

## AN ABSTRACT OF THE THESIS OF

Christopher Flanders Vick for the degree of Master of Science in Water Resources Engineering presented on November 12, 2004.

Title: Chemical and Isotopic Patterns of Nitrate Variability in the Southern Willamette Valley, Oregon.

Abstract Approved: \_\_\_\_\_

John S. Selker

A relatively stable, persistent and historical problem with elevated  $\text{NO}_3^-$  concentrations in rural drinking wells in the southern Willamette Valley, Oregon is evident. What is the origin of  $\text{NO}_3^-$  in rural drinking water wells in this area? The answer to the question is not simple. Many non-point sources contribute to the elevated levels of  $\text{NO}_3^-$  in ground water, including residential and agricultural. The objective of this study was to use isotopes of  $\text{NO}_3^-$  and other chemical indicators to determine the sources of  $\text{NO}_3^-$  in drinking water wells in the southern Willamette Valley, OR. Criteria for wells to be included in the study were (1) less than 75 feet in depth (2) installed after 1960 and (3) domestic use. Four hundred sixty-six wells met the criteria of the study and 120 wells were sampled during the summer of 2003. Geologic units, dominant land use and soil types were determined for each well in an attempt to determine vulnerability of wells for  $\text{NO}_3^-$  contamination. Twenty drinking water wells were selected to undergo isotopic and further chemical analyses. In order to determine the chemical and isotopic fingerprints of the dominant sources of  $\text{NO}_3^-$  contamination soil samples were augered from 10 septic drain fields and water samples were collected below 10 agricultural fields.  $\text{NO}_3\text{-N}$  concentrations in the study area ranged from below detection ( $<0.20$  mg/L) to 13.70 mg/L, with a mean concentration of 4.81 mg/L. There was a statistically

significant trend (i.e.  $P < 0.05$ ) in  $\text{NO}_3\text{-N}$  with well depth, well age, pH and  $\text{SO}_4^-$ .

Findings suggest that geologic units play an important role in determining vulnerability of wells to  $\text{NO}_3^-$  contamination, with land use also being important, yet less significant.

Attempts to determine a fingerprint of septic and agricultural sources of  $\text{NO}_3^-$  contamination were inconclusive, though various chemical indicators were found to suggest the origin of the  $\text{NO}_3^-$ .

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Chemical and Isotopic Patterns of Nitrate Variability in the  
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by  
Christopher Flanders Vick

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APPROVED:

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John S. Selker, Major Professor, representing Water Resources Engineering

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John S. Selker, Head of the Water Resources Graduate Program

---

Sally Francis, Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request

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Christopher Flanders Vick, Author

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# Chapter I

## Literature Review

### 1.1 Introduction

More than half of the population in the United States relies on ground water as their primary source of drinking water (Nolan, 2000). Nearly 70% of the population in Oregon actively uses groundwater, while 95% of the population in rural areas is dependent on groundwater (Oregon DEQ, 2001). Groundwater is a critical natural resource with purity often taken for granted, and thus contaminated by numerous non-point sources. Pollutants such as nitrates, pesticides, human and animal wastes are often found in shallow drinking wells. The problem of nitrate ( $\text{NO}_3^-$ ) contamination is widespread. The National Survey of Pesticides (NPS) in Drinking Wells estimated 57% of rural drinking water wells contained elevated levels of  $\text{NO}_3^-$  and pesticides (USEPA, 1990). The maximum contaminant level (MCL) for nitrate-Nitrogen ( $\text{NO}_3\text{-N}$ ) is 10 mg/L (10 ppm), which was exceeded in 2.4% of the wells (USEPA, 1990).

Over the past seventy years, various organizations have evaluated the quality of drinking water from domestic wells in the southern Willamette Valley, Oregon. The first study, performed by the USGS in 1938, indicated an average  $\text{NO}_3\text{-N}$  concentration of 4.3 mg/L (USGS, 1938). Thirty years later, in 1968, the Oregon State Engineer sampled twelve wells in the same area, obtaining an average  $\text{NO}_3\text{-N}$  concentration of 4.4 mg/L (OSE, 1970). In 1978, the consulting firm of Sweet, Edwards and Associates sampled thirty-one wells in the southern Willamette Valley, finding an average  $\text{NO}_3\text{-N}$  concentration of 4.1 mg/L (Smith et al., 1978). In 1994, Oregon State University (OSU)

Extension performed  $\text{NO}_3^-$  analysis on 824 private wells in the southern Willamette Valley, reporting an average concentration of 3.6 mg/L (Penhallagon, 1994). A relatively stable, persistent and historical problem with elevated  $\text{NO}_3^-$  concentrations in rural drinking wells in the southern Willamette Valley is evident. It is important to note that these data are not spatially random since wells from the early 20<sup>th</sup> century were often shallow and placed near pit toilets, therefore not allowing us to draw strong conclusions from these data.

Consumption of  $\text{NO}_3^-$  is a major health concern. Ingestion of  $\text{NO}_3^-$  laced drinking water can cause methemoglobinemia (blue baby syndrome) in infants under six months, and recently killed a child in South Dakota (Johnson et al., 1987). Minnesota experienced a 30 month period in the 1940's where 144 cases of methemoglobinemia were documented, 14 of which were fatal (Johnson and Kross, 1990).  $\text{NO}_3^-$  has also been documented to be associated with increased infant mortality (Super et al., 1981); central nervous system birth defects (Dorsch et al., 1984); prematurity and intrauterine growth restriction (Bukowski et al., 2001); hypertension (Malberg et al., 1978); stomach cancer (Hill et al., 1973); bladder cancer (Weyer et al., 2001); gastric cancer (Cuello et al., 1976); non-Hodgkins lymphoma (Weisenburger, 1991); hypertrophy of the thyroid (van Maanen et al., 1994); recurrent respiratory tract infections (Gupta et al., 2000); and spontaneous abortions (Morales-Suarez-Varela et al., 1996).

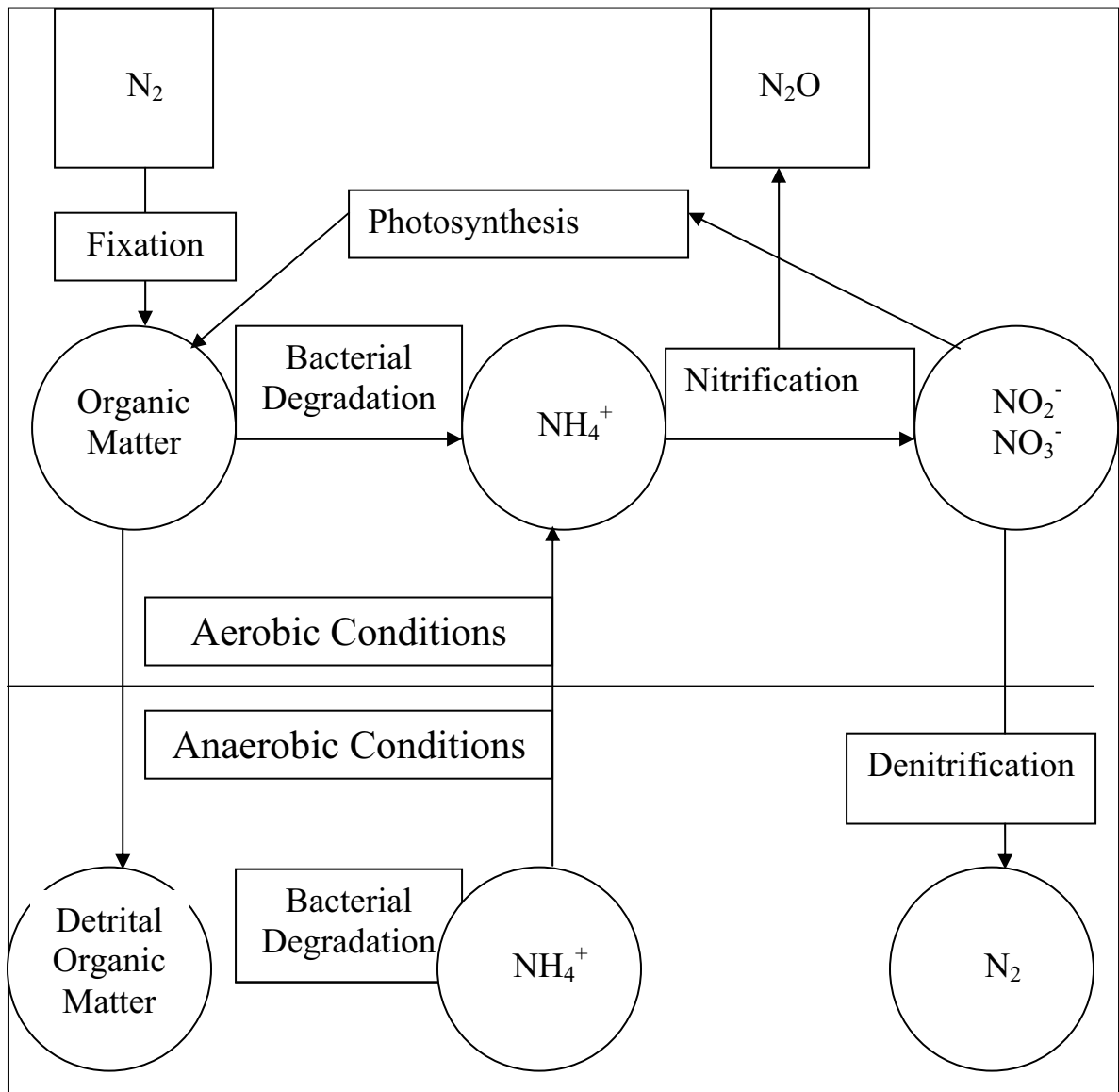
What is the origin of  $\text{NO}_3^-$  in rural drinking water wells in the southern Willamette Valley, OR? The answer to the question is not simple. Many non-point sources contribute to the elevated levels of  $\text{NO}_3^-$  in ground water, including residential

and agricultural. This thesis will attempt to identify the sources of  $\text{NO}_3^-$  in drinking water wells in the southern Willamette Valley, OR.

## 1.2 Review of Nitrate Contamination of Groundwater

### 1.2.1 Nitrogen Cycling

Nitrogen (N) is found within ecosystems in many different forms. The atmosphere contains 79% N, yet the amount of energy needed to convert it into other forms is limiting (Aber and Melillo, 1991). Therefore, only a small amount of N is actually fixed from dinitrogen ( $\text{N}_2$ ) by ecosystems (Figure 1.1).



**Figure 1. 1: The Nitrogen Cycle**

N fixation is the process of converting atmospheric N ( $N_2$ ) into forms suitable for consumption by plants and animals. The process of converting organic forms of N into  $NH_4^+$  is termed mineralization. Several types of bacteria and blue-green algae are primarily responsible for the natural conversion of  $N_2$  into ammonium ( $NH_4^+$ ), because they possess the enzyme *nitrogenase*. Other processes of nitrogen fixation include

atmospheric fixation by lightning and industrial fixation for use as fertilizers. The decomposition of animal wastes and detritus of plant and animal matter causes a change from organic nitrogen to a mixture of ammonia (NH<sub>3</sub>) and (NH<sub>4</sub><sup>+</sup>). The ammonia can be assimilated by plants to form proteins (Canter, 1997). While in the form of NH<sub>4</sub><sup>+</sup> nitrogen is subject to volatilization and fixation by both clays and soil organic matter (SOM) (Schlessinger, 1991). Also, microbes transform NH<sub>4</sub><sup>+</sup> into other forms of N (Aber and Melillo, 1991).

Nitrification, a two step process, is the result of microbes, both bacteria and fungi, biologically converting organic and inorganic nitrogenous compounds from a reduced state to a more oxidized state (Wetzel, 2001). The oxidation of NH<sub>4</sub><sup>+</sup> into nitrite (NO<sub>2</sub><sup>-</sup>) (Equation 1.1a), is controlled largely by *Nitrosomonas* (Nitrobacteriaceae, order Pseudomonadales) (Alexander, 1965). NO<sub>2</sub><sup>-</sup> is further oxidized into NO<sub>3</sub><sup>-</sup> (Equation 1.1b) by the bacterial genus *Nitrobacter* (Nitrobacteriaceae, order Pseudomonadales) (Alexander, 1965).



In order for nitrification to occur, the conditions must be aerobic and can occur as long as dissolved oxygen levels exceed 0.3 mg liter<sup>-1</sup> (Wetzel, 2001). Regardless of the source of ammonium, the process of nitrification will significantly decrease the pH of the soil by producing hydrogen ions (H<sup>+</sup>). This acidification causes the replacement of H<sup>+</sup> and aluminum (Al<sup>3+</sup>) ions on the exchange sites with calcium (Ca<sup>2+</sup>) and magnesium (Mg<sup>2+</sup>), typically resulting in the leaching of Ca<sup>2+</sup> and Mg<sup>2+</sup> (Brady and Weil, 2002).



Denitrification is the bacterial process of biochemically reducing the oxidized nitrogen compounds into  $N_2$ . The sequence of this process generally takes three steps:  $NO_3^- \rightarrow NO_2^- \rightarrow N_2O \rightarrow N_2$ . The bacteria responsible for this conversion are from the genera *Pseudomonas*, *Achromobacter*, *Escherichia*, *Bacillus*, and *Micrococcus* (Wetzel, 2001). The bacteria utilize the  $NO_3^-$  as a terminal H acceptor in the oxidation of organic substrates (Alexander, 1961). Denitrification can occur under aerobic and anaerobic conditions, but requires the enzyme nitrogen reductase and the cofactor of molybdenum (Wetzel, 2001).

$NO_3^-$  concentrations are typically reported in units of milligrams per liter (mg/L) with the mass representing either the fractional mass of  $NO_3^-$  ions in the water ( $NO_3^-$ ) or as the fractional mass of only the nitrogen ( $NO_3^-$ -N). The molecular weight of  $NO_3^-$  is 62 and N is 14, therefore the ratio of a concentration measured as  $NO_3^-$  to an equivalent concentration measured as  $NO_3^-$ -N is 4.43. The MCL of 10 mg/L  $NO_3^-$ -N is equivalent to 44.3 mg/L  $NO_3^-$ .

### 1.2.2 Sources of Nitrate Contamination in Groundwater

$NO_3^-$  contamination of groundwater is often associated with the following three sources: (1) natural; (2) waste materials; and (3) agriculture (Canter, 1997). Natural sources are typically atmospheric deposition and geologic nitrogenous sources that become mobilized, and leach into groundwater via irrigation practices. Perhaps due to the high redox potential, natural sources of  $NO_3^-$  contamination have not been considered to play a major role within areas that have been documented to have severely elevated  $NO_3^-$  levels, therefore are not discussed further in this review of literature. Wastes are here taken to encompass the following: animal manures from commercial operations;

land application of municipal and industrial sludge; septic system loss; and leachates from sanitary or industrial landfills. Agricultural sources are dominated by nitrogen losses following fertilizer application resulting from incomplete uptake of nitrogen by crops, excessive fertilizer application, and off-season mineralization of soil nitrogen (Canter, 1997).

#### 1.2.2.1 Septic influence

A septic system consists of two parts: a septic tank and a drain field. The septic tank is a watertight box, often made of concrete or fiberglass, with an inlet and outlet pipe. Wastewater flows from the source to the septic tank through the sewer pipe. The septic tank holds the wastewater in the tank long enough for solids and liquids to separate. The wastewater forms three layers inside the tank. Solids lighter than water (such as greases and oils) float to the top forming a layer of scum. The heavier solids settle at the bottom of the tank forming a layer of sludge. This leaves a middle layer of partially clarified wastewater

The layers of sludge and scum remain in the septic tank, and bacteria found naturally in the wastewater work to break down the scum and solids. The sludge and scum that can not be broken down are retained in the tank until the tank is pumped. The layer of clarified liquid flows from the septic tank to a manifold, which distributes the wastewater in the drain field. A standard drain field (also known as a leach field, disposal field, or a soil absorption system) consists of a series of trenches or a bed lined with gravel or coarse sand and buried one to three feet below the ground surface. Perforated pipes or drain tiles run through the trenches to distribute the wastewater. The drain field treats the wastewater by allowing it to slowly trickle from the pipes out into the gravel

and down through the soil. The gravel and soil act as biological treatment systems and filters.

Septic water discharged into the leach field proceeds vertically through the unsaturated zone and into groundwater. Once in groundwater, a septic plume develops and moves with groundwater flow. The time for septic effluent to pass through the unsaturated zone to groundwater depends on the volume of effluent, the distance to the groundwater and the hydraulic conductivity of the soil.

Septic systems can represent a significant fraction of the  $\text{NO}_3^-$  loading to groundwater (Cantor, 1997; USEPA, 1994; Sikora et al., 1976; Starr and Sawhney, 1979). Nearly 25% of the United States population relies upon septic systems as their primary means of disposing of human wastes (Cantor, 1997). Septic tank leach fields exhibit rapid nitrification under the aerobic conditions inherent of a leach field. Cation exchange is responsible for the loss of much of the  $\text{NH}_4^+$ -N in soils, while the  $\text{NO}_3^-$ -N remains soluble and is readily leached. If the cation exchange sites have been saturated, the  $\text{NH}_4^+$ -N will leach into the groundwater before it has a chance to nitrify (Cantor, 1997). Lysimeter tests of the impact of septic field leachate on groundwater indicate that when the soil is allowed to become oxidized large amounts of N are converted from  $\text{NH}_4^+$ -N to  $\text{NO}_3^-$  which is readily leached (Brown et al., 1977)

Several studies have demonstrated a positive correlation between water contamination and septic tank density. Woodward et al. (1961) reported a correlation between rural population density and well contamination near Coon Rapids, Minnesota. An area with a population density of 0.54 persons/acre had two percent of its private

water wells contaminated with  $\text{NO}_3^-$ , while an area with a population density of 2.7 persons/acre had more than 29 percent of its private water wells contaminated with  $\text{NO}_3^-$ .

A study in Colorado by Ford et al. (1980) reported that  $\text{NO}_3^-$  contamination of ground water was associated with increased housing density in unsewered residential areas of Jefferson County, Colorado. Contamination of ground water with  $\text{NO}_3^-$ -N concentrations exceeding 20 mg/L was associated with housing densities exceeding 1 septic system/acre.

Geraghty and Miller (1978) collected 865 ground water samples from 54 wells on Long Island, New York and correlated  $\text{NO}_3^-$  concentration with housing density. A  $\text{NO}_3^-$ -N concentration in groundwater of 10 mg/L or more was detected in fifty percent of the groundwater samples when housing density exceeded 2.8 septic systems/acre. Where densities were less than 1.25 septic system/acre, less than 10 percent of the ground water samples contained  $\text{NO}_3^-$ -N concentrations of 10 mg/L or more.

Konikow and Bredhoeft (1978) developed a computer simulation model to evaluate the effects of septic system density on water quality of the Rio Grande alluvial aquifer in New Mexico. They concluded that steady state levels of  $\text{NO}_3^-$  in ground water may not be reached for many decades, and that the effect of lot size on  $\text{NO}_3^-$  concentrations in ground water is not necessarily a linear function. Predicted  $\text{NO}_3^-$ -N concentrations of ground water after 10 years of septic system effluent applications in the Rio Grande Valley were 60 mg/L below 0.25 acre house lots and 35 mg/L under 1.2 acre house lots.  $\text{NO}_3^-$ -N concentration in ground water was dependent on lot size, ground water mixing, street orientation with respect to ground water flow direction, ground water velocity and climate.

Holzer (1975), Peavy and Brawner (1979), and Starr and Sawhney (1980) recommended that septic system density should not exceed an average of one septic system per acre on well drained soils, and Olivieri et al. (1981) suggested that maximum overall septic system density should be one septic system per 1.4 acres in order to maintain high-quality ground water and protect public health. These rules of thumb are not entirely satisfactory since they ignore many relevant factors.

A study by Bauman and Schafer (1985) used a model and sensitivity analysis to show that potential for groundwater contamination with  $\text{NO}_3^-$  depends heavily on septic tank densities along with several other factors. The other factors include hydraulic conductivity of the aquifer, gradient of the groundwater, natural rates of recharge, and concentrations of effluent  $\text{NO}_3^-$  reaching the aquifer. Areas with high velocities of groundwater flow (i.e. high conductivity; high recharge and/or high gradient) have greater dilution of  $\text{NO}_3^-$  than areas with low velocities. Sensitivity analysis showed groundwater  $\text{NO}_3^-$  levels increasing with increasing home densities, with a particularly high rate of increase at densities above 0.7 septic tank/acre. In high velocity systems, areas where saturated hydraulic conductivity of the aquifer is  $\geq 0.01$  cm/s and gradient of the water table is greater than 0.01, lot sizes of less than one acre may cause no pollution with  $\text{NO}_3^-$ . On the other hand, in low velocity systems, areas where saturated hydraulic conductivity is 0.001 cm/s and gradient is 0.001, may have  $\text{NO}_3^-$  levels in excess of drinking water standards with lot sizes of 5 acres or even greater.

There have been many studies focusing on septic system effects on  $\text{NO}_3^-$  distribution in groundwater. However, no study could be found that looked directly at

this effect in the Willamette Valley, Oregon. The following calculations reinforce the impact of septic tank density on contamination of the groundwater.

N loss to the environment from septic tank usage can be calculated using broad averages. Septic tank effluent contains 40-80 mg N/L (Sikora et al., 1976). An average household contains 2.59 persons (US Census, 2000).  $\text{NO}_3^-$  is considered to be the predominant species of N since passing septic effluent through a seepage field yields  $\text{NO}_3^-$  (Sikora and Corey, 1975). Denitrification is not of concern since biological oxygen demand (BOD) is too low to support the process (Sikora et al., 1976). Therefore, the average household contributes 43.5 g N/day to the ground water (Equation 1.2).

$$\left( \frac{280 \text{ liters}}{\text{person} \cdot \text{day}} \right) \cdot \left( \frac{60 \text{ mgN}}{\text{liter}} \right) \cdot \left( \frac{2.59 \text{ persons}}{\text{household}} \right) = 43.5 \text{ g N/household} \cdot \text{day} \quad (1.2)$$

Due to close proximities of households, mobile home parks present the greatest problem of septic effluent contribution to ground water. The majority of rural mobile home parks rely upon septic systems as the primary means of treating human waste. Also, mobile home parks vary in density of households per unit area. A dense mobile home park contains approximately 27 homes per hectare (1 mobile home/4000 ft<sup>2</sup>). In this scenario, the quantity of  $\text{NO}_3^-$  leaching into the ground water is 430 Kg  $\text{NO}_3^-$  /year·hectare (Equation 1.3). A typical mobile home park contains about 10 households per hectare, resulting in 160 Kg  $\text{NO}_3^-$ /year·hectare (Equation 1.4).

$$\left( \frac{43.5 \text{ gN}}{\text{day} \cdot \text{household}} \right) \cdot \left( \frac{27 \text{ households}}{\text{hectare}} \right) \cdot \left( \frac{365 \text{ days}}{\text{year}} \right) = 429 \text{ Kg } \text{NO}_3^-/\text{year} \cdot \text{hectare} \quad (1.3)$$

$$\left( \frac{43.5 \text{ gN}}{\text{day} \cdot \text{household}} \right) \cdot \left( \frac{10 \text{ households}}{\text{hectare}} \right) \cdot \left( \frac{365 \text{ days}}{\text{year}} \right) = 159 \text{ Kg } \text{NO}_3^-/\text{year} \cdot \text{hectare} \quad (1.4)$$

To estimate the long-term  $\text{NO}_3^-$  concentration that would be expected with these levels of loss, we must assume an annual recharge. In the Willamette Valley, with cold-season rain fall of 1 m/year, and potential evaporation of >1 m/year, Louie et al. (2000) found annual recharge of about 1 m for irrigated agriculture in the southern Willamette Valley. Mixing 430 kg/ha with 1 m of recharge would produce  $\text{NO}_3^-$  concentrations of 43 mg/L. Non-irrigated sites would have far less recharge, and proportionally higher resultant concentrations.

#### 1.2.2.2 Agricultural influence

The fact that agriculture production is a major source of  $\text{NO}_3^-$  ground water contamination has been widely documented (Feaga and Selker, 2003; Warren, 2002; Kladvico et al., 1999; Canter, 1997; Rothstein et al., 1996; Traub-Eberhard et al., 1995; Fleming and Bradshaw, 1992; Pivetz and Steenhuis, 1989). The combination of heavy winter rainfall in the Pacific Northwest and increased irrigation during the growing season creates opportunities for the loss of  $\text{NO}_3^-$  from agricultural fields into the groundwater (Irrigation Journal, 1979). According to the American Chemical Society (1980), the use of N based fertilizers increased at an average annual rate of 4% from 1969 to 1979. The application rate of the fertilizers has since reached steady state of ubiquitous use. Some modern agricultural practices apply fertilizers at higher rates than plants require, leading to N being lost to the groundwater.

When N is applied to agricultural land it generally takes years to have an effect on deep groundwater aquifer concentrations, including drinking water wells. By using a conservative tracer, such as bromide ( $\text{Br}^-$ ), which follows a similar path as  $\text{NO}_3^-$ , one can

predict the flow path of  $\text{NO}_3^-$ . A bromide ( $\text{Br}^-$ ) tracer was applied to two Ohio pastures and found that peak concentration in nearby groundwater springs was not reached for 2 years (Owens et al., 1985). No accurate  $\text{Br}^-$  tracer study could be found for the southern Willamette Valley, but groundwater loading rates in the area can be predicted. Based on recharge rates proposed by Louie et al. (2000) in the Willamette Valley, with vadose water content at 25% and a depth to water table of about 7 m, transit times would be expected to be on the order of 28 years.

Growers have begun to understand the movement of  $\text{NO}_3^-$  on the agricultural land, and have begun adopting management practices to minimize losses by optimizing timing, rate and method of N applications, rotating crops and using various tillage practices (Dinnes et al., 2002). The cropping system on agricultural land influences the concentration of  $\text{NO}_3^-$  found in groundwater (Barry et al., 1993). Young et al. (2000) reported that annual crops, row crops, and crops that are not rotated lose much more  $\text{NO}_3^-$  to leaching than alfalfa, grasses and perennial crops due to reduced ground cover and less efficient uptake. A study by Fried et al. (1976) shows that the absolute amount of N available for leaching is not as dependent on the levels of N application as the efficiency of nitrogen used by the crop. Therefore, high N fertilizer use is required to achieve maximum production with minimal impact on the groundwater.

The Willamette Valley has an extensive network of farms producing irrigated peppermint and row crops. However, over the past decade there has been a regional transition from vegetable and mint crops to greater grass seed production. The vegetable and mint crops have high N demand, but often low efficiency in the uptake of N (Feaga



and Selker, 2003). Significant amount of N are typically left within the soil profile at the onset of the rainy winter season. During these months, natural precipitation may be adequate to leach  $\text{NO}_3^-$  below the root zone and into the groundwater. In general, the greater total winter rainfall, the greater the amount of  $\text{NO}_3^-$  being leached.

A 5-year study, examining chemical effluent from various crops grown in the Willamette Valley, OR, recently concluded (Feaga and Selker, 2003). The study specifically concentrated on  $\text{NO}_3^-$  leaching from conventional vegetable and mint fields. Vegetable and mint crops were the most notable sources of  $\text{NO}_3^-$  leaching from agricultural fields. The study revealed an average loss of  $104 \text{ KgNO}_3^-/\text{year}\cdot\text{hectare}$  and  $92 \text{ KgNO}_3^-/\text{year}\cdot\text{hectare}$  for vegetable and mint crops, respectively (Feaga and Selker, 2003). A study of  $\text{NO}_3^-$  leaching from Willamette Valley grass seed fields found an average loss of  $7.8 \text{ KgNO}_3^-/\text{year}\cdot\text{hectare}$  (Warren, 2002).

### 1.2.3 Estimation of nitrate-N loading in the Willamette Valley, Oregon

The Willamette Valley, Oregon has a population of 2.3 million people (US Census, 2000). According to the Institute of a Sustainable Environment at the University of Oregon, 25% of the population (575,000 people) in the Willamette Valley depends upon septic systems as their primary means for disposal of solid waste (ISE, 2004). Therefore, approximately  $3.53 \times 10^6 \text{ KgNO}_3^-/\text{year}$  is leached into the groundwater from septic systems (Equation 1.5).

$$\left( \frac{575,000 \text{ people}}{2.59 \text{ people / household}} \right) \cdot \left( \frac{43.5 \text{ gN}}{\text{day} \cdot \text{household}} \right) \cdot \left( \frac{365 \text{ days}}{\text{year}} \right) = 3.53 \times 10^6 \text{ KgNO}_3^-/\text{year} \quad (1.5)$$

Table 1.1 was developed based on the estimates for Lane County, Oregon according to the 1999 Oregon County and State Agricultural Estimates (Sears, 2000). The weighted  $\text{NO}_3^-$ -N loss from agricultural fields in the Willamette Valley is approximately 17.89 kg/hectare. There are approximately 526,100 hectares of agricultural land in the Willamette Valley, Oregon (Sears, 2000). Therefore, approximately  $9.4 \times 10^6$   $\text{KgNO}_3^-/\text{year}$  is leached into the groundwater from agricultural fields. Hence it appears that total agricultural losses are about three times those of septic losses, though the instances of elevated  $\text{NO}_3^-$  will be related to the intensity of these losses.

**Table 1. 1: Approximate nitrate-N loading from agricultural fields in the Willamette Valley, Oregon**

Crop	Percentage of agriculture land***	$\text{NO}_3^-$ -N Loss (Kg/hectare)	Weighted $\text{NO}_3^-$ -N Loss (Kg/hectare)
Grass and Hays	84	7.8*	6.55
Field Crops	6.5	91**	5.92
Nut Trees	6	30**	1.80
Fruits/Berries	0.6	82**	0.49
Vegetable	3	104.2**	3.13
Total	-----	-----	17.89

\* Warren, 2003

\*\* Shelby, 1995

\*\*\* Sears, 2000

### 1.3 Review of Methods for Sourcing Nitrate

Several methods have been employed in attempting to differentiate the origin and vulnerability of  $\text{NO}_3^-$  in ground water. In the following two sections we will review the two major categories of methods: associated solutes and isotopes to identify N sources in groundwater.

### 1.3.1 Identifying the source of $\text{NO}_3^-$ with Chemical Indicators

In areas with high  $\text{NO}_3^-$  concentrations in shallow wells, septic system and agricultural effluent are often mixed in the groundwater. Various chemicals can act as conservative tracers for the origin of groundwater. Chemicals that are only found in water contaminated by septic sources include shower, toilet and laundry water; bacterial and viral pathogens; caffeine; and pharmaceuticals. Other chemical species found in septic tainted water include sodium ( $\text{Na}^+$ ); potassium ( $\text{K}^+$ ); bicarbonate ( $\text{HCO}_3^-$ ); chloride ( $\text{Cl}^-$ ); phosphorous (P); fluoride ( $\text{F}^-$ ); lead ( $\text{Pb}^{3+}$ ); copper (Cu) and carbon (C). Tracers of groundwater originating from agricultural leaching include pesticides and fertilizers. However, when similar pesticides and fertilizers are used on domestic lawns and gardens as those used on agricultural lands, it is difficult to discern the source of application. To a lesser degree, agricultural effluent may include pesticides, sulfate ( $\text{SO}_4^{2-}$ ), phosphate ( $\text{PO}_4^{3-}$ ), and arsenic ( $\text{As}^{5+}$ ).

