells or other clean sources and are forced to drink either surface water or polluted water from the upper depths of aquifers.

Although Nepal is a country rich in freshwater resources, these resources are unevenly distributed. There is either too much water during the monsoon season or too little water during the dry season. Significant water quality problems are present in the existing resources. More than 70% of Nepal's population does not have access to clean, safe drinking water and an estimated 37% of the population does not even have access to the most rudimentary water treatment systems (World Resources Institute, 1999). According to UNICEF-Nepal, 1 in 3 children die before the age of five due to water-borne illnesses. Diarrheal illnesses cause 44,000 childhood deaths every year making it the leading cause of childhood death in Nepal. Of those children who do survive, 67% have stunted growth due to the loss of essential nutrients (Murcott, 1999).

This report assesses the current status of drinking water quality in Nepal from nitrate and ammonia contamination. The study compares contamination levels of groundwater from tube wells, deep boring wells, and traditional water sources. In addition, special emphasis is given to comparing contamination in urban and rural regions.

The field research for this study was performed in Nepal during the month of January, 2000. More than 120 groundwater and surface water samples were collected and analyzed. Drinking water samples were collected from various regions around Nepal including the rural flatlands of the Terai and the rural and urban areas of the Kathmandu Valley. Samples were collected from different groundwater source types including tube wells, hand-dug wells, water spouts, and deep boring wells. Several surface water sources were also analyzed to assess groundwater contamination from the recharge of polluted river water into unconfined aquifers. In addition, this report investigates the possible sources of non-point source nitrate and ammonia pollutants. The following sections summarize and analyze the results of the water quality testing for nitrates and ammonia, outline recommendations for future testing, and recommend alternative drinking water supplies for the Nepali people.

1.1 NITROGEN CYCLE

Nitrogen exists in many forms in the natural environment and is an essential nutrient for life. Nitrogen is an important constituent of cellular protein and nucleic acids. The transformation of nitrogen between different phases forms the nitrogen cycle and occurs in all plants and microorganisms. The nitrogen cycle is shown in **Figure 1.1** below. There are five main processes that form the cycle: fixation, ammonification, synthesis, nitrification, and denitrification. Fixation is most commonly performed by plants and microorganisms. The process involves transforming inert atmospheric nitrogen gas into organic forms. Ammonification is the change of organic nitrogen to an ammonium form.[1] This process occurs during decomposition of plant and animal matter and human

[1] Ammonia can exist as ammonium, NH_4^+, or as ammonia, NH_3, depending only on pH. The pH of most soils and groundwaters dictates that ammonium is the dominant species. In this paper, unless otherwise stated, the term "ammonia" generically refers to the sum of the ammonium, NH_4^+, and the ammonia, NH_3, species.

and animal waste products. Synthesis refers to the biochemical mechanism that uses ammonia or nitrate compounds to form plant proteins.

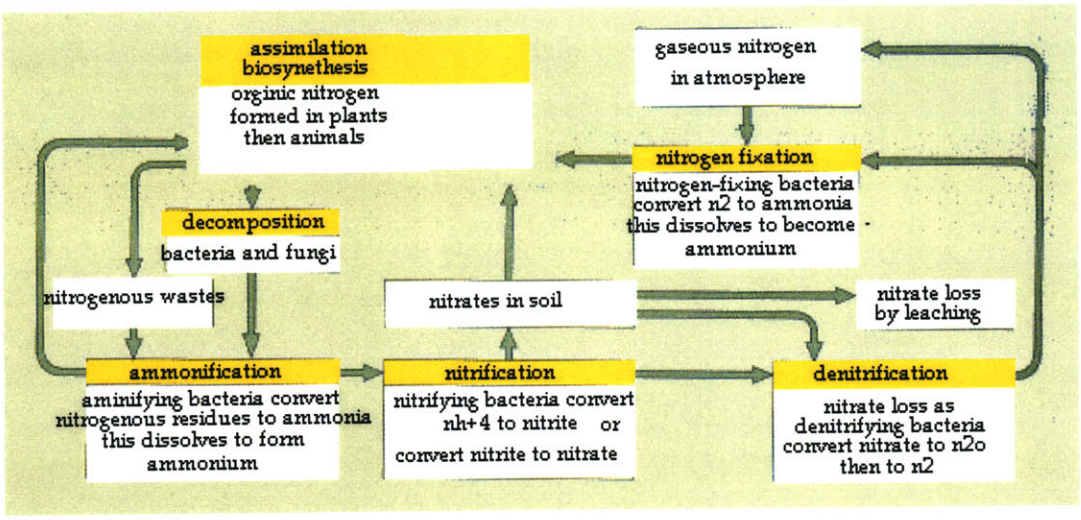

Figure 1.1: Nitrogen Cycle (USEPA, Managing Nonpoint Source Pollution From Agriculture, 1999)

Nitrification and denitrification are two of the most important processes for this water quality study. Nitrification is the biological oxidation of ammonium ions. This reaction proceeds rapidly in two steps as shown below. First, ammonium is oxidized to form nitrite which is then further oxidized to form nitrate. Two specific bacteria are involved in this reaction. *Nitrosomonas* bacteria facilitate the first reaction and *Nitrobacter* bacteria facilitate the second reaction. This reaction will not proceed in anaerobic environments.

Eqn. 1.1 $2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+$

Eqn. 1.2 $2NO_2^- + O_2 \longrightarrow 2NO_3^-$

Denitrification refers to the biological reduction of nitrate to nitrogen gas. The reaction pathway requires an organic carbon energy source, generically shown as "CH_2O" below.

Eqn. 1.3 $2NO_3^- + \text{“}CH_2O\text{”} \longrightarrow 2NO_2^- + CO_2 + H_2O$

Eqn. 1.4 $4NO_2^- + 3\text{“}CH_2O\text{”} + 4H^+ \longrightarrow 2N_2 + 3CO_2 + 5H_2O$

Denitrification generally proceeds in anaerobic environments because bacteria prefer to use oxygen when it is available as the electron acceptor instead of nitrate because it is energetically favorable.

1.2 Health Risks of Nitrate and Ammonia in Drinking Water

Consumption of nitrates can have several detrimental health effects. One adverse health effect is methemoglobinemia or "blue-baby" syndrome. Another adverse effect of nitrate consumption in drinking water is from the increased risks for certain types of cancer. Several studies have shown positive correlations between nitrate ingestion and gastric, esophageal, and stomach cancer.

The toxicity of methemoglobinemia occurs due to the body's conversion of nitrates to nitrites, which are less prevalent in the environment, but much more toxic to people. In adults, saliva naturally converts nitrates present in drinking water and foods to nitrites. In infants, most nitrates are converted to nitrites in the gastrointestinal tract. Nitrates that are absorbed into the bloodstream oxidize the Fe^{+2} (ferrous iron) "heme" group in the hemoglobin to Fe^{+3} (ferric iron) producing methemoglobin. Methemoglobin is unable to carry oxygen and thus reduces the ability of blood to supply oxygen to individual cells. At high nitrite concentrations, enough hemoglobin may be oxidized to cause cyanosis or cellular oxygen starvation. Symptoms of methemoglobinemia are bluish skin around the face and extremities, breathing trouble, diarrhea, and vomiting. Blood samples taken from victims of methemoglobinemia are dark brown and do not turn red when exposed to air. The effects of methemoglobinemia are rapidly reversible with no adverse cumulative effects if nitrate ingestion is halted. However, the condition can be fatal if left untreated.

Methemoglobin composes about 1% of the total blood supply in a healthy adult (American Academy of Pediatrics, 1999). Adults possess a methemoglobin reductase system that continually reconverts methemoglobin in the blood back to oxyhemoglobin.

Infants do not develop this ability until about 6 months of age and thus are extremely vulnerable to nitrate ingestion. In addition, infants have a higher pH in their stomach and intestines due to their inability to produce gastric acid. These alkaline conditions promote additional bacterial reduction of nitrate to nitrite. When the methemoglobin concentration reaches roughly 10% of the total hemoglobin supply, an infant will turn blue (Canter, 1997). Some studies have shown that methemoglobin concentrations approaching just 2% can be dangerous due to reduced oxygen levels. Death from asphyxia may occur when the methemoglobin level reaches 70% of the total hemoglobin supply (American Academy of Pediatrics, 1999). **Figure 1.2** below shows the mean methemoglobin levels in infants that live in areas with low, medium, and high nitrate concentrations in their tap water which is used to make milk solutions for feeding. The figure provides a good correlation between the levels of nitrates found in the environment and the potential adverse health effects they may cause.

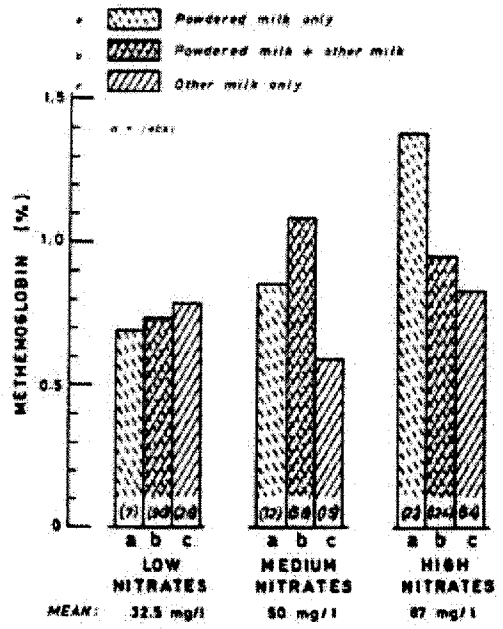

Figure 1.2: Methemoglobin levels in infants with low, medium, and high nitrate levels[2] in their tap water (Harremoes, pg. 188, 1977)

[2] These nitrate levels are provided as mg/L NO_3^- instead of mg/L NO_3^--N. 1 mg/L NO_3^--N = 4.43 mg/L NO_3^-.

The World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) have set maximum contaminant levels for nitrates at 10 mg/L NO_3^--N.[3] There is no safety factor incorporated into this number. The level was determined by clinical results that showed no instances of methemoglobinemia when nitrates were present in drinking water below 10 mg/L NO_3^-. However, there have been recorded cases of "blue-baby" syndrome caused by nitrate concentrations only slightly higher than 10 mg/L NO_3^- (Washington State Department of Health, 1999). In addition, individual vulnerability to nitrate ingestion varies widely. Some people might not show any ill effects from high nitrate concentrations, while other people might exhibit signs of methemoglobinemia resulting from nitrate concentrations much less than 10 mg/L NO_3^-.

The second adverse health effect of nitrates in drinking water is the possibility of increased cancer risk. Positive correlations between nitrates and certain types of cancer have been shown in recent studies . Nitrite reacts with secondary amines, amides, and carbamates to form N-nitroso compounds, some of which may be human carcinogens (Pontius, 1993). There are positive correlations of high nitrate drinking water concentrations to elevated gastric cancer occurrences in Chile and England (Canter, 1997). In rural Columbia, high stomach cancer rates have been attributed to excessive agricultural fertilization. Regions were divided into high cancer risk areas and low cancer risk areas. Nitrate concentrations in the low cancer risk areas were 5.6 mg/L NO_3^-. Nitrate concentrations in the high risk cancer were 31 mg/L NO_3^- (Pontius, 1993). Additionally, areas of Szalbolcs-Szatmar county in Hungary suffer from above average incidences of stomach cancer and correspondingly have nitrate drinking water concentrations in excess of 100 mg/L NO_3^- (Pontius, 1993).

The evidence, however, is conflicting. Some studies have shown negative correlations between nitrate consumption and cancer. Even though nitrosamines have been shown to cause liver damage, lung lesions, convulsions, and coma in laboratory rats, extrapolation

[3] For the remainder of this study, all concentration units shown are measured in terms of the elemental nitrogen present (mg/L –N) unless explicitly stated otherwise.

of this data from animals to humans is difficult (Amdur, 1993). In addition, there is contradictory information related to nitrates in food. Most vegetables contain high concentrations of nitrates, yet many of these foods still have antioxidant properties that help prevent cancer. Studies have shown that the average person consumes between 30 and 300 mg of NO_3^- per day, much of which comes from food intake (Gray, pg. 120, 1994). Nitrates in food have not yet been shown to have the same health effects as nitrates in drinking water. Due to these uncertainties, the WHO and the USEPA have jointly determined there is insufficient evidence to impose a stricter maximum contaminant limit on nitrates. However, in the Carcinogenic Risk Assessment, published by the USEPA, nitrate is classified as a *Class D* compound. This means that, so far, research has been inconclusive and more studies are required to provide nitrates with a stricter classification.

The WHO has set a guideline for ammonium in drinking water at 1.5 mg/L. Ammonia can exist as ammonium, NH_4^+, or as ammonia, NH_3, depending only on pH. The pH of most soils and groundwaters dictates that ammonium is the dominant species. However, frequently these two species are used interchangeably with the generic title of "ammonia." For this study, the term "ammonia" refers to the sum of both the ammonium and ammonia species. The drinking water standard is set based on the correlation between high ammonium concentrations and microbial contamination due to human and animal waste sources. In the presence of oxygen, ammonification will occur rapidly, transforming organic nitrogen into ammonia. In this respect, ammonia is often a good indicator for microbial contamination. The USEPA has not set any guideline for ammonia, since no direct relationship has been found linking ammonia directly to adverse health effects.

2.0 NON-POINT SOURCE POLLUTION OF NITRATES AND AMMONIA

Non-point source pollution is any contaminant that reaches a water body through some diffuse transport conveyance. It is often non-continuous. Non-point source pollution can originate from many different sources each of which may individually appear negligible, but are cumulatively substantial.

Nitrates are one of the most common and most serious non-point source pollutants. Common sources of nitrates in drinking water are from agricultural fertilizers, human and animal wastes, through poorly designed septic systems and untreated sewage discharges, and leaky landfills.

2.2 NON-POINT SOURCE POLLUTION IN RURAL AREAS

The most common non-point source pollutant in rural regions is from agricultural fertilizers. Nitrogen is a large component of both synthetic and organic agricultural fertilizers. Plants need nitrogen to grow. Often, nitrogen is the limiting nutrient for plant growth. Nitrate is a very soluble compound and, thus, is extremely mobile in the environment. After fertilizers are applied to fields, nitrogen not absorbed by crops nitrifies and migrates into the groundwater or flows over the ground surface into the nearest stream. Factors such as crop type, precipitation, hydrology, and soil type determine how quickly and how much nitrogen will reach a drinking water supply. Row crops, such as corn and vegetables, heavy rains, and well-drained soils all enhance nitrate migration toward water sources.

Nitrate contamination due to agricultural run-off is well documented. A study in the rural Upper Region of Ghana found nitrates in the groundwater at concentrations as high as 124 mg/L as NO_3^- (Pickford, 1995). The elevated concentrations were attributed to excessive use of chemical fertilizers. Another study found nitrates present in excess of 100 mg/L as NO_3^- in groundwater below agricultural fields in Nebraska (Canter, 1997).

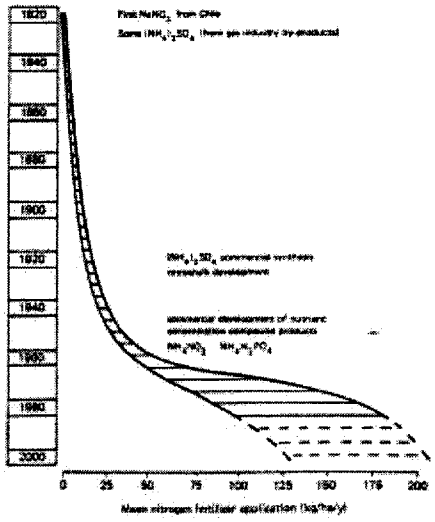

Figure 2.1: Agricultural Application of Fertilizers over Time (Gray, pg. 117, 1994)

Widespread use of synthetic fertilizers was uncommon both in the developing and developed world as recently as 50 to 100 years ago. However, during the 1980's, fertilizer use increased in developing countries by 160% (Follet, pg. 3, 1989). **Figure 2.1** illustrates how fertilization rates have increased globally from 1820 through 2000. Nitrate fertilizer is the single most important and widely used fertilizer in farming. However, nitrogen fertilizers are often applied at the wrong times of the year and in excessive amounts. This results in inefficient plant absorption and high amounts of residual nitrogen in the soil. **Figure 2.2** below shows the crop yield versus amount of fertilizer applied. It is clear from this diagram that there is a threshold beyond which additional fertilization will not increase crop yield. Above this threshold, additional fertilization simply increases the amount of residual nitrogen in the soil.

Plants absorb nitrogen from the soil as either nitrate or ammonia; nitrates are absorbed much more readily than ammonia and thus are more common in fertilizers. Nitrogen that is taken from the soil by plants must be replaced by fertilizers or natural processes to maintain long term soil viability. Natural processes do not resuppply nitrogen quickly enough to allow for sustained crop growth.

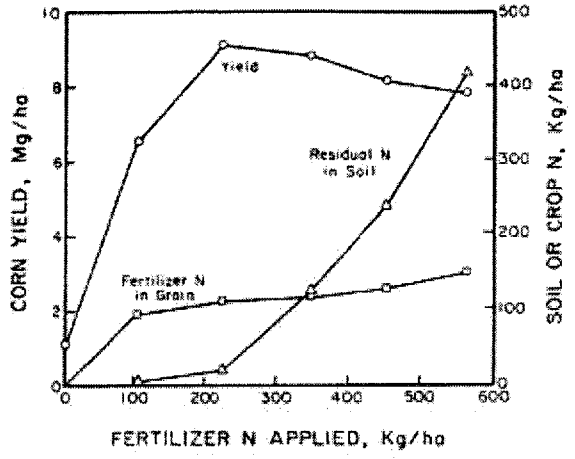

Figure 2.2: Crop yield versus fertilizer applied (Follet, pg. 10, 1989)

A study of nitrogen in soils proposed estimates for the amount of nitrogen uptake by agricultural crops. A summary of the results is shown in **Table 2.1** below.

Table 2.1: Nitrogen Uptake Rates Shown as Percentages of Total Nitrogen Applied (Gray, pg. 118, 1994)

50% – 70%	Absorbed by Plants
2% - 20%	Lost by Volatilization
15% - 25%	Sorbs to Organic Matter or Clays in Soil
2% - 10%	Leaches into Groundwater or Carried off by Surface Runoff

Most nitrogen, as it exists in the soil, is organic. Microbial activity in the soil converts organic nitrogen into an inorganic form that plants can use. If plants are not actively growing, nitrates are washed away by rainfall and infiltration. Nitrates are much more likely than other nitrogen species to be washed away by heavy rains because they are very soluble and exist in the environment with a negative charge which means that they will not cling to negatively charged soil particles. Ammonia, which generally exists in the environment with a positive charge in the form of ammonium, NH_4^+, is readily adsorbed onto soil particles, and thus migrates much more slowly.

Agricultural contamination from nitrates and ammonia is a concern in Nepal because more than 80% of Nepalis live in rural areas and earn a living through agriculture. Nitrate contamination of groundwater and surface water sources due to agricultural run-off is a potential risk. This report will summarize and analyze findings of water quality testing that was performed in heavy agricultural regions of Nepal.

2.2 NON-POINT SOURCE POLLUTION IN URBAN AREAS

Urban areas are also at risk of nitrate pollution due to the inadequate disposal of human and animal waste. There is particular risk in Kathmandu because private septic tanks are used by virtually all homeowners (NepalNet, 1999). Septic systems are designed to trap settleable solids and floating grease from raw sewage. Then a subsurface disposal system, usually a trench bed or leach field, disperses the remaining liquid sewage underground, where it is naturally attenuated. Septic tanks in Nepal rarely have adequate area for soak pits. Most plots of land in Kathmandu are no more than 60 square meters; this is an insufficient area for natural dissipation (NepalNet, 1999). Instead of attenuating, the semi-treated effluent becomes concentrated in residential yards. The septic effluent migrates to the groundwater and eventually to drinking water sources. A study of a typical septic field in New Jersey found ammonia concentrations between 20 and 55 mg/L (Canter, pg. 6, 1997). This is a dangerous condition due to the likely presence of human pathogens in the untreated waste products and because of the high nitrate concentrations that will be produced as ammonia is oxidized.

Inadequate disposal of human and animal waste in the streets of Nepal also contributes to nitrate and ammonia pollution. The picture in **Figure 2.3** below illustrates how livestock graze in close proximity to community water sources. In addition, latrines discharge waste products into open sewers that run along the sides of major streets and in close proximity to public water sources. The picture in **Figure 2.4** below shows an open sewer flowing immediately adjacent to a tube well. These untreated waste products seep into the underground aquifers and flow into nearby surface waters. In Kathmandu and surrounding urban areas, open sewers flow out of residential areas directly into the

Bagmati, Vishnumati, Manohara, and Hanumati Rivers (IUCN - The World Conservation Union, pg. 61, 1998). During the dry season when aquifer levels decline, these polluted rivers can recharge unconfined aquifers.

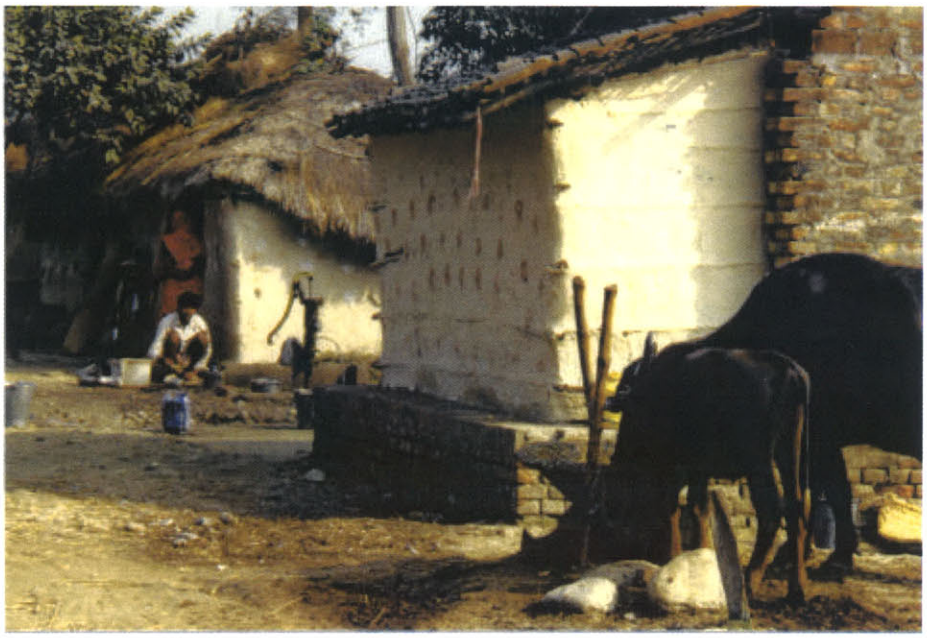

Figure 2.3: Livestock grazing in close proximity to community water source in Birganj, Nepal

Figure 2.4: Sewer flowing adjacent to tube well in Birganj, Nepal

A study of 904 watersheds in the United States that are prone to non-point source pollution showed that the areas with the highest levels of total nitrogen in the soil were agricultural watersheds with 5.5 mg/L-N. Urban watersheds had the second highest concentration of nitrogen in the soil with 3 mg/L-N (Follet, pg. 44, 1989). A compete listing of the watershed types versus soil nitrogen concentration is shown in **Figure 2.5** below.

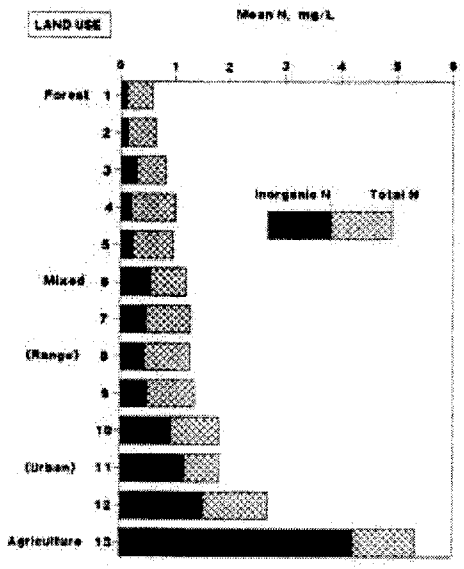

Figure 2.5: Watershed Type versus Soil Nitrogen Content (Follet, pg.44, 1989)

2.3 FATE OF NITRATES AND AMMONIA IN GROUNDWATER AND SURFACE WATER

When nitrates reach the groundwater, they are usually in high concentrations only in the top meter. This is the aerobically active region; microorganisms degrade organic carbon using oxygen as the terminal electron acceptor. Below this depth, oxygen cannot be replenished quickly enough and the environment becomes anaerobic. With no oxygen present, nitrates are used as electron acceptors and are denitrified quickly. The primary nitrogen species deep in an aquifer is ammonia. Nitrification of ammonia cannot occur deep in an aquifer due to the lack of oxygen. Thus, high ammonia concentrations can be

found at great depths whereas high nitrate concentrations are usually only found near the aquifer surface.

When high nitrate and ammonia concentrations drain into surface waters, they create a eutrophic environment. This is a condition where excess nitrogen accelerates the growth of algae and other aquatic plants. Excessive plant growth creates a foul taste and odor, kills fish by depleting the dissolved oxygen concentrations, alters the aquatic habitat, and provides hospitable environments for other disease causing organisms.

3.0 GEOLOGY AND NATURAL HISTORY OF NEPAL

Nepal is a geologically diverse country. It is a landlocked and sandwiched between India in the south and China in the north as shown in **Figure 3.1** below. Nepal has the largest elevation gain from low point to high point of any country in the world. The Himalayan massif, which dominates the northern portion of Nepal, is the dramatic transition between the lowlands of the Indo-Gangetic plains and the Tibetan plateau. Rivers such as the Kosi, Narayani, and Karnali drain out of these mountains forming gorges that are often thousands of feet deep. Flood conditions are common during the spring melt and continue through the summer monsoon season. River flow drops during the dry winter season.

The mountains of Nepal are relatively young on a geologic time-scale. They rose from the sea roughly 60 million years ago when the tectonic plate containing the Indian Subcontinent crashed into the Asian land mass. They gained their present height about 7 million years ago (Bhatt, pg. 32, 1977). The Himalayas are still growing today as the Indian subcontinent continues to subvert under the Asian land mass.

Figure 3.1: Map of Nepal

3.1 GEOLOGY OF SOUTHERN NEPAL

The southern half of Nepal is a flat plain of alluvial deposition known as the Terai. The Terai is only 100 to 200 meters above sea level and forms the northern portion of the Indo-Gangetic floodplain and watershed. The land is very fertile and is known as the granary of Nepal. Most people living in this region make their living from agriculture, however, there are several important industrial and commercial cities, such as Birganj, that provide enhanced commercial and trading opportunities due to their proximity to India.

Rivers flow out of the Himalayan mountains and the Churia Hill with great velocity carrying a large load of sediment through deep mountain gorges and down steep slopes on a long and arduous journey toward the Ganges River. However, the rivers lose speed as they reach the flatlands of the Terai and consequently drop the load of sediment they have carried all the way from the high mountains. Over millions of years, these deposits have grown thousands of meters thick and have become well-graded; larger particles are deposited first as velocities begin to decline and smaller particles are carried further south into the Terai. The thickness of alluviam in the Terai has been measured at depths greater than 5,000 feet in many regions (Bhatt, 1977). These well-graded deposits allow surface infiltration to penetrate quickly down into the aquifer. Due to the abundance of both groundwater and surface water sources and fertile soils, the Terai contains more than 70% of the cultivated land in all of Nepal and supports nearly half of the total Nepali population (Bhatt, 1977).

The parent rocks of the Terai consist of sand, shale, clay, and pebble beds. These give rise to sandy soil in the northern part of the plain, silty soil in the middle, and clayey soil in the southern regions. Additionally, the soil contains appreciable amounts of iron oxides in the form of soluble compounds.

The rocks that are found in the northern Terai zone are mostly sand stone, quartzite, and cherty dolomite (Sharma, 1984). Heavy precipitation infiltrates down through the

pebbles. Once in the ground, flow patterns carry the water due south. In general, the Terai alluviam is deficient in nitrogen, organic matter, and phosphorous. Thus, fertility is increased by the application of fertilizers and manure.

3.2 GEOLOGY OF CENTRAL NEPAL

Central Nepal is a hilly region that contains a variation of alluvial and lacustrine deposits. The Bagmati and the Seti Rivers flow past two of Nepal's largest cities in Central Nepal, Kathmandu and Pokhara. Both of these cities lie in large lacustrine valleys that have mostly sandy soils and many remnant lakes. Most of the Nepali urban centers are contained within central Nepal in the Kathmandu and Pokhara valleys. The Kathmandu Valley is a wide elliptical basin about 25 km long and 19 km wide (Sharma, 1984). For this study, research of central Nepal was focused in the Kathmandu Valley. The valley is surrounded by high mountains in all directions. In the northern section, mountains climb to above 2,600 meters and in the south to above 3,100 meters. There are low passes, about 1,800 meters high, in the east and west that allow access to the valley. Kathmandu itself sits at an elevation of about 1,340 meters (Sharma, pg. 98, 1984).

The Kathmandu Valley was once a large lake. At that time, lake sediments were deposited along with organic plant material. As the lake dried and receded, large deposits of humic material were left behind. This material produced black clay which is highly fertile due to its nitrogen and phosphorous content.

The valley is drained by the Bagmati River and its tributaries. The northern region of the valley is composed of sandy and silty soils. In the south, pebble clays are common. Lenses of peat and black clays occur frequently throughout the valley, but are primarily located in the central regions. Peat lenses have been shown to contain about 40% fixed carbon, 40% volatile material, and 20% ash. Most of the lenses are 0.3 to 1.0 meter in thickness (Sharma, pg. 100, 1984).

The soil geology of central Nepal consists of dolomite, quartzite, and phyllite which have low primary porosities (Sharma, 1984). Thus, infiltration is minimal. Artesian springs are not common in the area. Thus, clean water sources are a problem in rural areas where tube wells have not been drilled. In the Kathmandu Valley, groundwater wells have been drilled successfully to depths greater than 500 meters without encountering bedrock (Sharma, pg. 131, 1984). Because of this, there are many potentially clean groundwater sources in the valley.

Soils of the Kathmandu Valley consist of recent fluvio-lacustrine deposits of the Pleistocene era with alternating stratified layers of porous and impermeable materials. These soils contain large amounts of organic material. The influence of anaerobic conditions, leaching, and low temperatures beneath the ground surface have increased the populations of anaerobic micro-organisms. When these anaerobic bacteria act on the organic deposits, ammonia and methane gas are produced instead of the more typical products of nitrate and carbon dioxide.

3.3 GROUNDWATER OVERVIEW IN NEPAL

There are seven typical aquifer types in the Kathmandu Valley. They are as follows (Kharel, 1998).

1) Interbedded
2) Linear: old river channel deposits
3) Bedrock: limestone
4) Basal gravel: deep gravel overlying the bedrock
5) River deposits: recent alluvial material
6) Gravel fans
7) Gravel near the surface

Carbon-14 radioisotope dating of groundwater samples from the valley determined that shallow groundwater reserves are about 9,000 to 29,000 years old. Chlorine-36

radioisotope analysis determined that groundwater samples from the deep groundwater aquifers are approximately 200,000 years old (Kharel, 1998).

The average static water table depth is within a meter of the ground surface. Some areas in the northern part of the valley have a much deeper water table at depths of about 50 meters. Hand-dug wells and water spouts are not common in these areas. Annual precipitation in the Kathmandu Valley is quite high; however, the ground condition is generally not effective for recharging aquifers from precipitation. Groundwater recharge is controlled by wide spread silty lacustrine deposits, interbedded with impermeable black clay, which prevents easy access of percolating rainwater to the aquifers. Most of the annual precipitation falls during the monsoon season from June to September, but runs off quickly as surface flow and is not sustained during the dry season. However, in localized regions, especially in the southern portions of the valley, soil conditions are sufficient for rainfall to infiltrate and surface water to recharge into sub-surface aquifers.

Groundwater pumping in the Kathmandu Valley has caused increased depressions in the groundwater table over recent years. The water table is declining near Bansbari and Manohara by about 4 meters per year (Kharel, 1998).

The Terai is a region that is well suited for groundwater development. It is indeed one of the best groundwater reservoirs on the entire Indian Subcontinent. Aeromagnetic surveys have found that in some places bedrock is as deep as 2,500 meters below ground level (Bhatt, pg. 21, 1977). Additionally, well-graded soils have a high conductivity which allows for heavy infiltration and the formation of very deep aquifers.

3.4 HYDROLOGICAL CYCLE

The hydrological cycle in Nepal is not much different from any other areas of the Indian subcontinent. There are two rainy seasons; one, called the monsoon, occurs in the summer and is much heavier than the other which occurs in the winter. Technically, the monsoon season stretches from July to October. Maximum precipitation occurs in

southeast Nepal during this time producing about 2,000 mm of rain (Sharma, pg. 128, 1984). Winter rains are common in the hills and mountains of western Nepal. Rain is infrequent in central and southern Nepal during the winter season. Deep mountain valleys and gorges provide easy routes for surface rainfall to drain from the mountains into the flatlands of the Terai.

There is a perpetual snow cover in the northern mountains above 6,000 meters. All of the precipitation that falls on the high peaks is snow. The snow caps provide a large reservoir of water that partially drains in the summer months and refills in the colder winter months. During the dry season, ground water seepage and snow melt are the only two reservoirs of water that supply flow to the river gorges.

4.0 DATA COLLECTION IN NEPAL

The research for this paper was conducted during the month of January, 2000. The following sections explain the research that was conducted while in Nepal and give a quick overview of the results. Further analysis is performed in Section 5. In addition a detailed analysis of the various water sources in Nepal. A brief overview of the analytical test methods is also provided.

4.1 TRIP REPORT

Research for this study began in Kathmandu on January 7th, 2000. On January 13th, a trip to the Terai with a representative of the Nepal Department of Water Supply and Sewerage, Mr. Ram Mani Sharma, was arranged. Samples were collected in and around the city of Birganj, an industrial city in the Parsa District on the Indian border. Roughly 450,000 people live in the district of Parsa, while about 100,000 live in the actual city of Birganj. An additional 100,000 people commute into the city for work. The most important industries are textiles, steel, leather, and sugar. The following insert is a description about Birganj from the Lonely Planet Guidebook for Nepal.

> *Birganj is one of the main border crossings between Nepal and India, and one of Nepal's most important industrial cities. This is an unfortunate combination. It has been one of the most unattractive places on the planet for some time, but it is not resting on its laurels. It is growing rapidly and the pollution and squalor are getting worse.*
>
> *Birganj seems to stretch northwards for miles, strung along the impossibly congested main road. There are a large number of depressingly run down factories, as the corridor between Birganj and Hetauda is probably the most important center for industrial development in Nepal. Amongst tanneries and other unattractive places there are sugar factories and an agricultural implements factory.*
>
> *Birganj is probably the most important entry point for Indian imports, but most travelers enter through Sunauli to the west. Birganj remains the most convenient entry port, however, for those coming from Patna or Calcutta. Fortunately, there are plenty of day and night buses to and from Kathmandu, Pokkara, and points south in India so there should be no reason to stay more than a night – hopefully not even that. The Birganj bus station is the best and worse place in town, depending on whether you are coming or going.*

This account does not paint a favorable picture of Birganj; however, it does note the problems that rapidly growing populations and unregulated industry have on pollution levels and quality-of-life issues.