Caffeine is found in beverages, food products, and medications used by humans. Caffeine is excreted by humans and has been found in very low concentrations in wastewater discharges. Caffeine is also not used in the production of agricultural crops. As such, it would appear to be a useful indicator of contamination associated with human wastewater. For example, if a groundwater sample is taken in an unsewered area and found to contain caffeine, it would indicate that the aquifer had received some effluent from septic systems. Whereas the average cup of home-brewed coffee contains about 350 mg/L of caffeine, caffeine concentrations in groundwater typically ranges from 0.01 to 0.1  $\mu\text{g/L}$  (Seiler, 1999). This study, in Nevada by the USGS, found the highest level in wells at 0.23  $\mu\text{g/L}$ . This presents a problem for analytical laboratories which must be able

to measure very low caffeine concentrations. A recent study by the OR DEQ in the southern Willamette Valley that sampled 500 wells found only one with detectable concentrations of caffeine (Eldridge, 2002), where the detection limit was set at 40 ppb. Perhaps caffeine would be a good indicator of septic influence on the groundwater if detection limits were low enough to measure at parts per trillion (ppt), but at present caffeine is of limited utility in the Willamette Valley.

Pharmaceuticals found in groundwater would also be indicative of water derived from septic systems. Many pharmaceuticals are not fully metabolized in the human body and are not degraded in septic system, thus may pass through the leach field and into the groundwater. Verstraeten et al. (2004) found eight nonprescription drugs in water from 12 of 19 domestic wells at concentrations as high as 0.13 µg/l. Antibiotics were also detected in water from 3 of 26 shallow domestic wells. Concentrations varied from traces of ciprofloxacin to 0.75 µg/l of an erythromycin degradation product. It was decided not to use pharmaceuticals in this study for two reasons (1) the analysis of pharmaceutical compounds is laborious and expensive and; (2) issues regarding privacy for homeowners who may be on medications unbeknownst to the public.

It has been widely established that fecal coliform (*E. Coli*) and other pathogens are indicators of septic influence in anomalous NO<sub>3</sub><sup>-</sup> concentrations (Spalding and Exner, 1997; Teso et al., 1988; Mechenich, 1990; Panno et al., 1994; Heisig, 1999). Bacterial pathogens are typically attenuated between the soil and water interface of the septic leach field. Sometimes, especially when the water table is within a few feet of the system bottom, the pathogens can enter the groundwater (Yates, 1988). When this occurs, the pathogens have been known to travel long distances (Yates, 1988; Brown, 1980;

DeBorde et al., 1988). Yates and Yates (1988) observed virus transport of 400 ft within 100 days, though this is taken as exceptional since aquifers are typically considered to effectively filter most pathogens (Spalding and Exner, 1997). Eldridge (2002) noted that *E.Coli.* and bacteria assays performed on well water samples from the Willamette Valley, OR were qualitative, not quantitative, resulting in few bacteria detections, which were attributed to localized situations. Thus, though pathogen presence would indicate septic contribution, lack of pathogens does not demonstrate that septic sources were not important.

Household cleaning products, such as chlorine bleach, enter septic systems. The chemical constituents will often be found in drain fields and in drain field leachate that, ultimately, enters the groundwater.  $\text{Cl}^-$  also enters the waste stream in urine and water softeners. A study by Spalding and Exner (1987) demonstrated a relationship between  $\text{Cl}^-$  and  $\text{NO}_3^-$  as an indicator of septic wastes. Sweeten (1993) also showed a direct linear relationship between  $\text{Cl}^-$  and  $\text{NO}_3^-$  concentrations in a high density septic system community. Since agricultural production in the Willamette Valley is not known to be a significant leacher of  $\text{Cl}^-$ , quantifying anomalously high concentrations of  $\text{Cl}^-$  is an indication of potential septic contribution.

Numerous studies have found an association between  $\text{PO}_4^{3-}$  and effluent from septic waste. Mechenich and Shaw (1990) reported  $\text{PO}_4^{3-}$  concentrations ranging from 1 to 11 mg/L were found down gradient of four septic systems. Wilhelm et al. (1994) and Brown et al. (1978) reported that most  $\text{PO}_4^{3-}$  goes into septic tanks in organic forms, but orthophosphate accounts for 80% of the total  $\text{PO}_4^{3-}$  in the tank effluent.  $\text{PO}_4^{3-}$  precipitates in the unsaturated zone or is adsorbed in the aquifer close to the drain field.

Robertson et al. (1998) observed  $\text{PO}_4^{3-}$  migration exceeding 30 feet in six of ten plumes. Movement of  $\text{PO}_4^{3-}$  rarely exceeds 15 feet, even in very old systems (Wilhelm et al., 1994). However, a study by Yates and Yates (1988) found no significant difference in groundwater  $\text{PO}_4^{3-}$  under sewered and unsewered areas. Therefore,  $\text{PO}_4^{3-}$  is not an ideal chemical indicator to use in the Willamette Valley since plumes would rarely reach 100 ft., which is the minimum distance between a wellhead and a septic leach field as required by the Oregon Water Resources Department (OWRD).

Several researchers have noted the presence of various ions in defined septic plumes. Panno et al. (1994) found anomalously high concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  from septic tanks, attributing the high ion concentrations to water softeners used in surrounding households. Teso et al. (1988) characterized several septic related  $\text{NO}_3^-$  plumes to have linear relationships with elevated concentrations of  $\text{Cl}^-$ ,  $\text{PO}_4^{3-}$  and fluoride  $\text{F}^-$ . The authors attributed the increased  $\text{F}^-$  concentrations to toothpaste being washed into a septic system.  $\text{F}^-$  is not used on agricultural fields in the Willamette Valley and not detectable in a natural setting, therefore if it is observed in a well sample, it most likely originated from a septic source.  $\text{Na}^+$  will not likely be found in high concentrations in the groundwater of the Willamette Valley due to its cationic soil bonding properties.

Septic water is also a potential sources of  $\text{Pb}^{2+}$  and  $\text{Cu}^{2+}$  in the groundwater. Many households have plumbing systems that include  $\text{Pb}^{2+}$  and  $\text{Cu}^{2+}$  components. As these pipes age,  $\text{Pb}^{2+}$  and  $\text{Cu}^{2+}$  will be flushed into the drain field, and may eventually make their way into the groundwater. Since  $\text{Pb}^{2+}$  and  $\text{Cu}^{2+}$  are not major constituents of agricultural leachate in the Willamette Valley, their finding would be an indication of

potential contribution from septic sources, though since they are likely to be sorbed to soils, a lack of detection would not prove lack of septic contribution.

Consistent agricultural co-contaminants are more difficult to associate with elevated concentrations of  $\text{NO}_3^-$  in groundwater. An obvious candidate would be pesticides. Pesticides are generally large, organic, degradable, non polar molecules that have strong adsorption characteristics, while  $\text{NO}_3^-$  is small, mobile, water soluble and polar anion. Therefore, pesticides will be transported through the soil at far slower and uneven rates than  $\text{NO}_3^-$ . Dumaglaski and Dubrovsky (1992) found no significant difference in  $\text{NO}_3^-$  concentrations between wells with and without triazine herbicide residues in the San Joaquin valley of California. Baker et al. (1994) found a significant relationship between  $\text{NO}_3^-$  and pesticide vulnerability in samples collected from rural wells in 17 states. Spalding et al. (1980) found the occurrence of atrazine in groundwater samples to be correlated with higher  $\text{NO}_3^-$ -N concentrations. A recent groundwater study conducted in the southern Willamette Valley reported no correlation between  $\text{NO}_3^-$  and pesticide occurrences (Eldridge, 2002) (Figure 1.1; Figure 1.2). Since Eldridge (2002) found no correlation between the occurrence of pesticides and  $\text{NO}_3^-$  in the same study area, and the cost of running the analysis for pesticides is high, they were not analyzed in this study.

Other agriculturally sourced constituents such as  $\text{PO}_4^{3-}$  and  $\text{As}^{5+}$  have been shown to be persistent. Mueller (1998) found a positive correlation between  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  concentrations in groundwater under agricultural lands.  $\text{As}^{5+}$  has been shown to be a source of water contaminated by agriculture.  $\text{As}^{5+}$  is a major by-product of agriculture on

orchards. Due to the ease of analysis and persistence of these chemicals in agricultural effluent both were analyzed for the study.



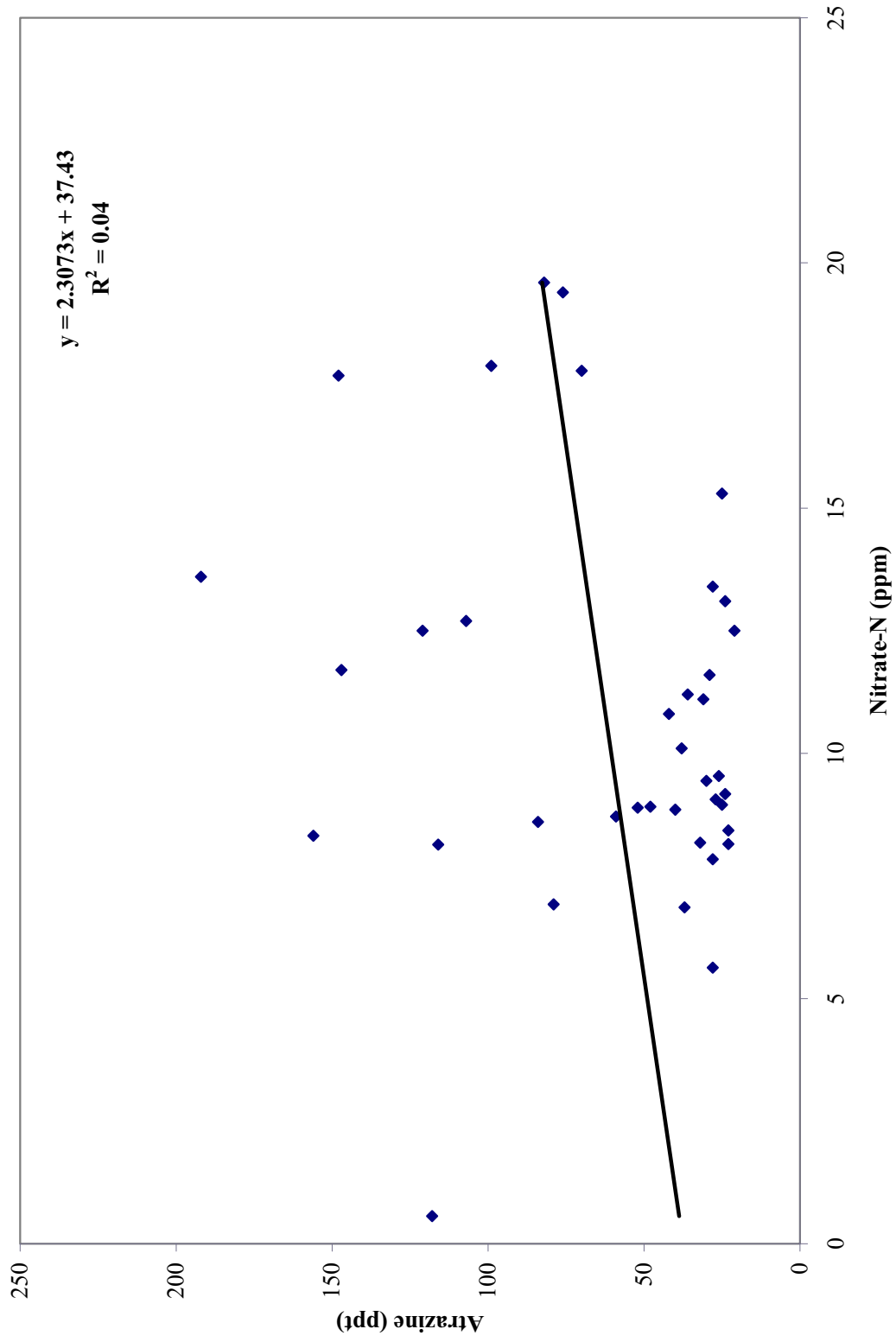


Figure 1. 2: Atrazine and NO<sub>3</sub><sup>-</sup> concentrations in southern Willamette Valley, Oregon.

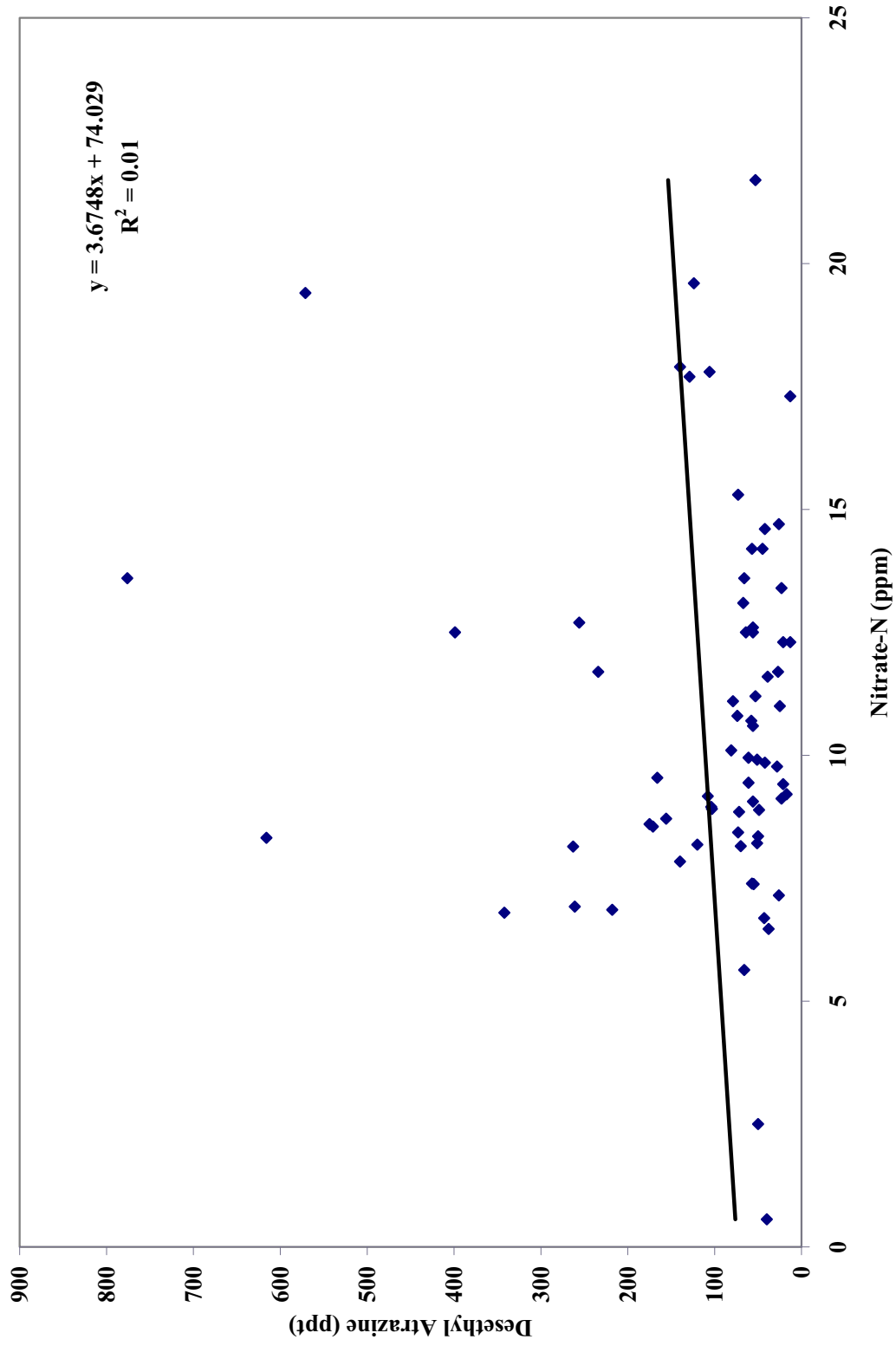


Figure 1. 3: Desethyl Atrazine and NO<sub>3</sub>-N concentrations in southern Willamette Valley, Oregon.

### 1.3.1 Identifying the source of $\text{NO}_3^-$ with isotopes of nitrogen and oxygen

The application of the  $\text{NO}_3^-$ -oxygen and  $\text{NO}_3^-$ -nitrogen isotope ratios is a useful technique to help identify sources and fate of  $\text{NO}_3^-$  found in aquifers with variable  $\text{NO}_3^-$  inputs (Kreitler and Browning, 1983; Heaton, 1986; Mariotta et al., 1988; Wells and Krother 1989; Aravena et al., 1993; Komor et al., 1993; Wilson et al., 1994; Kendall et al., 1995). The concept is that differing sources of  $\text{NO}_3^-$  have different ratios of isotopic fractionation of both N and O.

#### 1.3.1.1 Nitrogen ( $^{15}\text{N}$ )

Isotopes of nitrogen are measured in ratios of  $^{15}\text{N}/^{14}\text{N}$  and are expressed in units of parts per thousand (‰) of  $^{15}\text{N}$  higher or lower than that in a reference standard material (Silva et al., 2002) (Equation 1.6). The isotopic composition of N is expressed in terms of its  $\delta^{15}\text{N}$  concentration, where:

$$\delta^{15}\text{N} (\text{‰}) = (\text{R}_{\text{sample N}}/\text{R}_{\text{standard N}} - 1) \times 10^3 \quad (1.6)$$

In equation 1.6, R is defined as the atomic  $^{15}\text{N}/^{14}\text{N}$  ratio (Heaton, 1986).  $\text{R}_{\text{standard}} = 0.3663\text{‰}$  is the quantity of  $^{15}\text{N}$  in atmospheric N, with abundance that does not fluctuate spatially or temporally (Junk and Svec, 1958; Mariotti, 1983; Heaton, 1986).

Industrial production of  $\text{NO}_3^-$  and  $\text{NH}_4^+$  based fertilizers rely on the fixation of atmospheric N (Edwards, 1973; Shearer et al., 1974).  $\text{NH}_4^+$  based fertilizers have lower  $^{15}\text{N}$  concentrations than atmospheric N, because the lighter  $^{14}\text{N}$  is favored (Freyer and Aly, 1974). Therefore, the production of  $\text{NH}_4^+$  based fertilizers results in negative  $\delta$

values. Heaton (1986) found this process results in little isotopic fractionation, therefore the products have a  $\delta^{15}\text{N}$  close to zero.  $\text{NO}_3^-$  based fertilizers have higher  $^{15}\text{N}$  concentrations than both  $\text{NH}_4^+$  based fertilizers and atmospheric N (Table 1.2) (Heaton, 1986). The enrichment of  $^{15}\text{N}$  in the production of  $\text{NO}_3^-$  based fertilizers is explained by the following isotopic exchange reactions, where  $^{15}\text{N}$  becomes dominant to  $^{14}\text{N}$  (Spindel, 1954) (Equations 1.7a, 1.7b):



Septic effluent creates a unique fractionation of N isotopes. When waste from septic systems drain in a leaching field, hydrolysis of urea occurs, creating a temporary rise in the pH of the waste. Increasing the pH of the solution is conducive to the formation of  $\text{NH}_3$  gas rather than the aqueous  $\text{NH}_4^+$  ion (Fahlman and Jin, 2002). The lighter isotopes ( $^{14}\text{N}$ ) preferentially evaporate from the solution leaving behind the heavier isotopes ( $^{15}\text{N}$ ) (Heaton, 1986). Therefore, septic waste will commonly have a higher isotope value than atmospheric N and fertilizer N.

Isotopic fractionation of N also occurs during the mineralization of soil organic N. A four step process takes place to convert the organic N to  $\text{NO}_3^-$ :



Most organic soil N is preferentially converted to  $\text{NH}_4^+$  (Heaton, 1986). Significant isotopic fractionation occurs during the conversion of  $\text{NH}_4^+$  to  $\text{NO}_2^-$  and from  $\text{NO}_2^-$  to  $\text{NO}_3^-$ , but is negligible during the production of  $\text{NH}_4^+$  from soil organic N (Mariotti et al., 1980; Heaton, 1986). The total isotopic fractionation for the kinetic conversion of  $\text{NH}_4^+$  to  $\text{NO}_3^-$  is estimated at -5‰ for normal, undisturbed soils (Delwiche and Steyn, 1970;

Myak and Wada, 1971; Freyer and Aly, 1975). Therefore, the  $\delta^{15}\text{N}$  of the  $\text{NO}_3^-$  decreases slightly from the original  $\delta^{15}\text{N}$  soil organic N. Heaton (1986) reviewed thirteen papers, which were based on ~350 soil tests, finding an average  $\delta^{15}\text{N}$  range of +4‰ to +9‰ from soil organic N.

Precipitation and atmospheric deposition are often overlooked as sources of  $\text{NO}_3^-$ . Several studies have concluded an average  $\delta^{15}\text{N}$  of slightly less than 0 ‰ in atmospheric deposition (Moore, 1977; Heaton, 1986; Garten, 1992). Heaton (1986) found an annual mean average of ~-3‰  $\delta^{15}\text{N}$  for precipitation in Pretoria, South Africa. Paerl and Fogel (1994) reported an average atmospheric deposition between 0 ‰ and -1 ‰  $\delta^{15}\text{N}$  for the coastal western Atlantic Ocean. Therefore, precipitation can dilute the  $\delta^{15}\text{N}$ , causing a lower value of  $\delta^{15}\text{N}$  in areas with high precipitation.

Numerous studies have used  $\delta^{15}\text{N}$  (‰) to identify the source of  $\text{NO}_3^-$  in groundwater (Kreitler and Browning, 1983; Heaton, 1986; Mariotta et al., 1988; Wells and Krother 1989; Aravena et al., 1993; Komor et al., 1993; Wilson et al., 1994; Kendall et al., 1995). Several studies apply  $\delta^{15}\text{N}$  (‰) signatures to known sources of  $\text{NO}_3^-$  contaminations. Most studies use previous research to interpret  $\delta^{15}\text{N}$  (‰) ranges observed in their data. By summarizing the previous research, a range of  $\delta^{15}\text{N}$  (‰) for the various sources of  $\text{NO}_3^-$  has been developed, which was adapted from Fahlman and Jin (2002) (Table 1.2). The range for identifying agricultural influence (fertilizers) in  $\text{NO}_3^-$  is -15.7 to +3.5  $\delta^{15}\text{N}$  (‰). The range for identifying natural, soil organic influence in  $\text{NO}_3^-$  levels is +1 to +11  $\delta^{15}\text{N}$  (‰). The range for identifying septic influence in  $\text{NO}_3^-$  is +5.3 to +58.3  $\delta^{15}\text{N}$  (‰).

**Table 1. 2: Nitrogen isotope fractionation source data.**

Reference	Location	$\delta^{15}\text{N}$ (‰)		
		Fertilizer	Soil Organic	Septic
Aravena and				
Robertson (1998)	Lake Erie, ON			+6.4 to +58.3
Wilson et al. (1994)	Sandstone, England	-15.7 to -1.3	+5.4 to +9.3	+22.7 to +31.1
Fogg et al. (1988)	Davis, CA	+1.5	+2.5	+7.3 to +10
Fogg et al. (1988)	Salinas Valley, CA	+3.5	+2.5	+10.3 to +14
Western Kalahari,				
Heaton (1984)	South Africa		+4.9 to +8.0	+9.3 to +18.7
Spalding et al.				
(1982)	Burbank-Wallula, WA		+4.1	+12.8 to +18.7
Aravena et al.				
(1993)	Cambridge, ON		+9.9	
Komor and				
Anderson (1993)	Minnesota		+3.1 to +7.4	+6.0
Kaplan and				
Magaritz (1986)	Coastal Plain, Israel	-2.2 to +1.0	+4.7 to +11.4	+19 to +28.8
Wassenaar (1994)	Abbotsford, BC	-1.5 to -0.6		>+8
Exner and Spalding				
(1985)	SE Nebraska			+5.3 to +20.6
Smith et al. (1991)	Cape Cod, MA			+11.3 to +42
Kreitler (1975)	Runnels County, TX	-5.0 to +3.0	+2 to +8	
Kohl, et al. (1971)	Decatur, Illinois	+3.0		
Gormaly and				
Spalding (1979)	Central Nebraska	+3.5		
Benrdt (1990)				+8.9 to 16.7
<b>Extremes</b>		<b>-15.7 to +3.5</b>	<b>+1.3 to +11.4</b>	<b>+5.3 to +58.3</b>

In summary,  $\delta^{15}\text{N}$  has been proven to be a useful tool in discerning the sources of  $\text{NO}_3$  contamination. Several studies have shown a range of similar values for  $\delta^{15}\text{N}$  from

septic, agricultural and natural sources. This study will use the extremes of  $\delta^{15}\text{N}$  from the previous studies as a guideline in differentiating the sources.

### 1.3.1.2 Oxygen ( $^{18}\text{O}$ )

Isotopes of oxygen are measured in ratios of  $^{18}\text{O}/^{16}\text{O}$  and are expressed in units of parts per thousand (‰) of  $^{18}\text{O}$  higher or lower than that in a reference standard material (Silva et al., 2002). Just as with N, the isotopic composition of O is expressed in terms of its  $\delta^{18}\text{O}$  concentration, where (Equation 1.9):

$$\delta^{18}\text{O} (\text{‰}) = (R_{\text{sample O}}/R_{\text{standard O}} - 1) \times 10^3 \quad (1.9)$$

The international standard for O is VSMOW (Vienna Standard Mean Ocean Water), which has a defined  $\delta$  of O.

Synthetic  $\text{NO}_3^-$  fertilizers incorporate O from air, thus their  $\delta^{18}\text{O}$  is similar to atmospheric oxygen, which has  $\delta^{18}\text{O}$  of 23‰ (Kroopnick and Craig, 1972; Amberger and Schmidt, 1987; Durka et al., 1994; Bohlke et al., 1997). Amberger and Schmidt (1987) analyzed a number of types of anthropogenic  $\text{NO}_3^-$  and determined that synthetic  $\text{NO}_3^-$  formed from atmospheric O has  $\delta^{18}\text{O}$  values between +18 and +22‰, quite similar to that of atmospheric O.

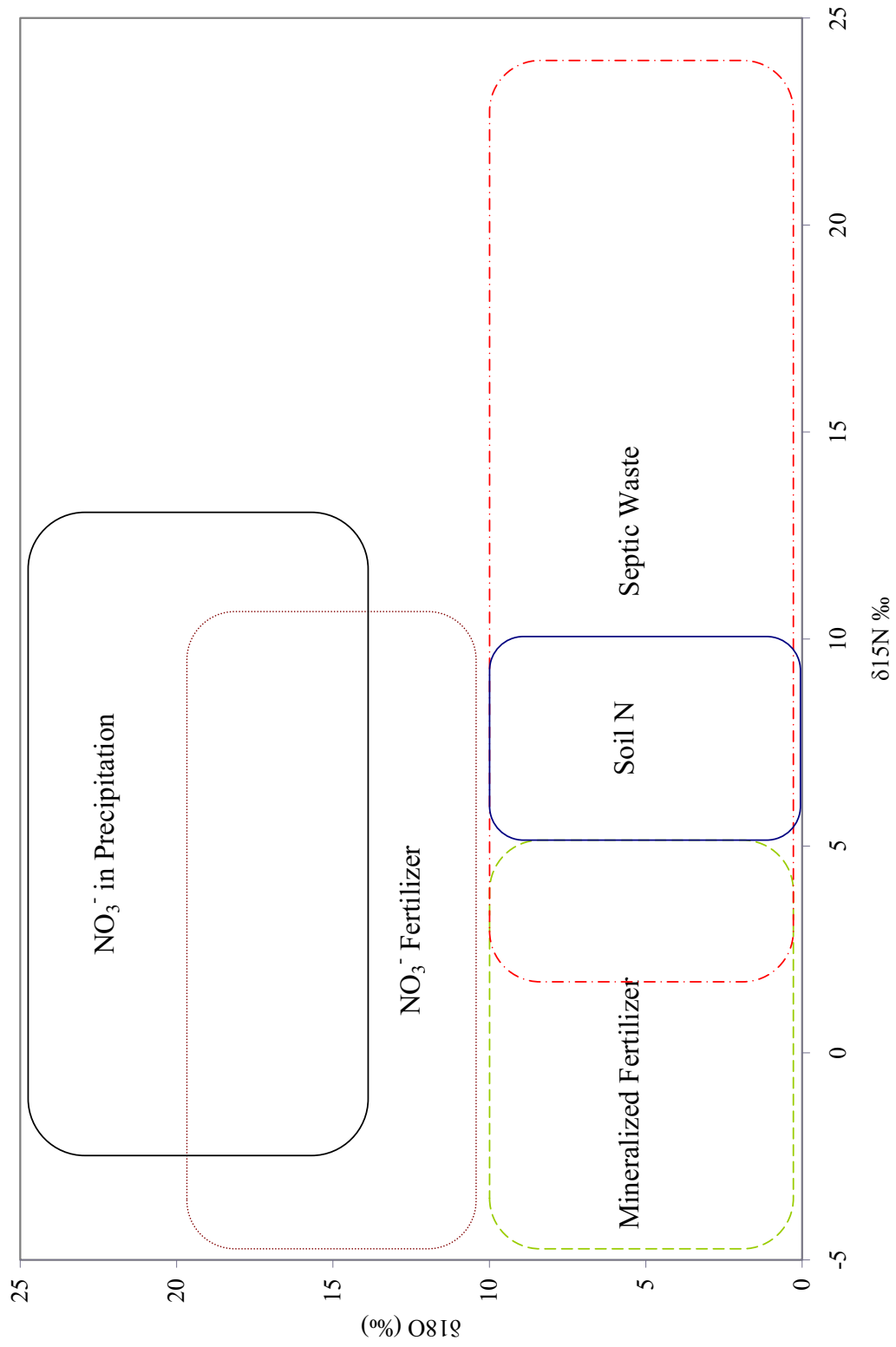
$\text{NO}_3^-$  derived from mineralization in the vadose zone receives its oxygen contribution from atmospheric inputs (Wassenaar, 1994). The process of mineralization ( $\text{NH}_4^+$  to  $\text{NO}_3^-$ ) results in one third of the oxygen being derived from the air while the

remaining two-thirds are derived from water, therefore resulting in values of  $<10\%$   $\delta^{18}\text{O}$  (Anderson and Hooper, 1983; Wassenaar, 1995; Bohlke et al., 1996) (Equation 1.10).

$$\delta^{18}\text{O} [\text{NO}_3^-] = \frac{2}{3} \delta^{18}\text{O} [\text{H}_2\text{O}] + \frac{1}{3} \delta^{18}\text{O} [\text{O}_2] \quad (1.10)$$

The use of N isotopes is a well established method of identifying  $\text{NO}_3^-$  sources, but the method has some significant limitations due to overlapping signals and changes in the isotopic signal with denitrification within an aquifer (Kendall, 1998). Complementing the  $\delta^{15}\text{N}$  with  $\delta^{18}\text{O}$  allows separation of some cases which would otherwise be obscure. During microbial denitrification of  $\text{NO}_3^-$  to  $\text{N}_2$  there is an isotopic fractionation which preferentially utilizes  $^{14}\text{N}$  in the conversion of  $\text{NO}_3^-$  to  $\text{N}_2$ . This leaves the remaining  $\text{NO}_3^-$  isotopically more enriched in  $^{15}\text{N}$ . This can make  $\text{NO}_3^-$  from partially denitrified fertilizer have the same  $^{15}\text{N}$  value as  $\text{NO}_3^-$  derived from septic waste. The technique of determining the oxygen isotopic ratio of  $\text{NO}_3^-$  has the potential to overcome these limitations (Kendall, 1998). Like  $\delta^{15}\text{N}$ , the  $\delta^{18}\text{O}$  of the  $\text{NO}_3^-$  compound also, becomes more enriched in  $\delta^{18}\text{O}$  in the remaining  $\text{NO}_3^-$  during denitrification. Therefore, the amount of  $\delta^{18}\text{O}$  of can be used to factor out the effects of denitrification when using N signature for  $\text{NO}_3^-$  source identification (Mengis et al., 1999) (Figure 1.3). Also, analysis of  $\delta^{18}\text{O}$  can be particularly useful in identifying denitrification, because when it occurs, the remaining  $\text{NO}_3^-$  becomes heavier in both  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$  (2:1 for  $\delta^{15}\text{N}$ :  $\delta^{18}\text{O}$  ratio) (Amberger and Schmidt 1987; Bottcher et al, 1990).