There are between 6,000 and 7,000 wells in the region surrounding and including Birganj (Sharma, 1984). Here, the population drinks almost exclusively from groundwater. Surface water is not used for drinking due to heavy contamination. Most of the groundwater sources are from shallow wells, both hand-dug wells to depths of 20 to 30 feet and tube wells extending to depths of about 250 feet. There are some deep boring wells. However, these are rare and thus none were sampled. Septic fields are used in the residential areas of Birganj.

Samples were collected and analyzed in Birganj for four days. Analysis for nitrates and ammonia was performed using two spectrophotometers. The first was a HACH DR/2010 portable spectrophotometer. The second was a Spectronic 20 Genesys loaned to the project by Spectronics Instruments.

In Birganj, water samples were collected and analyzed from a wide range of sites. Samples were collected from the urban, industrial regions of Birganj, remote, rural areas, and heavy agricultural regions along the city's periphery. In addition, every effort was made to sample from a wide variety of well types and depths. Only one well was found in Parsa that was contaminated with nitrates and ammonia; it was a 24-foot deep hand-dug well contaminated with nitrates at 16 mg/L. All other wells tested were tube wells varying from 50 feet in depth to 250 feet in depth. Most of these wells had been installed by UNICEF in the previous fifteen years. Nitrates were not present in any of these wells at concentrations higher than 1 mg/L. These results show that the top few meters of the aquifer are possibly contaminated with nitrates and ammonia, most likely due to anthropogenic sources from the ground surface; however, water that is found at greater depths in the region is clean of nitrates and ammonia.

Sampling in the Kathmandu Valley began on Jan. 17th. Samples were collected from the ancient city of Bhaktapur, in what is known as the Dathali Water Supply Project. Water from this project is collected from several streams and pumped into an open sedimentation tank at the rate of 1.5 L/s. The water then flows into a covered storage

tank from which it is distributed to villagers for one hour in the morning and one hour in the evening. Water is pumped underground to various communal water spouts. Samples were collected and analyzed from several different locations during the treatment and distribution process. Sampling was also performed in the city of Thimi, which is just east of Kathmandu. Drinking water samples were tested from hand-dug wells, tube wells, and from water served directly at restaurants.

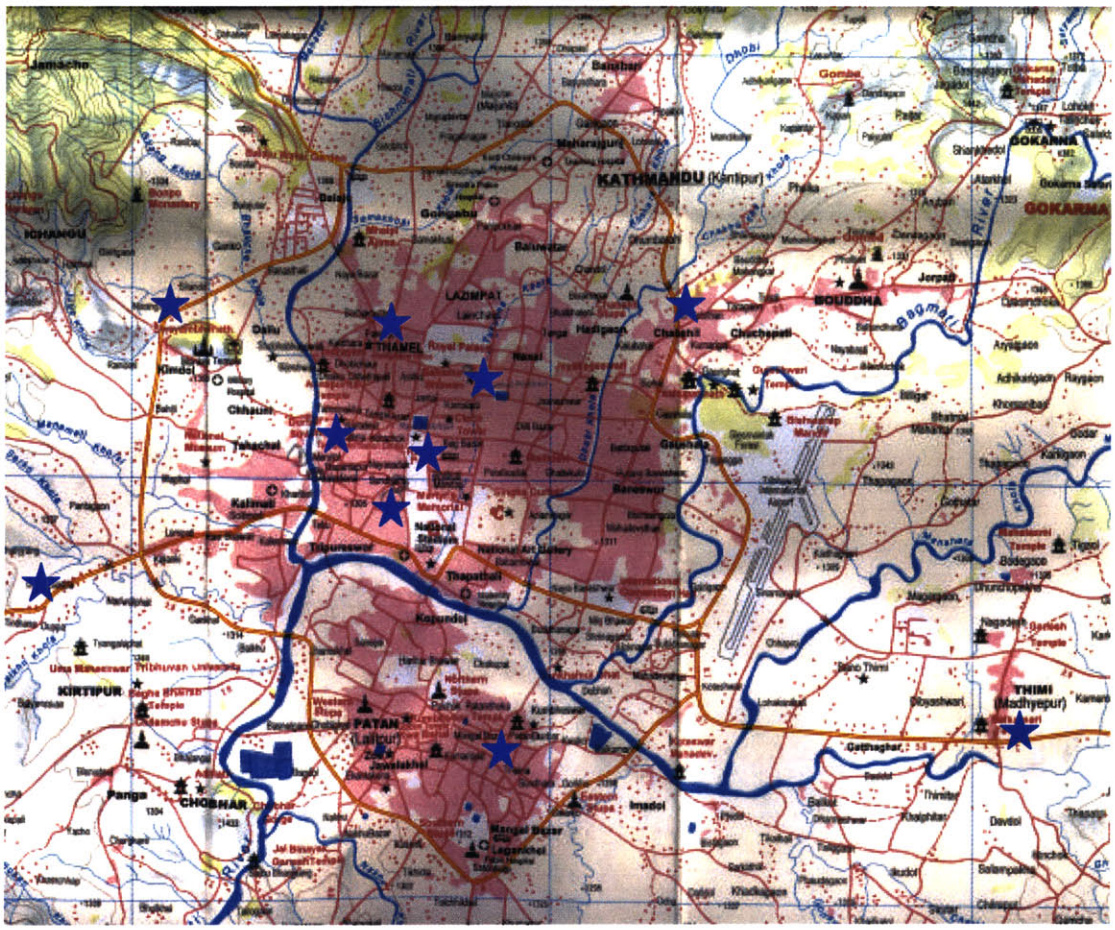

Figure 4.1: Map of Kathmandu and Patan (blue stars show sampling sites)

Many samples were collected from urban locations throughout Patan and Kathmandu upon the recommendation of several UNICEF-Nepal representatives. The map shown in **Figure 4.1** has a blue star placed on each location where samples were collected in and around Kathmandu.

Both traditional water sources and municipally supplied water sources were analyzed in Nepal. Traditional water sources have been used for hundreds of years as a water supply and generally draw water from the top of unconfined aquifers. Recently, however, water treatment plants have begun serving some areas of Kathmandu and Patan and UNICEF has installed a large number of tube wells deeper into the ground than traditional sources.

All of the nitrate and ammonia data is explicitly summarized and outlined in Section 5. Recommendations and conclusions regarding the data are located in Section 6. Appendix A and B contain a complete overview of the source information for each sample and the complete listing of analytical results.

4.2 WATER SOURCES IN NEPAL

The following sections outline the primary water sources that were analyzed for nitrates and ammonia in Nepal: tube wells, water spouts, hand-dug wells, deep boring wells, and surface water sources. Several samples were also collected from restaurants and stores serving water in Kathmandu, but due to the lack of reliable source information, this data was not included in this analysis.

4.2.1 Tube Wells

Tube wells are common throughout Nepal and the Kathmandu Valley. Most of these wells were installed in the past 10 to 15 years by the Nepal government or international agencies such as UNICEF and others to provide an alternative water source to the polluted water spouts, hand-dug wells, and surface waters. These tube wells have a simple hand pump which creates a vacuum and sucks water out of the ground. **Figure 4.2** below shows a schematic for how the hand pump operates. The typical tube that goes into the ground is only about 2 inches in diameter. **Figure 4.3** show a picture of a typical tube well and hand pump in Nepal.

Most tube wells sampled were set to depths of between 50 and 250 feet. It is unknown how many tube wells are currently in use throughout Nepal, but they are much more prevalent in the Terai region of southern Nepal than in the more urban and mountainous regions farther north.

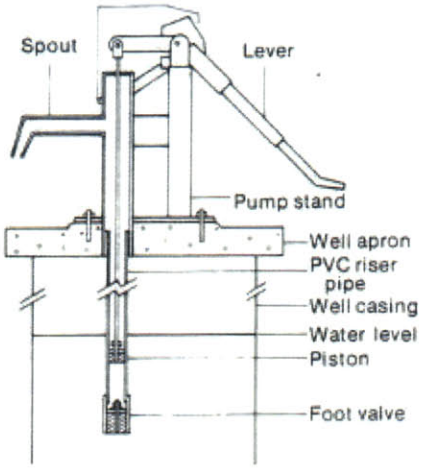

Figure 4.2: Schematic of a typical Hand Pump (International Development Research Council, pg. 21, 1981)

Figure 4.3: Typical tube well in Nepal

4.2.2 Water Spouts

Stone water spouts were the primary source of water in Kathmandu and other urban areas in Nepal during medieval times. Known by the traditional word "dhungedhara," they remain a source of water in many remote areas. Nepalis collect water from these traditional stone taps for drinking, bathing, washing, and irrigation. Stone spouts were constructed at or below the water table of phreatic aquifers. Water then flows to the spout through a brick channel. In 1989, a study sponsored by the Nepal Department of Mines and Geology and the German Federal Institute for Geosciences and Natural Resources, found that there were still 16 active traditional water spouts in Patan, 14 active traditional water spouts in Kathmandu, and 24 active traditional water spouts in the ancient city of Bhaktapur (Kharel, 1998). There are hundreds more scattered throughout the Kathmandu Valley that have been abandoned. There is currently active interest in reclaiming some of these abandoned taps to alleviate the water scarcity concerns.

The flow rate from each of these spouts varies seasonally and is directly affected by precipitation. During the pre-monsoon season, the discharge from these stone spouts is about 6 l/s. During the post-monsoon season, the discharge is about 10 l/s (Kharel, 1998). **Figures 4.4 and 4.5** below depict several pictures of traditional water spouts in the Kathmandu Valley.

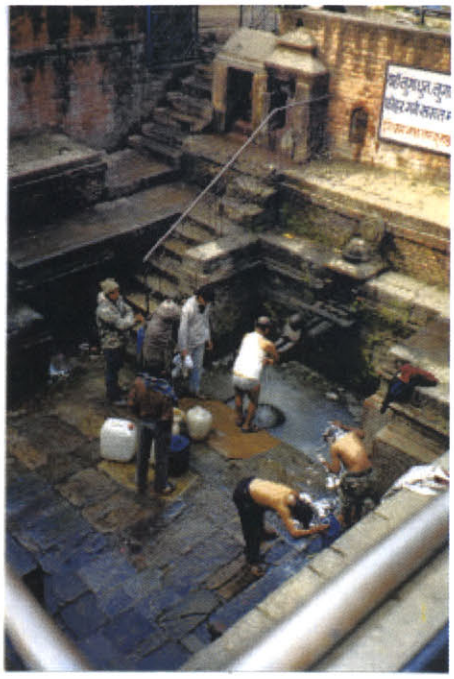

Figure 4.4: Traditional water spout in Kathmandu

Figure 4.5: Traditional water spout in Patan

4.2.3 Hand-Dug Wells

Hand-dug wells are currently the main source of water for domestic purposes, such as washing and bathing, in the Kathmandu Valley (Sharma, 1984). In addition, they are used as a supplemental water source for the municipal drinking supply. In some remote areas, hand-dug wells are still the only source of water. Hand-dug wells in Nepal are

usually less that 8 meters deep with an average depth of 5 meters and an average diameter of 1 meter. Most of the hand-dug wells are constructed in clayey, silty sediments. Older wells are lined with bricks which allow contamination to enter the well more easily. Newer wells are constructed with cement rings. The total number of hand-dug wells in the Kathmandu Valley is unknown, but it is estimated to be greater than 1,000 (Kharel, 1998). **Figure 4.6,** below, illustrates an example of a hand-dug well in Nepal.

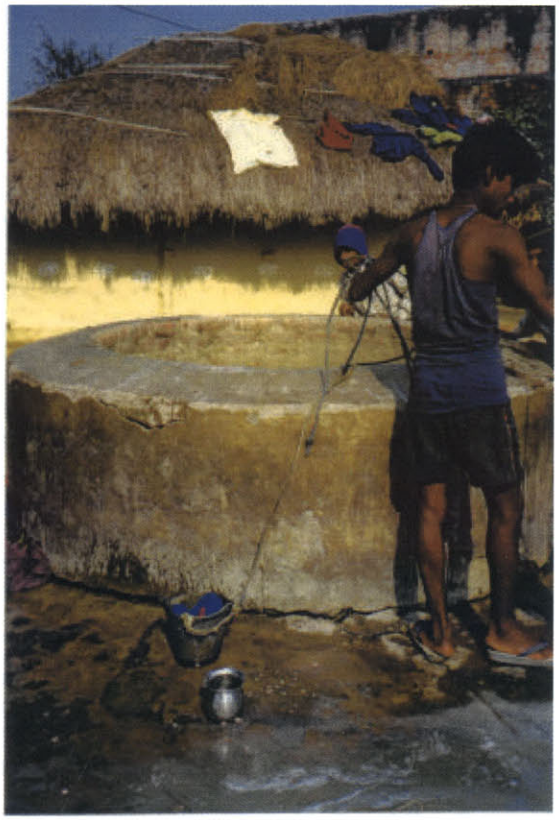

Figure 4.6: Typical hand-dug well in Nepal.

4.2.4 Deep Boring Wells

There are about 320 deep boring wells throughout the Kathmandu Valley set in coarse, sandy-gravelly sediments. These deep wells tap various aquifers, but are generally at depths greater than 90 meters. Several of the water treatment plants throughout the Kathmandu Valley use deep boring wells as their intake source of water. The deep boring wells that were tested as part of this study were drilled to depths between 200 and 300 meters. Deep boring wells draw water out of groundwater sources that have not been contaminated from surface anthropogenic pollutants.

4.2.5 Surface Water Sources

Several surface water sources in the Kathmadu Valley were tested for this study. Most of the samples were from intakes to water treatment plants. However, water samples were also collected and analyzed directly from the Bagmati River. Upstream, the Bagmati River quality is very good, but as it traverses through the urban areas of the Kathmandu Valley, it becomes loaded with pollutants, mostly from untreated sewage, but also from the numerous carpet factories and dying industries that discharge directly into the river. When the groundwater table falls below the river bed in the dry season, aquifers can be recharged with this polluted river water.

4.3 ANALYTICAL TEST METHODS

The laboratory tests that were used to analyze nitrate and ammonia concentrations in drinking water during the MIT-Nepal Water Project Field Study in January 2000 are outlined below.

4.3.1 Nitrate Test Methods

Two nitrate test methods were used during the January 2000 field study: the cadmium reduction method and an enzyme nitrate reduction method. In the cadmium reduction method, nitrate is reduced to nitrite by copper activated cadmium. The nitrite is then converted to nitrous acid which diazotizes an aromatic amine. The diazotized product is coupled with an amine or phenol to produce a dye, which can be analyzed spectrophotometrically (Crompton, pgs. 23 – 41, 1992). A spectrophotometer analyzes the light absorbency of the dyed sample in comparison to a blank water sample which is usually deionized water. I used two spectrophotometers to analyze water samples: the HACH DR/2010 and the Spectronics 20 Genesys spectrophotometer. Both spectrophotometers were used to the compare accuracies. **Figures 4.7 and 4.8** below show pictures of each spectrophotometer.

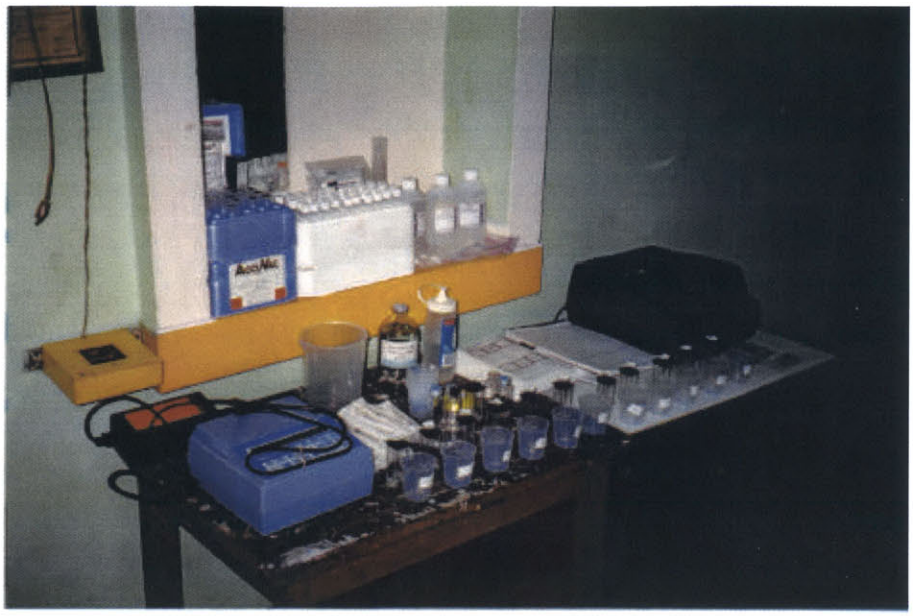

Figure 4.7: HACH DR/2010 spectrophotometer in hotel laboratory – Birganj, Nepal

Figure 4.8: Spectronics 20 Genesys spectrophotometer

The second test method used during the January field study was an enzyme nitrate reduction. The nitrate reduction test kit, produced by The Nitrate Elimination Company, uses a purified enzyme test method. The kit is designed to be used in the field and requires no electricity. In addition, the kit does not require any harmful reagents. The kit, however, does not achieve a high degree of accuracy because it uses a colorimetric comparison method. The color breakdowns are only in units of 2.5 mg/L. Thus, for example, using this test, one can only find a range of possible nitrate concentrations to within 2.5 mg/L. However, this test was useful when used in conjunction with the

standard spectrophotometric methods described above and due to its ability to be used in the field. **Figure 4.9** below shows a picture of the nitrate reduction kit.

Figure 4.9: Nitrate Elimination Kit

4.3.2 Ammonia Test Methods

Only one test method was used to analyze ammonia samples. It was the ammonia salicylate spectrophotometric method. An ammonia salicylate reagent and an ammonia cyanurate reagent are combined with the sample to produce a green-dyed solution (Crompton, 1992). The color of this dye is then analyzed using a spectrophotometer and compared to a blank solution of deionized water.

5.0 PRESENTATION AND ANALYSIS OF DATA

The following section summarizes all of the data collected while in Nepal and analyzes any outstanding trends. A complete listing of my data including source information, analytical results, and comments is included in Appendices A and B. In addition, at the end of this section, a comparison is provided of this studies analytical results with the data of other similar groundwater studies. One of these studies was performed in Nepal by a joint team of Nepali and German engineers. The other three were studies performed in agricultural regions of the United States.

5.1 NITRATE CONCENTRATION VERSUS WELL DEPTH

The level of nitrate contamination in groundwater is related to depth. Deep wells are generally free from nitrate contamination because microbes and bacteria in the absence of oxygen use the nitrates as an oxygen source and reduce it to elemental nitrogen. This process is known as denitrification. **Figure 1.1** gave an overview of the entire nitrogen cycle. Groundwater wells that extract water from the surface of an aquifer are possible candidates for nitrate contamination. Near the aquifer surface, nitrates are often present in high concentrations because microbes and bacteria use the available oxygen instead of the nitrates as an oxygen source.

There are several sources of nitrates in the environment that can contaminate the upper reaches of an aquifer. In urban areas, nitrates in groundwater sources generally come from septic fields and other sources of animal and human waste. In rural areas, nitrates generally enter the groundwater as a result of agricultural fertilization. These sources often contain nitrogen both in the form of ammonia and nitrates. As ammonia infiltrates into the soil and migrates with the groundwater, it quickly nitrifies first into a nitrite form and then into a nitrate form as shown in Equations 1.1 and 1.2. Nitrates remain until bacteria exhaust the oxygen supply and begin searching for alternative oxygen sources. Rarely will bacteria deplete the oxygen supply near the groundwater surface because there is a steady source of oxygen from the atmosphere that will continually replenish the

oxygen that is consumed. Thus, nitrates generally must migrate to deeper depths before they will be denitrified.

Nitrate contamination in Nepal was expected to be the most prevalent in the shallow drinking water wells, and thus this study concentrated most of its effort on sampling shallow drinking water sources. A survey of 124,000 wells across the United States in 1985 showed that 6.4% were contaminated with nitrates above the maximum contaminant level of 10 mg/L NO_3^- (Follet, 1989). Nearly all of these contaminated wells were less than 30 meters deep in unconfined aquifers. There is an inverse relationship of nitrate concentrations to aquifer depth as shown in **Figure 5.1** below.

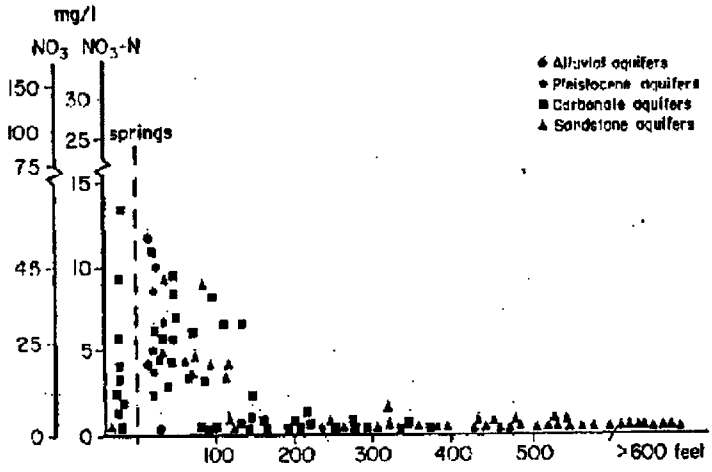

Figure 5.1: Nitrate Concentration versus Aquifer Depth and Soil Type (Follet, pg. 49, 1989)

A distinct correlation between depth and nitrate concentrations exist in groundwater. In Nepal, the data collected, displayed in **Figure 5.2**, showed the same correlations as above but more data points are really needed to fully fill in this curve. All of the samples that contained nitrates at levels above the WHO standard of 10 mg/L were found in unconfined aquifers from wells at depths above 100 feet. Several of these positive results occurred in very shallow hand-dug wells at depths of 25 feet or less. No wells at depths greater than 100 feet had nitrates present at concentrations greater than 1 mg/L. Many of these wells draw water from confined aquifers, which further reduces the likelihood that nitrates will be present. The correlation can be made from this data that wells at depths

of more than 100 feet are free from nitrate contamination. Nineteen percent of the wells tested at depths less than 50 feet were contaminated with nitrates above the WHO limit. It can be inferred that nitrate contamination is not widespread in all shallow drinking water wells. However, shallow wells have a much higher probability of containing significant nitrate levels than deep wells. This observation is consistent with the data presented in **Figure 5.1**. However, to obtain a clearer idea of the nitrate contamination levels versus depth in Nepal, more samples need to be collected and more analysis needs to be performed.

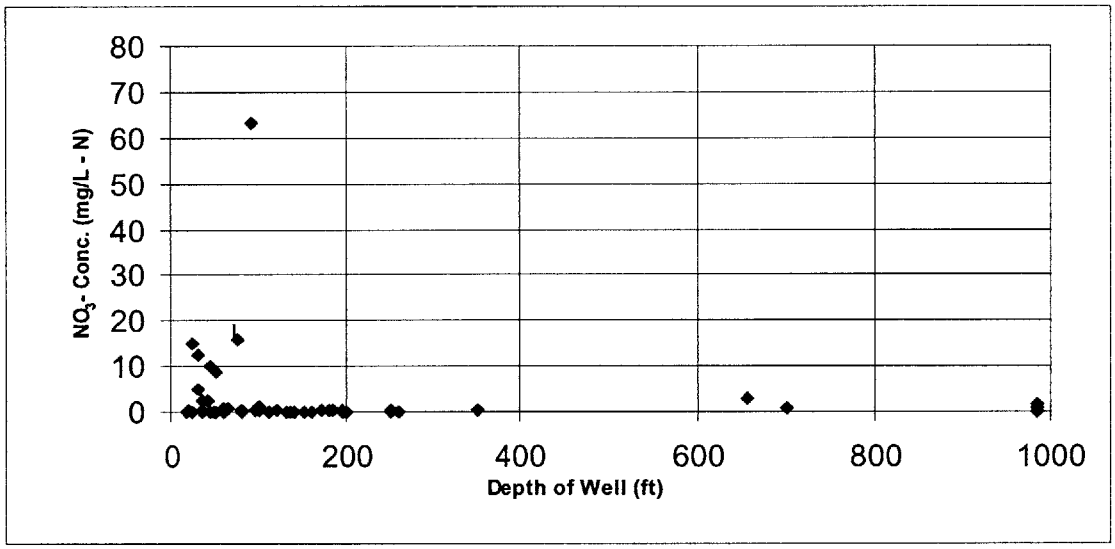

Figure 5.2: Nitrate Concentration vs. Well Depth

5.2 AMMONIA CONCENTRATION VERSUS WELL DEPTH

Ammonia contamination in groundwater is also related to depth. Ammonia in the presence of oxygen is quickly nitrified to nitrites and nitrates. Thus, the presence of ammonia in a drinking water source generally indicates that a source of ammonia is in close proximity to the water intake

A study has shown that about 3% of organically bound nitrogen in soils is mineralized by soil bacteria into ammonia (Gray pg. 119, 1994). Mineralization is an extremely slow process compared to the nitrification of ammonia to nitrate which occurs very rapidly.

The anthropogenic sources of ammonia that could be near a water intake are generally some sort of animal or human waste product.

In Nepal, 16 samples contained ammonia at levels above the WHO limit of 1.5 mg/L. This represents 23% of all the samples tested for ammonia. The water samples that had the highest concentrations of ammonia came from deep boring wells. Samples TP1, TP2, and TP5 are from treatment plants in Mahankal and Balaju which contained ammonia at levels of 19 mg/L, 16 mg/L, 12 mg/L respectively. These treatment plants draw water from boring wells at depths ranging from 200 to 300 meters. Another treatment plant that draws water from two different 300 meter deep boring wells had ammonia present at 96 mg/L in each. These are samples 27/03 and 27/04 on the attached data sheet in Appendix B. The source of ammonia in these deep boring wells cannot come from the surface migration of human and animal waste products because of the great depth. The ammonia sources are naturally occurring due to groundwater contact with peat and lignite beds that are common throughout the Kathmandu Valley. As explained in Section 3, millions of years ago the Kathmandu Valley contained a large lake. Organic material from the lake settled out and formed beds of lacustrine material which were buried with sediment over subsequent years. These organic deposits were interlaced with peat as the lake started to recede and dry. These deposits are very high in ammonia, but it cannot be nitrified because there is no oxygen present at these great depths.

Samples 19/02, 19/03, and 19/04 also show high levels of ammonia but are not displayed on **Figure 5.3** due to the lack of reliable source information. Sample 19/02 and 19/03 were supplied water sources in Thimi and contained 36 mg/L and 10 mg/L of ammonia, respectively. The sources were located directly across the street from one another. Sample 20/05 was taken from the water served to customers at the Pilgrim Restaurant in Kathmandu and contained 18.4 mg/L of ammonia. The Pilgrim restaurant is located in the Thamel region of Kathmandu and caters to many foreign tourists. The restaurant uses municipally supplied tap water but filters it prior to serving. The source information is unknown, but because it comes from the tap, there is a strong possibility that the water came from a treatment plant that draws water from a deep boring well.

Nearly all of the samples that have high ammonia concentrations are either from surface water sources or deep boring wells. In addition, all the samples from groundwater sources other than deep boring wells had negligible ammonia concentrations as shown in **Figure 5.3.**

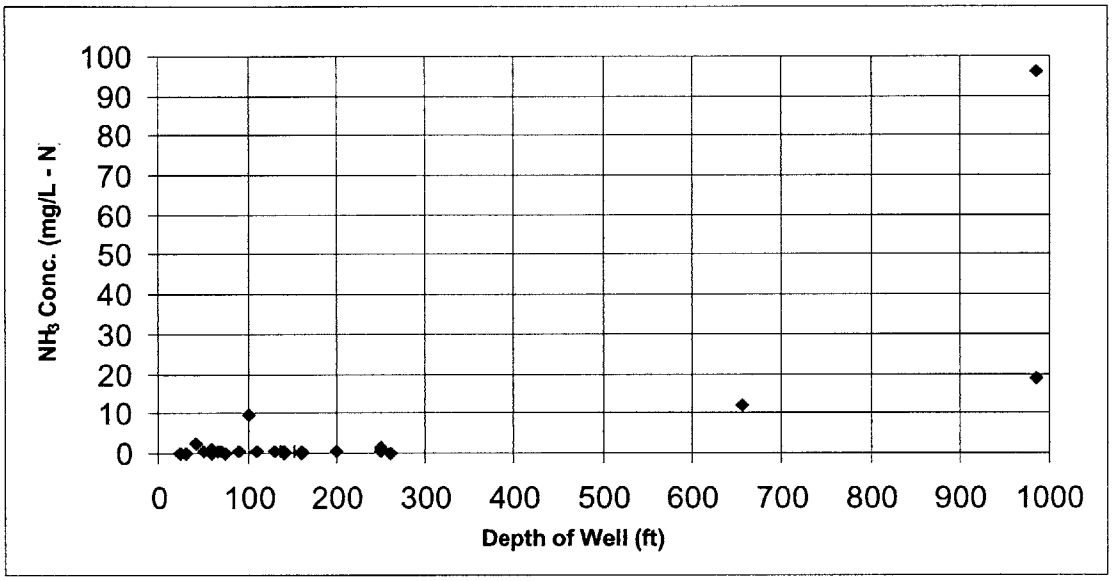

Figure 5.3: Ammonia Concentration vs. Well Depth

5.3 NITRATE CONCENTRATION VERSUS WELL AGE

There was no distinct correlation between well age and nitrate contamination in drinking water supplies in Nepal as illustrated in **Figure 5.4** below. Older wells are generally more worn and consequently do not have a good seal between the tube and the well pad. The well pad shown in **Figure 5.5** below is an example of an older well that has a deteriorated well pad which will be more prone to contamination as years pass. Surface water might be able to drain down the outside of the well tube and contaminate groundwater supplies.

However, nearly all of the wells tested were installed in the past 20 years and thus have not had significant time to sustain serious wear. Indeed, most wells were installed in the previous 5 years. Of these, only three were contaminated with nitrates above the WHO

standard of 10 mg/L, samples 26/03, 26/04, and 29/07. Sample 26/03 and 26/04 were both private tube wells located in the city of Chabahil. Sample 29/07 was a tube well in the village of Ramawapur in the southern district of Lumbini. In total, these represent only 5% of all the wells tested. There were three water sources tested that were older than 20 years. Of these, one contained nitrates above the WHO limit of 10 mg/L, sample 14/05. Sample 14/05 came from a hand-dug well in the village of Elachhmania in the southern district of Parsa. There are some data points that were collected and analyzed that do not appear in **Figure 5.4** due to a lack of reliable well age information.

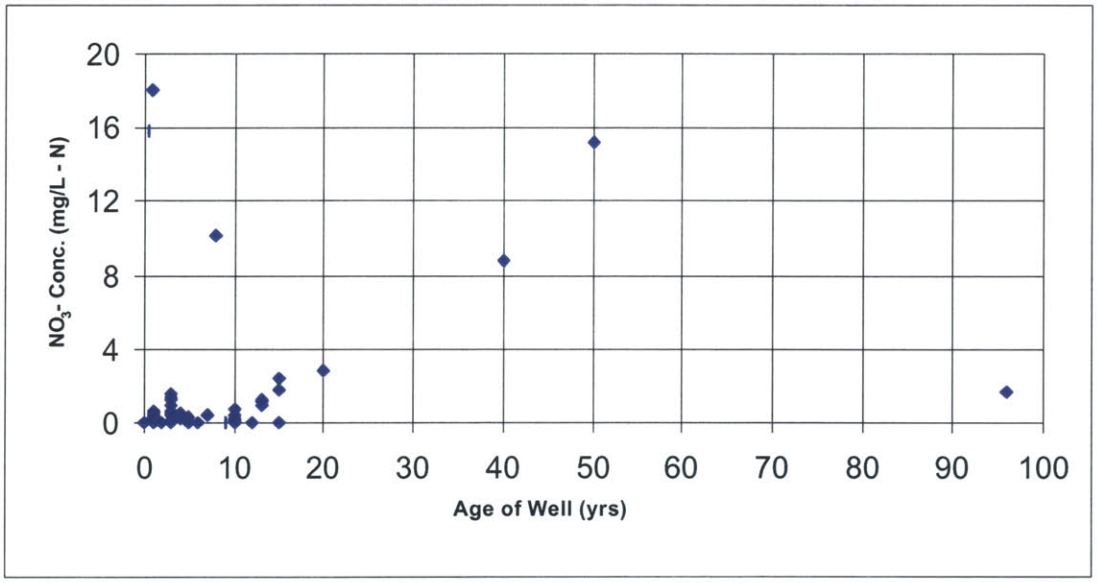

Figure 5.4: Nitrate Concentration vs. Well Age

Figure 5.5: Author in front of a worn well-pad

5.4 AMMONIA CONCENTRATION VERSUS WELL AGE

There is no distinct correlation between well age and ammonia contamination in drinking water supplies in Nepal as illustrated in **Figure 5.6** below. Older wells are often more worn and consequently do not have a good seal between the tube and the well pad which can lead to increased contamination of groundwater supplies.

Nearly all of the wells tested had been installed in the past 20 years. Of these only two were contaminated with ammonia above 10 mg/L, samples TP1 and TP5. However, 16 samples contained ammonia at levels greater than the WHO guideline. This is 23% of all the samples tested. These samples however appear to be contaminated with ammonia from reasons other than contamination along the well shaft. Both samples TP1 and TP5 are from deep boring wells in the Kathmandu Valley at water treatment plants in the regions of Mahankal and Balaju. There were only three water sources tested that were older than 20 years. None of these contained ammonia above the 10 mg/L. There is some ammonia data that does not appear in **Figure 5.6** due to a lack of reliable well age information.