**Figure 1. 4: From Kendall, 1998: Schematic of typical ranges of  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values of  $\text{NO}_3^-$  from various sources.**

$\text{NO}_3^-$  derived from ammonium fertilizer, soil organic matter, and animal manure have overlapping  $\delta^{18}\text{O}$  values; for these sources,  $\delta^{15}\text{N}$  is a better discriminator (Wassenaar, 1995). In contrast,  $\text{NO}_3^-$  derived from  $\text{NO}_3^-$  fertilizer or atmospheric sources are readily separable from microbial  $\text{NO}_3^-$  using  $\delta^{18}\text{O}$ , even though the  $\delta^{15}\text{N}$  values are overlapping (Aravena et al., 1993). Therefore, in systems where the dominant sources of  $\text{NO}_3^-$  are isotopically distinctive, source contributions can be determined despite significant denitrification.

### 1.3.2 Statistical analysis used to demonstrate vulnerability

Statistical analysis is useful in discerning the vulnerability of areas to  $\text{NO}_3$  contamination in groundwater. Multiple studies have attempted to identify and rate the importance of various indicators of groundwater vulnerability or groundwater quality. Many statistical methods have been used to rate the vulnerability of a region to  $\text{NO}_3$  contamination and several of those will be described in the following section.

Chen and Druliner (1987) used multiple linear regression to compare concentrations of  $\text{NO}_3^-$  and herbicides in 82 wells in the High Plains Aquifer in Nebraska. They found that three variables (Well depth, irrigation well density, and N fertilizer use) explain 51% of the variation in  $\text{NO}_3^-$  concentrations, and that two variables (specific discharge and well depth) explain 60% of the variation in pesticide concentrations.

Burjart and Koplín (1993) studied the influence of hydrogeologic and land-use factors on the concentrations of  $\text{NO}_3^-$  and atrazine in shallow aquifers over twelve states in the Midwest United States. Using statistical tests such as the Mann-Whitney rank sum test and contingency tables, they found significant differences in  $\text{NO}_3^-$  and atrazine

concentrations when wells were grouped by aquifer class and by depth of unconsolidated material over the aquifer.

Nightingale and Bianchi (1980) used simple linear regression and multiple linear regression to study the difference in relationship between soil and aquifer characteristics and concentrations of anions and cations. They found that salinity was correlated to soil and aquifer permeability, but that  $\text{NO}_3^-$  levels only correlated with the estimated specific yield of the aquifer system.

Helgesen et al. (1992) studied the relationship between land use and water quality in the High Plains aquifer in southern Kansas. The study selected one well at random from each region and tested a water sample for a suite of chemicals. Non-parametric hypothesis tests showed significantly higher mineral concentrations under irrigated crops than under undeveloped range land.

Baker et al. (1994) collected well water samples from 43,000 participants in twelve states and analyzed the samples for  $\text{NO}_3^-$  and herbicide concentrations. Non-parametric statistical methods were applied to compare the results with descriptions of the wells and surrounding areas submitted by the participants. The study found statistical significance when comparing  $\text{NO}_3^-$  with well age, well depth, and proximity to feedlots.

Teso et al. (1988) used discriminant analysis to identify one square mile sections in Fresno, California as susceptible contamination to a pesticide. The study compared the pesticide concentrations with soil taxonomic groups. Each soil taxonomic group was either considered contaminated or not contaminated. The discriminant function yielded a 0.776 success rate for classification of one square mile sections in Fresno County. When

the function was tested on an independent data set from a nearby county, the same function yielded a success rate of 0.573.

Previous studies have shown the importance of statistical analysis in evaluating the potential risk of an aquifer to groundwater contamination. It has also been shown that statistical analysis can suggest by correlation the source of this contamination. In the Willamette Valley it is important to know the land use and geologic units of an area to assess its vulnerability to potential  $\text{NO}_3^-$  contamination.

#### 1.4 Physical Landscape and historical background of the Willamette Valley, Oregon.

The Willamette Valley is nestled between the Cascade Mountain range and the Coastal Range of Oregon. The valley is approximately one hundred miles long by eighteen to thirty miles wide and is divided into ecoregions by low-lying hills (O'Connor, 2001). The largest of these sections is the alluvial plain that lies south of the Santiam River. The valley is nearly level to a slightly sloping floodplain, with elevations ranging from 100 to 300 feet (Uhrich and Wentz, 1999). The hill slopes surrounding the valley are steeper and range from 1,000 feet in the north to over 4,000 feet in the central and southern outskirts. The Willamette River and its tributary, the McKenzie River, flow north through the alluvial plain, eventually becoming a tributary of the Columbia River (Uhrich and Wentz, 1999).

The Willamette Valley's climate and flora are indicative of its coastal location. South of the valley is known for warm, stable air masses, while north of the valley has a cool, stormy North Pacific climate (Bowen, 1978). As the two air masses circulate, the valley has a climate that reflects both the northern and southern qualities. Typically, the

months between October and March are cool and wet, while the months between May and September are warm and dry. The Willamette Valley receives 80% of the mean annual precipitation between the months of October and March (Woodward et al., 1998). Mean monthly temperatures are 17-20°C during the summer months, and 3-5°C during the winter months. The temperature may climb above 25°C, while the winter months may have an extreme low temperature of -30°C (Bowen, 1978). During the rainy season, the valley typically receives forty to fifty inches of precipitation per year (Bowen, 1978).

Native Americans occupied the Willamette Valley for centuries prior to its inhabitation by Europeans and other immigrants, due to the mild climate, lush soil, and abundance of water, game and flora (Bowen, 1978). The Willamette Valley was first seen by non-Native Americans by British Captain Robert Gray in 1792, while he explored the Columbia River (Bowen, 1978). The settlement of the Willamette Valley by non-Native Americans began with the routing of an overland pass by Meriwether Lewis and William Clark in 1806 (Uhrich and Wentz, 1999). At this time, Clark wrote in his journal, “The Cal-lar-poe-wah Indian Nation are very numerous and inhabit the country on each side of the Multnomar (present day Willamette River) from its falls as far up as the knowledge of those people extend” (Woodward et al., 1998). Dr. John McLoughlin (referred as the “father of Oregon”), in 1825 established a trading post at Fort Vancouver on the north side of the Columbia, near the mouth of the Willamette River. In 1829, Dr. McLoughlin allowed a group of French Canadians to establish farms along the Willamette River, between present-day Portland and Salem. Between 1840 and 1860, roughly 53,000 people moved into Oregon via the Oregon Trail (Uhrich and Wentz,

1999). The earliest settlements were all located on the banks of the Willamette River, taking advantage of the ease of transportation of people and merchandise.

Agriculture has been the cornerstone of the Oregon economy since the migration of the middle 1800's. Also, the importing of swine, sheep, long-horned cattle, Durham cattle, and dairy cattle created a ranching industry in the Willamette Valley (Uhrich and Wentz, 1999). The Willamette Valley began to develop its distinct regions of agricultural production in the middle 1800's. The northern low-lying areas grew perishable produce, such as vegetables, potatoes and dairy products. The Portland area was known for its production of large, commercial gardens. In the prairies surrounding Salem, grains such as wheat and oats were predominate. The area east of the Pudding River and north of the Santiam River, crops such as grains and potatoes were most frequently grown. The area south of the Santiam was known for its livestock herds and dairy products (Uhrich and Wentz, 1999).

## 1.5 Geology and hydrology of the Willamette Valley, Oregon

### 1.5.1 Surface water hydrology of the Willamette Valley, Oregon

The Willamette River, the major surface water in the study area, meanders northward through the Willamette Valley. The Willamette River originates at the junction of the Coast Fork and Middle Fork of the Willamette River, just south of Eugene, Oregon. The river winds its way north for 187 miles until it becomes a tributary for the Columbia River. The Willamette River's width ranges from 60 m to 300 m, and averages 150 m. The river has a gradient of 0.4 m/km near the confluence of the Coast Fork and the Middle Fork, and a gradient of  $7.5 \times 10^{-3}$  m/km near its mouth on the Columbia River (Woodward et al., 1998). Fifteen major tributaries add to the Willamette

River's total discharge. The mean annual discharge of the river at Portland, Oregon is  $3.28 \times 10^6 \text{ m}^3/\text{hr}$  ( $\sim 1000 \text{ m}^3/\text{s}$ ). This discharge is mainly achieved from precipitation runoff. Snowmelt also adds to an increase in discharge during the late spring.

Groundwater also adds to the discharge of the river, but mostly affects the tributaries of the Willamette River (Woodward et al., 1998). In general, the rain in early fall recharges the soil, and upon reaching field capacity, in late fall, the change in river discharge closely resembles the change in precipitation. Major flooding of the Willamette River, and its tributaries usually occur during November and February, but may occur as early as October, and as late as April (Woodward et al., 1998). Flooding is typically triggered by a coupling of intense rainfall and snowmelt. There are 17 reservoirs within the Willamette Valley, providing  $4.16 \times 10^6 \text{ ha}\cdot\text{m}$  ( $\sim 2$  years) for flood control, power, irrigation, navigational improvements, conservation, pollution control, water supply and recreation (Woodward et al., 1998).

### 1.5.2 Sub-surface hydrology of the Willamette Valley, Oregon

Five major factors control the groundwater flow system of the Willamette Valley: recharge, evapotranspiration, geometry of hydrogeologic units, hydraulic conductivity, and properties of the surface waters.

The Willamette Silt layer plays a significant role in the groundwater recharge, discharge and flow. The fine grained sediment forms a poorly drained, low-permeability hydrogeologic unit, which acts as a “leaky, confining layer above the Pleistocene sand and gravel deposits” (Woodcock, 2002). Water recharging the Willamette Silt unit moves vertically down through the Willamette Aquifer, where the flow is directed horizontally towards a primary discharge point, like a stream (Woodward et al., 1998).

Water in the Willamette confining unit has an upward movement, back into the Willamette Aquifer, until the water reaches a discharge point. Water in the Columbia River basalt aquifer moves laterally and downward from recharge areas in uplands, then upward from the basalt into overlying units (Woodward, 1998).

The Willamette Silt unit is recharged primarily through precipitation infiltration. Woodward et al. (1998) reports most of the sub-surface water moves into the Willamette Aquifer within a hundred meters of where it entered the saturated zone. Woodward et al. (1998), using MODPATH, found the downward vertical hydraulic gradient to range from 0.014 to 0.015 m/m. The horizontal hydraulic gradient within the Willamette Silt unit was modeled to range from  $4 \times 10^{-5}$  to 0.015 m/m. Evapotranspiration will account for some of the water discharge, when the water table is above the rooting depth. Certain streams (Pudding and Calapooia Rivers), within the Willamette Silt unit, create an upward vertical hydraulic gradient ranging from 0.017 to 0.13 m/m (Woodward et al., 1998).

### 1.5.3 Geology of the Willamette Valley, Oregon

The Willamette Valley, located in northwestern Oregon, sits upon a broad alluvial plain. The Coast Range Tertiary marine sediments and volcanic rocks bound the western edge of the valley. The Cascade Range, the eastern border of the valley, is comprised of Tertiary and Quaternary volcanic and volcanistic rocks (O'Connor, 2001). Many tributaries and perennial streams drain the two mountain ranges into the Willamette River. The Willamette River flows north through the extensive lowland of the valley, before it becomes a tributary to the Columbia River.



The Willamette Valley has undergone significant changes throughout geological time. The northern Willamette Valley has undergone sub-basin subsidence and faulting, creating uplands of Columbia River Basalt (O'Connor, 2001). These uplands, found between Albany and Salem, have created a distinct, geological separation between the northern and southern Willamette Valley. The southern Willamette Valley is characterized by a strike valley formed by preferential excavation of softer geologic units (O'Connor, 2001). The Willamette Valley has accumulated 500 m of Neogene and Quaternary fill from the surrounding mountains and Columbia River Basin (O'Connor, 2001). Underlying the valley floor, this fill contains most of the subsurface water. The valley sediments include Pliocene fluvial-lacustrine and fine-grained Miocene deposits near the bottom of the basin, while the upper 100 m contain coarse grained fluvial deposits of the Quaternary age, which were derived from the Cascade Range and Missoula Flood sediment (O'Connor, 2001).

Four major units of Quaternary-age sediment, which can be further divided into five distinct surficial geologic units are found in the Willamette Valley. These units are referred to as (1) Pre-Missoula Flood Pleistocene sand and gravel (Qg<sub>2</sub>), (2) Post-Missoula Flood Pleistocene sand and gravel (Qg<sub>1</sub>), (3) Missoula Flood Deposits (Qfc), and (4) Holocene floodplain deposits (Qalc). Each of these deposits has unique characteristics that will greatly influence the chemical, biological and hydrologic properties of the groundwater.

The Pleistocene sand and gravel sediments are characterized by channel instability, high sediment supply, and having sediment derived from the Cascade and Coastal Ranges (O'Connor, 2001). In the southern half of the Willamette Valley, these

coarse-grained proximal alluvial fan and braided stream deposits encompass the majority of the shallow aquifer. The Pleistocene sand and gravels were deposited during two different time periods: the first ( $Qg_2$ ) was deposited prior to the Missoula Floods, while the second ( $Qg_1$ ) was deposited after the floods. The  $Qg_2$  unit contains most of the Pleistocene sand and gravel, while the  $Qg_1$  unit has much thinner sand and gravel deposits. Quaternary-age gravel and sand deposited in thin, widespread sheets is found in the upper 5 to 50 m of these deposits (O'Connor, 2001). O'Connor (2001) describes the thickness of the deposits as generally being 10m to 30m in major tributary valleys, while at fan apices, the deposits range from 40m to over 100m. The deposits have been characterized as cobbly, sandy gravel in the tributary valley to silt and sand in the distal portions of the valley's lowlands (O'Connor, 2001). Hydrogeologic properties are controlled by the sedimentary characteristics, like clast size and sorting (O'Connor, 2001). Secondary influences that affect the hydrogeologic properties are the compaction and cementation of the older deposits ( $Qg_2$ ). The cementing agents include silt, clay, iron, manganese, silica, calcium and carbonates (O'Connor, 2001). The Pleistocene deposits are generally regarded to be hydrogeologically homogenous over distances of a few hundred meters. When comparing the two Pleistocene deposits,  $Qg_2$  is more permeable than the post-Missoula Flood deposit,  $Qg_1$  (O'Connor, 2001).

The Missoula Flood Deposits (Willamette Silt layer), blanket the lowlands of the Willamette Valley, greatly influencing the sub-surface hydrologic dynamics. Multiple, large floods from Glacial Lake Missoula occurred between 15 and 12.7 thousand years ago. The floods deposited parallel sheets of silt, clay and sand along the valley floor. Since the deposit came from the north of the Willamette Valley, the deposits are greatest

in the northern valley, and thin southward. The northern valley has been documented to have deposits as thick as 100 m, while the southern valley has a layer less than 10 m thick (Woodward et al., 1998). The effects of the flood end near the city of Harrisburg, Oregon, where the Willamette Silt no longer plays a major role in the sub-surface hydrology.

The fourth major Quaternary-age sediment is the floodplain deposits of the Willamette River and its tributaries, the Holocene floodplain deposits (Qalc). The Holocene alluvium, comprised of sand, silt and gravel, in a strip up to 6 km wide along the valley and lowland bottoms (O'Connor, 2001). The Holocene alluvium is considered to range from 1 to 3 m in thickness (O'Connor, 2001). The deposit is considered to be largely homogenous in its hydrogeologic properties. Woodward et al. (1998) demonstrated that the Holocene floodplain deposits have significantly larger values of specific capacity, hydraulic conductivity, and transmissivity than the underlying units of the Willamette aquifer (Qg<sub>1</sub> and Qg<sub>2</sub>).

#### 1.5.4 Modern land use of the Willamette Valley, Oregon

The population of the Willamette Valley has grown steadily since the great migration in the mid-1800's. In 1992, the U.S. Bureau of the Census estimated 70% of the total population of Oregon lived within the Willamette Valley. According to the 2000 U.S. census, nearly 3.4 million people reside in the State of Oregon, 2.4 million of which live within the Willamette Valley. The U.S. Bureau of the Census projects that the population will increase to approximately 4.4 million people by 2025, with 3.1 million people residing within the Willamette Valley (U.S. Census, 2000).

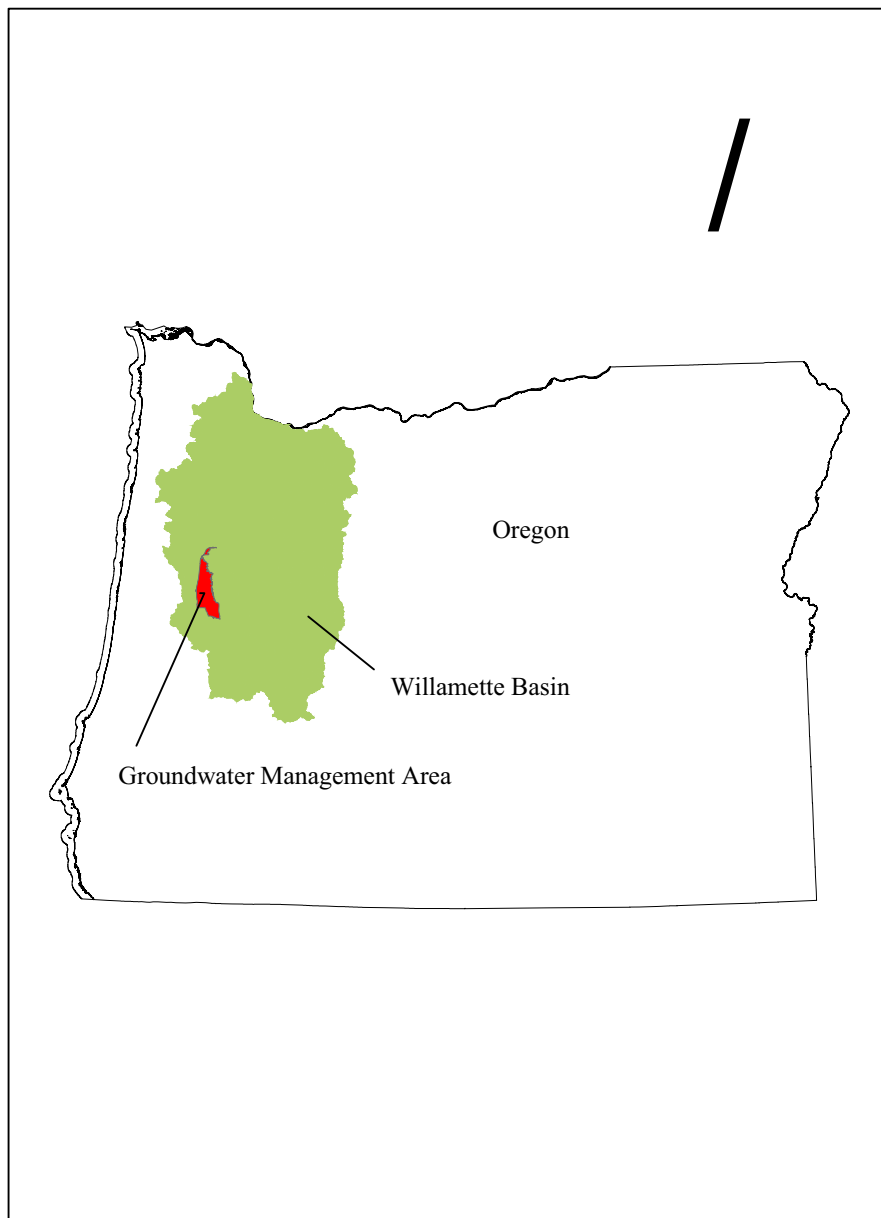
The Willamette Valley supports one of the most diverse agricultural pallets in the United States. Agriculture accounts for 22% of the land-use in the Willamette Valley, which is second only to forest land, which comprises 70% of the land use (Ulrich and Wentz, 1999). In 1992, the Willamette Valley produced more agricultural commodities such as grass seed, blackberries, boysenberries, loganberries, black raspberries, hazelnuts, peppermint and Christmas trees than any other state (Ulrich and Wentz, 1999). In 1993, the Willamette Valley supported 200 various agricultural commodities, including grains, hay, mint, nursery crops, fruits, nuts, hops, grass seed, and vegetable seed (Ulrich and Wentz, 1999).

## Chapter II

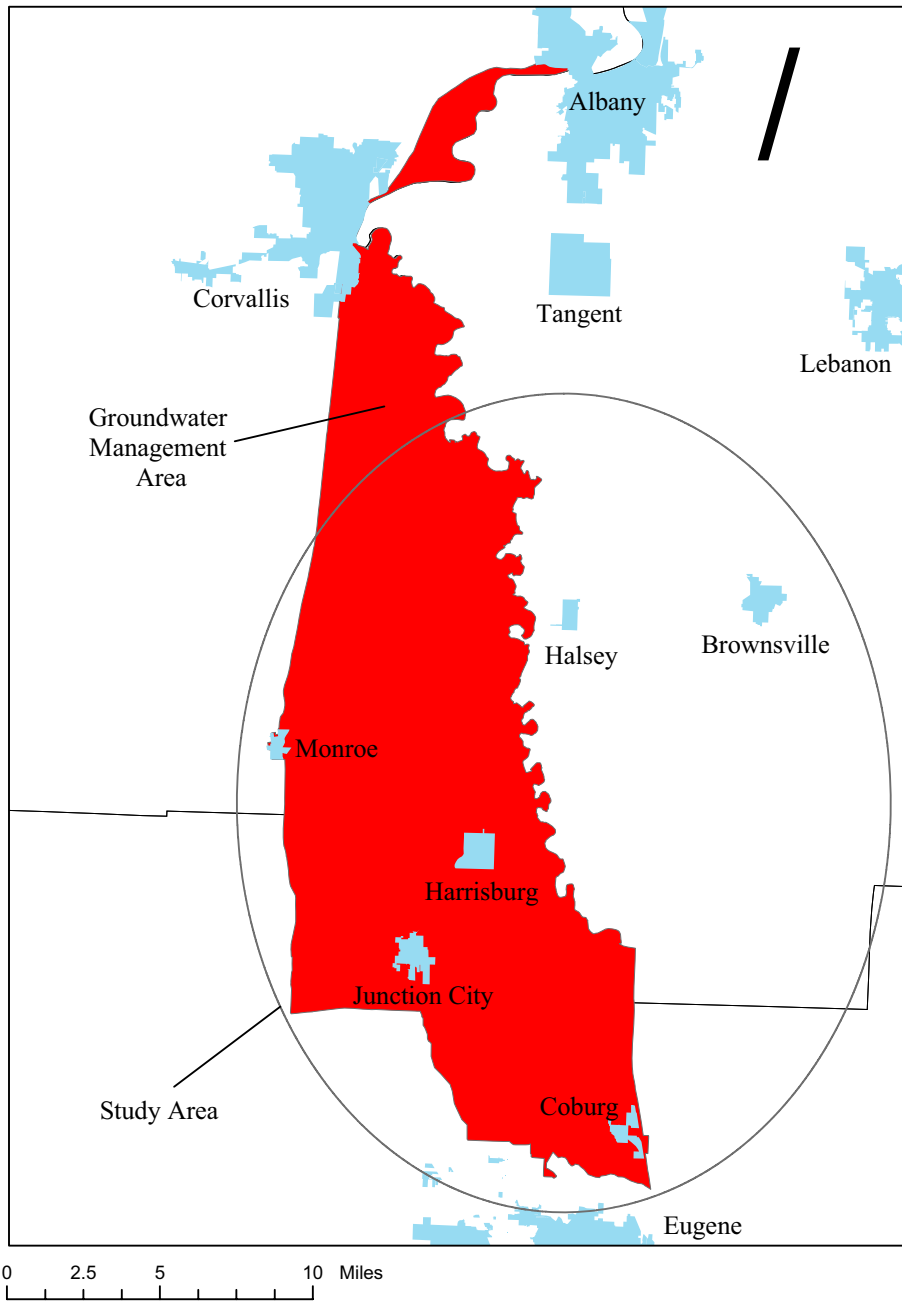
### Materials and Methods

#### 2.1 Study Site

As discussed in chapter I, the study area was selected to allow testing of hypothesis of sources of NO<sub>3</sub> contamination in the southern Willamette Valley. We chose an area within the then proposed (now adopted, Eldridge, 2004) southern Willamette Valley Groundwater Management Area (Figures 2.1 and 2.2).



**Figure 2. 1: Location of the Willamette Valley and Groundwater Management Area in Oregon.**

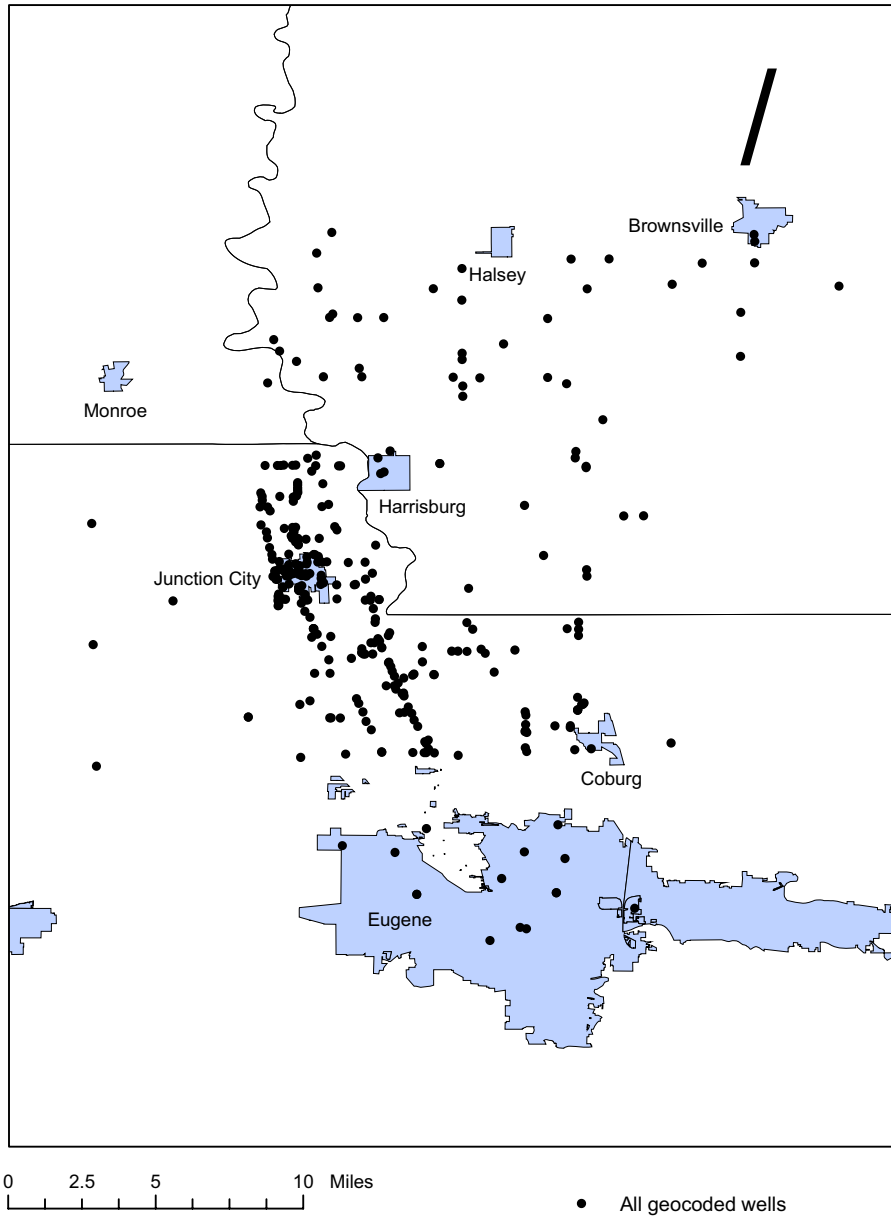


**Figure 2. 2: Location of Study Area.**

## 2.2 Selection of sampling sites

The sampling of domestic drinking water wells was carried out at sites throughout the southern Willamette Valley, Oregon. A search of all drinking water wells logs that met the criteria of the study was performed. The criteria of wells to be included in the study was (1) less than 75 feet in depth (2) installed after 1960 (3) domestic use and (4) be located in the southern Willamette Valley. The search yielded 466 well logs (Figure 2.3). Addresses from these well logs were geocoded to determine their respective coordinates. Using ArcGIS, the wells were imported into a GIS layer. A GIS layer of 1990 land-use was overlain on the well layer (Enright et al., 1990). Each well was coded with its respective land-use, yielding sixty-six codes. The codes were then placed into one of four categories: High Intensity Agriculture, Low Intensity Agriculture, High Intensity Housing and Low Intensity Housing (Table 2.1). High intensity agriculture includes the production of mint and row crops. Low intensity agriculture represents the production of grass seed, trees, shrubs, blueberries and orchards. High intensity housing was used for areas that included two or more homes per acre. Low intensity housing represents areas that had one or less homes per acre.