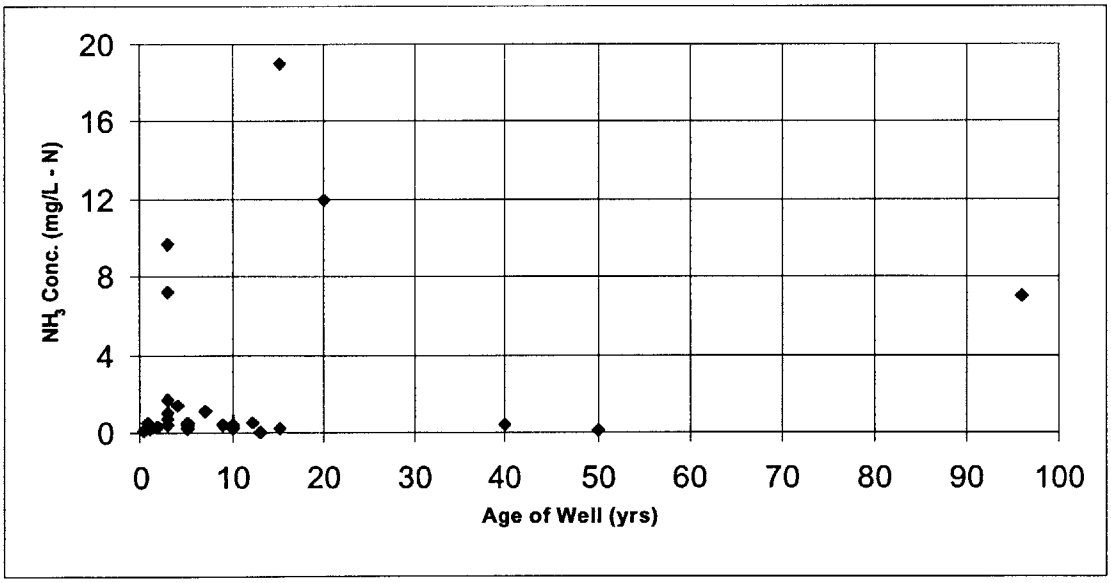

Figure 5.6: Ammonia Concentration vs. Well Age

5.5 NITRATE CONCENTRATIONS IN URBAN AND RURAL REGIONS

In Nepal, a distinct difference exists between urban and rural well nitrate concentrations. Sixty-three rural wells were sampled and tested in Nepal. The average nitrate concentration in all of the rural wells was 1.2 mg/L. Only 3 of these, or 5%, contained nitrates above the WHO limit of 10 mg/L as shown in **Figure 5.7** below. These samples were 14/05, 29/07, and 29/09. They contained nitrate concentrations of 15 mg/L, 10 mg/L, and 12 mg/L, respectively. Each of these three samples came from wells in the Terai region of Nepal. Sample 14/05 was from a well in the Parsa district in a rural village outside of Birganj. Samples 29/07 and 29/09 were from wells in the southern district of Lumbini in the rural villages of Ramawapur and Sonbarsha.

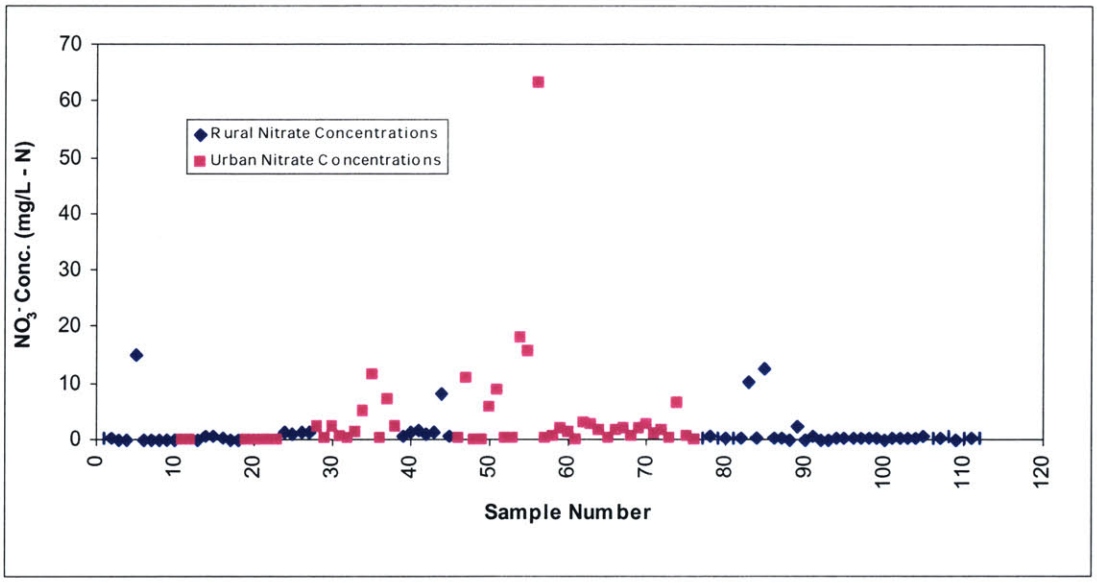

Figure 5.7: Nitrate Concentrations in Urban vs. Rural Regions

Rural and agricultural areas usually have high nitrate levels due to excessive applications of manure and nitrogen based fertilizers to fields as discussed in Section 2. It was a surprise to the author that, in Nepal, nitrates were not present in higher concentrations based on the January 2000 field study data. This discrepancy might be due to the fact that during the dry season, there is very little rain and consequently very little infiltration and runoff. For this study, sampling was only performed in the dry winter season.

Figure 5.8 below displays the seasonal and long term time varying nitrate concentrations in a river in England. Higher runoff during the wet season accounts for significantly higher nitrate concentrations in the river. In Nepal, this trend may be even more pronounced since the wet and dry seasons are more distinct. Year round sampling would have to be performed in agricultural areas to verify if there are indeed any seasonal fluctuations in nitrate concentrations, as we would expect.

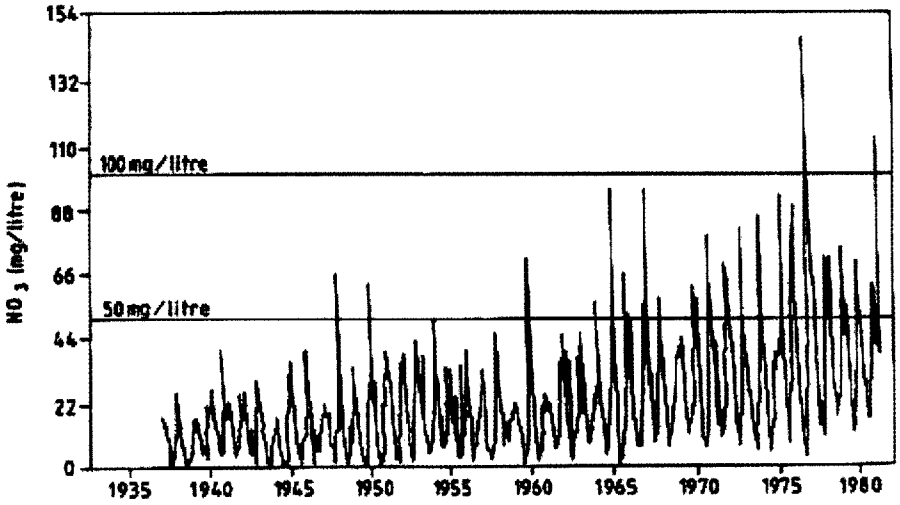

Figure 5.8: Seasonal and Yearly Fluctuations in Nitrate Concentrations in the River Stour in England (Gray, pg.124, 1994)

Forty-nine urban wells were sampled and tested in Nepal. The average nitrate concentration in all of these urban wells was 3.9 mg/L. Five of these, or 10%, contained nitrates above the 10 mg/L limit as shown in **Figure 5.7**. These samples were 20/02, 24/02, 26/03, 26/04, and 26/05. These samples contained nitrates at concentrations of 11.6 mg/L, 10.9 mg/L, 18 mg/L, 15.8 mg/L, and 63.3 mg/L, respectively. Sample 20/02, shown in the picture in **Figure 4.5**, was taken from a traditional water spout in Durbar Square, Patan. Sample 24/02, shown in the picture in **Figure 4.4**, was taken from another traditional water spout in Naradeni, Kathmandu. Samples 26/03, 26/04, and 26/05 were all taken from wells along the same street in the city of Chabahil which is on the road from Kathmandu to Bouddha. A plume of high nitrate concentrations exists in the groundwater in this region. It poses a health risk to the Chabahil residents because each

well tested was a private drinking water well. Many of these wells are new, having just been installed in the last year. Extrapolating this data throughout Chabahil clearly shows that many infants may be at risk to methemoglobinemia. It can be presumed that there are other urban regions that have similarly high nitrate concentrations in their drinking water, but more research needs to be performed to identify these sites.

Urban areas frequently have high nitrate concentrations due to the inadequate disposal of human and animal waste and inadequate leach fields from septic tanks. In Kathmandu, most home owners, install septic tanks, but the average leach field is only approximately 60 square meters. This is not a sufficient area for adequate dilution; thus, waste products tend to concentrate underground and infiltrate into groundwater supplies. In addition, untreated sewage flows openly along most urban streets and is a possible source of groundwater contamination.

5.6 AMMONIA CONCENTRATIONS IN URBAN AND RURAL REGIONS

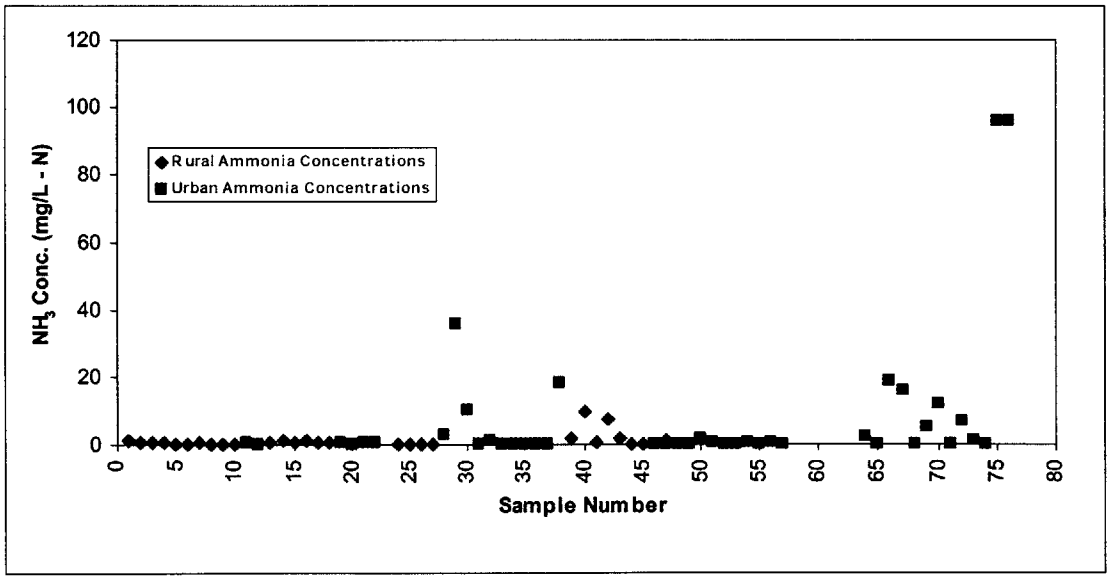

Figure 5.9: Ammonia Concentrations in Urban and Rural Regions

Similar to the nitrate results, there was a very drastic difference between rural and urban ammonia results. Twenty-eight rural wells were sampled and tested for ammonia in Nepal. The average ammonia concentration in all of these wells was 1.1 mg/L. No rural

samples contained ammonia above the 10 mg/L as shown in **Figure 5.9**. In addition, only 3 samples contained ammonia at levels above the WHO guideline of 1.5 mg/L. This is 11% of the total number of rural samples tested.

Forty-two urban wells were sampled and tested for ammonia in Nepal. The average ammonia concentration in all of these urban wells was 7.8 mg/L. Eight urban samples contained ammonia above 10 mg/L and 13 contained ammonia at levels greater than the WHO guideline of 1.5 mg/L as shown in **Figure 5.9**. Thirty-one percent of urban wells had ammonia present above 1.5 mg/L. The samples above 10 mg/L were 19/02, 19/03, 20/06, TP1, TP2, TP5, 27/03, and 27/04.

5.7 NITRATE AND AMMONIA CONCENTRATIONS BY SOURCE TYPE

This section provides an overview of nitrate and ammonia contamination based on source type. The source type of each individual sample is shown in Appendix A. The source types used for this analysis are tube wells, deep boring wells, hand-dug wells, surface water sources, and water spouts. Samples were collected mostly from tube wells, thus it is difficult to gain a complete understanding as to the level of contamination in the other source types. To get a more complete picture of the level of contamination in each source, more samples will have to be collected. The breakdown of nitrate levels in each source is shown below.

5.7.1 Tube Wells

Tube wells were, by far, the most common water source sampled with a total of 57 tube wells sampled. Most of the tube wells had very good water quality relative to nitrate and ammonia contamination. Only 9% of the tube wells tested had nitrates at concentrations above the WHO limit of 10 mg/L. Most of the tube wells contained nitrates at levels between 0.1 and 1 mg/L as shown in **Figure 5.10** below. Ammonia levels in the tube wells were also relatively low. Only 4% of the wells tested contained ammonia at concentrations greater than 10 mg/L and 14% contained ammonia at concentrations

greater than 1 mg/L. **Figure 5.11** delineates the complete breakdown of ammonia in tube wells.

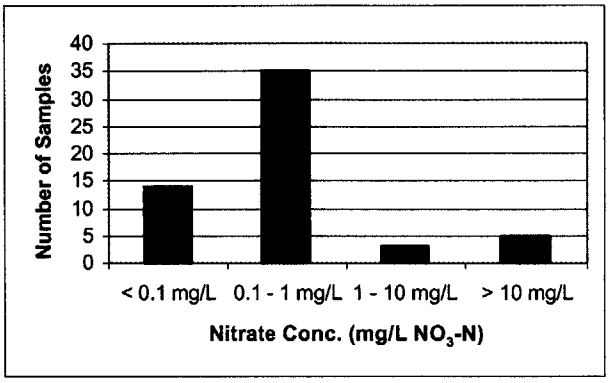

Figure 5.10: Nitrates in Tube Wells

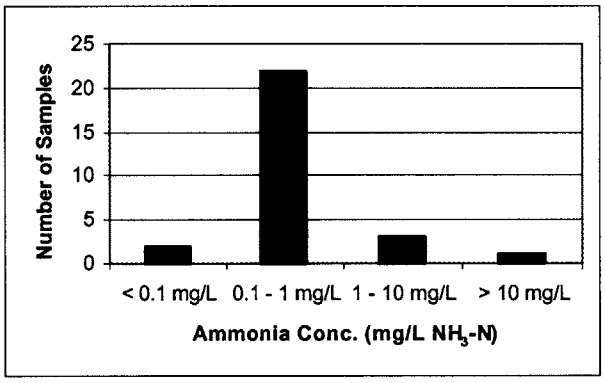

Figure 5.11: Ammonia in Tube Wells

5.7.2 Water Spouts

Water spouts are a traditional water source in Nepal and in particular in the ancient cities of Kathmandu, Patan, and Bhaktapur. Most water spouts have histories dating back to medieval times. Since water spouts are no longer common sources of drinking water, I was only able to sample four for nitrates during this study. Those that do remain and are still in active use are more contaminated than the primary groundwater source for this study, tube wells. However, those that remain are revered and thought to be sacred. All of the water spouts tested were either in Kathmandu or Patan. One of the water spouts sampled contained nitrates at levels above 10 mg/L; while two others contained nitrates at levels between 1 and 10 mg/L. Further testing is required to ascertain definitively if

traditional water spouts are more polluted than other water sources. **Figure 5.12** below delineates the breakdown of nitrates in water spouts.

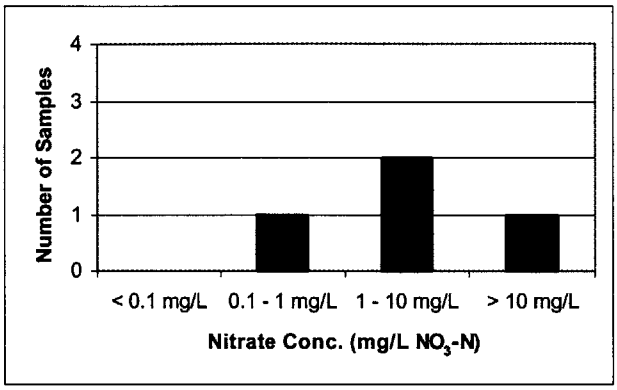

Figure 5.12: Nitrates in Water Spouts

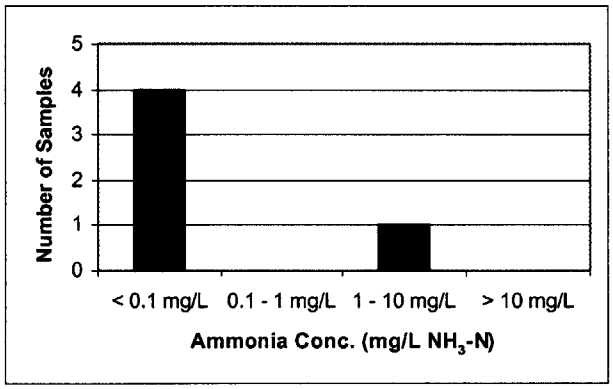

Figure 5.13: Ammonia in Water Spouts

Five water spouts were sampled and tested for ammonia. Four of these contained ammonia at levels below 0.1 mg/L. Only one had nitrates present between 1 and 10 mg/L. **Figure 5.13** provides a full delineation of the amount of ammonia present in water spouts.

5.7.3 Hand-Dug Wells

Hand-dug wells in Nepal are common in rural areas that cannot afford the installation costs of a tube well. Thus, hand-dug wells tend to be more of a traditional water source, that are not used for drinking water except in poor regions. Several hand-dug wells were tested in Nepal. Most of these were either in the rural regions of the Terai or in the rural

regions outside of Kathmandu. One hand-dug well contained nitrates at levels above 10 mg/L, while three hand-dug wells contained nitrates between the levels of 1 and 10 mg/L. **Figure 5.14** below shows a graphical breakdown of the amount of nitrates found in hand-dug wells in Nepal.

Only one hand-dug well was found to contain ammonia with a concentration between 1 and 10 mg/L. Each of the other hand-dug well samples contained less that 1 mg/L of ammonia. **Figure 5.15** below shows a graphical representation of the amount of ammonia present in hand-dug wells in Nepal.