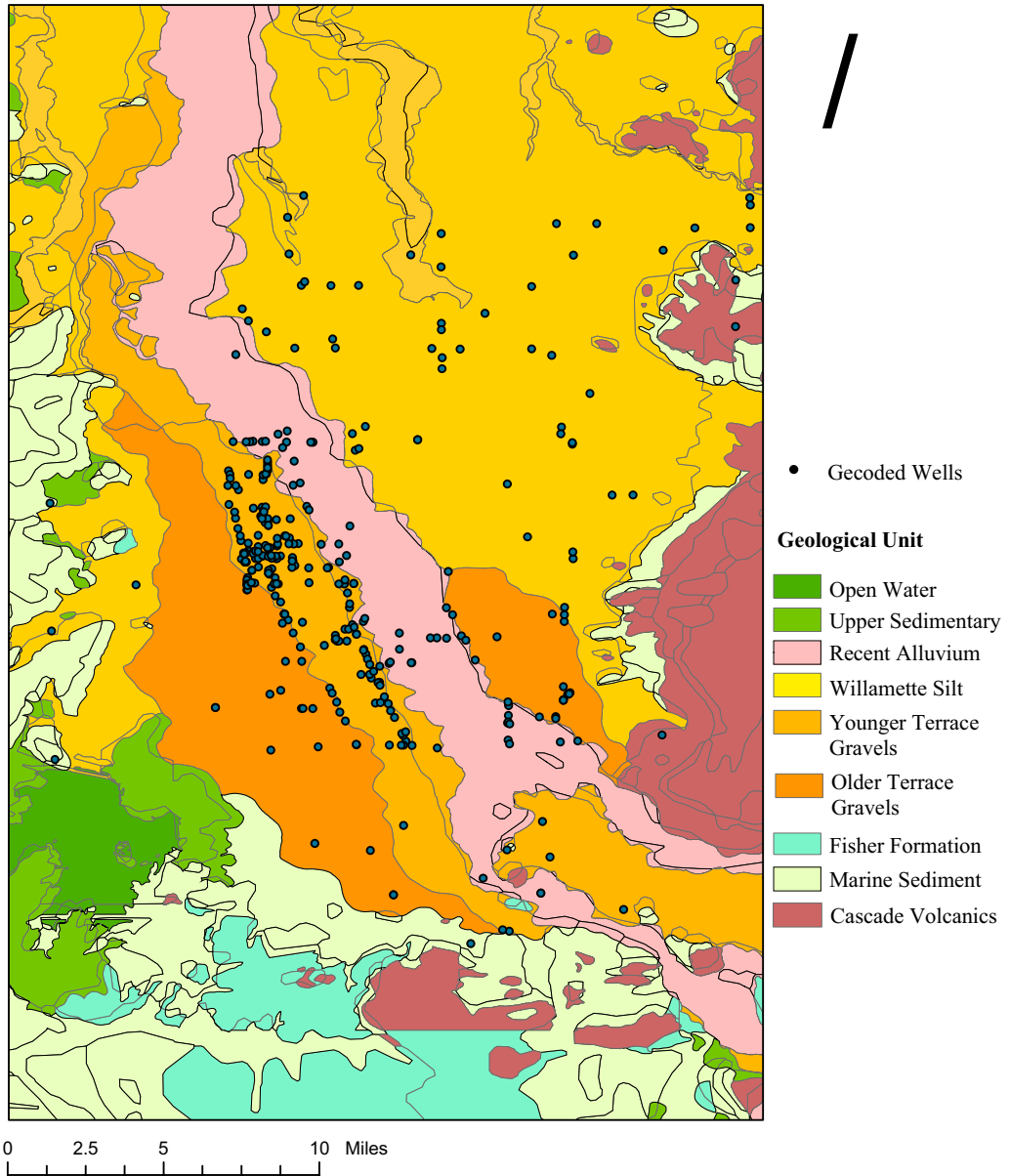


**Figure 2. 3: All geocoded wells in the southern Willamette Valley study area.**

**Table 2. 1: Description of land use codes used in the selection of wells to be included in the study**

Code	Description	Criteria
LIH	Low-Intensity Housing	$2 \geq$ house/acre
HIH	High-Intensity Housing	$2 <$ house/acre
LIA	Low-Intensity Agriculture	Grass Seed, Shrubs, Trees, Orchards, Blueberries
HIA	High-Intensity Agriculture	Mint and Row Crops

The GIS layer of the drinking water wells was combined with a geologic map of quaternary units in the Willamette Valley, Oregon (Figure 2.4). The well locations represented six different geologic units: Recent Alluvium, Willamette Silt, Younger Terrace Gravels, Older Terrace Gravels, Marine Sediments and Cascade Volcanics. The geologic units were coded as either Willamette Silt Layer or non-Willamette Silt Layer in order to test the hypothesis put forward by Argihi (2004) and Iverson (2002) (Table 2.2).

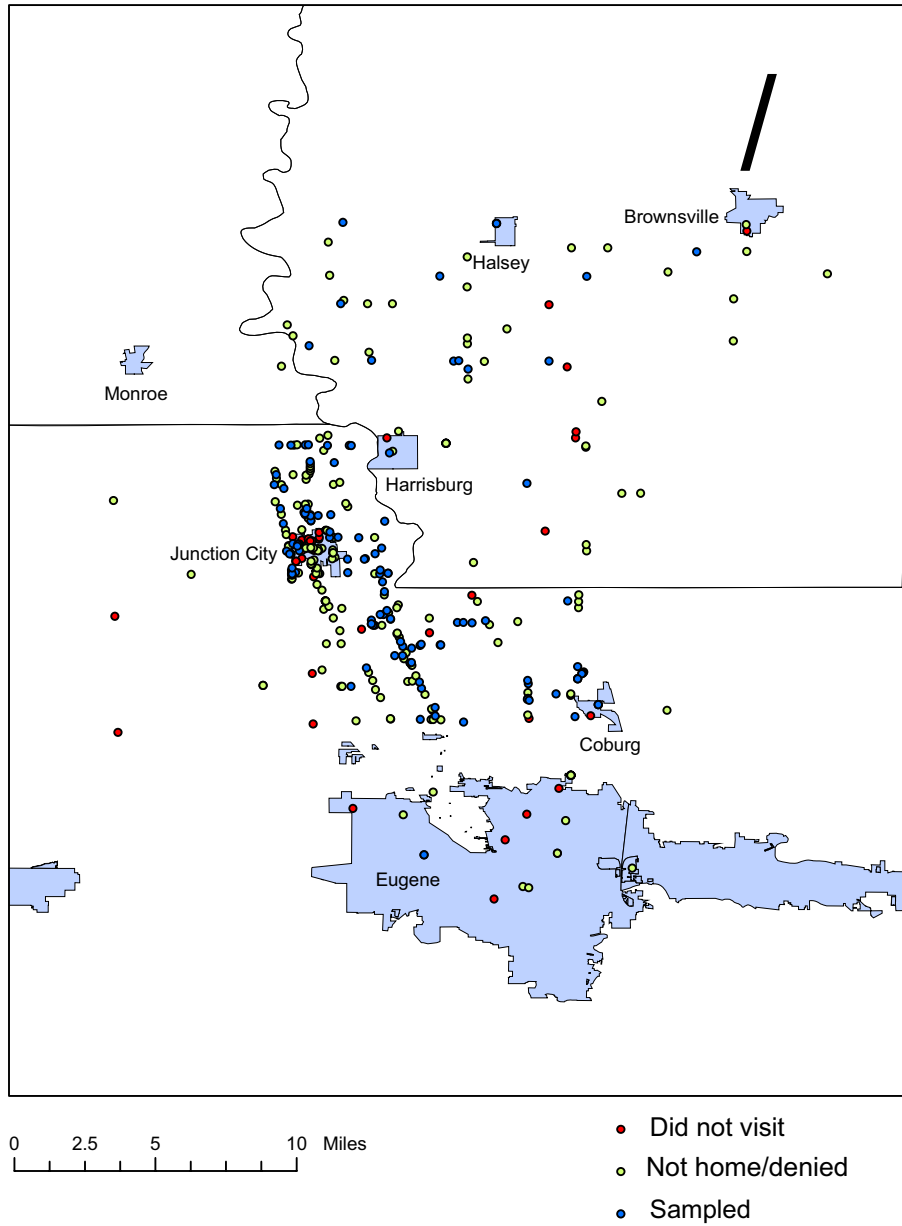


**Figure 2. 4: All geocoded wells within respective geological units.**

**Table 2. 2: Description of geologic unit codes used in the selection of wells to be included in the study.**

Code	Geologic Unit
Willamette Silt Layer	Willamette Silt Layer
Non-Willamette Silt Layer	Recent Alluvium
Non-Willamette Silt Layer	Younger Terrace Gravels
Non-Willamette Silt Layer	Older Terrace Gravels
Non-Willamette Silt Layer	Marine Sediments
Non-Willamette Silt Layer	Cascade Volcanics

A letter was drafted, asking for voluntary participation in the study by the owners of the drinking water wells. A toll-free number was established, allowing homeowners to volunteer for participation in the study. Fifty-four homeowners volunteered to participate in the study. After sampling the 54 volunteers' wells, impromptu visitation of the remaining homes began, which yielded an additional 66 sampling sites. Of the 466 homes that were sent letters, 110 homes were not visited, 236 homes were visited but either the homeowner was not home or refused to give a sample of their well water, and 120 wells were sampled (Figure 2.4).



**Figure 2. 5: Well visit log for the southern Willamette Valley study area.**

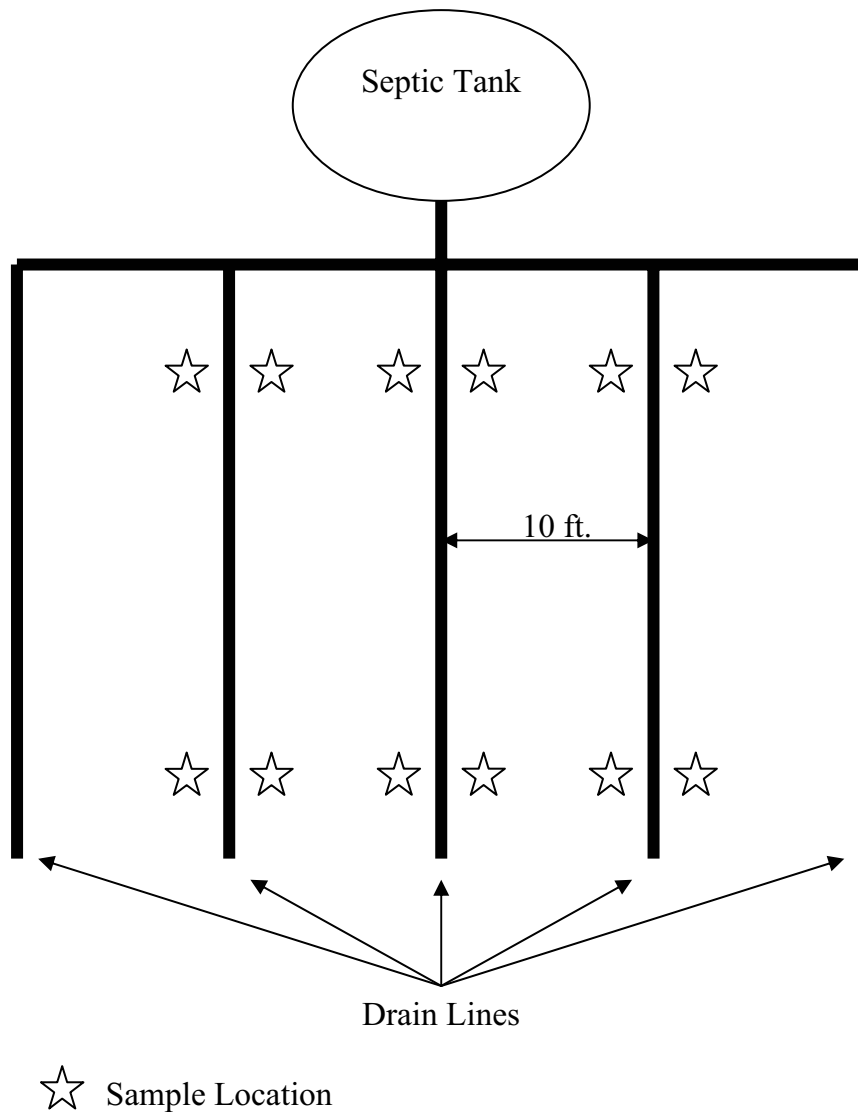
## 2.3 Sample Collection

### 2.3.1 Sample Collection-Wells

Samples were collected directly from the aquifer, using the well as the sampling mechanism. Each well was pumped for fifteen minutes, ensuring the water was collected directly from the aquifer. Four samples were collected in 20 mL HDPE scintillation bottles. One sample was collected in a 60 mL HDPE bottle. These samples were placed directly on ice. Once back at the laboratory, all samples were placed in a -20°C freezer until the time of analysis. A final sample was taken using a Quanta Hydrolab (Hydrolab Incorporated Loveland, Colorado). The 250 mL Quanta Hydrolab's sampling flask was rinsed three times with the well's water before the final sample was drawn. The Quanta Hydrolab quantified the temperature, pH, DO, conductivity and TDS of the sample. This information was recorded directly in the field. A calibration was performed of the instrument prior to field sampling.

### 2.3.2 Sample Collection-Septic Drain Fields

Soil samples were collected from 10 septic drain fields between the 4<sup>th</sup> and 18<sup>th</sup> of November 2003. For each sampling event, 12 samples were taken at a depth of 1 meter. All tile lines were identified, collecting augured samples in accordance to Figure 2.6. The stars in Figure 2.6 represent the sampling locations. The samples were thoroughly mixed together, creating one representative sample per site. All samples were immediately place on ice and placed in a -20°C freezer upon return to the laboratory.



**Figure 2. 6: Plan view of sampling locations on Septic Drain Fields.**

### 2.3.3 Sample Collection- Agricultural Fields

Agriculture samples were collected during December 1994 and December 1995. Samples were collected using suction cup lysimeters. High flow ceramic cups (5 cm O.D., 6 cm length, 1 bar air entry pressure) from Soil Moisture Equipment, Santa Barbara, CA (#653X01-B1M3) were used for sampler construction. A 5.08 cm I.D. PVC pipe was sealed with a rubber stopper. Two 3.175 mm I.D. HDPE tubes were used as the sample

and vacuum connections to the sampler. Sample tubing extended to the bottom of the cup to prevent dead volume. Each suction cup sampler was checked to ensure they held a vacuum before they were used in the field. The suction cups were installed at the greatest depth that could be reached using a hand auger, which was typically at the water table height between 3 and 5 m. Samples were collected in 20 mL HDPE bottles and frozen at -12.7°C until time of analysis.

**Table 2. 3: Agriculture signature samples used in study.**

Sample ID	Date Collected	Crop
F-1	Dec-95	Mint
F-2	Dec-95	Row Crop
F-3	Dec-95	Orchard
F-4	Dec-95	Rye Grass Seed
F-5	Dec-94	Orchard
F-6	Dec-95	Orchard
F-7	Dec-95	Mint
F-8	Dec-95	Mint
F-9	Dec-94	Rye Grass Seed
F-10	Dec-94	Rye Grass Seed

## 2.4 Sample Analysis

### 2.4.1 Water Analysis

Water samples were analyzed for anion concentration using a Dionex 2000i ion chromatograph with a Dionex A4-SC separator and an AG4A-SC guard column (Dionex Corporation Sunnyvale, CA). This procedure yielded results for NO<sub>3</sub>-N, SO<sub>4</sub><sup>-</sup>, Cl<sup>-</sup>, Br<sup>-</sup> and NO<sub>2</sub>-N. Water samples were analyzed for cations using a Perkin Elmer 3000DV ICP (Wellesley, MA). The samples were also assayed for HCO<sub>3</sub><sup>-</sup> using EPA Standard Methods 2320.



## 2.4.2 Soil Analysis

After thawing, the samples were mixed once again, ensuring homogenization. A 50 g. sub-sample was taken from each of the samples for the determination of gravimetric water content. The wet weight was recorded and the samples were placed in tin drying pans and oven dried for 8 hours at 105°C. The dry weight was measured to calculate the gravimetric water content.

Soil cations were extracted from each sample using a 2N potassium chloride (KCl) solution. Samples were mechanically shaken in a 250 mL HDPE container for one hour. After shaking, the samples were gravimetrically filtered using Whatman No. 42 filter paper. The extract was analyzed using an Astoria 305D colorimetric spectrophotometer (Astoria Pacific Incorporated Clackamas, OR).

Soil anions were extracted from each sample using a 1N ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>) Solution. Samples were mechanically shaken in a 250 mL HDPE container for one hour. After shaking, the samples were gravimetrically filtered using Whatman No. 42 filter paper. The extract was analyzed using a Waters Capillary Ion Analyzer (Millipore Corporation Mildford, MA).

Isotopes of N and O were analyzed by the University of Waterloo's Environmental Isotope Laboratory. The groundwater nitrate was converted to AgNO<sub>3</sub> using a modified version of the method described by Silva et al. (2000).

## 2.5 Statistical Analysis

The data collected from the initial 120 wells and the subsequent 40 signature samples was analyzed using descriptive statistics, simple linear regression, multiple linear

regression, F-tests, two-sided T-tests and Analysis of Variance (ANOVA). Descriptive statistics showed means, medians, maximums, minimums and standard deviations.

The backward multiple linear regression employed F-tests to determine the significance of land use, soil types and geologic units for each backward step. All of these statistical tests were conducted using SPSS v.11. A *P*-value level of 0.05 was used to evaluate the significance of all statistical tests. A spatial representation of NO<sub>3</sub>-N concentrations and geologic units and soil types was created using ArcGIS 8.0 software.

## Chapter III

### Results

#### 3.1 Chemical Characteristics

NO<sub>3</sub>-N concentrations in the study area ranged from below detection (<0.20 mg/L) to 13.70 mg/L, with a mean concentration of 4.81 mg/L (Table 3.1; Figure 3.1). Of the total of 120 wells sampled, 8.3 % of the wells had NO<sub>3</sub>-N concentrations exceeding the accepted drinking water limit of 10 mg/L NO<sub>3</sub>-N.

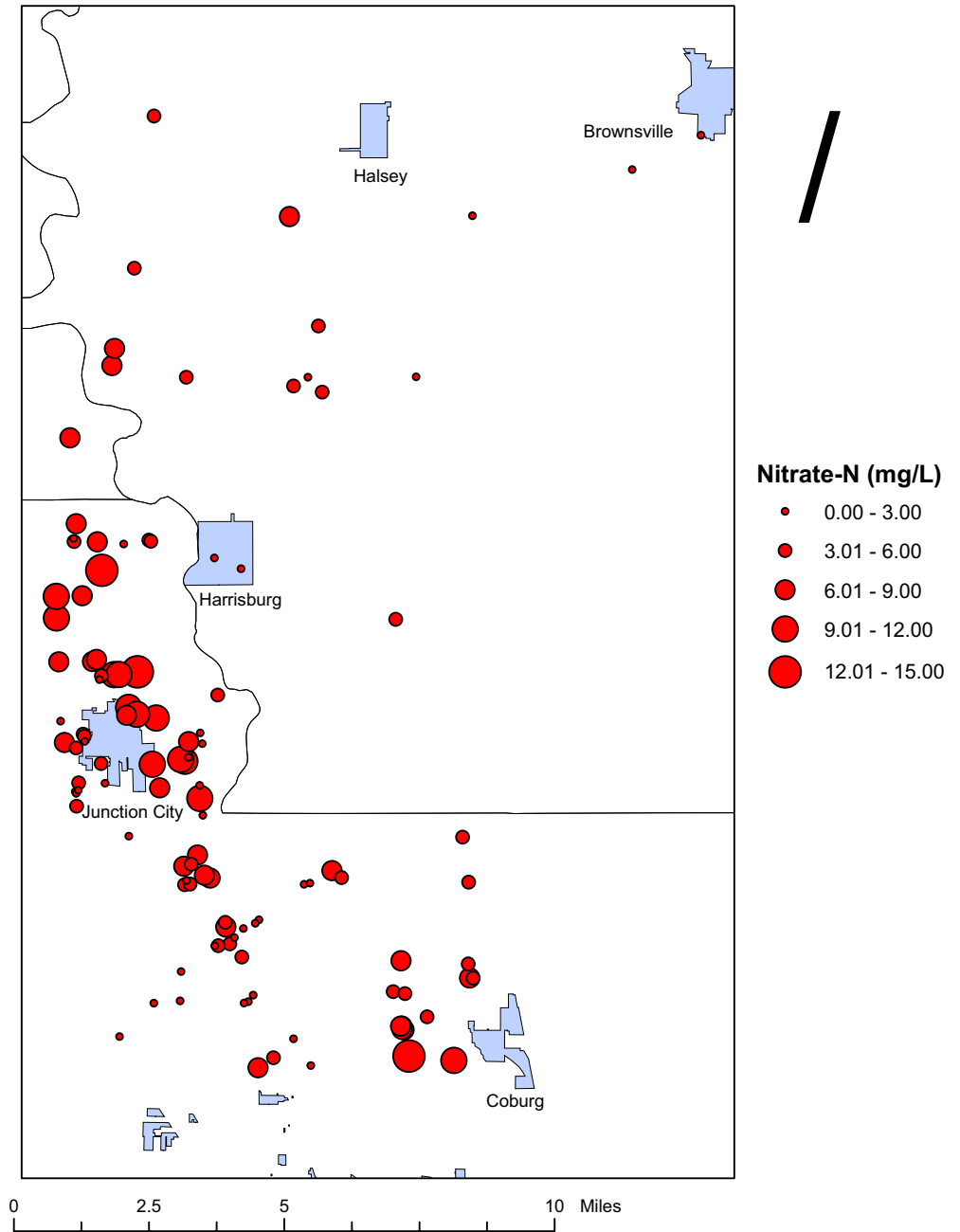
**Table 3. 1: Summary statistics of results for analytes found in wells tested in the study.**

	NO <sub>3</sub> -N (mg/L)	SO <sub>4</sub> <sup>2-</sup> (mg/L)	Cl <sup>-</sup> (mg/L)	HCO <sub>3</sub> <sup>-</sup> (mg/L)
Mean	4.81	11.15	14.88	85
Median	4.05	10.31	7.81	84
Minimum	<0.20	<0.20	1.79	28
Maximum	13.70	35.11	192.77	200
Standard Deviation	3.40	7.65	24.98	28

	DO (mg/L)	TDS (g/L)	Conductivity (mS/cm)	pH
Mean	3.82	0.20	0.29	7.77
Median	3.87	0.20	0.28	7.70
Minimum	1.58	0.00	0.06	7.03
Maximum	6.21	0.80	1.17	9.05
Standard Deviation	1.05	0.09	0.13	0.36

The highest NO<sub>3</sub>-N concentrations occur in the western and southern areas of the study area, while the lowest NO<sub>3</sub>-N concentrations occur in the northern and eastern areas (Figure 3.1)

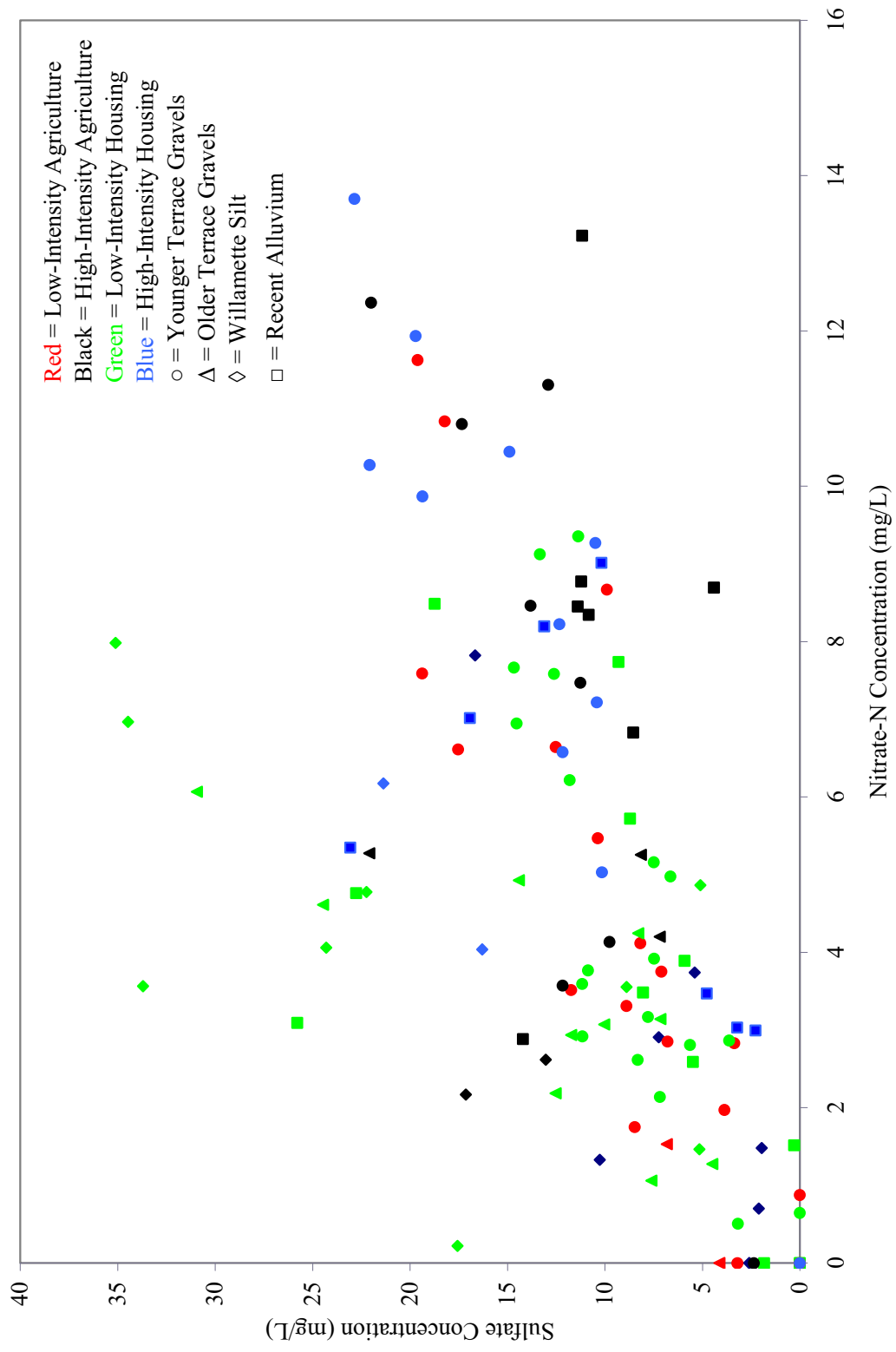


**Figure 3. 1: Map of NO<sub>3</sub>-N concentrations found in each well in the southern Willamette Valley study area in this study.**

There was a statistically significant trend (i.e.  $P < 0.05$ ) of decreasing  $\text{NO}_3\text{-N}$  with increasing well depth, decreasing well age, pH and  $\text{SO}_4^{2-}$  (Table 3.2). There was less correlation between  $\text{NO}_3\text{-N}$  concentrations and  $\text{Cl}^-$ , Conductivity, TDS, DO and  $\text{HCO}_3^-$ . The proportion of variability in  $\text{NO}_3\text{-N}$  concentration that can be explained by, or that is associated with,  $\text{SO}_4^{2-}$  is 0.303 or 30.3% (Figure 3.2), while pH explains 23.3% (Figure 3.3), well depth 8.7% (Figure 3.4), and well age 5.6% (Figure 3.5). It is notable that no wells with  $\text{pH} > 7.8$  had  $\text{NO}_3 > 10$  ppm. In each case simple linear regressions are employed without transformation of variables since no structured discrepancy with linearity is apparent in the data, perhaps due to the considerable scatter.

**Table 3. 2: Summary of analyses of variance showing the associated variation between the characteristics and analyte concentrations on  $\text{NO}_3\text{-N}$  concentration in all wells, with significant values in bold.**

Source of Variation	<i>P</i> -value	Slope (per ppm $\text{NO}_3$ )
<b><math>\text{SO}_4^{2-}</math> (ppm)</b>	<b>&lt;0.0001</b>	<b>0.2468</b>
<b>pH (ppm)</b>	<b>&lt;0.0001</b>	<b>-4.1525</b>
<b>Well Age (yrs.)</b>	<b>0.0015</b>	<b>0.6411</b>
<b>Well Depth (ft.)</b>	<b>0.0016</b>	<b>-0.0838</b>
$\text{Cl}^-$ (ppm)	0.0626	-0.0232
DO (ppm)	0.1531	0.4214
$\text{HCO}_3^-$ (ppm)	0.1889	-0.0144
TDS (g/L)	0.5103	2.3601
Conductivity (mS/cm)	0.7338	0.8456



**Figure 3. 2:  $\text{SO}_4^{2-}$  concentration and  $\text{NO}_3\text{-N}$  concentration for all wells.**



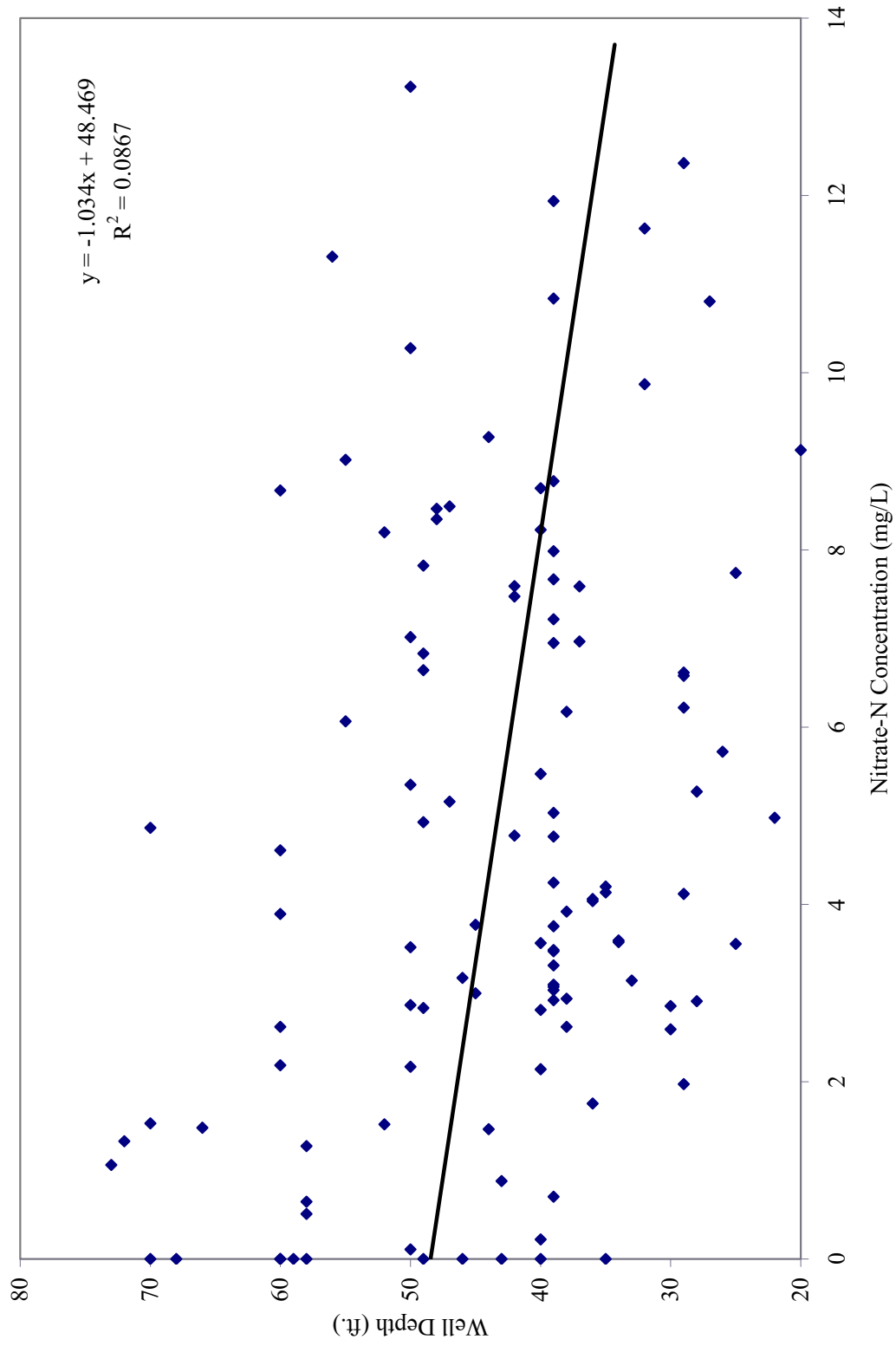
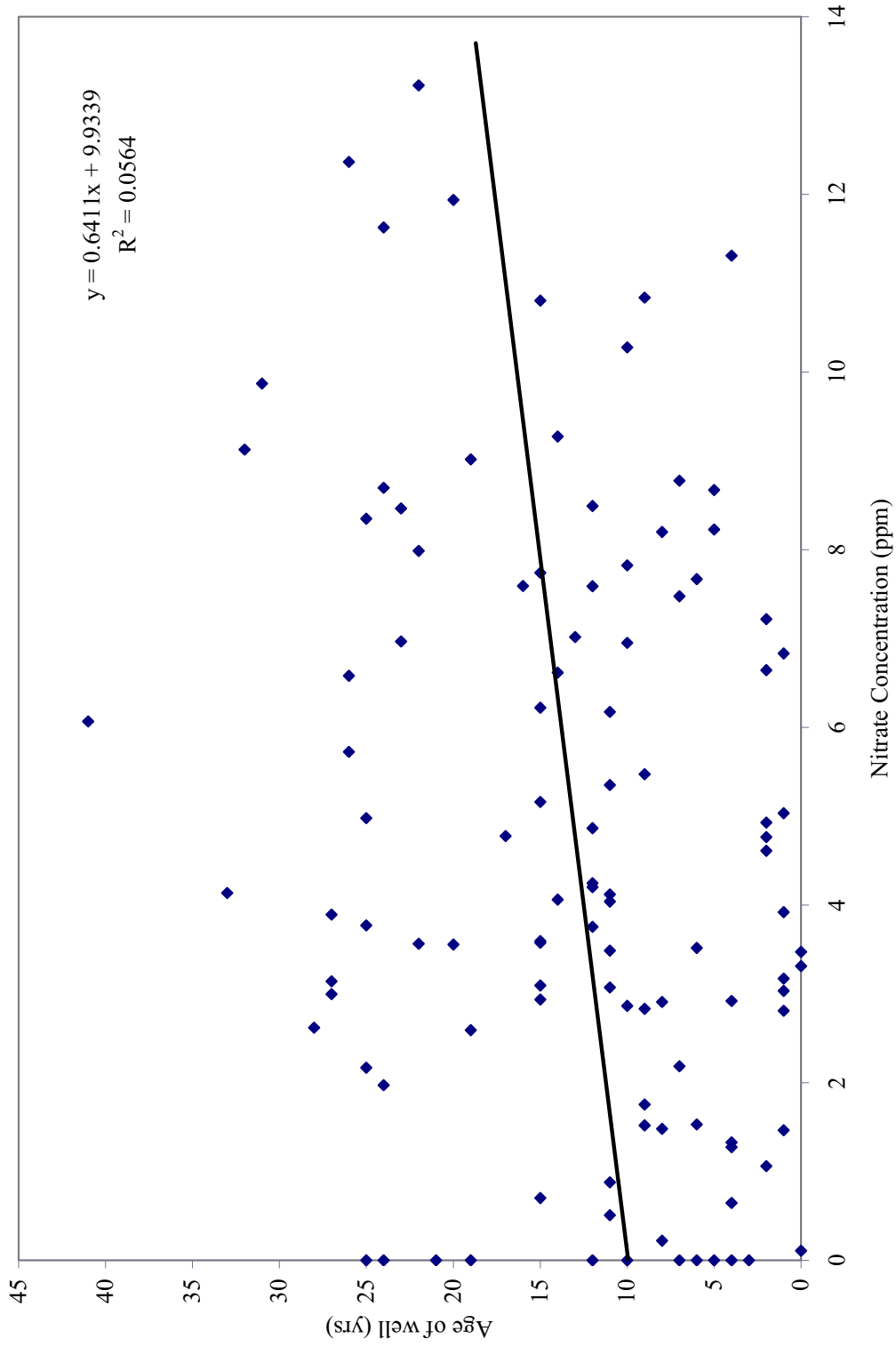


Figure 3. 4: Well depth and NO<sub>3</sub>-N concentration for all wells.





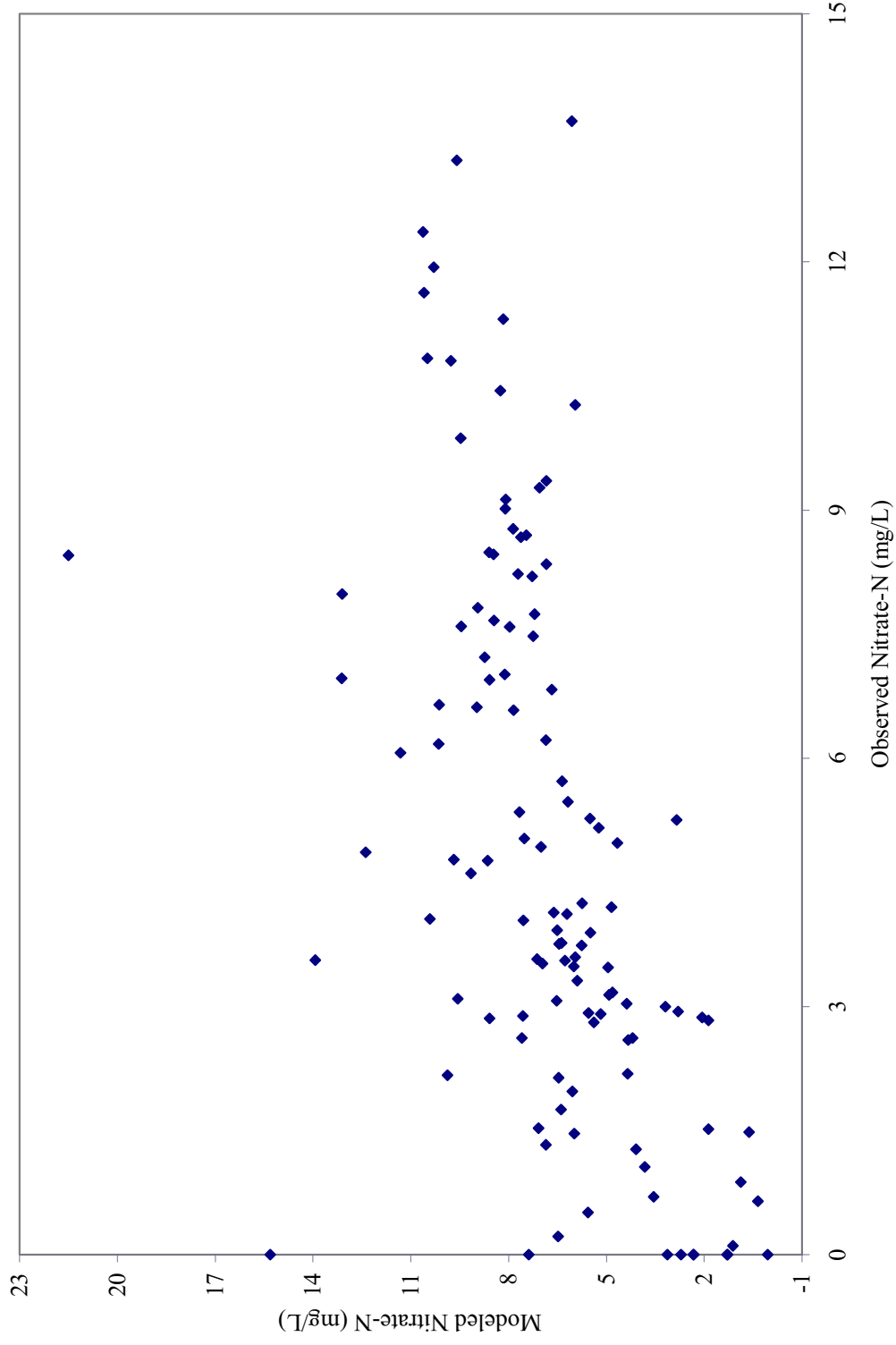
A backward multivariable regression was conducted to evaluate the relationship between NO<sub>3</sub>-N concentration and other explanatory variables. NO<sub>3</sub>-N concentration was used as the dependent variable, with analytes being subtracted from the model in order of individual significance (Table 3.3, Figure 3.6). The proportion of variability in NO<sub>3</sub>-N concentration that can be explained by, or that is associated with, using SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, Cl, Geology, Soil, Well Depth, Conductivity, Well Age, DO is 0.7759, or 77.59%. The basic linear regression model is structure as equation 3.1, where  $\alpha_0$  is the offset,  $\alpha_1$  is the linear multiplier for variable  $v_1$ , etc. The model parameters for each regression model tested are listed in Table 3.3.

$$\alpha_0 + \alpha_1 v_1 + \alpha_2 v_2 + \dots + \alpha_n v_n = \text{NO}_3\text{-N} \quad (3.1)$$

**Table 3. 3: Backward multivariable analysis with NO<sub>3</sub>-N as the dependent variable.**

Independent Variables	P-Value	R-Squared
<b>1 SO<sub>4</sub></b> Model: $\alpha_{\text{SO}_4}=0.2437$ ; $\alpha_o=2.1320$	< <b>0.0001</b>	<b>0.3032</b>
<b>2 SO<sub>4</sub>, pH</b> Model: $\alpha_{\text{SO}_4}=0.2118$ ; $\alpha_{\text{pH}}=-3.8896$ ; $\alpha_o=37.7026$	< <b>0.0001</b>	<b>0.4752</b>
<b>3 SO<sub>4</sub>, pH, HCO<sub>3</sub></b> Model: $\alpha_{\text{SO}_4}=0.2275$ ; $\alpha_{\text{pH}}=-3.5562$ ; $\alpha_{\text{HCO}_3}=-0.0200$ ; $\alpha_o=31.6494$	< <b>0.0001</b>	<b>0.5011</b>
<b>4 SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use</b> Model: $\alpha_{\text{SO}_4}=0.2102$ ; $\alpha_{\text{pH}}=-3.4262$ ; $\alpha_{\text{HCO}_3}=-0.0211$ ; $\alpha_{\text{Land Use}}=0.2411$ ; $\alpha_o=31.2520$	< <b>0.0001</b>	<b>0.5755</b>
<b>5 SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS</b> Model: $\alpha_{\text{SO}_4}=0.2054$ ; $\alpha_{\text{pH}}=-3.5227$ ; $\alpha_{\text{HCO}_3}=-0.0238$ ; $\alpha_{\text{Land Use}}=0.2483$ ; $\alpha_{\text{TDS}}=3.3158$ ; $\alpha_o=31.6720$	< <b>0.0001</b>	<b>0.5811</b>
<b>6 SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, Cl</b> Model: $\alpha_{\text{SO}_4}=0.1926$ ; $\alpha_{\text{pH}}=-3.1028$ ; $\alpha_{\text{HCO}_3}=-0.0270$ ; $\alpha_{\text{Land Use}}=0.2727$ ; $\alpha_{\text{TDS}}=11.3451$ ; $\alpha_{\text{Cl}}=-0.0377$ ; $\alpha_o=27.0513$	< <b>0.0001</b>	<b>0.6007</b>
<b>7 SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, Cl, Geology</b> Model: $\alpha_{\text{SO}_4}=0.2054$ ; $\alpha_{\text{pH}}=-2.3823$ ; $\alpha_{\text{HCO}_3}=-0.0176$ ; $\alpha_{\text{Land Use}}=0.4204$ ; $\alpha_{\text{TDS}}=11.1454$ ; $\alpha_{\text{Cl}}=-0.2025$ ; $\alpha_{\text{Geology}}=-0.1854$ ; $\alpha_o=20.2855$	< <b>0.0001</b>	<b>0.6499</b>

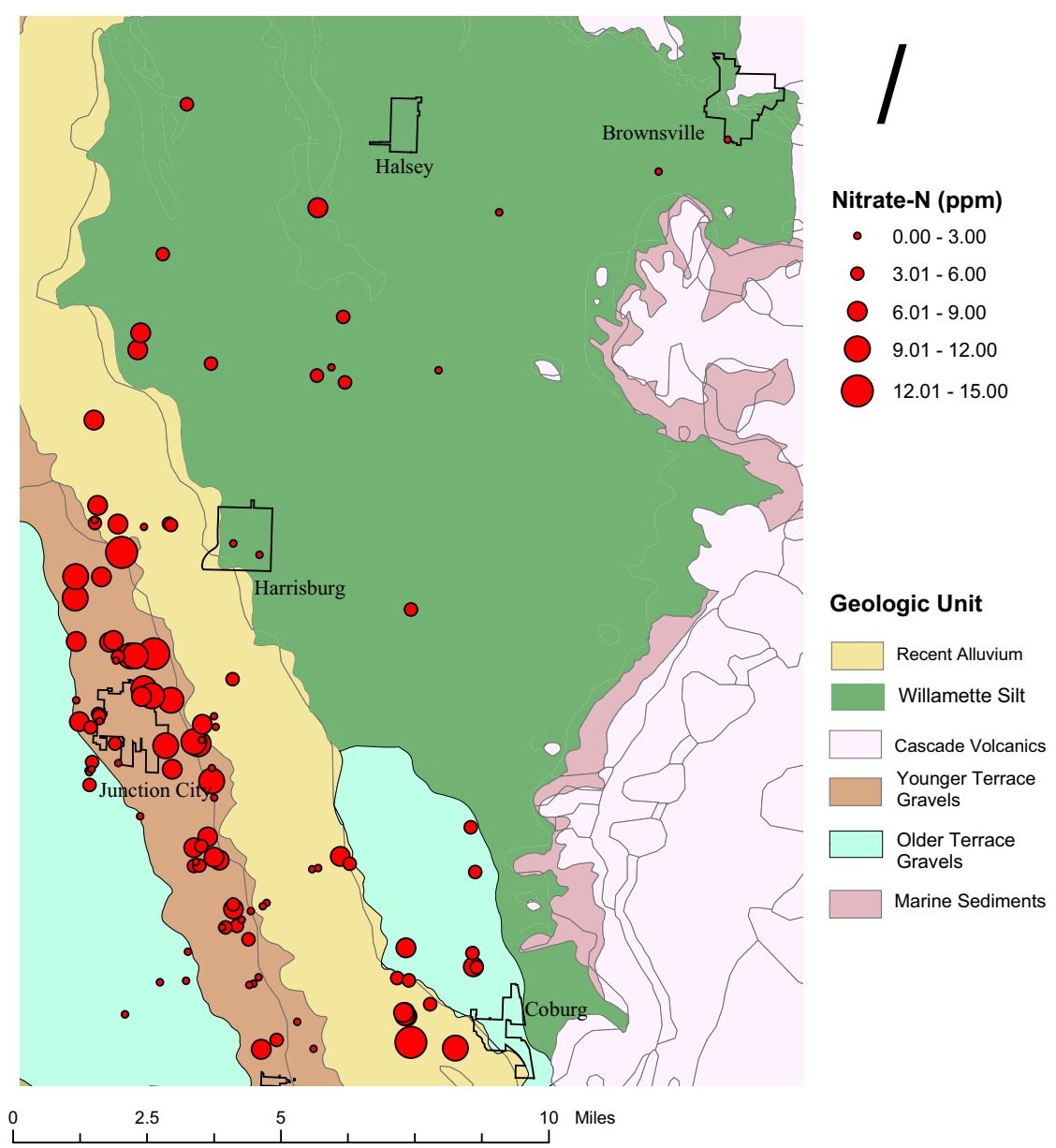
8	<b>SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, C-, Geology, Soil</b> Model: $\alpha_{\text{SO}_4}=0.2571$ ; $\alpha_{\text{pH}}=-2.1650$ ; $\alpha_{\text{HCO}_3}=-0.0224$ ; $\alpha_{\text{Land Use}}=0.3802$ ; $\alpha_{\text{TDS}}=12.9511$ ; $\alpha_{\text{Cl}}=-0.0199$ ; $\alpha_{\text{Geology}}=-0.2596$ ; $\alpha_{\text{Soil}}=0.5860$ ; $\alpha_0=18.0043$	< <b>0.0001</b>	<b>0.7253</b>
9	<b>SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, C-, Geology, Soil, Well Depth</b> Model: $\alpha_{\text{SO}_4}=0.2469$ ; $\alpha_{\text{pH}}=-2.0777$ ; $\alpha_{\text{HCO}_3}=-0.0220$ ; $\alpha_{\text{Land Use}}=0.3421$ ; $\alpha_{\text{TDS}}=14.0197$ ; $\alpha_{\text{Cl}}=-0.0236$ ; $\alpha_{\text{Geology}}=-0.2386$ ; $\alpha_{\text{Soil}}=0.5852$ ; $\alpha_{\text{Well Depth}}=0.0011$ ; $\alpha_0=17.0907$	< <b>0.0001</b>	<b>0.733</b>
10	<b>SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, Cl, Geology, Soil, Well Depth, Conductivity</b> Model: $\alpha_{\text{SO}_4}=0.2282$ ; $\alpha_{\text{pH}}=-2.2497$ ; $\alpha_{\text{HCO}_3}=-0.0226$ ; $\alpha_{\text{Land Use}}=0.4127$ ; $\alpha_{\text{TDS}}=-1.2590$ ; $\alpha_{\text{Cl}}=-0.0444$ ; $\alpha_{\text{Geology}}=-.2467$ ; $\alpha_{\text{Soil}}=0.4932$ ; $\alpha_{\text{Well Depth}}=0.0074$ ; $\alpha_{\text{Conductivity}}=15.2672$ ; $\alpha_0=15.2672$	< <b>0.0001</b>	<b>0.7426</b>
11	<b>SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, Cl, Geology, Soil, Well Depth, Conductivity, DO</b> Model: $\alpha_{\text{SO}_4}=0.2292$ ; $\alpha_{\text{pH}}=-2.1658$ ; $\alpha_{\text{HCO}_3}=-0.0219$ ; $\alpha_{\text{Land Use}}=0.4075$ ; $\alpha_{\text{TDS}}=-1.4729$ ; $\alpha_{\text{Cl}}=-0.0476$ ; $\alpha_{\text{Geology}}=-.2729$ ; $\alpha_{\text{Soil}}=0.4844$ ; $\alpha_{\text{Well Depth}}=0.0047$ ; $\alpha_{\text{Conductivity}}=15.7931$ ; $\alpha_{\text{DO}}=-0.1226$ ; $\alpha_0=16.9780$	< <b>0.0001</b>	<b>0.7436</b>
12	<b>SO<sub>4</sub>, pH, HCO<sub>3</sub>, Land Use, TDS, Cl, Geology, Soil, Well Depth, Conductivity, DO, Well Age</b> Model: $\alpha_{\text{SO}_4}=0.2074$ ; $\alpha_{\text{pH}}=-2.8950$ ; $\alpha_{\text{HCO}_3}=-0.0249$ ; $\alpha_{\text{Land Use}}=0.3786$ ; $\alpha_{\text{TDS}}=-7.1554$ ; $\alpha_{\text{Cl}}=-0.0577$ ; $\alpha_{\text{Geology}}=-.2227$ ; $\alpha_{\text{Soil}}=0.4864$ ; $\alpha_{\text{Well Depth}}=.0214$ ; $\alpha_{\text{Conductivity}}=21.3522$ ; $\alpha_{\text{DO}}=-0.1057$ ; $\alpha_{\text{Well Age}}=-0.0238$ ; $\alpha_0=21.6766$	< <b>0.0001</b>	<b>0.7759</b>



**Figure 3. 6: Multivariable model plot of NO<sub>3</sub>-N concentration.**

### **3.2 Geology**

A total of 119 wells were located in four geologic units (Figure 3.7). The largest number of wells occurs within the Younger Terrace Gravels (n=57) (Table 3.4). This unit also contains the highest mean NO<sub>3</sub>-N concentration (5.63 mg/L) (Table 3.5). The least number of wells occurs within the Older Terrace Gravels and Willamette Silt geologic units (n=17). These units also contain the lowest mean NO<sub>3</sub>-N concentrations (3.31 mg/L). Approximately 90% of the wells with NO<sub>3</sub>-N concentrations above 10 mg/L are located within the Younger Terrace Gravels geologic unit.



**Figure 3. 7: Geologic unit classes and NO<sub>3</sub>-N concentrations of all wells in the southern Willamette Valley study area. Few wells are located in the Recent Alluvium since much of this land is at risk of flooding and river meander.**

**Table 3. 4: The number of wells within each geologic unit, with the percentage of total sample in parentheses.**

Geologic Unit	Frequency (%)
Recent Alluvium	28 (23.5%)
Willamette Silt	17 (14.3%)
Younger Terrace Gravels	57 (47.9%)
Older Terrace Gravels	17 (14.3%)

**Table 3. 5: Average chemical results for each class of geologic units with coefficient of variance in parentheses.**

Geologic Unit	NO <sub>3</sub> -N (mg/L)	DO (mg/L)	Cl <sup>-</sup> (mg/L)
Recent Alluvium	5.04 (0.61)	4.16 (0.25)	7.53 (0.47)
Willamette Silt	3.31 (0.74)	3.20 (0.38)	41.63 (1.26)
Younger Terrace Gravels	5.63 (0.66)	3.84 (0.25)	9.69 (0.63)
Older Terrace Gravels	3.47 (0.60)	3.86 (0.27)	18.29 (1.52)

Geologic Unit	SO <sub>4</sub> <sup>2-</sup> (mg/L)	TDS (g/L)	HCO <sub>3</sub> <sup>-</sup> (mg/L)
Recent Alluvium	9.34 (0.76)	0.16 (0.31)	75.21 (0.30)
Willamette Silt	15.43 (0.77)	0.29 (0.55)	111.76 (0.31)
Younger Terrace Gravels	10.46 (0.56)	0.19 (0.21)	79.61 (0.26)
Older Terrace Gravels	12.18 (0.61)	0.20 (0.35)	97.65 (0.33)

Geologic Unit	pH	Dissolved Oxygen (% Sat)	Conductivity (mS/cm)
Recent Alluvium	7.64 (0.05)	41.25 (0.26)	0.24 (0.29)
Willamette Silt	8.05 (0.03)	32.52 (0.38)	0.46 (0.48)
Younger Terrace Gravels	7.72 (0.05)	38.22 (0.25)	0.27 (0.22)
Older Terrace Gravels	7.92 (0.03)	38.84 (0.03)	0.29 (0.28)

A two sample t-test of unequal variances was conducted to evaluate the differences between mean concentrations of various analytes within respective geologic units (Table 3.6). The dependent variable was the geologic unit and the independent



variable was the analyte. When comparing the Willamette Silt geologic unit to the other geologic units, statistical significance was found for 63% of the tests. When comparing the Recent Alluvium geologic unit to the other geologic units, statistical significance was found for 54% of the tests. When comparing the Younger Terrace Gravels geologic unit to the other geologic units, statistical significance was found for 46% of the tests. When comparing the Older Terrace Gravels geologic unit to the other geologic units, statistical significance was found for 46% of the tests.

**Table 3. 6: P-Values for the null hypothesis of no correlation between geologic units and respective chemistry, with statistically significant values in bold.**

<i>Willamette Silt</i>	Recent Alluvium	Younger Terrace Gravels	Older Terrace Gravels
NO <sub>3</sub> -N	0.0540	<b>0.0046</b>	0.8384
SO <sub>4</sub> <sup>2-</sup>	0.0676	0.1124	0.3467
Cl <sup>-</sup>	<b>0.0165</b>	<b>0.0233</b>	0.1176
pH	<b>0.0165</b>	<b>&lt;0.0001</b>	<b>0.0233</b>
Conductivity	<b>0.0008</b>	<b>0.0022</b>	<b>0.0074</b>
TDS	<b>0.0034</b>	<b>0.0135</b>	<b>0.0371</b>
DO	<b>0.0110</b>	0.0562	0.0949
HCO <sub>3</sub> <sup>-</sup>	<b>0.0008</b>	<b>0.0020</b>	0.2342

<i>Recent Alluvium</i>	Willamette Silt	Younger Terrace Gravels	Older Terrace Gravels
NO <sub>3</sub> -N	0.0540	0.4739	0.0603
SO <sub>4</sub> <sup>2-</sup>	0.0676	0.4766	0.2168
Cl <sup>-</sup>	<b>0.0165</b>	<b>0.0439</b>	<b>0.0233</b>
pH	<b>0.0165</b>	0.3646	<b>0.0076</b>
Conductivity	<b>0.0008</b>	0.0896	<b>0.0330</b>
TDS	<b>0.0034</b>	<b>0.0220</b>	<b>0.0484</b>
DO	<b>0.0110</b>	0.1857	0.3586
HCO <sub>3</sub> <sup>-</sup>	<b>0.0008</b>	0.3882	<b>0.0196</b>

<i>Younger Terrace Gravels</i>	Willamette Silt	Recent Alluvium	Older Terrace Gravels
NO <sub>3</sub> -N	<b>0.0046</b>	0.4739	<b>0.0036</b>
SO <sub>4</sub> <sup>2-</sup>	0.1124	0.4766	0.3915
Cl <sup>-</sup>	<b>0.0233</b>	<b>0.0439</b>	0.2222
pH	<b>&lt;0.0001</b>	0.3646	<b>0.0180</b>
Conductivity	<b>0.0022</b>	0.0896	0.2304
TDS	<b>0.0135</b>	<b>0.0220</b>	0.4476
DO	0.0562	0.1857	0.9386
HCO <sub>3</sub> <sup>-</sup>	<b>0.0020</b>	0.3882	<b>0.0442</b>

<i>Older Terrace Gravels</i>	Willamette Silt	Recent Alluvium	Younger Terrace Gravels
NO <sub>3</sub> -N	0.8384	0.0603	<b>0.0036</b>
SO <sub>4</sub> <sup>2-</sup>	0.3467	0.2168	0.3915
Cl <sup>-</sup>	0.1176	<b>0.0233</b>	0.2222
pH	<b>0.0233</b>	<b>0.0076</b>	<b>0.0180</b>
Conductivity	<b>0.0074</b>	<b>0.0330</b>	0.2304
TDS	<b>0.0371</b>	<b>0.0484</b>	0.4476
DO	0.0949	0.3586	0.9386
HCO <sub>3</sub> <sup>-</sup>	0.2342	<b>0.0196</b>	<b>0.0442</b>

### 3.3 Land Use

A total of 113 wells were located in four land use units (Table 3.7). The largest number of wells occurs within the Low-Intensity Agriculture unit (n=53). The least number of wells occurs within the High-Intensity Agriculture unit (n=19). This unit also contains the highest mean NO<sub>3</sub>-N concentration (7.01) (Table 3.8). Low-Intensity Housing contains the lowest mean NO<sub>3</sub>-N concentration (3.66). Approximately 80% of the wells with NO<sub>3</sub>-N concentrations above 10 mg/L are located either within the High-Intensity Agriculture unit (40% of wells) or the High-Intensity Housing unit (40% of wells).

**Table 3. 7: The number of wells within each land use unit, with percentage of the total sample in parentheses.**

Land Use Code	Land Use	Frequency (%)
LIH	Low-Intensity Housing	20 (17.7)
HIH	High-Intensity Housing	19 (16.8)
LIA	Low-Intensity Agriculture	53 (46.9)
HIA	High-Intensity Agriculture	21 (18.6)

**Table 3. 8: Chemical results for respective land use codes, with coefficient of variance in parentheses.**

Land Use Code	NO <sub>3</sub> -N (mg/L)	DO (mg/L)	Cl <sup>-</sup> (mg/L)
LIH	3.66 (0.88)	3.84 (0.29)	13.81 (1.08)
HIH	6.82 (0.55)	4.08 (0.23)	11.45 (0.59)
LIA	3.95 (0.68)	3.78 (0.26)	14.56 (1.85)
HIA	7.01 (0.48)	3.66 (0.30)	13.70 (1.62)

Land Use Code	SO <sub>4</sub> <sup>2-</sup> (mg/L)	TDS (g/L)	HCO <sub>3</sub> <sup>-</sup> (mg/L)
LIH	8.52 (0.68)	0.19 (0.42)	83.00 (0.36)
HIH	11.52 (0.39)	0.20 (0.25)	86.53 (0.32)
LIA	11.55 (0.79)	0.20 (0.50)	88.87 (0.33)
HIA	13.70 (0.52)	0.18 (0.28)	74.00 (0.24)

Land Use Code	pH	DO (% SAT)	Conductivity (mS/cm)
LIH	7.76 (0.05)	38.67 (0.28)	0.28 (0.32)
HIH	7.63 (0.03)	40.84 (0.24)	0.30 (0.20)
LIA	7.87 (0.05)	37.67 (0.26)	0.30 (0.50)
HIA	7.64 (0.03)	36.49 (0.29)	0.26 (0.31)

A two sample t-test of unequal variances was conducted to evaluate the differences between mean concentrations of various analytes within respective land use units (Table 3.9). The dependent variable was the land use unit and the independent variable was the analyte. The differences between Low Intensity Housing's NO<sub>3</sub>-N concentrations, when tested against High Intensity Housing ( $P=0.0078$ ) and High Intensity Agriculture ( $P=0.0024$ ), were statistically significant. Differences between High Intensity Housing's NO<sub>3</sub>-N concentrations, when tested against Low Intensity Housing ( $P=0.0078$ ) and Low Intensity Agriculture ( $P=0.0050$ ), were statistically significant. Differences between Low Intensity Agriculture's NO<sub>3</sub>-N concentrations, versus High Intensity Housing ( $P=0.0050$ ) and High Intensity Agriculture ( $P=0.0008$ ), were statistically significant. High Intensity Agriculture's NO<sub>3</sub>-N concentrations, when

tested against Low Intensity Housing ( $P=0.0024$ ) and Low Intensity Agriculture ( $P=0.0008$ ), were also different with statistical significance. Low Intensity Housing's  $\text{SO}_4^{2-}$  concentrations, when tested against High Intensity Agriculture ( $P=0.0155$ ) was also different with statistical significance. Low Intensity Agriculture's pH units, when tested against High Intensity Agriculture ( $P=0.0007$ ) and High Intensity Housing ( $P=0.0050$ ), were also different with statistical significance. Low Intensity Agriculture's  $\text{HCO}_3^-$  concentrations, when tested against High Intensity Agriculture ( $P=0.0001$ ) was also different with statistical significance.