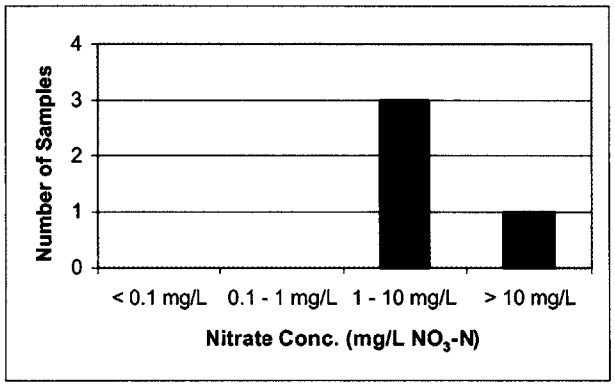

Figure 5.14: Nitrates in Hand-Dug Wells

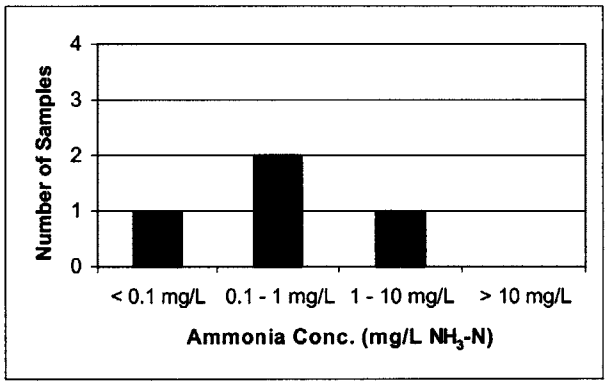

Figure 5.15: Ammonia in Hand-Dug Wells

5.7.4 Deep Boring Wells

Several deep boring wells were sampled and tested in Nepal. Many of these are used as a prime intake for water treatment plants that supply municipal areas around Kathmandu. Each of these boring wells was drilled to depths between 200 and 300 meters. Three of

the five samples tested contained nitrates at levels between 1 and 10 mg/L. The other deep boring well samples contained nitrates at levels less than 1 mg/L. The amount of nitrates in deep boring wells is summarized below in **Figure 5.16**.

All five of the deep boring wells tested contained ammonia at levels greater than 10 mg/L. This data is shown in **Figure 5.17**. The high ammonia concentrations are due to the anaerobic soil conditions at great depths and to the high concentration of organic matter and peat beds.

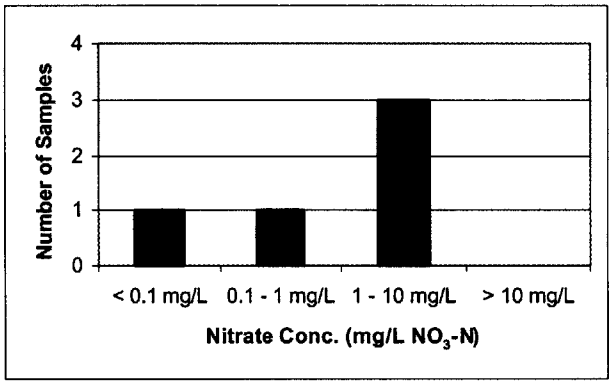

Figure 5.16: Nitrates in Deep Boring Wells

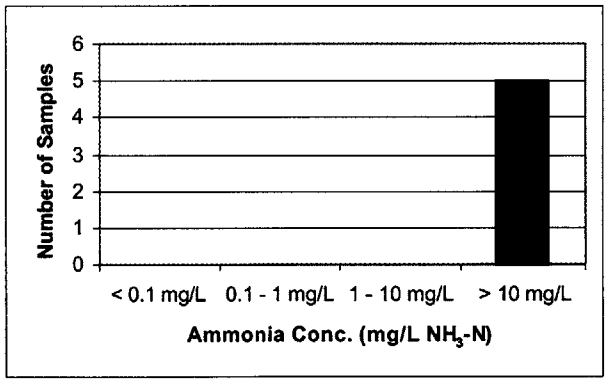

Figure 5.17: Ammonia in Deep Boring Wells

5.7.5 Surface Water Sources

Many surface water samples were also tested while in Nepal. Frequently, the Bagmati River is used as the intake for water treatment plants that supply the city of Kathmandu. Other samples were not explicitly drinking water sources, but were tested because they will provide information as to how much contaminated surface water is being recharged into groundwater aquifers. It is believed that during the dry season when aquifer levels decline, ground water is recharged from rivers and streams into the upper aquifers. This is most prevalent in the southern regions of Kathmandu Valley where the soil conditions allow more infiltration. The southern regions of the Kathmandu Valley are also downstream of most of the untreated sewage and industrial outfalls and thus are more susceptible to contaminated surface water.

Seventeen surface water samples were tested in Nepal, most of these were from the Bagmati River. Of these, only one had nitrates present at levels greater than 10 mg/L. However, 59% had nitrates present at levels between 1 mg/L and 10 mg/L. **Figure 5.18** below summarizes the breakdown of nitrate concentrations in surface water sources tested. It is possible to assume from this data that surface water sources are a source of nitrate contamination for groundwater resources.

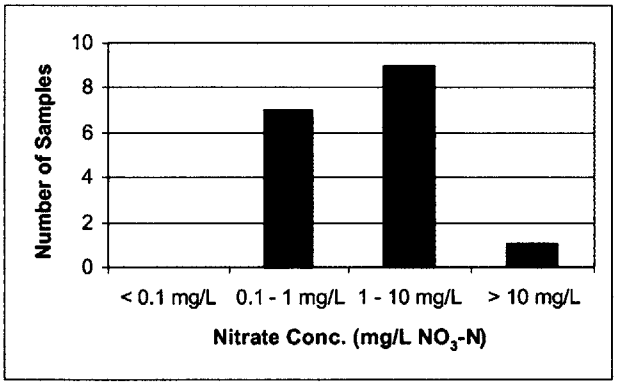

Figure 5.18: Nitrates in Surface Water Sources

Ammonia was present at concentrations between 1 and 10 mg/L in two of the twelve surface water samples tested. All other samples contained ammonia at levels below 1

mg/L. This data is summarized in **Figure 5.19** below. From this information, one can assume that surface water sources are not a significant source of ammonia contamination into the upper aquifers.

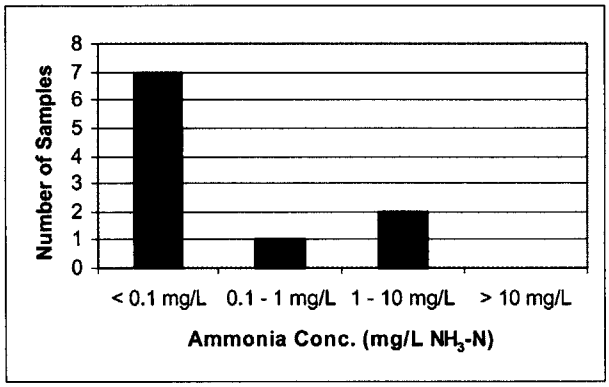

Figure 5.19: Ammonia in Surface Water Sources

5.8 NITRATE CONCENTRATIONS IN SUPPLIED WATER SOURCES VERSUS TRADITIONAL WATER SOURCES

This section provides a more generalized overview of nitrate concentrations in supplied water sources versus traditional water sources than appears in Section 5.7. For this analysis, supplied water sources consist of tube wells, which have often been installed by UNICEF or some other agency in the recent past, and municipally supplied and treated waters. Traditional water sources consist of water taps, water spouts, artesian springs, and hand-dug wells which have been used as a water source for many generations. Traditional water sources have been in use for much longer than supplied water sources and are generally taken from the upper reaches of an aquifer that tend to be more polluted. Data from this study shows a very drastic discrepancy between nitrate concentrations in supplied water sources compared to traditional water sources. Increasing population, inadequate disposal methods, and the wear of time have had an effect on traditional water sources usually causing higher levels of pollution. Indeed, often tube wells are installed to provide an alternative to the more polluted traditional water sources.

More supplied water sources were tested for this study than traditional sources. Traditional sources used for drinking are rare, especially when there are municipally supplied waters nearby. One hundred and three supplied water sources were sampled and tested. These samples had an average nitrate concentration of 1.9 mg/L as shown below in **Figure 5.20**. Only five of these samples, or 5%, had nitrate levels above the WHO standard of 10 mg/L. These samples were 26/03, 26/04, 26/09, 29/07, and 29/09. Samples 26/03, 26/04, and 26/05 were taken from the aforementioned contaminated groundwater in Chabahil. Likewise, samples 29/07 and 29/09 were taken from rural regions of the Lumbini district in the Terai.

Nine traditional water samples were sampled and tested for this study in Nepal. The average nitrate concentration in these samples was 7.6 mg/L. Three of the nine samples contained nitrates at levels above the WHO limit of 10 mg/L as shown in **Figure 5.20**. This represents 33% of all the traditional water sources tested. The samples which were above 10 mg/L were 14/05, which is a hand-dug well in a rural region outside of Birganj, 20/02, which is a sacred water spout in Durbar Square, Patan, and 24/02, which is a water spout in Naradeni, Kathmandu.

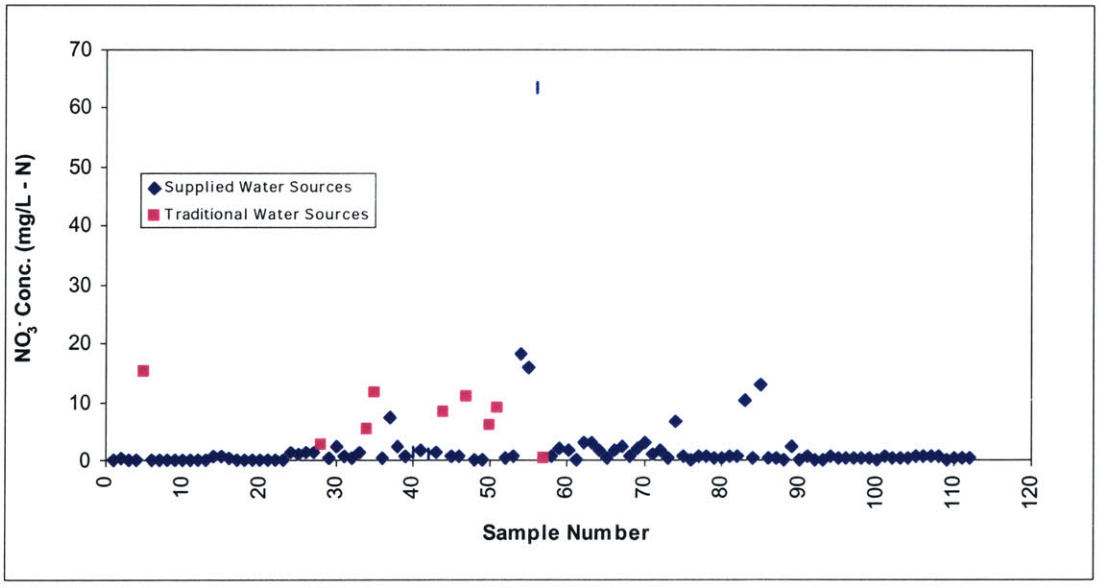

Figure 5.20: Nitrate Concentrations in Supplied Water Sources vs. Traditional Water Sources

Most Nepalis were open to using supplied water sources instead of their traditional water sources if it was easily accessible. One notable exception to this is when water is chlorinated at a water treatment plant. Nepalis, especially those in the more rural areas outside Kathmandu, do not like the taste of chlorine and thus are skeptical when they are told that a chlorinated water source is cleaner than their traditional water source. **Figure 5.21** shows a woman gathering water from a traditional artesian spring instead of using treated water from a nearby plant.

Figure 5.21: Nepali woman collecting water from a traditional artesian spring

5.9 AMMONIA CONCENTRATIONS IN SUPPLIED WATER SOURCES VERSUS TRADITIONAL WATER SOURCES

This section provides a more generalized overview of ammonia concentrations in supplied water sources versus traditional water sources than appears in Section 5.7. Ammonia contamination showed an opposite relationship for supplied vs. traditional sources than nitrates. Sixty-seven samples of supplied water were tested for ammonia in Nepal. These had an average ammonia level of 5.3 mg/L as shown in **Figure 5.22** below. Eight of the supplied water sources contained ammonia at levels greater than 10 mg/L

and fourteen contained ammonia at levels greater than 1.5 mg/L. The samples that contained more than 10 mg/L of ammonia were 19/02, 19/03, 20/05, TP1, TP2, TP5, 27/03, and 27/04. Notable among these are five deep boring wells: TP1, TP2, TP5, 27/03, and 27/04, which are used as intake water for several Kathmandu Valley treatment plants.

Nine traditional water sources were tested for ammonia. These contained an average of only 0.6 mg/L which is shown in **Figure 5.22**. Only two of these wells contained ammonia in concentrations greater than 1.5 mg/L.

Nitrate contamination is much more prevalent in traditional water sources. This is because most traditional water sources are drawn from near the surface. The advent of deep drinking water wells is a relatively new concept in Nepal. For thousands of years, neither the resources nor the technology were available in Nepal to drill deep wells. Deep in the aquifers, conditions are hospitable for ammonia presence. However, only supplied water sources draw water from these depths. Near the surface, where traditional sources draw water, nitrate contamination is more common instead of ammonia because the abundance of oxygen will nitrify ammonia.

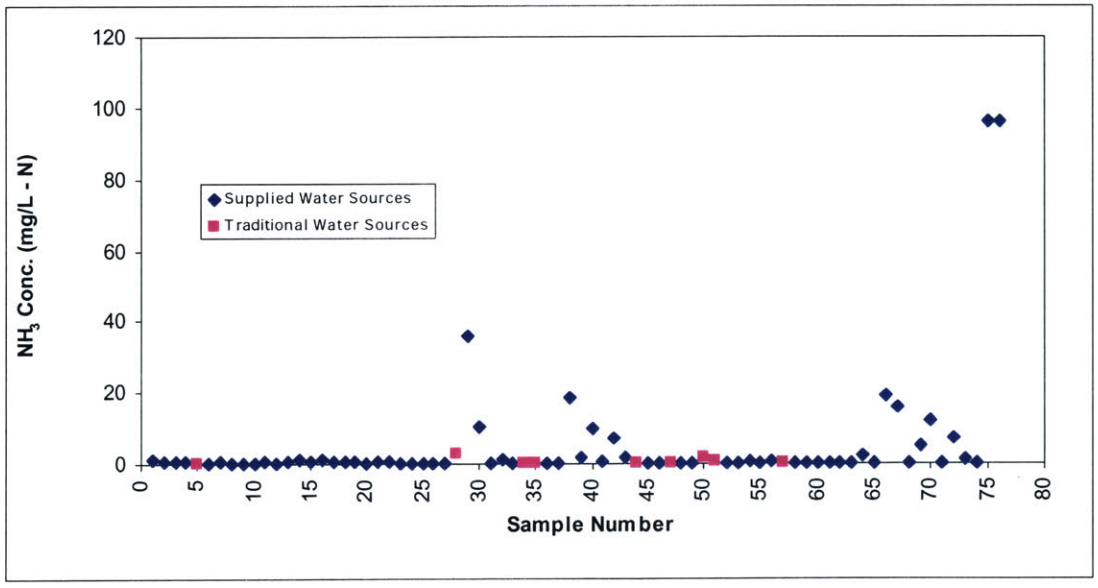

Figure 5.22: Ammonia Concentrations in Supplied Water Sources vs. Traditional Water Sources

5.10 Comparisons of Data From this Study with Previously Studied Datasets

Nitrate and ammonia data from this January 2000 field study in Nepal were compared to several other water quality studies. This section summarizes the results of four studies. The first study was performed jointly by The Institute for Geosciences and Natural Resources in Nepal and the Department of Mines and Geology. Samples for this Institute for Geosciences/Department of Mines study were collected in the Kathmandu Valley. This is valuable because it allows direct comparison between data from two different studies that were performed in the same region. The other three studies were all performed in agricultural areas of the United States. These provide a perspective on the typical levels of nitrate contamination in agricultural areas.

5.10.1 Study by The Institute for Geosciences and Natural Resources in Nepal and the Department of Mines and Geology

The first study was performed by The Institute for Geosciences and Natural Resources in Nepal and the Department of Mines and Geology. Water samples from this study were divided into two categories: deep groundwater sources and shallow groundwater sources. The study discovered that many shallow groundwater sources are contaminated with nitrates from anthropogenic influences stemming from sewage, inappropriate dumping of solid wastes, cultivation of agrochemicals, and lack of treatment of urban and industrial liquid waste. The study determined that the water quality of deep aquifers was primarily affected by geologic formation and were not contaminated by anthropogenic sources. High concentrations of iron, manganese, ammonia, and methane occur in the deep sources.

In total, 71 water samples were collected in two phases. Forty seven samples were collected during the end of the rainy season from August to September, 1997. An

additional 24 samples were collected several months later after the end of the rainy season in November, 1997.

Twenty-four samples were collected from deep boring wells. Fifteen samples were collected from shallow hand-dug wells. Fourteen samples were collected from tube wells. Six samples were taken from artesian springs. Five samples were taken from stone water spouts. Seven samples were collected from surface water sources.

Electrical conductivity is the measure of the ability of water to conduct an electric current and for a given water body is related to the concentrations of total dissolved solids and major ions. Often, high electrical conductivities correlate to contamination by anthropogenic sources. Analysis of the deep groundwater samples found low values of electrical conductivity compared to the shallow groundwater sources. This implies that the deep aquifer has not been contaminated by anthropogenic sources such as human and industrial waste products. In Nepal, the median value of electrical conductivity in the shallow aquifers is about 100 μs/cm higher than the median value found in the deep aquifers.

The median value of ammonia in the deep groundwater sources was 7 mg/L. Eighty-eight percent of the samples tested had ammonia present in concentrations greater than the WHO limit of 1.5 mg/L. The study found that concentrations of ammonia increase across the Kathmandu Valley from the Northeast to the Southwest. Ammonia contaminated water is thought to derive from contact with peat and lignite beds stratified in a sedimentary sequence.

Only one deep groundwater source was contaminated with nitrates above the WHO limit of 10 mg/L. It is believed that the source of contamination from this well is due to surface contamination through the well shaft.

Ammonia concentrations in shallow aquifers were much less than those found in deep aquifers. All the shallow groundwater sources that were tested had ammonia concentrations below the WHO guideline of 1.5 mg/L.

Nitrate concentrations in the shallow water sources were considerably higher than the nitrate concentrations in deep wells. Hand-dug wells and stone spouts had the highest nitrate concentrations. This is because hand-dug wells and stone spouts are traditional sources very close to the surface and are thus more susceptible to contamination than tube wells which can be drilled to depths of between 50 and 250 feet.

General trends in the Institute of Geosciences/Department of Mines data correspond well with the results presented in this thesis based on the January 2000 field study. High nitrate concentrations were found in shallow wells but not in deep wells and high ammonia concentrations were found in deep boring wells but not in shallow wells.

5.10.2 Study of Nitrate Levels in Agricultural Areas throughout the United States

In 1985, a study (Dezuane, 1997) was conducted in which 1,479 samples were taken from agricultural areas around the United States. Fifty-six percent of these samples contained nitrates at levels greater than 0.3 mg/L. However, only 1.4% contained nitrates greater than 10 mg/L. The mean nitrate concentration for all the samples taken was 1.8 mg/L.

The average nitrate concentration in all of the rural groundwater sources presented in the Dezuane study was 1.2 mg/L. Five percent of all the rural wells contained nitrates above the WHO limit. The data from the study in the United States and the January 2000 field study in Nepal correlate well. The average nitrate concentration in rural areas presented in this January 2000 field study in Nepal was 1.2 mg/L which is identical to the 1985 Dezuane study.

5.10.3 Study of Nitrate Levels in Agricultural Areas in Minnesota

In 1947, samples were taken from groundwater sources in agricultural areas throughout Minnesota. Two studies were conducted (Mackenthum pg. 16, 1965). In the first study, 514 wells were sampled. More than 5% of these samples contained nitrates at concentrations greater than 5 mg/L. Nitrate concentrations greater than 10 mg/L were found in 3.1% of the wells tested. This data correlates well with the results from this thesis based on the January 2000 field study in Nepal. Five percent of the wells in rural regions of Nepal contained nitrates at concentrations greater than 10 mg/L.

A second study was conducted in an agricultural area that had recently experienced 139 cases of "blue-baby" syndrome. One hundred and twenty-five wells were tested in a tight geographical proximity to one another. Every well tested contained nitrates present at levels above 10 mg/L. The maximum nitrate level found was 103 mg/L (Mackenthum pg. 16, 1965). This data supports the findings from Nepal that high nitrate concentrations can exist in highly localized areas that are subject to certain geological conditions and/or have experienced excessive pollution. Chabahil, on the northeast side of Kathmandu, is an example of this. Nitrate levels in Chabahil were found ain concentrations up to 63 mg/L. All the samples tested in Chabahil were above the WHO limit.

5.10.4 Study of Nitrate Levels in Agricultural Areas in Nebraska

An extensive study conducted in Nebraska between 1984 and 1988 sampled 5,826 groundwater samples (Canter, pg. 50, 1997). The results of the study are shown below in **Figure 5.23.** Roughly 30% of all the wells sampled were found to contain nitrates above the WHO and USEPA limit of 10 mg/L. The dataset is inherently biased because known areas of contamination were sampled more heavily than other areas. However, the number of tests that exceeds drinking water standards is unusually large. This data shows considerably more contamination due to agricultural fertilizers than the data collected as part of the January 2000 field study in Nepal. Only 3% of all rural groundwater samples in Nepal were found to be contaminated with nitrates above the 10 mg/L WHO limit, compared to 30% in the Canter study.

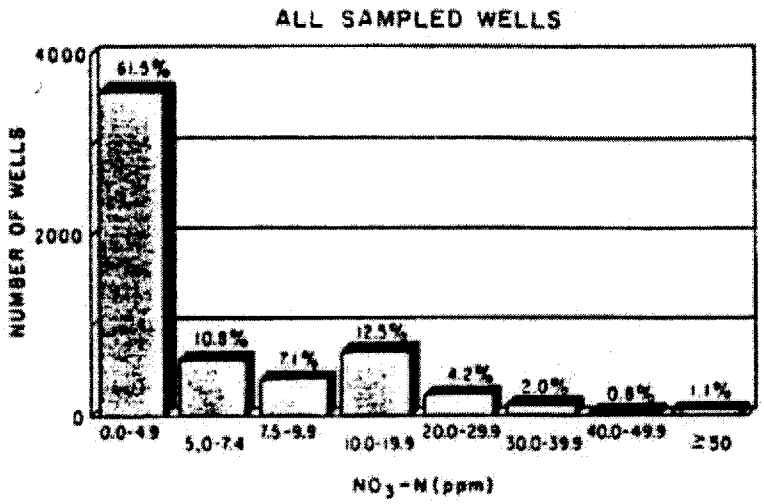

Figure 5.23: Results of Nitrate Groundwater Study in Nebraska (Canter, pg. 51, 1997)

6.0 CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to assess the contamination due to nitrates and ammonia of drinking water in Nepal. The following sections restate the most important findings of this study, offer solutions to help curb water quality problems from nitrates and ammonia, and make recommendations for follow-up studies of nitrate and ammonia contamination in Nepal.

6.1 CONCLUSIONS

Nitrate contamination in Nepal is much more prevalent at shallow depths due to anthropogenic sources such as septic systems, agricultural fertilizers, and inadequate treatment and disposal of sewage wastes. Nineteen percent of the wells sampled that were shallower than 50 feet were contaminated with nitrates above the World Health Organization limit of 10 mg/L. There were no wells deeper than 100 feet that were contaminated with nitrates above the WHO guidelines. Ammonia contamination is very minimal in shallow wells because oxygen will nitrify ammonia to form nitrates. However, high ammonia concentrations exist deep in the aquifers due to the geologic depositions of peat and lignite and anaerobic conditions deep below the surface.

Based on samples from the Kathmandu Valley and the Parsa District in the Terai, nitrate contamination in Nepal is much more prevalent in urban areas than in the rural agricultural regions. There are many urban anthropogenic sources of nitrate contamination in Nepal such as septic systems, inadequate sewage containment and treatment, and animal waste. The main anthropogenic source of nitrate contamination in rural regions is from the leaching of nitrate fertilizers into the soil. The average urban nitrate concentration was 3.9 mg/L. Ten percent of the urban samples contained nitrates above the WHO limit of 10 mg/L. The average rural nitrate concentration was 1.2 mg/L. Only, five percent of these contained nitrates above the WHO guidelines. The lack of rural nitrate contamination is possibly just due to a seasonal result of reduced infiltration

and surface run-off. Both dry-season and monsoon season sampling must be performed to verify if agricultural nitrate concentrations are consistent year-round.

Nitrate concentrations were lower in supplied and treated water sources than in traditional water sources. For the purpose of this study, supplied water sources included water that is treated at plants and supplied through piped networks to large urban centers and tube wells that have been installed by UNICEF-Nepal and other organizations in the past 15 years. Traditional water sources consist of those sites that have been used as drinking water sources for hundreds of years such as water spouts and hand-dug wells. The average nitrate concentration in supplied water sources was 1.9 mg/L; however, the average nitrate concentrations in traditional water sources was 7.6 mg/L.

No trend was discovered showing a link between well age and nitrate or ammonia contamination due to the relatively recent construction of most of the tube wells. UNICEF-Nepal and other governmental and non-governmental agencies drilled most of the wells in the past 15 years, which has perhaps not been an adequate time for sufficient wear to occur on the well pad.

6.2 POTENTIAL HEALTH RISKS

Nitrates in drinking water can cause methemoglobinemia or "blue-baby" syndrome in infants less than a year of age. The WHO has set a limit of 10 mg/L based on the occurrence of "blue-baby" syndrome. There are urban regions of Nepal that are using nitrate contaminated groundwater as a source of drinking water and are thus putting infants at risk. Chabahil, a northeast suburb of Kathmandu, is a city whose residents collect water from contaminated sources. Nitrates contaminate groundwater sources in Chabahil at levels as high as 63 mg/L. This is one region that is at a high risk of "blue-baby" syndrome. There could well be other such regions which have not yet been identified.

6.3 RECOMMENDATIONS FOR REDUCING NITRATE AND AMMONIA CONTAMINATION OF DRINKING WATER

The first recommendation from this study is that, in general, the deeper the water source the better the water quality. UNICEF-Nepal has done a good job of installing tube wells throughout the rural Terai and providing alternatives to the traditional and shallow water sources. The average drinking water quality of the Terai has probably improved dramatically because of this. However, there are still many remote and rural regions that have not been able to afford the cost of constructing tube wells and are still forced to use hand-dug wells and water spouts as drinking water sources. In urban areas, there are regions where the upper levels of an unconfined aquifer are already extremely contaminated with high levels of nitrates. In these areas, deeper wells need to be installed to reach water that has not been contaminated.

The second recommendation from this study is to decrease the amounts of untreated sewage and other waste products that infiltrate into the groundwater supplies. This is an expensive proposition and one that is not likely to be undertaken by the Nepali government any time soon, yet untreated waste products are the prime source of nitrate contamination in the large urban areas of Nepal. Removing this source would dramatically improve urban water quality.

The last recommendation is to paint a red mark around the base of any well that is found to be contaminated with nitrates above the WHO limit of 10 mg/L. This would notify users that the water source is not safe, especially for infants under 6 months of age.

6.4 RECOMMENDATIONS FOR FUTURE STUDIES

This study has gained a deeper understanding of nitrate and ammonia contamination of drinking water in Nepal yet it has also raised some questions that need to be addressed further in follow-up studies. The most obvious is that more sampling and analysis needs to be performed to gain a broader picture of the nitrate and ammonia contamination in Nepal and to verify the conclusions drawn here. A larger dataset will allow us to

conclude definitively the depth vs. nitrate and ammonia relationships and the well-age vs. nitrate and ammonia relationships. Another question that needs to be resolved is whether seasonal weather fluctuations cause changes in the infiltration and run-off that lead to seasonal variations of nitrate and ammonia concentrations in the rural, agricultural regions. Sampling must be performed year round, through the dry season and through the monsoon season, to adequately verify if these seasonal differences exist. This will also allow us to determine if contamination of groundwater in agricultural regions due to nitrate fertilizers is a significant health risk.

Another recommendation for future testing is to perform nitrogen isotope testing. Nitrogen isotope testing allows one to determine the sources of nitrates in the environment. The technique is based on the idea that nitrates in soils and groundwater have different nitrogen isotope ratios ($^{15}N/^{14}N$) based on their source (Wolterink, 1979). In particular, this method is able to differentiate between nitrates from urban anthropogenic sources such as septic tanks, animal waste, and municipal wastewater, from rural anthropogenic sources such as agro-fertilizers, and from nitrates of geologic origin. This information would allow one to determine more definitively the primary sources of nitrate contamination in Nepal and thus to determine the most effective remediation and prevention alternatives.

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APPENDICES

Appendix A: Source Information
Appendix B: Analytical Test Results

APPENDIX A

SOURCE INFORMATION

APPENDIX A
SOURCE INFORMATION

Sample Number:	Cumulative Sample Number:*	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
14/01	1	Jan. 14, 2000	8:40 AM	Inaruwa, Ward 19, Birganj Periphery	STW	250	4	35	Drainage ditch flows under well; Cows, chickens, goats grazing nearby
14/02	2	Jan. 14, 2000	9:15 AM	Naguwa, Ward 19, Birganj Periphery	STW	200	10	10	Pond across from street used for washing clothes; Sonde results of pond water: Temp. 17.4 C, NO_3^- 0.44 mg/L, NH_4^+ 1.06 mg/L, Turb. 2.2 NTU, DO 5.68 mg/L
14/03	3	Jan. 14, 2000	9:45 AM	Biauwwa, Ward 18, Birganj Periphery	STW	135	1	5-6	No well pad - just bricks; Possibly leaky
14/04	4	Jan. 14, 2000	10:00 AM	Badelhi, Ward 18, Birganj Periphery	STW	160	3	16	
14/05	5	Jan. 14, 2000	10:35 AM	Elachhmania, Ward 18, Birganj Periphery	HD	24	>50	15	Not used for drinking except during emergencies; 5-6 foot diameter, STWs in area are shallow (20-30 ft) - water comes from same aquifer as this HD well
14/06	6	Jan. 14, 2000	10:35 AM	Elachhmania, Ward 18, Birganj Periphery	STW	60	15	1	Private Well; Older man with skin problems typical of Arsenicosis - dark black spots on hands and legs
14/07	7	Jan. 14, 2000	11:05 AM	Pipara, Ward 17, Birganj Periphery	STW	160	1	5	
14/08	8	Jan. 14, 2000	11:25 AM	Bahuari, Ward 17, Birganj Periphery	STW	140	5	15	Not a good seal for tube - possibly leaky
14/09	9	Jan. 14, 2000	1:45 PM	Bazaar Zhhapkaiya, Ward 1, Birganj Periphery	STW	260	>10	26	Possiible adverse health effects typical of Arsenicosis found on two men; Flooded well pad with stagnant water
14/10	10	Jan. 14, 2000	2:30 PM	Near India Customs, Ward 2, Birganj Periphery	STW	160	1	>20	Near large stagnant pond
14/11	11	Jan. 14, 2000	2:45 PM	Ghadi Arwa, Ward 12, Birganj City Center	STW	160	10	20	
14/12	12	Jan. 14, 2000	3:10 PM	Resan Kothi, Ward 7, Birganj City Center	STW	200	10	20	
15/01	13	Jan. 15, 2000	9:15 AM	Bagahi Village, Ward 2, Village outside Birganj	STW	250	5	Public well near school; used mostly by children	Rural site; Bagahi Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/02	14	Jan. 15, 2000	9:35 AM	Bagahi Village, Ward 2, Village outside Birganj	STW	60	3	15	Rural site; Bagahi Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/03	15	Jan. 15, 2000	9:50 AM	Bagahi Village, Ward 6, Village outside Birganj	STW	65	10	7	Rural site; Bagahi Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/04	16	Jan. 15, 2000	10:20 AM	Lalpasa Village, Ward 2, Village outside Birganj	STW	60	7	7	Rural site; Lalpasa Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total; There are two aquifers one at about 60 ft. and the other at about 110 feet; The shallow aquifer is contaminated with iron (2.5 - 10 mg/L) which creates asthetic problems, taste, dyes clothes, and creates long term stomach problems; Only wealthy can afford wells in deep aquifer
15/05	17	Jan. 15, 2000	10:40 AM	Lalpasa Village, Ward 1, Village outside Birganj	STW	110	3	5	Rural site; Lalpasa Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total; There are two aquifers one at about 60 ft. and the other at about 110 feet; The shallow aquifer is contaminated with iron (2.5 - 10 mg/L) which creates asthetic problems, taste, dyes clothes, and creates long term stomach problems; Only wealthy can afford wells in deep aquifer
15/06	18	Jan. 15, 2000	11:00 AM	Lalpasa Village, Ward 4, Village outside Birganj	STW	50	10	5	Rural site; Lalpasa Village is agricultural; Population is 3,000 - 4,000, 9 or 10 wells total
15/07	19	Jan. 15, 2000	2:00 PM	Tajpur Village, Ward 3, Village outside Birganj	STW	130	12	10	Industrial site; Pharmaceutical Industry, 3 yrs old, nearby; Discharge to stream is 250 m away
15/08	20	Jan. 15, 2000	2:25 PM	Kodyiadoll, Ward 3, Village outside Birganj	STW	110	2	4	Industrial site; Immediately adjacent to medical facility and leather tannery; Textile mill 200 m away
15/09	21	Jan. 15, 2000	2:40 PM	Powanipu, Ward 6, Village outside Birganj	STW	140	5	Private well + unlimited use	Industrial site; Motor oil and grease manufacturing facility adjacent; Food processing plant adjacent
15/10	22	Jan. 15, 2000	3:00 PM	Chainpur, Ward 8, Village outside Birganj	STW	150	9	Public well + unlimited use	Industrial site; Gas station adjacent
15/11	23	Jan. 15, 2000		Birganj, Hotel Kailas Tap Water	Piped	NA			
18/01	24	Jan. 18, 2000		Dathali Public Water Supply, Intake to sedimentaion tank - directly from nearby streams; Near Bhaktapur	Treatment Plant / Stream Intake	NA	Water Supply System is 13 years old	Population of 10,000	Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauiflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source