**Table 3. 9: P-Values for the null hypothesis of no correlation between land use and respective chemistry, with statistically significant values in bold.**

<i>Low Intensity Housing</i>	High Intensity Housing	Low Intensity Agriculture	High Intensity Agriculture
NO <sub>3</sub> -N	<b>0.0078</b>	0.7296	<b>0.0024</b>
SO <sub>4</sub> <sup>2-</sup>	0.0838	0.1029	<b>0.0155</b>
Cl <sup>-</sup>	0.5263	0.8814	0.9852
pH	0.1642	0.2995	0.2201
Conductivity	0.5097	0.5952	0.3425
TDS	0.7944	0.8133	0.3708
DO	0.4756	0.8285	0.6083
HCO <sub>3</sub> <sup>-</sup>	0.7027	0.4510	0.2430

<i>High Intensity Housing</i>	Low Intensity Housing	Low Intensity Agriculture	High Intensity Agriculture
NO <sub>3</sub> -N	<b>0.0078</b>	<b>0.0050</b>	0.8700
SO <sub>4</sub> <sup>2-</sup>	0.0838	0.9862	0.2520
Cl <sup>-</sup>	0.5263	0.4402	0.6616
pH	0.1642	<b>0.0007</b>	0.8851
Conductivity	0.5097	0.9807	0.0644
TDS	0.7944	0.9176	0.1550
DO	0.4756	0.2510	0.2061
HCO <sub>3</sub> <sup>-</sup>	0.7027	0.7600	0.1036

<i>Low Intensity Agriculture</i>	Low Intensity Housing	High Intensity Housing	High Intensity Agriculture
NO <sub>3</sub> -N	0.7296	<b>0.0050</b>	<b>0.0008</b>
SO <sub>4</sub> <sup>2-</sup>	0.1029	0.9862	0.2868
Cl <sup>-</sup>	0.8814	0.4402	0.8888
pH	0.2995	<b>0.0007</b>	<b>0.0050</b>
Conductivity	0.5952	0.9807	0.1328
TDS	0.8133	0.9176	0.1668
DO	0.8285	0.2510	0.6714
HCO <sub>3</sub> <sup>-</sup>	0.4510	0.7600	<b>0.0100</b>

<i>High Intensity Agriculture</i>	Low Intensity Housing	High Intensity Housing	Low Intensity Agriculture
NO <sub>3</sub> -N	<b>0.0024</b>	0.8700	<b>0.0008</b>
SO <sub>4</sub> <sup>2-</sup>	<b>0.0155</b>	0.2520	0.2868
Cl <sup>-</sup>	0.9852	0.6616	0.8888
pH	0.2201	0.8851	<b>0.0050</b>
Conductivity	0.3425	0.0644	0.1328
TDS	0.3708	0.1550	0.1668
DO	0.6083	0.2061	0.6714
HCO <sub>3</sub> <sup>-</sup>	0.2430	0.1036	<b>0.0100</b>

### 3.4 Soils

A total of 112 wells were located in seven soil classes (Table 3.10; Figure 3.8). The largest number of wells occurs within the Silty Clay Loam class (n=57). The least number of wells occurs within the Silty Clay class (n=3). The Loam soil type contains the highest mean NO<sub>3</sub>-N concentration (5.90 mg/L) (Table 3.11). The Silty Clay has the lowest mean NO<sub>3</sub>-N concentration (2.94 mg/L).

**Table 3. 10: The number of wells within each soil class, with percentages of the total sample in parentheses.**

Soil Unit	Frequency (%)
Silt Loam	9 (8.0)
Silty Clay Loam	57 (47.8)
Silty Clay	3 (2.5)
Gravelly Sandy Loam	5 (4.2)
Loam	25 (21.0)
Gravelly Silt Loam	9 (7.6)

**Table 3. 11: Chemical results for respective soil types, with the coefficient of variance in parentheses.**

	NO <sub>3</sub> <sup>-</sup> (mg/L)	DO (mg/L)	Cl <sup>-</sup> (mg/L)
Silt Loam	3.14 (0.78)	3.74 (0.28)	36.91 (1.62)
Silty Clay Loam	4.87 (0.70)	3.82 (0.28)	12.89 (1.31)
Silty Clay	2.94 (0.83)	2.52 (0.44)	74.59 (0.97)
Gravelly Sandy Loam	5.35 (0.58)	4.17 (0.16)	6.89 (0.24)
Loam	5.90 (0.66)	4.12 (0.02)	7.73 (0.46)
Gravelly Silty Loam	5.08 (0.75)	3.55 (0.35)	15.39 (0.83)
	SO <sub>4</sub> <sup>2-</sup> (mg/L)	TDS (g/L)	HCO <sub>3</sub> <sup>-</sup> (mg/L)
Silt Loam	19.24 (0.65)	0.30 (0.67)	101.33 (0.38)
Silty Clay Loam	11.68 (0.67)	0.19 (0.26)	87.82 (0.35)
Silty Clay	9.35 (0.76)	0.37 (0.41)	117.33 (0.20)
Gravelly Sandy Loam	8.49 (0.73)	0.16 (0.31)	83.20 (0.20)
Loam	8.93 (0.59)	0.17 (0.35)	77.28 (0.25)
Gravelly Silty Loam	9.85 (0.64)	0.19 (0.47)	81.11 (0.21)
	pH	DO (% SAT)	Conductivity (mS/cm)
Silt Loam	7.94 (0.04)	37.39 (0.29)	0.45 (0.64)
Silty Clay Loam	7.81 (0.05)	38.14 (0.27)	0.28 (0.29)
Silty Clay	8.09 (0.01)	26.70 (0.49)	0.57 (0.33)
Gravelly Sandy Loam	7.64 (0.03)	41.04 (0.15)	0.25 (0.20)
Loam	7.69 (0.04)	41.08 (0.23)	0.26 (0.23)
Gravelly Silty Loam	7.75 (0.06)	35.53 (0.31)	0.26 (0.42)

A two-sample t-test of unequal variances was conducted to evaluate the differences between mean concentrations of various analytes within respective soil types (Table 3.12). The dependent variable was the soil type and the independent variable was NO<sub>3</sub>-N concentration. The only statistically significant difference found in NO<sub>3</sub>-N was between Silt Loam and Loam ( $P=0.0312$ ), both of which presented end members of low and high NO<sub>3</sub><sup>-</sup> concentrations, respectively.

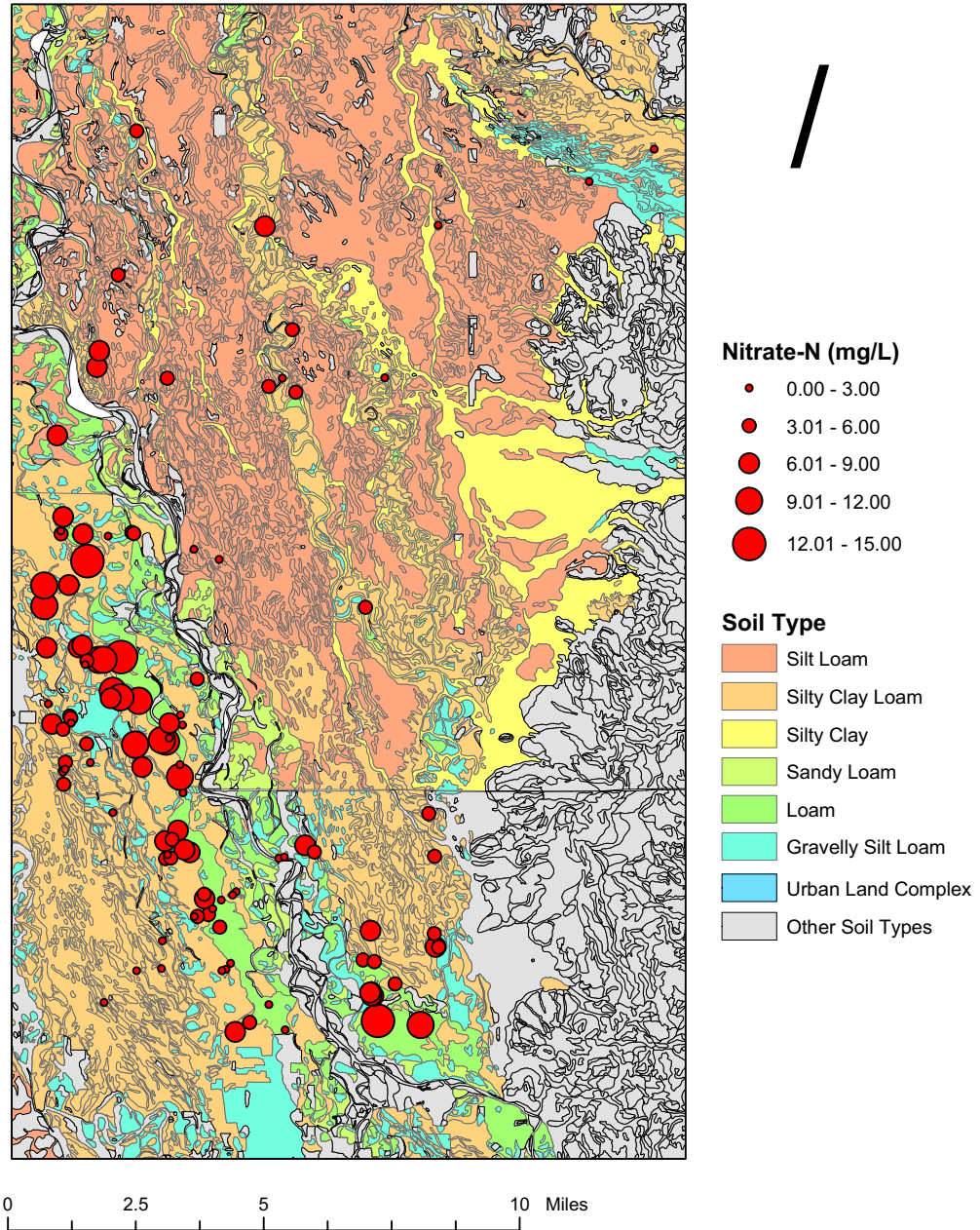


**Table 3. 12: *P*-Values for the null hypothesis of no correlation between NO<sub>3</sub>-N concentrations and soil types, with statistically significant values in bold.**

Soil Type	Silt Clay Loam	Silty Clay	Gravelly Sand Loam
Silt Loam	0.0863	0.9106	0.2150
Silt Clay Loam	XXXX	0.3198	0.7593
Silty Clay	0.3198	XXXX	0.2783
Gravelly Sand Loam	0.7593	0.2783	XXXX
Loam	0.2572	0.1616	0.7391
Gravelly Silt Loam	0.8816	0.3018	0.8895

Soil Type	Gravelly Silt Loam	Loam
Silt Loam	0.2205	<b>0.0223</b>
Silt Clay Loam	0.8816	0.2572
Silty Clay	0.3018	0.1616
Gravelly Sand Loam	0.8895	0.7391
Loam	0.5890	XXXX
Gravelly Silt Loam	XXXX	0.5890



**Figure 3. 8: Map of soil types and NO<sub>3</sub>-N concentrations of all wells in the southern Willamette Valley study area.**

### 3.5 Signature samples

Twenty well samples were selected to receive additional chemical analyses. These well samples are referred to as the signature well samples. In addition to the signature well samples, ten agricultural effluent samples and ten septic drain field samples were collected to provide chemical characteristics of their respective environments.

#### 3.5.1 Signature well samples

NO<sub>3</sub>-N concentrations for the signature samples had a mean value of 8.98 mg/L and a standard deviation of 2.82 mg/L (Table 3.13). Of the total of 20 wells that were sub sampled, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, pH, conductivity, DO, S<sup>2-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and Na<sup>+</sup> had detectable concentrations. Concentrations of PO<sub>4</sub><sup>3-</sup>, K<sup>+</sup>, Mn<sup>2+</sup>, Fe<sup>2+</sup>, Cu<sup>2+</sup>, B<sup>3+</sup>, Zn<sup>2+</sup>, Al<sup>3+</sup>, As<sup>5+</sup>, Ba<sup>2+</sup>, Cd<sup>2+</sup>, Co<sup>2+</sup>, Mo<sup>3+</sup>, Ni<sup>2+</sup>, Pb<sup>2+</sup>, Se<sup>2-</sup> and Cr<sup>3+</sup> were below the level of detection.

**Table 3. 13: Summary of results for signature wells, with the coefficient of variance in parentheses, detection limits shown if concentration was below detectability.**

Analyte	Concentration	Analyte	Concentration
NO <sub>3</sub> -N (mg/L)	8.98 (0.31)	Mn <sup>2+</sup> (mg/L)	<0.04
Cl <sup>-</sup> (mg/L)	10.47 (0.71)	Fe <sup>2+</sup> (mg/L)	<0.1
SO <sub>4</sub> <sup>2-</sup> (mg/L)	15.30 (0.44)	Cu <sup>2+</sup> (mg/L)	<0.1
HCO <sub>3</sub> <sup>-</sup> (mg/L)	77.90 (0.35)	B <sup>3+</sup> (mg/L)	<1
pH	7.59 (0.02)	Zn <sup>2+</sup> (mg/L)	<0.1
Conductivity (mS/cm)	0.28 (0.29)	Al <sup>3+</sup> (mg/L)	<1
DO (mg/L)	3.71 (0.26)	As <sup>5+</sup> (mg/L)	<0.1
TDS (g/L)	0.19 (0.32)	Ba <sup>2+</sup> (mg/L)	<0.05
DO (% SAT)	36.77 (0.26)	Cd <sup>2+</sup> (mg/L)	<0.01
S <sup>2-</sup> (mg/L)	6.00 (0.47)	Co <sup>2+</sup> (mg/L)	<0.03
Ca <sup>2+</sup> (mg/L)	25.75 (0.19)	Mo <sup>3+</sup> (mg/L)	<1
Mg <sup>2+</sup> (mg/L)	12.85 (0.34)	Ni <sup>2+</sup> (mg/L)	<0.06
Na <sup>+</sup> (mg/L)	7.70 (0.56)	Pb <sup>2+</sup> (mg/L)	<0.04
PO <sub>4</sub> <sup>3-</sup> (mg/L)	<1	Se <sup>2-</sup> (mg/L)	<1
K <sup>+</sup> (mg/L)	<1	Cr <sup>3+</sup> (mg/L)	<0.02

There was a statistically significant trend observed between concentration of NO<sub>3</sub>-N with the concentrations of pH ( $P=0.0055$ ) and Ca<sup>2+</sup> ( $P=0.0269$ ) (Table 3.14). There was no statistical significance between NO<sub>3</sub>-N concentrations and SO<sub>4</sub><sup>2-</sup>, Well Age, S<sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, well depth, Na<sup>+</sup>, conductivity, TDS and DO.

**Table 3. 14: : P-Values for the null hypothesis of no correlation between NO<sub>3</sub>-N concentrations and analytes in signature wells, with significant values in bold.**

Source of Variation	NO <sub>3</sub> -N Concentration
	<i>P</i> -value
<b>pH</b>	<b>0.0055</b>
<b>Ca<sup>2+</sup></b>	<b>0.0269</b>
SO <sub>4</sub> <sup>2-</sup>	0.0512
Well Age	0.0534
S <sup>2-</sup>	0.0641
HCO <sub>3</sub> <sup>-</sup>	0.0715
Mg <sup>2+</sup>	0.1382
Cl <sup>-</sup>	0.2869
Well Depth	0.4381
Na <sup>+</sup>	0.5477
Conductivity	0.6328
DO	0.7836
TDS	0.9696

The signature wells were represented by all four geologic units and all four land use units (Table 3.15). Twelve of the wells were in the Younger Terrace Gravels, five wells were in the Recent Alluvium, two wells were in the Older Terrace Gravels and one well was in the Willamette Silt layer. Nine wells were in the High Intensity Housing land use unit, eight wells were in the High Intensity Agriculture unit, two wells were in the Low Intensity Housing unit, and one well was in the Low Intensity Agriculture unit.

**Table 3. 15: Signature well descriptions.**

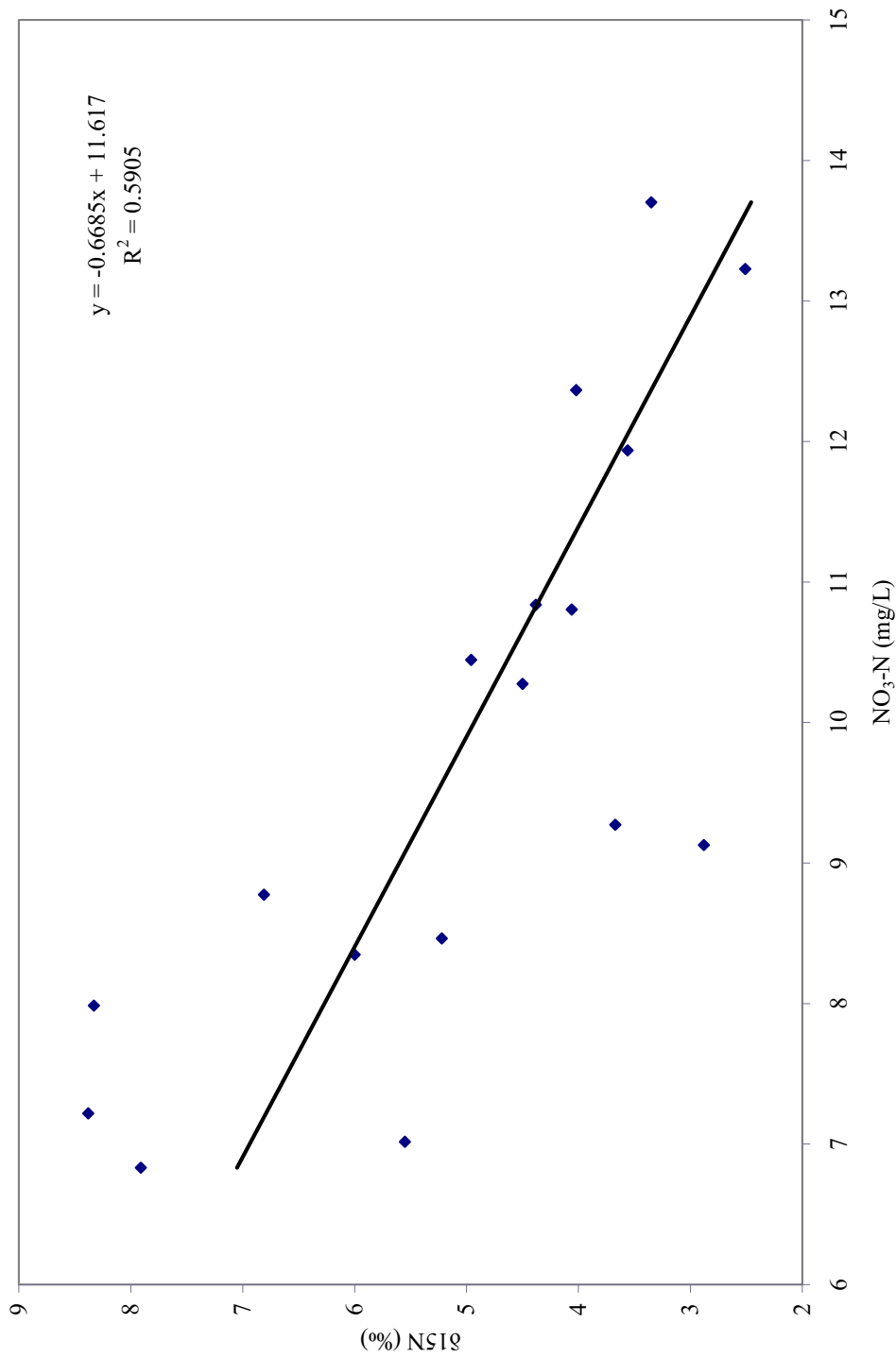
Sample	Geologic Unit	Land Use	NO <sub>3</sub> -N (mg/L)
W-1	Younger Terrace Gravels	High Intensity Agriculture	11.94
W-2	Younger Terrace Gravels	High Intensity Housing	12.37
W-4	Younger Terrace Gravels	High Intensity Agriculture	13.70
W-9	Younger Terrace Gravels	High Intensity Agriculture	10.27
W-12	Younger Terrace Gravels	High Intensity Housing	10.80
W-13	Younger Terrace Gravels	Low Intensity Housing	3.52
W-18	Younger Terrace Gravels	Low Intensity Agriculture	10.84
W-21	Recent Alluvium	High Intensity Agriculture	7.02
W-32	Younger Terrace Gravels	High Intensity Agriculture	10.45
W-37	Older Terrace Gravels	High Intensity Housing	4.20
W-44	Older Terrace Gravels	High Intensity Housing	5.26
W-49	Younger Terrace Gravels	High Intensity Agriculture	7.22
W-50	Younger Terrace Gravels	High Intensity Housing	8.46
W-64	Recent Alluvium	High Intensity Housing	8.35
W-65	Recent Alluvium	High Intensity Housing	8.78
W-70	Willamette Silt	High Intensity Agriculture	7.99
W-77	Younger Terrace Gravels	Low Intensity Agriculture	9.13
W-95	Younger Terrace Gravels	High Intensity Agriculture	9.27
W-106	Recent Alluvium	High Intensity Housing	6.83
W-113	Recent Alluvium	High Intensity Housing	13.23

The N and O isotopic composition was measured (Table 3.16). The  $\delta^{15}\text{N}$  (‰) values for the signature wells ranged from 2.51 to 8.33 ‰, with an average value of 5.06 ‰ a standard deviation of 1.86 ‰ (Table 3.16). NO<sub>3</sub>-N concentrations were too low to analyze for  $\delta^{15}\text{N}$  in three wells (W-13, W-37 and W-44). The  $\delta^{18}\text{O}$  (‰) values for the signature wells ranged from 3.07 to 9.05 ‰, with an average value of 5.68 ‰ a standard deviation of 1.95 ‰ (Table 3.16). NO<sub>3</sub>-N concentrations were too low to analyze for  $\delta^{18}\text{O}$  in seven wells (W-12, W-13, W-18, W-21, W-32, W-37 and W-44).

**Table 3. 16:  $\delta^{15}\text{N}$  (‰) results for signature wells.**

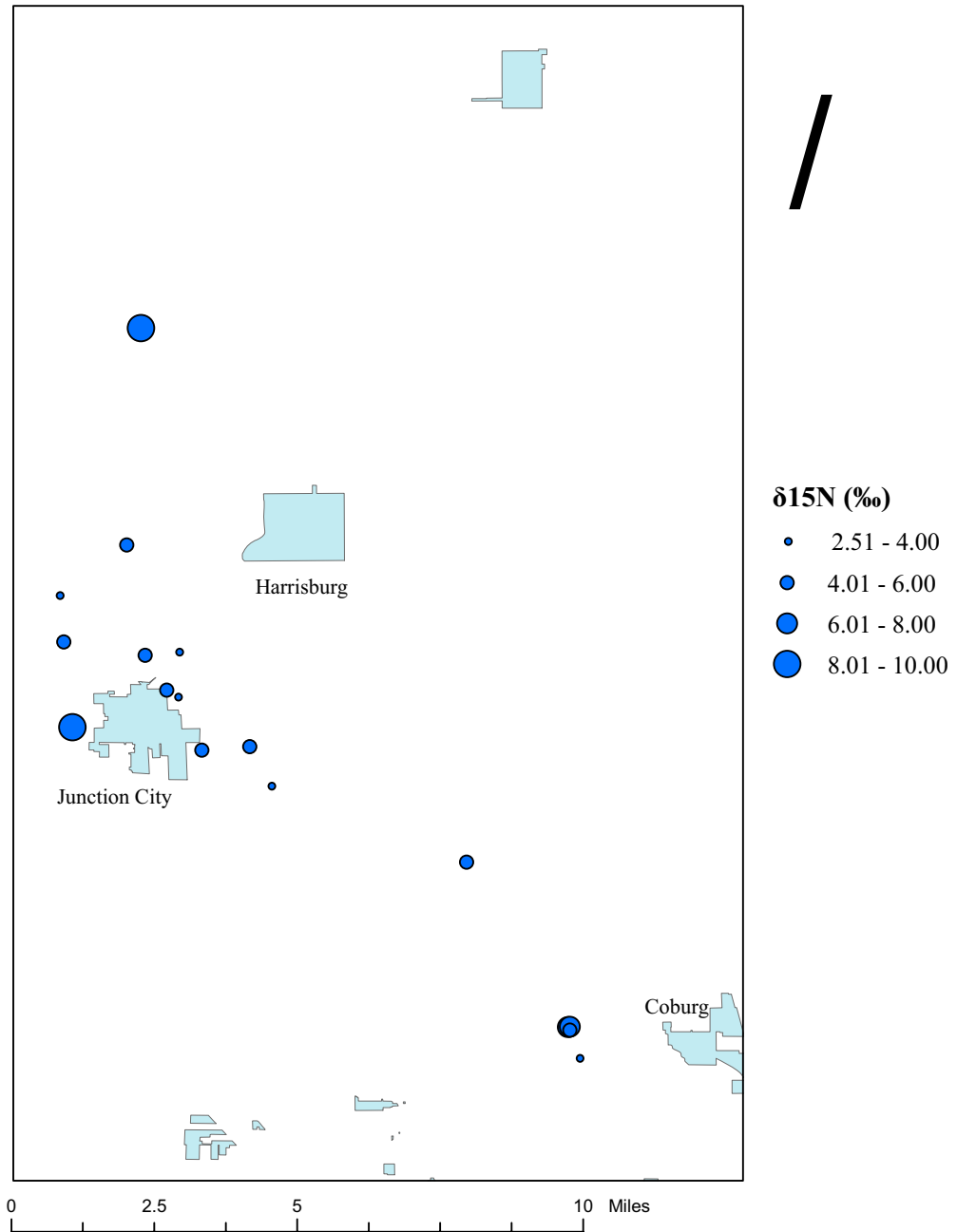
Sample	$\text{NO}_3\text{-N}$ (mg/L)	$\delta^{15}\text{N}$ (‰)	$\delta^{18}\text{O}$ (‰)	$\delta^{15}\text{N}:\delta^{18}\text{O}$	$\delta^{18}\text{O}:\delta^{15}\text{N}$
W-1	11.94	3.56	6.36	0.56	1.79
W-2	12.37	4.02	4.78	0.84	1.19
W-4	13.70	3.35	3.82	0.88	1.14
W-9	10.27	4.50	8.81	0.51	1.96
W-12	10.80	4.06	N/A	N/A	N/A
W-13	3.52	N/A	N/A	N/A	N/A
W-18	10.84	4.38	N/A	N/A	N/A
W-21	7.02	5.55	N/A	N/A	N/A
W-32	10.45	4.96	N/A	N/A	N/A
W-37	4.20	N/A	N/A	N/A	N/A
W-44	5.26	N/A	N/A	N/A	N/A
W-49	7.22	8.38	7.64	1.10	0.91
W-50	8.46	5.22	6.17	0.85	1.18
W-64	8.35	6.00	4.88	1.23	0.81
W-65	8.78	6.81	4.58	1.49	0.67
W-70	7.99	8.33	9.05	0.92	1.09
W-77	9.13	2.88	3.07	0.94	1.07
W-95	9.27	3.67	5.38	0.68	1.47
W-106	6.83	7.91	6.16	1.28	0.78
W-113	13.23	2.51	3.12	0.80	1.24
Ave (CV)	8.98 (0.31)	5.06 (0.37)	5.68 (0.34)	0.93 (0.30)	1.18 (0.32)

The  $\delta^{15}\text{N}$  (‰) values for the signature wells were plotted against their respective  $\text{NO}_3\text{-N}$  concentrations (Figure 3.9). A negative correlation was found between the  $\delta^{15}\text{N}$  (‰) values and the  $\text{NO}_3\text{-N}$  concentrations, and was able to explain 59.1% of the variability. The data in Figure 3.10 shows a site view of  $\delta^{15}\text{N}$  variability. The highest  $\delta^{15}\text{N}$  values occur in the western, northern southern areas of the study area, while the lowest  $\delta^{15}\text{N}$  values occur in the central areas.



**Figure 3. 9: δ<sup>15</sup>N (‰) and NO<sub>3</sub>-N concentrations for the signature wells**





**Figure 3. 10:  $\delta^{15}\text{N}$  (‰) values of signature wells in the southern Willamette Valley study area.**

The  $\delta^{18}\text{O}$  (‰) values for the signature wells were plotted against their respective  $\text{NO}_3\text{-N}$  concentrations (Figure 3.11). A negative correlation was found between the  $\delta^{18}\text{O}$  (‰) values and the  $\text{NO}_3\text{-N}$  concentrations, which explained 20.9% of the variability. The data in Figure 3.12 shows a site view of  $\delta^{18}\text{O}$  variability. The highest  $\delta^{18}\text{O}$  values occur in the western, northwest areas of the study area, while the lowest  $\delta^{18}\text{O}$  values occur in the central area.

The values of  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  for their respective land use units (agriculture versus housing) have values of (2.88-8.38 ‰  $\delta^{15}\text{N}$ ) and (3.07-9.05 ‰  $\delta^{18}\text{O}$ ) for areas mostly influenced by agricultural production and values of (2.51-7.91 ‰  $\delta^{15}\text{N}$ ) and (3.12-6.17 ‰  $\delta^{18}\text{O}$ ) for areas dominated by housing (Table 3.17). These values were also plotted on a schematic adapted from Kendall, 1999 (Figure 3.12). The values of  $\delta^{15}\text{N}$  were also compared against the  $\delta^{15}\text{N}$  ranges collected into Table 1.2 (Table 3.18).