APPENDIX A
SOURCE INFORMATION

Sample Number:	Cumulative Sample Number:*	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
18/02	25	Jan. 18, 2000		Dathali Public Water Supply, Sample from sedimentation tank: Near Bhaktapur	Treatment Plant / Surface Intake	NA	Water Supply System is 13 years old	Population of 10,000	Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauiflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source
18/03	26	Jan. 18, 2000		Dathali Public Water Supply, Water tap in distribution system: Near Bhaktapur	Treatment Plant / Surface Intake	NA	Water Supply System is 13 years old	Population of 10,000	Dathali Water Supply; System is 13 years old which serves a population of about 10,000 people; Two reservoirs - currently only one is working; The only treatment used is a sedimentation tank; The source is from three nearby streams; Yield is 1.5 L/sec; Area has heavy agricultural, heavy use of fertilizers; crops include wheat, potatoes, mustard, tomatoes, garlic, and cauiflower; During rainy season, water quality declines visually; Algae growth in tank; no cover on sedimentation tank - photosynthesis can occur; no tests ever conducted on this water source
18/04	27	Jan. 18, 2000		Kiwachowk Public Water Supply, Water tap near outflow from above ground tank: Near Bhaktapur	Surface	NA	NA	Poplation of 1,500	Kiwachowk Water Supply; Water from 5 or 6 springs is collected and pumped into a large covered above ground tank; Spring source is 3.5 km away near cultivated agricultural lands; no water quality testing ever performed
19/01	28	Jan. 19. 2000	10:00 AM	Thimi Gas Station	HD	42.64	NA		5 - 6 ft. diameter, pumped through hose to gas station, not used for drinking, high iron content
19/02	29	Jan. 19. 2000	10:00 AM	Thimi household	STW	NA	NA		Tube sticking out of ground with a plunger used to pump water to surface - depth estimated to be consistent with depths of other hand dug wells
19/03	30	Jan. 19. 2000	10:15 AM	Thimi; Kyung Hee Nepal Health Centre, sink	Piped	NA	NA		Not used for drinking;
19/04	31	Jan. 19. 2000	10:30 AM	Thimi local market	Piped	NA	NA		Drinking water
19/05	32	Jan. 19. 2000	10:30 AM	Thimi, Chandramukhi Cabin Restaurant	Store/Restaurant	NA	NA		Drinking water
19/06	33	Jan. 19. 2000		Kirtipur, Central laboratory tap water	Piped	NA	NA		Drinking water
20/01	34	Jan. 20, 2000	9:25 AM	Patan	HD	30	NA		Not used for drinking, 5 - 6 ft diameter
20/02	35	Jan. 20, 2000	9:45 AM	Patan	Traditional Water Spout	NA	NA		Durbar Square water spout; used for drinking and bathing; traditional water source
20/03	36	Jan. 20, 2000	9:50 AM	Patan	Store/Restaurant	NA	NA		Cafe du Temple Restaurant tap water; used for drinking
20/04	37	Jan. 20, 2000	10:30 AM	Kathmandu	Store/Restaurant	NA	NA		Kathmandu Guest House tap water; used for drinking; Sonde results showed nitrate concentrations at 14 mg/L
20/05	38	Jan. 20, 2000	10:35 AM	Kathmandu	Store/Restaurant	NA	NA		Pilgrim Restaurant and Bar Tap water; used for drinking; filtered at restaurant before use
23/01	39	Jan. 23, 2000	8:30 AM	Naikap, source of water to system from sump well	Sump Well - Underneath Surface Water Source	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house
23/02	40	Jan. 23, 2000	8:45 AM	Naikap, source of water to system from tube well	STW	100	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house
23/03	41	Jan. 23, 2000	8:50 AM	Naikap, sample from Balkhu Stream that feeds sump well	Surface	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house
23/04	42	Jan. 23, 2000	9:20 AM	Naikap, sample from treatment system aeration tank, only deep tube well water, tube well and sump well water combine after aeration	Treatment Plant / Surface and STW Intake	NA	Treatment system is 3 yrs. Old	762 households served @ about 6 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house

APPENDIX A
SOURCE INFORMATION

Sample Number:	Cumulative Sample Number:*	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
23/05	43	Jan. 23, 2000	9:20 AM	Naikap, after filtration	Treatment Plant / Surface and STW Intake	NA	Treatment system is 3 yrs. Old	782 households served @ about 8 people per household	Naikap treatment system, 762 households, near Balkhu stream (polluted), industrial (automobile, food processing, oil tankers) and agricultural (rice) sites upstream, system provides water 1 - 2 hours per day, Naikap is 5 km from Kathmandu city center, Pump house takes water from 2 sources (1) sump well 2 ft below Balkhu Stream bed and (2) deep tube well 100 ft. deep in pump house
23/06	44	Jan. 23, 2000	9:20 AM	Naikap, traditional source, people use this water because they think it is better than the municipally supplied treated water	Traditional Water Spout	NA	NA		traditional water source
23/07	45	Jan. 23, 2000	10:05 AM	Sitapaila, stream surface water source, pipeline takes untreated water from stream for water supply	Surface	NA	NA		
24/01	46	Jan. 24, 2000	10:15 AM	Kathmandu	Store/Restaurant	NA	NA		Store in front of Royal Palace, municipal tap water, used for drinking
24/02	47	Jan. 24, 2000	10:50 AM	Kathmandu	Traditional Water Spout	NA	NA		Sundhara public water spout used for bathing and drinking, traditional water source
24/03	48	Jan. 24, 2000	11:00 AM	Kathmandu	Store/Restaurant	NA	NA		Store near Sundhara
25/01	49	Jan. 25, 2000	8:25 AM	Kathmandu	Store/Restaurant	NA	NA		Drinking water from a store near Kathmandu Durbar Square
25/02	50	Jan. 25, 2000	8:30 AM	Kathmandu	Traditional Water Spout	NA	NA		Naradeni Spout; traditional water source for bathing and drinking
25/03	51	Jan. 25, 2000	8:35 AM	Kathmandu	STW	50	40		Hand pump near Kathmandu Durbar Square
26/01	52	Jan. 26, 2000	9:20 AM	Mitrapark/Cholobol	STW	NA	NA		On the road to Bouddha; store in Cholobol near Temple, drinking water
26/02	53	Jan. 26, 2000	9:30 AM	Mitrapark/Cholobol	Store/Restaurant	NA	NA		On the road to Bouddha, store in Cholobol on main street
26/03	54	Jan. 26, 2000	9:30 AM	Mitrapark/Cholobol	STW	70	0.83		On the road to Bouddha, hand pump well used for drinking
26/04	55	Jan. 26, 2000	9:30 AM	Mitrapark/Cholobol	STW	75	0.33		On the road to Bouddha, hand pump well used for drinking
26/05	56	Jan. 26, 2000	9:30 AM	Mitrapark/Cholobol	STW	90	NA		On the road to Bouddha, hand pump well used for drinking
26/06	57	Jan. 26, 2000	9:45 AM	Mitrapark/Cholobol	Traditional Water Spout	NA	NA		On the road to Bouddha, water spout near bus station
BR1	58	Jan. 18, 2000		Bagmati River Sample	Surface	NA	NA		
BR2	59	Jan. 18, 2000		Bagmati River Sample	Surface	NA	NA		
BR3	60	Jan. 18, 2000		Bagmati River Sample	Surface	NA	NA		
BR4	61	Jan. 18, 2000		Bagmati River Sample	Surface	NA	NA		
BR5	62	Jan. 20, 2000		Bagmati River Sample	Surface	NA	NA		
BR6	63	Jan. 20, 2000		Bagmati River Sample	Surface	NA	NA		
BR7	64	Jan. 24, 2000		Bagmati River Sample	Surface	NA	NA		
BR8	65	Jan. 24, 2000		Bagmati River Sample	Surface	NA	NA		
TP1	66	Jan. 24, 2000		Mahankal	Treatment plant - Intake from DBW	984	15		well - 15 yrs old, 15 L/s, pretreated water called DK5
TP2	67	Jan. 24, 2000		Mahankal	Treatment plant - Intake from DBW	NA	NA		tank was for pH pretreatment for the water from several wells including the Gokarna and Manohara as well as DK5. We had to remove a great to get to the water. After this, the water goes into a biological reactor to treat with nitrious bacterial.
TP3	68	Jan. 24, 2000		Mahankal	Treatment plant - Intake from Surface	NA	NA		surface water from Sundarijal. Source was outside the coagulation mixing plant
TP4	69	Jan. 24, 2000		Mahankal	Treatment Plant	NA	NA		source next to pumping station, residual chlorine 3 mg/L
TP5	70	Jan. 24, 2000		Balaju	Treatment plant - Intake from DBW	656	20		well - 200 m or more deep, 20 yrs old, 2-3 MLD, called Bishnumati #2, water untreated
TP6	71	Jan. 24, 2000		Balaju	Treatment Plant	NA	NA		water from reservoir (collected with hose), this is the finished, supplied
TP7	72	Jan. 24, 2000		Maharajganj	Treatment Plant	NA	96		this is the same water as at the Bansbari treatment plant, the plant is just an underground resevoir built by the British and is 96 years old.
27/01	73	Jan. 27, 2000		Maheshwor's Tap Water	Piped	NA	NA		Drinking water
27/02	74	Jan. 27, 2000		Shallow well near Maheshwor's house	HD	NA	NA		Drinking water
27/03	75	Jan. 27, 2000		Deep boring well, before treatment	DBW	984	NA		Central Laboratory measured Ammonia at 96 mg/L
27/04	76	Jan. 27, 2000		Deep boring well, after treatment	DBW	984	NA		Central Laboratory measured Ammonia at 96 mg/L
29/01	77	Jan. 29, 2000		Sonbarshi	STW	180	1	3	
29/02	78	Jan. 29, 2000		Sonbarshi	STW	195	3	15	
29/03	79	Jan. 29, 2000		Sonbarshi	STW	185	3	10	
29/04	80	Jan. 29, 2000		Sonbarshi	STW	185	3	10	
29/05	81	Jan. 29, 2000		Ramawapur	STW	180	1	37	
29/06	82	Jan. 29, 2000		Ramawapur	STW	180	1	37	
29/07	83	Jan. 29, 2000		Ramawapur	STW	45	8	5	diarrhea, leucorrhoea, giardia
29/08	84	Jan. 29, 2000		Sonbarsha	STW	195	1	25	diarrhea, leucorrhoea, dysentery

APPENDIX A
SOURCE INFORMATION

Sample Number:	Cumulative Sample Number:*	Date:	Time of Sample:	Location of Well/Water Source:	Water Source / Well Type:	Depth of Well (ft):	Age of Well (yrs):	Number of Households Served:	Comments:
29/09	85	Jan. 29, 2000		Sonbarsha	STW	30	NA		
29/10	86	Jan. 29, 2000		Sonbarsha	STW	25	NA		
30/01	87	Jan. 30, 2000		New Ramawapur	STW	20	10	8	diarrhea, leucorrhoea
30/02	88	Jan. 30, 2000		New Ramawapur	STW	195	1	15	
30/03	89	Jan. 30, 2000		New Ramawapur	STW	35	15	5	yes, health problems
30/04	90	Jan. 30, 2000		Bhagatpuruwa	STW	140	2	12	abdominal problems
30/05	91	Jan. 30, 2000		Bhagatpuruwa	STW	100	1	7	
30/06	92	Jan. 30, 2000		Shivagadiya	STW	75	NA	20	diarrhea,leucorrhoea,dysn,cholera
30/07	93	Jan. 30, 2000		Shivagadiya	STW	17	15	5	abdominal problems
30/08	94	Jan. 30, 2000		Ramawapur	STW	NA	NA		
30/09	95	Jan. 30, 2000		Sonbarshi	STW	NA	NA		
30/10	96	Jan. 30, 2000		Chinese Monastery	STW	NA	NA	7 monks	Chinese Monastery
31/01	97	Jan. 31, 2000		Dhodadwa	STW	350	1	65	
31/02	98	Jan. 31, 2000		Dhodadwa	STW	35	5	1	
31/03	99	Jan. 31, 2000		IBS - Outside tubewell	STW	80	1	40	
31/04	100	Jan. 31, 2000		IBS - Across Street	STW	35	1		
31/05	101	Jan. 31, 2000		IBS - 3rd Floor Tap	Piped	170	3	150 - 200 people/day	abdominal problems
31/06	102	Jan. 31, 2000		Private - Ramachandra	STW	45	1	1	
31/07	103	Jan. 31, 2000		Madhuvani Primary School	STW	250	NA	300 children,150 others	
31/08	104	Jan. 31, 2000		Mailawari	STW	180	1	12	
31/09	105	Jan. 31, 2000		Buddhanagar	STW	700	10	30	abdominal problems
1/01	106	Feb. 1, 2000		Kapilavastu - Palace Gate	STW	120	3	200 people	
1/02	107	Feb. 1, 2000		Kapilavastu -	STW	95	4	40 people	
1/03	108	Feb. 1, 2000		Student's Tubewell	STW	195	3	500 students	
1/04	109	Feb. 1, 2000		Teachers Tubewell	STW	48	6	40 people	
1/05	110	Feb. 1, 2000		Private Home - Vihara	STW	80	1	50 people	
1/06	111	Feb. 1, 2000		IBS - Across Street	STW	35	1		
1/07	112	Feb. 1, 2000		Siddhartha Hotel	Piped	NA	NA		

Source Types and Codes

STW = Shallow Tube Well	Surface = Surface Water Source	Treatment Plants
HD = Hand Dug Well	Piped = Tap Water	Traditional Water Spouts
DBW = Deep Boring Well	Restaurant/Store - source unknown	

* The cumulative sample number helps to relate sample numbers to the data that is presented in sections 5.5, 5.6, 5.8, and 5.9

APPENDIX B

ANALYTICAL TEST RESULTS

APPENDIX B
ANALYTICAL TEST RESULTS

	Nitrate Test Results							Ammonia Test Results			Turbidity Test Results
	with Hach DR/2010 Spectrophotometer				with Spectronic 20 Genesys Spectrophotometer		with Nitrate Elimination Field Kit	with Hach DR/2010 Spectrophotometer			with Hach DR/2010 Spectrophotometer
Sample Number:	Powder Pack Pillows - Medium Range mg/L	Powder Pack Pillows - High Range mg/L	Ampules - Medium Range mg/L	Ampules - High Range mg/L	Powder Pack Pillows - Medium Range mg/L	Powder Pack Pillows - High Range mg/L	mg/L	Powder Pack Pillows mg/L	Test N Tube Reagent Vials - Low Range mg/L	Test N Tube Reagent Vials - High Range mg/L	FAU Turbidity Units
14/01			0.2							1.35	
14/02			0.2							0.35	
14/03			0							0.3	
14/04			0							0.4	
14/05		16	Over Range	13		18.5				0.1	
14/06			0							0.2	
14/07			0							0.3	
14/08			0							0.2	
14/09			0							0.2	
14/10			0							0.2	
14/11			0							0.6	
14/12			0							0.25	
15/01	0		0		0		0			0.4	
15/02	0.5		0.55		1		0.5			0.95	
15/03	0.6		0.75		1		0.5			0.8	
15/04	0.4		0.3		1		0			1.05	
15/05	0.1		0		0		0.5			0.4	
15/06	0.3		0.25		0		0			0.55	
15/07	0		0		0		0			0.5	
15/08	0.1		0		0		0			0.25	
15/09	0.2		0		0		0			0.5	
15/10	0		0		0		0			0.35	
15/11			0								
18/01	0.8			1.6					0	0	
18/02	0.8			1.1					0	0	
18/03	0.8			1.7					0	0	
18/04	0.3			2.2					0	0	
19/01		2.35		2.1		3			1.57	3.55	37
19/02		0.8		0.6		0			>2.5	36.1	12
19/03		1.9		2.85		2			>2.5	10.05	42.5
19/04		0.6		1.4		0			0.05	0.25	3.5
19/05		0.45		0.8		0			0.79	1	8.5
19/06		1.1		1.9		1			0.01	0	3.5
20/01	>4.5	5.15							0.18	0.2	11.5
20/02	>4.5	11.6							0	0	3.5
20/03	0.3	0.3							0.1	0.1	6.5
20/04	>4.5	7.3							0.1	0.15	5
20/05	1.35	3.2							>2.5	18.35	18
23/01		0.8							1.25	1.6	6
23/02		1.25							>2.5	9.7	9
23/03		1.55							0.34	1.1	15
23/04		0.9							>2.5	7.2	9
23/05		1.4							1.5	1.95	4.5
23/06		8.1							0	0.15	7.5
23/07		0.75							0.01		10.5
24/01		0.5							0.02		2
24/02		10.85							0.04		1
24/03		0.15							0.03		4
25/01		0							0		2.5
25/02		5.9							1.88		3
25/03		8.75							0.38		4
26/01		0.25							0		3
26/02		0.5							0		4
26/03		18							0.45		5
26/04		15.8							0.05		6.5
26/05		63.3							0.5		6
26/06		0.4							0		10
BR1				0.8							16.5
BR2				2							40.5
BR3				1.5							27.5
BR4				0.15							14.5
BR5	3										68.5
BR6	2.8										72
BR7		1.55						2			15.5
BR8		0.2						0			4
TP1		1.8						19			
TP2		2.2						16			
TP3		0.55						0			
TP4		1.95						5			
TP5		2.8						12			
TP6		1.1						0			

APPENDIX B
ANALYTICAL TEST RESULTS

	Nitrate Test Results							Ammonia Test Results			Turbidity Test Results
	with Hach DR/2010 Spectrophotometer				with Spectronic 20 Genesys Spectrophotometer		with Nitrate Elimination Field Kit	with Hach DR/2010 Spectrophotometer			with Hach DR/2010 Spectrophotometer
Sample Number:	Powder Pack Pillows - Medium Range mg/L	Powder Pack Pillows - High Range mg/L	Ampules - Medium Range mg/L	Ampules - High Range mg/L	Powder Pack Pillows - Medium Range mg/L	Powder Pack Pillows - High Range mg/L	mg/L	Powder Pack Pillows mg/L	Test N Tube Reagent Vials - Low Range mg/L	Test N Tube Reagent Vials - High Range mg/L	FAU Turbidity Units
TP7		1.65						7			
27/01		0.2						1			
27/02		6.45						0			
27/03		0.8						>50			
27/04		0						>50			
29/01		0.5									
29/02		0.6									
29/03		0.4									
29/04		0.4									
29/05		0.5									
29/06		0.5									
29/07		10.2									
29/08		0.3									
29/09		12.7									
29/10		0.2									
30/01		0.4									
30/02		0									
30/03		2.4									
30/04		0									
30/05		0.8									
30/06											
30/07		0									
30/08		0.5									
30/09		0.2									
30/10		0.4									
31/01		0.4									
31/02		0.3									
31/03		0.3									
31/04		0									
31/05		0.5									
31/06		0.2									
31/07		0.4									
31/08		0.3									
31/09		0.7									
1/01		0.5									
1/02		0.5									
1/03		0.6									
1/04		0									
1/05		0.2									
1/06		0.2									
1/07		0.4									