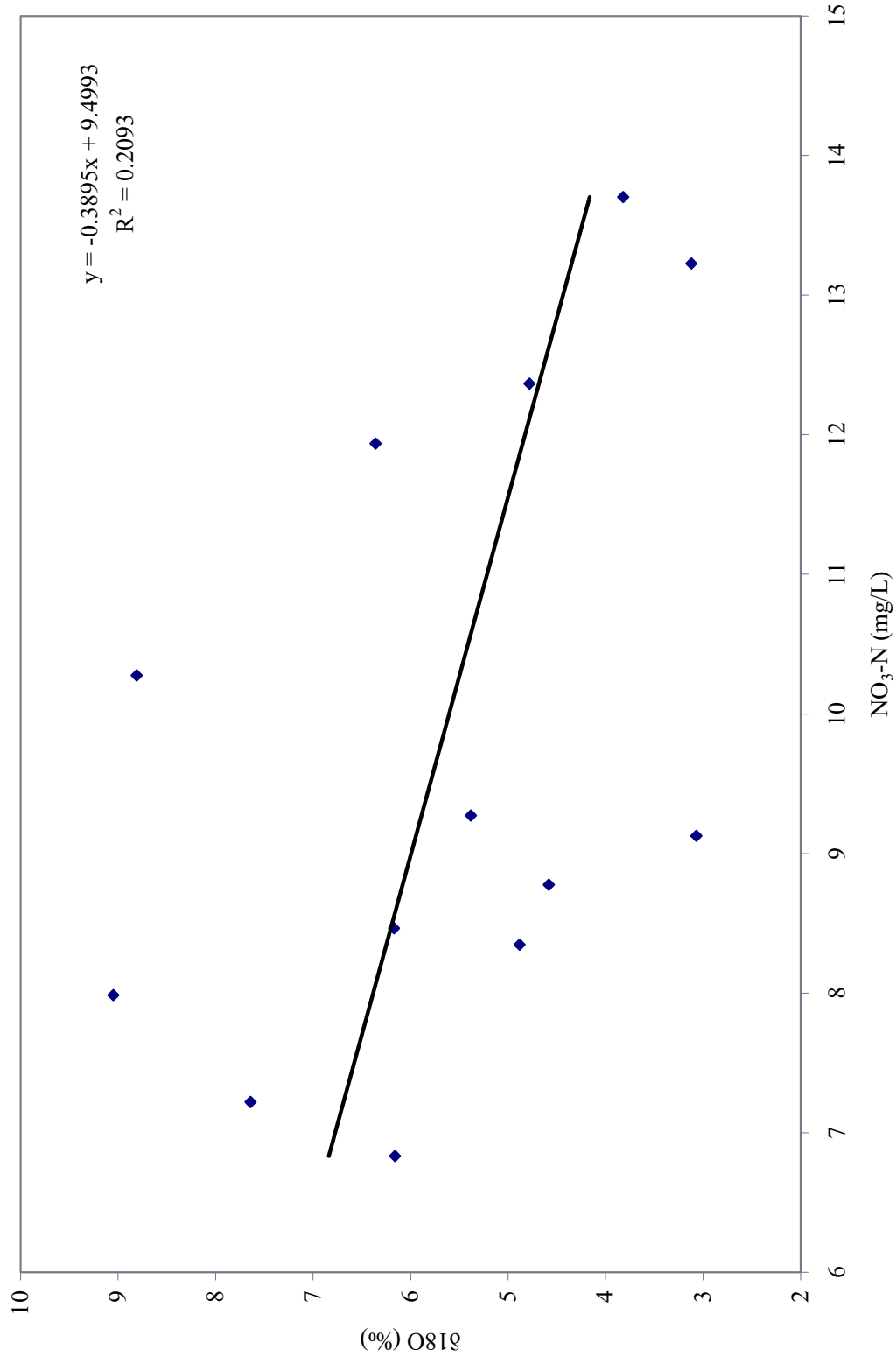


Figure 3. 11: δ<sup>18</sup>O (‰) and NO<sub>3</sub>-N concentrations for the signature wells.



**Figure 3. 12: Map of  $\delta^{18}\text{O}$  (‰) values of signature wells in the southern Willamette Valley study area.**

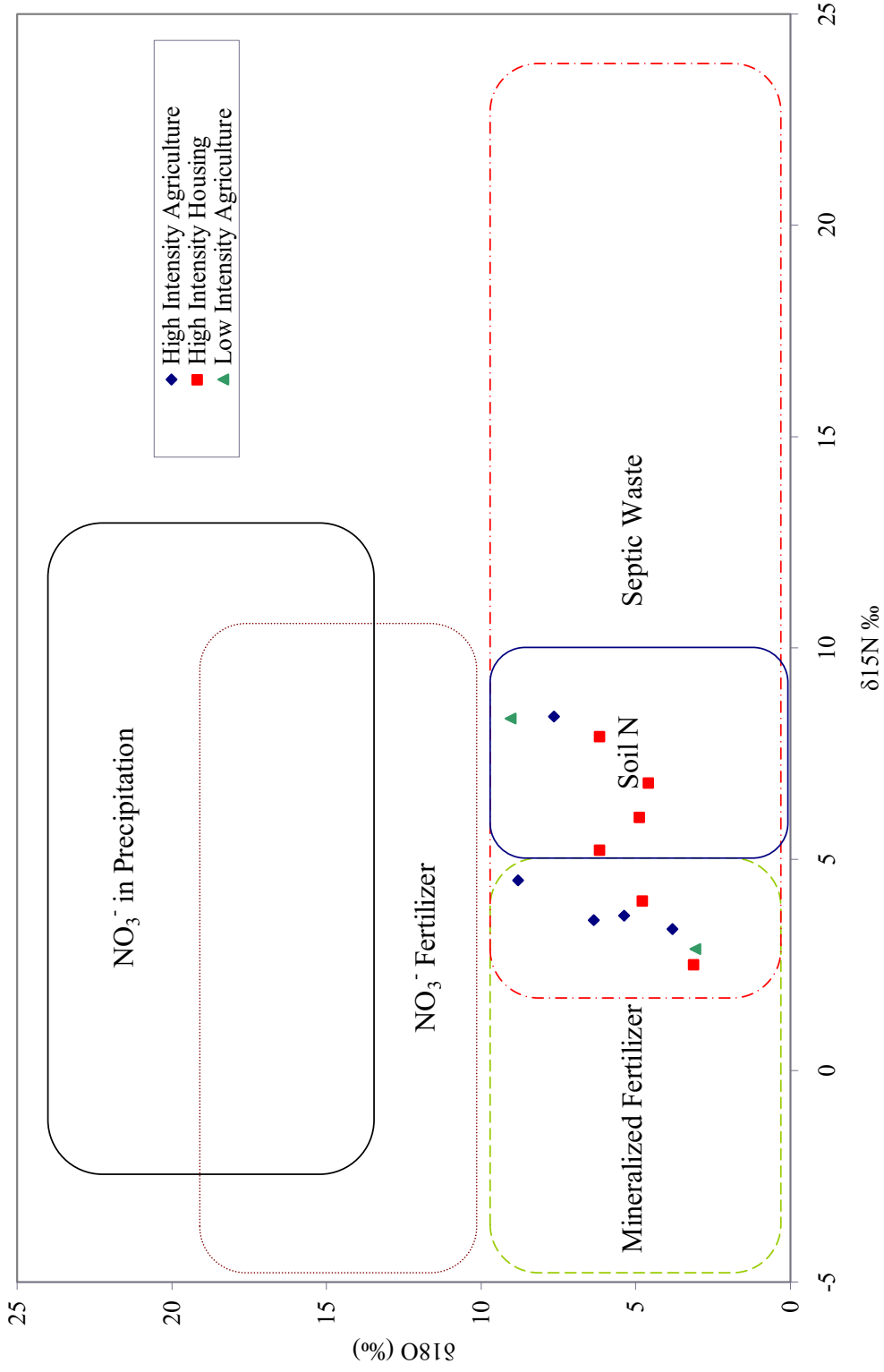


Figure 3. 13: Range of  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values of  $\text{NO}_3^-$  for the signature wells, with schematic adapted from Kendall, 1998.

**Table 3. 17: Land use and respective values of  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$ .**

Sample	Land Use	$\delta^{15}\text{N}$ (‰)	$\delta^{18}\text{O}$ (‰)
W-1	High Intensity Agriculture	3.56	6.36
W-4	High Intensity Agriculture	3.35	3.82
W-9	High Intensity Agriculture	4.50	8.81
W-21	High Intensity Agriculture	5.55	N/A
W32	High Intensity Agriculture	4.96	N/A
W-49	High Intensity Agriculture	8.38	7.64
W-70	High Intensity Agriculture	8.33	9.05
W-95	High Intensity Agriculture	3.67	5.38
W-18	Low Intensity Agriculture	4.38	N/A
W-77	Low Intensity Agriculture	2.88	3.07
Ave (CV)		4.96 (0.40)	6.30 (0.37)
W-2	High Intensity Housing	4.02	4.78
W-12	High Intensity Housing	4.06	N/A
W-37	High Intensity Housing	N/A	N/A
W-44	High Intensity Housing	N/A	N/A
W-50	High Intensity Housing	5.22	6.17
W-64	High Intensity Housing	6.00	4.88
W-65	High Intensity Housing	6.81	4.58
W-106	High Intensity Housing	7.91	6.16
W-113	High Intensity Housing	2.51	3.12
W-13	Low Intensity Housing	N/A	N/A
Ave (CV)		5.22 (0.35)	4.95 (0.23)

**Table 3. 18: Signature wells and Using Table 1.2, N isotope fractionation source data, to determine sources of signature well's NO<sub>3</sub><sup>-</sup>.**

Sample	Nitrate (mg/L)	δ <sup>15</sup> N (‰)	δ <sup>15</sup> N (‰) from Table 1.2	Land Use	
W-1	11.94	3.56	Soil Organic	HIA	N/A
W-2	12.37	4.02	Soil Organic	HIH	N/A
W-4	13.70	3.35	Fertilizer	HIA	Correct Range
W-9	10.27	4.5	Soil Organic	HIA	N/A
W-12	10.80	4.06	Soil Organic	HIH	N/A
W-13	3.52	N/A	N/A	LIH	N/A
W-18	10.84	4.38	Soil Organic	LIA	N/A
W-21	7.02	5.55	Septic	HIA	Wrong Range*
W-32	10.45	4.96	Soil Organic	HIA	N/A
W-37	4.20	N/A	N/A	HIH	N/A
W-44	5.26	N/A	N/A	HIH	N/A
W-49	7.22	8.38	Septic	HIA	Wrong Range*
W-50	8.46	5.22	Soil Organic	HIH	N/A
W-64	8.35	6	Septic	HIH	Correct Range
W-65	8.78	6.81	Septic	HIH	Correct Range
W-70	7.99	8.33	Septic	LIA	Wrong Range
W-77	9.13	2.88	Fertilizer	LIA	Correct Range
W-95	9.27	3.67	Soil Organic	HIA	N/A
W-106	6.83	7.91	Septic	HIH	Correct Range
W-113	13.23	2.51	Fertilizer	HIH	Wrong Range*

### 3.5.2 Agricultural Samples

NO<sub>3</sub>-N concentrations for the agricultural samples had a mean value of 26.44 mg/L and a standard deviation of 25.40 mg/L (Table 3.19). Of the 10 agricultural samples, NO<sub>3</sub>-N, Cl<sup>-</sup>, SO<sub>4</sub><sup>-</sup>, S<sup>2-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> had detectable concentrations. Concentrations of P<sup>5+</sup>, Mn<sup>2+</sup>, Fe<sup>2+</sup>, Cu<sup>2+</sup>, B<sup>3+</sup>, Zn<sup>2+</sup>, Al<sup>3+</sup>, As<sup>5+</sup>, Ba<sup>2+</sup>, Cd<sup>2+</sup>, Co<sup>2+</sup>, Mo<sup>3+</sup>, Ni<sup>2+</sup>, Pb<sup>2+</sup>, Se<sup>2-</sup> and Cr<sup>3+</sup> were below the level of detection.

**Table 3. 19: Summary of results for agricultural samples with the coefficient of variance in parentheses, detection limit reported if the result was below detectability.**

Analyte	Average (CV)	Analyte	Average
NO <sub>3</sub> -N (mg/L)	26.44 (0.96)	Mn <sup>2+</sup> (mg/L)	<0.04
Cl <sup>-</sup> (mg/L)	11.02 (1.27)	Fe <sup>2+</sup> (mg/L)	<0.1
SO <sub>4</sub> <sup>2-</sup> (mg/L)	63.11 (2.07)	Cu <sup>2+</sup> (mg/L)	<0.1
S <sup>2-</sup> (mg/L)	15.5 (1.18)	B <sup>3+</sup> (mg/L)	<1
Ca <sup>2+</sup> (mg/L)	28.4 (0.32)	Zn <sup>2+</sup> (mg/L)	<0.1
Mg <sup>2+</sup> (mg/L)	13.6 (0.42)	Al <sup>3+</sup> (mg/L)	<1
Na <sup>+</sup> (mg/L)	93 (0.29)	As <sup>5+</sup> (mg/L)	<0.1
K <sup>+</sup> (mg/L)	1.4 (0.39)	Ba <sup>2+</sup> (mg/L)	<0.05
Co <sup>2+</sup> (mg/L)	<0.03	Cd <sup>2+</sup> (mg/L)	<0.01
Mo <sup>3+</sup> (mg/L)	<1	Pb <sup>2+</sup> (mg/L)	<0.04
Ni <sup>2+</sup> (mg/L)	<0.06	Se <sup>2-</sup> (mg/L)	<1
PO <sub>4</sub> <sup>3-</sup> (mg/L)	<1	Cr <sup>3+</sup> (mg/L)	<0.02

There was a statistically significant trend in NO<sub>3</sub>-N with Cl<sup>-</sup>. (Table 3.20). There was no statistical significance between NO<sub>3</sub>-N concentrations and K<sup>+</sup>, SO<sub>4</sub><sup>2-</sup>, S<sup>2-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Na<sup>+</sup>.

**Table 3. 20: Summary of analyses of variance showing the sources of variation on NO<sub>3</sub>-N concentration in the agricultural samples, with significant values in bold.**

Source of Variation	Nitrate Concentration
	<i>P</i> -value
<b>Cl<sup>-</sup></b>	<b>0.0085</b>
K <sup>+</sup>	0.0953
SO <sub>4</sub> <sup>2-</sup>	0.3127
Mg <sup>2+</sup>	0.3622
Ca <sup>2+</sup>	0.5361
S <sup>2-</sup>	0.6483
Na <sup>+</sup>	0.8276

The results for δ<sup>15</sup>N (‰) in the agricultural samples varied from 1.95 to 9.40, with an average value of 5.64 ‰ and a standard deviation of 2.61 ‰ (Table 3.21). The results



for  $\delta^{18}\text{O}$  (‰) varied from 2.15 to 7.60, with an average value of 5.25 ‰ and a standard deviation of 1.78 ‰ (Table 3.21). All of the analyzed samples were plotted against their respective  $\text{NO}_3\text{-N}$  concentrations (Figure 3.14). Four of the results (F-3, F-4, F-6 and F-7) had  $\text{NO}_3\text{-N}$  concentrations that were too low to analyze for both  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$ . These results were plotted on a schematic adapted from Kendall, 1999 (Figure 3.18).

**Table 3. 21:  $\delta^{15}\text{N}$  (‰) and  $\delta^{18}\text{O}$  (‰) results for agricultural samples.**

Sample	$\text{NO}_3\text{-N}$ (mg/L)	$\delta^{15}\text{N}$ (‰)	$\delta^{18}\text{O}$ (‰)	$\delta^{15}\text{N}:\delta^{18}\text{O}$	$\delta^{18}\text{O}:\delta^{15}\text{N}$
F-1	15.04	5.69	5.64	1.01	0.99
F-2	19.25	4.25	5.74	0.74	1.35
F-3	1.05	N/A	N/A	N/A	N/A
F-4	9.22	N/A	N/A	N/A	N/A
F-5	57.83	7.62	4.86	1.57	0.64
F-6	3.65	N/A	N/A	N/A	N/A
F-7	6.07	N/A	N/A	N/A	N/A
F-8	37.39	1.95	5.53	0.35	2.84
F-9	76.44	9.4	2.15	4.37	0.23
F-10	38.5	4.9	7.6	0.64	1.55
Ave. (CV)	26.44 (0.96)	5.64 (0.46)	5.25 (0.34)	1.45 (1.03)	1.28 (0.71)

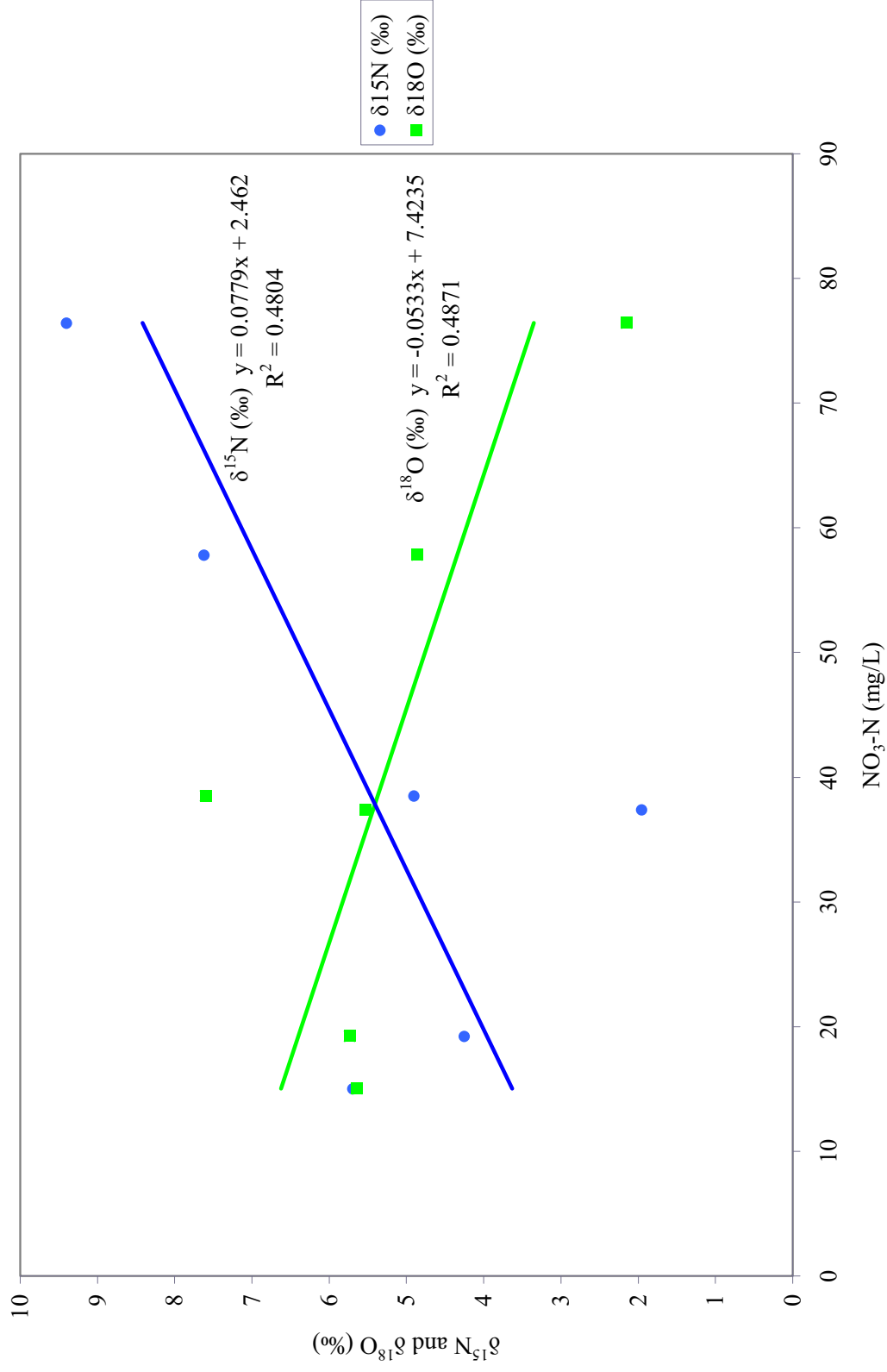


Figure 3. 14:  $\delta^{18}\text{O}$ ,  $\delta^{15}\text{N}$  and  $\text{NO}_3\text{-N}$  concentrations for the agricultural samples.

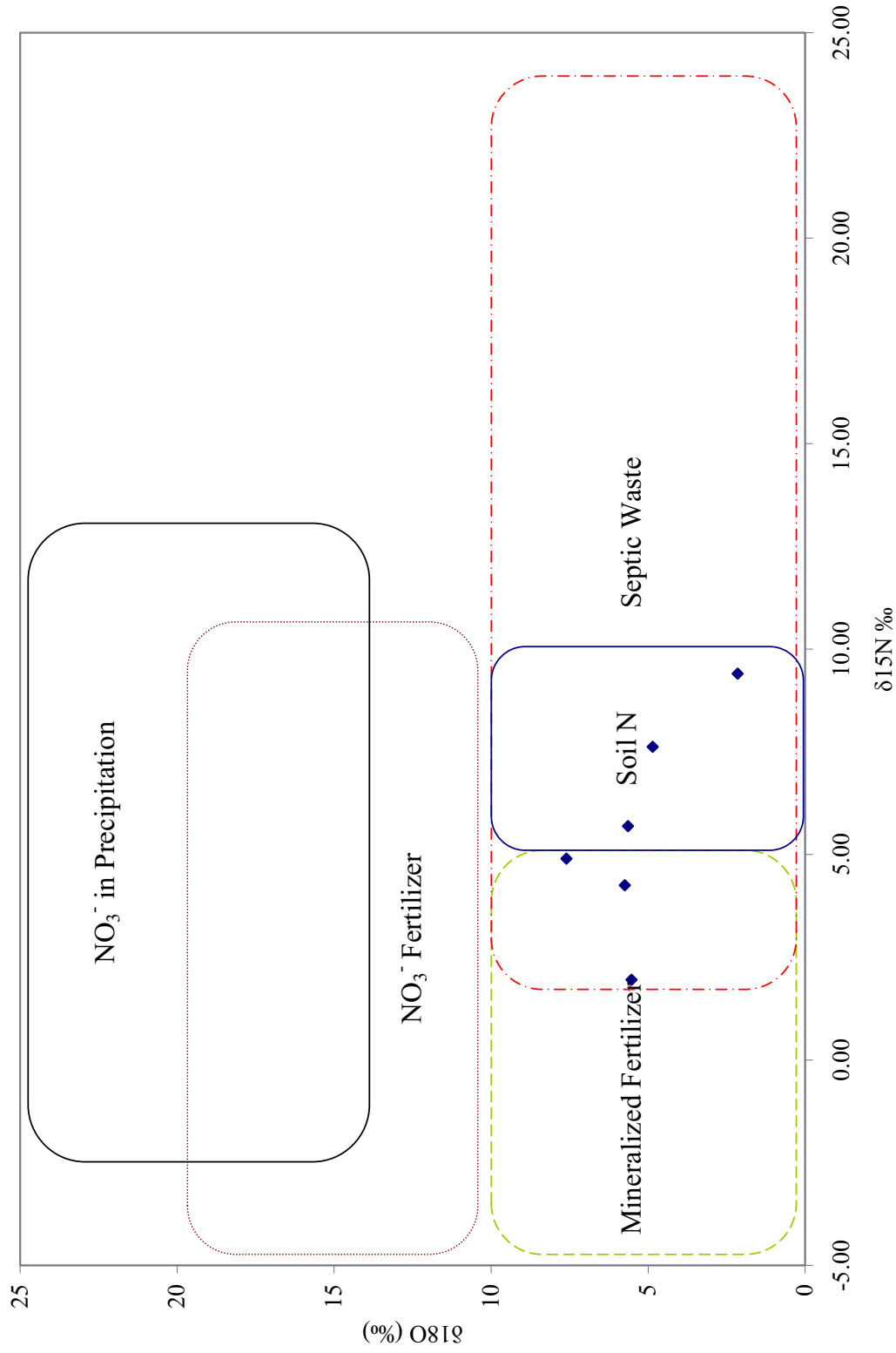


Figure 3. 15: Range of  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values of  $\text{NO}_3^-$  for the agricultural samples, with schematic from Kendall, 1998.

### 3.5.3 Septic Samples

NO<sub>3</sub>-N concentrations for the septic samples had a mean value of 5.57 mg/L and a standard deviation of 4.92 mg/L (Table 3.22). Ca<sup>2+</sup> had an average concentration of 218.20 mg/L (52.67), Cl<sup>-</sup> had an average concentration of 15.52 mg/L (4.21), SO<sub>4</sub><sup>2-</sup> had an average concentration of 18.07 mg/L (17.42), Mg<sup>2+</sup> had an average concentration of 67.44 mg/L (24.03), Na<sup>+</sup> had an average concentration of 11.18 mg/L (5.48) and K<sup>+</sup> has an average concentration of 248 mg/L (93.30).

**Table 3. 22: Summary of results for septic samples with the coefficient of variance in parentheses.**

Analyte	Average (CV)
NO <sub>3</sub> -N (mg/L)	5.57 (0.88)
Cl <sup>-</sup> (mg/L)	15.52 (0.27)
SO <sub>4</sub> <sup>2-</sup> (mg/L)	18.07 (0.96)
Ca <sup>2+</sup> (mg/L)	218.20 (0.24)
Mg <sup>2+</sup> (mg/L)	67.44 (0.36)
Na <sup>+</sup> (mg/L)	11.18 (0.49)
K <sup>+</sup> (mg/L)	248 (0.38)

There was a statistically significant trend in NO<sub>3</sub>-N with K<sup>+</sup> (Table 3.23). There was no statistical significance between NO<sub>3</sub>-N concentrations and SO<sub>4</sub><sup>2-</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, S and Na<sup>+</sup>.

**Table 3. 23: Summary of analyses of variance showing the sources of variation on NO<sub>3</sub>-N concentration in the septic samples, with significant vales in bold.**

Source of Variation	NO <sub>3</sub> -N Concentration
	<i>P</i> -value
<b>K<sup>+</sup></b>	<b>0.0306</b>
Cl <sup>-</sup>	0.1614
Na <sup>+</sup>	0.7548
Ca <sup>2+</sup>	0.7831
Mg <sup>2+</sup>	0.7869
SO <sub>4</sub> <sup>2-</sup>	0.9461

$\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  were not analyzed for the septic samples because the extraction solution used on the soil samples contained too high of a concentration of salts for the analytical procedure.

## Chapter IV

### Discussion

Many factors influence regional and local variability in aquifer  $\text{NO}_3^-$  concentrations, including land use, geologic units, soil types, and individual well characteristics. This study used multiple investigative tools in an attempt to determine the cause of long-standing high  $\text{NO}_3^-$  concentrations in the upper aquifer of the southern Willamette Valley, Oregon.

#### 4.1 Extent of $\text{NO}_3^-$ contamination in the southern Willamette Valley

Long-term temporal stability in  $\text{NO}_3^-$  concentration is appears to have held within the southern Willamette Valley. Over the last 65 years,  $\text{NO}_3\text{-N}$  concentration of the shallow groundwater in the Willamette Valley appears to have remained remarkably constant. The first study, performed by the USGS in 1938, indicated an average  $\text{NO}_3\text{-N}$  concentration of 4.3 mg/L (USGS, 1938). Thirty years later, in 1968, the Oregon State Engineer sampled twelve wells in the same area, obtaining an average  $\text{NO}_3\text{-N}$  concentration of 4.4 mg/L (OSE, 1970). In 1978, the consulting firm of Sweet, Edwards and Associates sampled thirty-one wells in the southern Willamette Valley, finding an average  $\text{NO}_3\text{-N}$  concentration of 4.1 mg/L (Smith et al., 1978). In this study of 120 wells <75 ft. in depth, concentrations of  $\text{NO}_3\text{-N}$  had a mean of 4.81 mg/L and ranged from <0.2 mg/L to 13.70 mg/L.  $\text{NO}_3\text{-N}$  concentrations exceeded the USEPA MCL of 10 mg/L in 8.3% of these wells. This result is comparable to the results of a 2000-2001 sampling of the same region by the Oregon Department of Environmental Quality (OR DEQ), which found 9% of the wells less than 75 ft. in depth exceeded the USEPA MCL (Eldridge,

2002). Another study within the same area, conducted in 1993, found 9% of the wells less than 75 ft. in depth exceeded the USEPA MCL (Hinkle, 1997). A study by Penhallagon in 1994 within the same area, found 8.2% of the wells to exceed the USEPA MCL for  $\text{NO}_3^-$  concentration. These results are also comparable to a study in the mid-1990s that sampled rural wells throughout the entire country, which found 11% of the wells exceeded the USEPA MCL of 10 mg/L  $\text{NO}_3\text{-N}$  (Squillace, 2002). The Willamette Valley's high  $\text{NO}_3\text{-N}$  concentrations in the shallow groundwater appears constant over the past seventy years and, when compared to other aquifers across the nation, has a similar number of wells that exceed the USEPA MCL. It is important to note that these data are not spatially random since wells from the early 20<sup>th</sup> century were often shallow and possibly placed near pit toilets, therefore care must be taken with these data.

Many factors influence the variability of  $\text{NO}_3^-$  in wells including seasonality and market based transitions of crops. Seasonality will affect the  $\text{NO}_3^-$  concentration due to mobilization and dilution during the rainy winter months, application of N based fertilizers in the fall and spring months, and drawdown of the aquifer from irrigation during the summer months. Over the past decade, the Willamette Valley has witnessed a transition from the majority of acres devoted to mint, row crop and vegetable agriculture to a much greater emphasis on grass seed production. Due to the high application of fertilizers and subsequent intense irrigation, mint, row crops and vegetable crops leach substantially more  $\text{NO}_3^-$  than grass seed crops (Feaga and Selker, 2003). With the transition to grass seed, a  $\text{NO}_3^-$  scavenging crop, a tendency for decreasing  $\text{NO}_3^-$  concentrations in the shallow aquifer is a plausible future trend.

## 4.2 The role of Land Use

Regional and local variations in  $\text{NO}_3^-$  concentrations were explained in part by land use. In section 3.3, we assessed the relationship between land use and  $\text{NO}_3^-$  concentrations. In our investigation, two types of land use were strongly correlated with elevated  $\text{NO}_3^-$  concentrations in the southern Willamette Valley, Oregon: High-Intensity Housing and High-Intensity Agriculture. The highest  $\text{NO}_3^-$  concentrations were found in areas with High Intensity Agriculture (7.01 mg/L) and High Intensity Housing (6.82 mg/L). In contrast, the lowest  $\text{NO}_3^-$  concentrations were found in areas with Low Intensity Agriculture (3.95 mg/L) and Low Intensity Housing (3.65 mg/L). This result is as we would expect since  $\text{NO}_3^-$  would only be expected to be in excess resulting from anthropogenic activities.

Areas of High-Intensity Housing without centralized waste water treatment plants (such as found in the Willamette Valley study area) will have a higher frequency of septic systems per area than an area with Low-Intensity Housing. It has been broadly observed that the higher the density of septic tanks, the higher the  $\text{NO}_3^-$  loading to the groundwater (Woodward et al., 1961; Miller, 1972; Holzer, 1975; Geraghty and Miller, 1978; Konikow and Bredhoeft, 1978; Peavy and Brawner, 1979; Ford et al., 1980; Starr and Sawhney, 1980; Bauman and Schafer, 1985). With a threshold of 1 septic system acre<sup>-1</sup> being typical for observed  $\text{NO}_3^-$  plumes in aquifers, and the density of High-Intensity Housing being >2 septic systems acre<sup>-1</sup>, the findings of this study are consistent with previous research.

High-Intensity Agriculture, in general, contributes more  $\text{NO}_3^-$  to the shallow aquifer than Low-Intensity Agriculture, and agricultural leachate is widely known to



significantly contribute to  $\text{NO}_3^-$  to groundwater (Pivetz and Steenhuis, 1989; Fleming and Bradshaw, 1992; Traub-Eberhard et al., 1995; Rothstein et al., 1996; Canter, 1997; Kladvico et al., 1999; Warren, K. 2002; Feaga and Selker, 2003). Therefore, these results suggest the Willamette Valley follow the patterns of previous studies which established the rule of thumb: if an area has a high density of septic tanks or is heavily fertilized, it is more likely to have a problem with  $\text{NO}_3^-$  contamination than an area with a low density of septic systems and no agricultural lands.

Regions with diverse land use patterns are known to have separate, yet overlapping patterns in isotope relationships. When  $\delta^{18}\text{O}$  values were plotted against  $\delta^{15}\text{N}$  values (Figure 3.16), no distinction could be found between natural soil N, fertilizers and septic waste. The reasons for this result are thought to be two-fold twofold. First,  $\delta^{18}\text{O}$  values are diagnostic for  $\text{NO}_3^-$  based fertilizers, but not for  $\text{NH}_4$  based fertilizers which are more widely used in the Willamette Valley. Secondly, only three sources of  $\delta^{15}\text{N}$  values were used in the construction of Kendall's schematic (1998). When  $\delta^{15}\text{N}$  values from Table 1.2 were used to distinguish the sources of  $\text{NO}_3^-$ , more separation was found (Table 3.18). Five out of the nine wells that fell into distinctive  $\delta^{15}\text{N}$  ranges for either septic or fertilizer ranges fell into their ground-truthed categories. Three of the four wells that did not fall into their ground-truthed categories were identified in Table 3.18 to be in the septic range, but fell into the fertilizer range. One explanation could be the use of fertilizers for domestic use, such as lawn and garden nitrate supplements, which would skew the ground-truthed categories in the direction of fertilizer use. Secondly, it is possible that sufficient mixing of the groundwater is occurring by the time the  $\text{NO}_3^-$  reaches the inlet of the drinking water well (40+ ft.), to obscure a distinctive isotopic

signature. Third, a number of researchers have criticized using  $\delta^{15}\text{N}$  to separate the sources of  $\text{NO}_3^-$  contamination noting extensive spatial variability of  $\delta^{15}\text{N}$  values when taken from soil cores (Bremner and Tabatabai, 1973; Edwards, 1975; Meints et al., 1975).

Other studies have found high  $\delta^{15}\text{N}$  values for septic sources and lower values of  $\delta^{15}\text{N}$  for agricultural lands (Kreitler and Browning, 1983; Heaton, 1986; Mariotta et al., 1988; Wells and Krother 1989; Aravena et al., 1993; Komor et al., 1993; Wilson et al., 1994; Kendall et al., 1995). Our investigation revealed decreasing  $\delta^{15}\text{N}$  values with increasing  $\text{NO}_3^-$  concentrations ( $R^2=0.5905$ ) (Figure 3.10). At lower  $\text{NO}_3^-$  concentrations, the  $\delta^{15}\text{N}$  values fall in the range typically associated with septic leachate, while at higher  $\text{NO}_3^-$  concentrations, the  $\delta^{15}\text{N}$  values fall in the range typically associated with agricultural production. These results suggests that at lower  $\text{NO}_3^-$  concentrations septic leachate may be responsible for  $\text{NO}_3^-$  leaching, while at higher  $\text{NO}_3^-$  concentrations agricultural effluent appears to be the primary contaminator. Also, from the analyzed agricultural samples, we found denitrification to be occurring at higher  $\text{NO}_3^-$  concentrations. When the  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values were plotted against  $\text{NO}_3^-$  concentration (Figure 3.17), a negative slope was found ( $R^2=0.4871$ ) for  $\delta^{18}\text{O}$ , while  $\delta^{15}\text{N}$  had a positive slope ( $R^2=0.4804$ ). Other studies with similar results have suggested that most likely, the fertilizers are applied at high rates, but quickly converted into N and  $\text{N}_2\text{O}$  by denitrification (Amberger and Schmidt 1987; Bottcher et al, 1990; Kendall, 1998). Therefore, the  $\text{NO}_3^-$  contributions from agriculture may be less due to the dominant influence of denitrification occurring on agricultural lands.

Variability in chemical characteristics of groundwater affected by different land uses has been widely documented (Brown et al., 1978; Spalding et al., 1980; Spalding

and Exner, 1987; Teso et al., 1988; Yates and Yates, 1988; Mechenich and Shaw, 1990; Dumaglaski and Dubrovsky, 1992; Sweeten, 1993; Baker et al., 1994; Panno et al., 1994; Wilhelm et al., 1994; Mueller, 1998; Robertson et al., 1998; Eldridge, 2002). In our study,  $\text{SO}_4^{2-}$  was highest for High Intensity Agriculture (13.70 mg/L) and lowest for Low Intensity Housing (8.52 mg/L). This result can be attributed to the application of  $\text{SO}_4^{2-}$  based fertilizers ( $\text{NH}_4\text{SO}_4$ ,  $\text{KSO}_4$ ) on agricultural lands (ODA, 2004). We also found a significantly lower pH values for High Intensity Housing (7.63) and High Intensity Agriculture (7.64) when contrasted against Low Intensity Agriculture (7.87). The result suggests an increase in denitrification, which is causing localized depressions in pH values.

#### *Agricultural Samples*

The trend of larger  $\delta^{15}\text{N}$  values and smaller  $\delta^{18}\text{O}$  values with higher  $\text{NO}_3^-$  concentrations for the agricultural samples (Figure 3.18) suggests that more denitrification is occurring at higher  $\text{NO}_3^-$  concentrations. The evidence for denitrification occurring is that the remaining  $\text{NO}_3^-$  becomes heavier in both  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$  (2:1 ratio for  $\delta^{15}\text{N}:\delta^{18}\text{O}$ ) (Amberger and Schmidt 1987). When the results of  $\delta^{15}\text{N}$  and  $\delta^{18}\text{O}$  were plotted on the schematic by Kendall (1998), only half of the values fell into the  $\text{NH}_4$  based fertilizer category, while the other half fell into an overlap of the soil N and septic waste categories. It is possible that the Willamette Valley had different soil and geologic properties than the studies used to develop Kendall's 1998 schematic. If this is the case, a new schematic should be developed for use within the Willamette Valley.

The only analyte that was statistically correlated with  $\text{NO}_3^-$  variability in the agricultural samples was  $\text{Cl}^-$ .  $\text{Cl}^-$  is considered a conservative tracer and most likely followed the same path of the  $\text{NO}_3^-$  into the groundwater. It is possible the  $\text{Cl}^-$  is derived from  $\text{NH}_4\text{Cl}$  fertilizer solution. Where in the  $\text{Cl}^-$  is mobile to move through the soil matrix into the groundwater.

### *Septic Samples*

The only analyte that was statistically correlated to  $\text{NO}_3^-$  variability in the septic samples was  $\text{K}^+$ . Potassium Chloride (KCl) is a typical water softener used in septic systems, which could explain the correlation between  $\text{NO}_3^-$  and  $\text{K}^+$  concentrations (Teso et al., 1988; Panno et al., 1994). Also, although variation in  $\text{Cl}^-$  did not statistically explain the  $\text{NO}_3^-$  variability, but the two ions' concentrations were correlated ( $P=0.1614$ ). It is important to remember that the septic samples were analyzed from soil extractions rather than water samples. By analyzing soil samples, the anions should closely resemble the concentrations found in water samples, but the cations obtained from soil samples will generally be found in much higher concentrations than water samples due to the chemical properties of soils and the extraction process employed (Sparks, 2003).

In summary, values of  $\delta^{15}\text{N}$  proved to be useful in separating the source of  $\text{NO}_3^-$  contamination. If more than 17 wells were analyzed for  $\delta^{15}\text{N}$ , we believe separation of the source solely by this technique would be clear in numerous cases. We found that  $\delta^{18}\text{O}$  did not provide information to assist in identifying the origin of the  $\text{NO}_3^-$ , most likely due to the lack of  $\text{NO}_3^-$  based fertilizer use in the Willamette Valley. This study showed  $\text{SO}_4^{2-}$  to be a valuable analyte when attempting to distinguish the source of contamination, since  $\text{SO}_4^{2-}$  is often used in fertilizers that are applied to agricultural land.

Also,  $\text{Cl}^-$  should not be used as an indicator of  $\text{NO}_3^-$  origin, since it is commonly found in both agricultural effluent and septic waste. This study also suggests  $\text{K}^+$  should be further investigated to determine if it is an indicator of septic effluent in the Willamette Valley by analyzing water samples.

### 4.3 The role of Geology

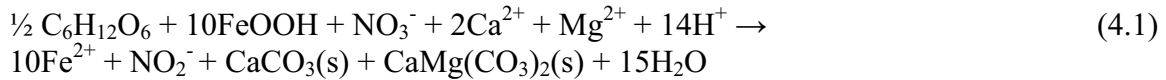
Geologic units play an important role in influencing regional and local variations in  $\text{NO}_3^-$  concentrations. In part, this study assessed the relationship between geologic units and  $\text{NO}_3^-$  concentrations. Many chemical and physical properties vary with different geologic units, which can help explain the reason for the statistically differing  $\text{NO}_3^-$  concentrations between units. In general, we observed that the higher the hydraulic conductivity of the geologic unit, the higher the  $\text{NO}_3^-$  concentration within that area. Hydraulic conductivity is a physical property that is frequently reported, which makes separation of the geologic units easier. However, no direct causal relationship can be inferred between hydraulic conductivity and corresponding  $\text{NO}_3^-$  levels, and will only be referred to as an associative property of respective geologic units. The geologic unit with the highest hydraulic conductivity, the Younger Terrace Gravels, also had the highest mean  $\text{NO}_3\text{-N}$  concentration (5.63 mg/L). The geologic unit with the lowest hydraulic conductivity, the Willamette Silt, also had the lowest mean  $\text{NO}_3\text{-N}$  concentration (3.31 mg/L). It is important to realize several factors may be affecting  $\text{NO}_3^-$  variability within different geologic units. Among other things, lower hydraulic conductivity is associated with greater groundwater residence time. These findings are similar to those from the 2000-2001 study by the OR DEQ, which found the Willamette Silt layer to have the highest percentage of wells with  $\text{NO}_3\text{-N}$  concentrations between 0 and 3 mg/L and that

highest conductivity, Younger Terrace Gravels, had the highest mean  $\text{NO}_3\text{-N}$  concentrations (Eldridge, 2002). A study by Harter et al. (2002) in California, had similar findings with geologic units of higher hydraulic conductivity having higher mean  $\text{NO}_3\text{-N}$  concentrations. A study by Jury and Nielsen (1989) found  $\text{NO}_3^-$  leaching losses are minimized by maximizing the residence time of the chemical in the root zone. A geologic unit with low hydraulic conductivity will allow the  $\text{NO}_3^-$  more time to be denitrified and leave the system as  $\text{N}_2\text{O}$  or  $\text{N}_2$ . However, the increased residence time in the soils with lower hydraulic conductivity most likely is not telling the whole story.

Due to its low hydraulic conductivity, the Willamette Silt unit is not ideal for growing high value crops expected to lose  $\text{NO}_3^-$ , such as mint, vegetable and row crops, which are associated with greater nutrient application and leaching (Feaga and Selker, 2004). Farmers have found these heavy soils better suited for growing  $\text{NO}_3^-$  scavenging crops such as grass seed. In contrast, the geologic units with higher hydraulic conductivity, such as the Younger Terrace Gravels are better growing conditions for crops that tend to leach higher amounts of  $\text{NO}_3^-$ . It has been documented that grass seed leaches much less  $\text{NO}_3^-$  than other crops such as mint, vegetable, and row crops (Feaga, 2003). In general, less  $\text{NO}_3^-$  is being applied to the Willamette Silt units than the units with higher hydraulic conductivities, such as the Younger Terrace Gravels. Therefore, with less  $\text{NO}_3^-$  being applied to the Willamette Silt unit, it is reasonable to assume less  $\text{NO}_3^-$  will be found in the shallow aquifer below.

Biochemical reactions have also been theorized as being responsible for the denitrification in the Willamette Silt layer (Argihi, 2004; Iverson, 2002). Iverson hypothesized an oxidation-reduction (RedOx) boundary in the Willamette Silt layer,

where autotrophic denitrification is responsible for the conversion of the nitrate into N<sub>2</sub>O or N<sub>2</sub>. Argihi followed up the research of Iverson to hypothesize an abiotic chemical reaction, not autotrophic denitrification, is the primary controller of denitrification within the layer:



The findings in our study generally support this conceptualization. CaCO<sub>3</sub> was found in higher concentrations within the Willamette Silt unit when contrasted against the other units. Statistical significance was compelling when comparing the concentration of CaCO<sub>3</sub> between the Willamette Silt unit and the Recent Alluvium (*P*=0.0008) and Younger Terrace Gravel (*P*=0.0020) units. Another important facet of this reaction, due to the production of CaCO<sub>3</sub> and loss of 14H<sup>+</sup>, is an increase in the pH of the groundwater below the RedOx layer. Our study found statistically significant higher pH levels in the Willamette Silt layer than all other layers. Our study also found a statistically significant higher electrical conductivity in the Willamette Silt unit than the other strata. The explanation for the higher electrical conductivity is most likely associated with: (1) stripping of the Ca<sup>2+</sup> and Mg<sup>2+</sup> from the soil profile and forming a larger molecule; (2) the dissolution of the FeOOH into Fe<sup>2+</sup> and H<sub>2</sub>O; and (3) the fine grained nature of the silt combined with the increased availability of H<sub>2</sub>O to carry the fine sediments. An apparent exception was NO<sub>2</sub><sup>-</sup>, which was analyzed for twenty Willamette Silt layer samples below the RedOx layer. NO<sub>2</sub><sup>-</sup> was not found in any sample, but NO<sub>2</sub><sup>-</sup> is considered to be an unstable phase of the N-cycle, it is plausible that no NO<sub>2</sub><sup>-</sup> was found due to further denitrification into more stable forms of the N-cycle, such as N<sub>2</sub>O or N<sub>2</sub>.

Therefore, from the information garnered in our study, it is believed that the reaction described by Argihi (2004) is, at least in part, responsible for the denitrification occurring in the Willamette Silt layer. The low hydraulic conductivity of the Willamette Silt layer would also allow more residence time for this reaction to occur.

#### 4.4 The role of Soils

We observed that soil types were weakly correlated to  $\text{NO}_3^-$  concentrations. Significantly less  $\text{NO}_3^-$  was found in Silt Loam than Loam ( $P=0.0223$ ). A plausible explanation for this significant variation is the difference in its physical and chemical properties. Hydraulic conductivity is a widely reported property of soils and aids in separating the physical and chemical properties of each soil type. As previously discussed, the physical and chemical properties of a soil type is going to have an effect on the fate and transport of  $\text{NO}_3^-$ , generally, the higher the hydraulic conductivity the higher the concentration of  $\text{NO}_3^-$  in the aquifer. Loam has a hydraulic conductivity of  $10^{-3}$  to  $10^{-2}$ , while Silt Loam has a hydraulic conductivity of  $10^{-7}$  to  $10^{-3}$  (Selker et al., 1999), consistent with the variations in observed  $\text{NO}_3^-$ . As with the geologic units, the hydraulic conductivity is not only going to increase the residence time of the analytes, but affect what types of crops are grown in the soil. Due to its properties associated with having low hydraulic conductivity, Silt Loam is not ideal for growing high  $\text{NO}_3^-$  leaching crops such as mint, vegetable and row crops, but is better suited for growing  $\text{NO}_3^-$  scavenging crops such as grass seed. In contrast, the Loam soils are associated with better growing conditions for crops that tend to leach higher amounts of  $\text{NO}_3^-$ . In general, less  $\text{NO}_3^-$  is being applied to the Silt Loam than the soils with higher hydraulic conductivities, such as



Loam. Therefore, with less  $\text{NO}_3^-$  being applied to the Silt Loams, it is reasonable to assume less  $\text{NO}_3^-$  will be found in the shallow aquifer below.

#### 4.5 Conclusion and Recommendations

The results of analyses for major chemical constituents and isotopes of N and O in water from drinking water wells do not conclusively show the source of  $\text{NO}_3^-$  contamination in the southern Willamette Valley, Oregon. However, many important findings were discovered in the course of this study.

**(1) Anthropogenic activities are associated with increased vulnerability of wells to  $\text{NO}_3^-$  contamination.** The sources of  $\text{NO}_3^-$  contamination in the Willamette Valley should continue to be focused on to assure that proper management of the agricultural and septic leachate is taking place. Cover crops, nutrient management and other management practices not only save the grower time and money, but also minimize the impact of  $\text{NO}_3^-$  contamination to the groundwater. Septic systems should continue to be managed properly and frequently inspected to ensure proper working conditions.

**(2) Simple and inexpensive means exist to predict vulnerability of drinking water wells to  $\text{NO}_3^-$  contamination.** Using data available on the internet, including well logs (well age and well depth) and GIS layers (geologic units, soil maps, and land use) it is possible to predict 35.6% of the variability of  $\text{NO}_3^-$  concentrations in any given well in the southern Willamette Valley. By adding a simple on-site analysis with a Hydro Lab, which measures DO, pH, Conductivity, and TDS to the data available on the internet, it is possible to predict 52.4% of the variability of  $\text{NO}_3^-$  concentrations in any given well in the southern Willamette Valley.

**(3) Geologic units play an important role in  $\text{NO}_3^-$  variability within the Willamette Valley.** Areas with the geologic units Older Terrace Gravels, Younger Terrace Gravels and Recent Alluvium should focus on proper  $\text{NO}_3^-$  management. Educating growers as to proper  $\text{NO}_3^-$  fertilization rates and timing not only saves them money, but limits the impact on the groundwater.

**(4) Future  $\text{NO}_3^-$  levels will be determined by what levels of  $\text{NO}_3^-$  are presently applied.** A rough estimate of the travel time of the  $\text{NO}_3^-$  from the surface to a well of 75 ft. in the Willamette Valley is approximately 25 years (Brandi-Dohrn, 1998), so care must be taken when expectations are raised on the efficacy of changes in land use practices to improve groundwater quality. The age of water in the wells should be calculated to determine when the  $\text{NO}_3^-$  found in the wells first entered the system. It is difficult to form management decisions when we do not know what conditions gave rise to problematic observations. Perhaps the  $\text{NO}_3^-$  found in the wells was originally applied to agricultural fields in the early 1990's when mint, row and vegetable crops, all heavy  $\text{NO}_3^-$  leachers, dominated the market. With the market based transition to grass seed, a  $\text{NO}_3^-$  scavenging crop, perhaps  $\text{NO}_3^-$  concentrations will begin to decline in shallow wells over the next decade.

**(5) The potential health risks associated with ingestion of  $\text{NO}_3^-$  at concentrations >10 ppm warrants continued education of the public on issues associated with drinking water contamination, including regular testing of well water**

**(6) Isotopes are useful in separating sources of  $\text{NO}_3^-$  contamination, but caution is warranted.**  $\delta^{18}\text{O}$  values are not as informative as  $\delta^{15}\text{N}$  values in the Willamette Valley since  $\text{NH}_4$  based fertilizers are more widely used. However, in locations where  $\text{NO}_3^-$

fertilizers are widely used,  $\delta^{18}\text{O}$  values are valuable for determining the influence of agriculture on  $\text{NO}_3^-$  contamination. The schematic developed by Kendall (1998) is widely used when distinguishing sources of  $\text{NO}_3^-$  contamination by using both  $\delta^{18}\text{O}$  and  $\delta^{15}\text{N}$  values. In the Willamette Valley, where  $\text{NH}_4$  based fertilizers are more widely used, the literature values compiled in Table 1.2 may be of better use in separating the sources of the contamination.

Future studies of  $\text{NO}_3^-$  contamination within the southern Willamette Valley need to focus on ways to lessen and best manage septic and agricultural effluent. Septic system users should be educated on proper maintenance and construction of septic units. Agricultural growers need to adopt management practices, which minimize  $\text{NO}_3^-$  leaching by not only describing optimal timing and application rates of fertilizers, but ultimately save the grower money by only applying the needed amount of fertilizer (e.g. Feaga and Selker, 2004). A study to monitor nutrients in several wells over an extended period of time could give insight into aquifer properties and temporal changes in nutrient loading. Future studies should also further examine the role of hydrogeology in the process of denitrification.

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## Appendix A: Well Chemistry Results



Well No	Nitrate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Bicarb (mg/L)	DO (mg/L)	DO % SAT	TDS (g/L)	Cond. (mS/cm)	pH	Temperature (°C)
1	11.94	19.72	7.28	72	3.04	30.09	0.2	0.305	7.5	14.61
2	12.37	21.99	7.17	64	3.2	28.8	0.2	0.29	7.43	13.4
3	0.00	4.12	70.79	152	1.86	27.6	0.4	0.532	7.8	19.68
4	13.70	22.85	7.58	60	2.79	26.7	0.1	0.122	7.41	13.86
5	5.72	8.71	2.81	36	2.1	20.7	0.1	0.152	7.03	14.42
6	7.59	12.60	4.71	80	3.01	30.3	0.2	0.259	7.42	15.29
7	7.67	14.67	8.89	104	3.01	29.9	0.2	0.297	7.41	15.5
8	6.64	12.53	14.38	100	1.79	19.5	0.3	0.397	7.7	19.45
9	10.27	22.07	5.48	52	2.84	33.1	0.1	0.078	7.54	21.82
10	6.95	14.53	7.92	68	2.54	25.9	0.2	0.277	7.55	16.1
11	8.23	12.33	3.47	60	2.46	26.9	0.2	0.233	7.54	16.47
12	10.80	17.34	8.33	48	3.62	37	0.2	0.289	7.47	16.28
13	3.52	11.74	16.46	88	1.58	13	0.2	0.284	7.74	17.97
14	6.62	17.52	16.63	56	5.51	54.3	0.2	0.306	7.59	14.59
15	4.87	5.11	30.83	100	2.16	22.4	0.4	0.611	8.03	16.62
16	5.27	22.10	106.03	44	1.83	18.5	0.2	0.37	8.04	15.66
17	3.74	5.39	157.79	144	1.62	16.3	0.5	0.732	8.07	15.63
18	10.84	18.22	8.28	36	3.42	33.8	0.2	0.301	7.57	14.52
19	11.63	19.61	6.29	32	3.61	35.1	0.2	0.304	7.67	14.24
20	8.49	18.74	7.41	72	4.09	39.6	0.2	0.249	7.62	13.58
21	7.02	16.93	5.23	88	3.46	36	0.2	0.256	7.66	16.91
22	0.51	3.18	6.56	32	3.7	36.2	0.2	0.271	8.17	14.01
23	9.87	19.37	9.30	80	4	39.2	0.2	0.314	7.63	14.16
24	1.53	6.83	4.67	84	3.23	32.3	0.2	0.276	7.64	15.2
25	7.59	19.38	7.94	60	4.6	47	0.2	0.259	7.48	16.1
26	2.14	7.18	5.85	64	3.06	29.2	0.1	0.211	7.09	14.42
27	0.00	0.00	192.77	76	1.6	15.5	0.8	1.169	8.66	14.51
29	1.48	1.96	5.26	80	5.5	53.8	0.1	0.184	8.51	14.02
30	3.77	10.87	9.08	84	4.28	44.5	0.2	0.274	7.85	17.33
31	3.92	7.47	5.75	84	2.98	35.6	0.2	0.264	7.55	23.5
32	10.45	14.89	9.33	56	4.27	41	0.2	0.31	7.66	13.86
33	3.56	33.71	9.88	44	4.5	46.6	0.2	0.376	7.91	17.3

Well No	Nitrate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Bicarb (mg/L)	DO (mg/L)	DO % SAT	TDS (g/L)	Cond. (mS/cm)	pH	Temperature (°C)
34	2.62	8.31	6.46	72	3.48	34.7	0.2	0.242	8.48	15.07
35	9.36	11.36	8.33	72	4.89	47.9	0.2	0.288	7.59	14.01
36	2.85	6.79	1.79	48	4.71	49.2	0.2	0.309	7.38	16.91
37	4.20	7.19	5.71	32	3.95	37.8	0.1	0.207	7.83	13.79
38	3.75	7.10	12.25	64	3.66	35.9	0.2	0.294	7.79	14.25
39	0.00	2.35	24.18	96	2.5	23.9	0.2	0.262	7.96	14.09
40	4.78	22.23	8.79	108	3.47	34.8	0.2	0.357	7.94	14.79
41	4.14	9.76	15.95	84	4.03	39.8	0.2	0.287	7.58	14.35
42	5.35	23.06	6.03	104	6.21	60.7	0.2	0.278	8.16	13.75
43-A	2.89	14.20	12.59	64	4.75	49.4	0.2	0.312	7.71	16.96
43-B	5.03	10.15	6.90	96	3.63	36.1	0.2	0.279	7.36	14.85
44-A	5.26	8.15	6.16	112	4.12	40.8	0.1	0.206	7.62	14.25
44-B	3.07	10.04	7.95	92	4.09	39.6	0.2	0.269	7.62	13.61
45	1.06	7.62	13.17	112	3.56	37.2	0.2	0.258	8.29	17.2
46	2.81	5.64	5.49	100	3.43	30.1	0.2	0.231	7.43	13.72
47	0.00	3.20	15.71	72	4.18	42.4	0.2	0.245	8.42	15.78
48	3.17	7.80	6.99	96	4.72	47.38	0.2	0.239	7.84	15.13
49	7.22	10.41	34.95	92	2.78	27.5	0.3	0.393	7.55	15.07
50	8.46	13.81	12.87	112	3.42	39.1	0.2	0.342	7.58	13.95
51	8.70	4.41	9.92	72	4.6	47.8	0.2	0.366	7.73	17.4
52	3.31	8.89	28.39	112	4.78	52.9	0.2	0.367	7.87	20.08
53	2.94	11.73	4.74	140	5.13	51.3	0.1	0.217	8	15.01
54	1.33	10.27	5.98	132	4.24	42.8	0.2	0.274	7.49	15.67
55	5.47	10.36	20.57	104	2.91	28.7	0.2	0.332	7.92	14.97
56	6.58	12.17	17.52	68	4.89	48.2	0.2	0.31	7.53	14.35
57	3.14	7.15	8.29	72	4.28	43.3	0.2	0.269	8.08	15.58
58	1.27	4.49	28.35	68	4.69	46.8	0.2	0.325	8.39	15.12
59	9.02	10.18	6.48	84	5.56	59.1	0.2	0.287	7.38	17.8
60	3.89	5.91	6.26	100	4.82	46	0.2	0.236	7.53	13.16
61	3.09	25.78	7.24	120	5.12	50.9	0.2	0.304	7.69	15.12
63	8.45	11.40	7.81	84	NA	NA	NA	NA	NA	NA
64	8.35	10.83	7.76	100	5.94	59.8	0.2	0.296	7.7	15.42

Well No	Nitrate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Bicarb (mg/L)	DO (mg/L)	DO % SAT	TDS (g/L)	Cond. (mS/cm)	pH	Temperature (°C)
65	8.78	11.22	9.22	100	5	49.4	0.2	0.29	7.27	14.67
66	7.82	16.66	14.98	128	5.89	59.2	0.3	0.392	7.97	15.29
67	4.25	8.30	7.51	112	3.24	30.1	0.2	0.273	7.66	13.67
68	4.61	24.46	7.36	84	3.64	35.7	0.2	0.271	8.01	14.19
69	6.97	34.47	27.66	200	2.16	19.8	0.3	0.525	7.96	15.04
70	7.99	35.11	25.85	132	3.54	36.1	0.3	0.455	8.08	15.98
71	4.06	24.30	38.06	124	4.34	43.9	0.3	0.458	8.03	15.7
72	1.46	5.16	53.76	140	5.77	57.7	0.3	0.528	8.26	16.5
73	0.22	17.56	35.14	108	3.78	41.4	0.2	0.358	8.17	19.53
75	8.20	13.11	8.74	92	5.07	49.6	0.2	0.274	7.66	14.06
77	9.13	13.33	7.86	84	4.91	47.6	0.2	0.305	7.48	13.81
78	7.74	9.30	7.57	64	4.5	45.1	0.2	0.247	7.3	15.33
79	0.00	0.00	7.71	66	2.62	28.9	0.1	0.182	9.05	20.71
80	3.00	2.27	7.07	48	3.64	35.9	0.1	0.145	7.51	14.9
81	3.57	12.17	7.03	104	4.88	49.9	0.2	0.267	7.4	16.1
82	4.12	8.18	11.46	120	4.89	47.3	0.2	0.3	7.41	14.16
83	1.75	8.47	5.62	104	5.2	51	0.2	0.277	7.49	14.38
84	11.31	12.91	10.56	80	5.37	52.6	0.2	0.28	7.47	14.69
85	4.98	6.63	7.02	100	4.37	44.7	0.2	0.254	7.72	16.36
86	1.97	3.87	4.69	80	4.24	41.2	0.2	0.262	7.38	14.04
87	2.59	5.49	5.81	72	4.53	44.6	0.1	0.213	7.52	15.12
88	2.91	7.24	5.79	72	4.11	42.5	0.1	0.202	7.28	16.95
89-B	0.11	NA	3.97	36	3.4	35.2	0	0.061	7.41	17.43
90	0.00	0.00	4.04	64	3.01	28.3	0.1	0.118	8.35	14.09
91	5.16	7.49	6.63	100	4.25	44.1	0.2	0.255	7.79	16.89
92	8.67	9.90	6.96	100	4.56	44.2	0.2	0.288	7.46	13.8
93	0.88	0.00	14.58	84	3.6	35.9	0.1	0.204	8.11	14.98
94	0.00	0.00	5.94	80	4.52	42.9	0.1	0.145	8.69	13.4
95	9.27	10.50	8.30	86	4.56	43.1	0.2	0.285	7.65	13.53
96	2.83	3.37	7.17	84	4.01	37.8	0.1	0.224	8.33	12.43
97	6.22	11.80	8.33	112	3.93	40.7	0.2	0.292	7.55	16.89
98	2.92	11.15	6.36	80	4.53	44.6	0.2	0.244	7.97	14.44

Well No	Nitrate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Bicarb (mg/L)	DO (mg/L)	DO % SAT	TDS (g/L)	Cond. (mS/cm)	pH	Temperature (°C)
100	0.65	0.00	4.65	60	4.21	40.5	0.1	0.164	8.49	13.52
101	2.87	3.63	5.59	88	3.43	33.3	0.1	0.213	8.23	13.98
102	3.03	3.22	5.29	72	3.78	36.3	0.1	0.198	7.34	13.42
103	1.52	0.29	6.27	60	4.33	40.7	0.1	0.173	7.97	12.93
104	0.00	0.00	22.66	84	2.49	24	0.1	0.22	8.16	13.54
105	3.49	8.04	9.42	92	3.31	33.8	0.2	0.267	7.64	16.15
106	6.83	8.54	7.94	96	3.54	34.5	0.2	0.303	7.77	15.19
107	4.76	22.76	6.16	88	5.2	50.1	0.2	0.298	8.04	13.45
108	2.62	13.04	32.61	144	4.18	39.6	0.3	0.407	7.78	13.1
109	2.17	17.13	13.05	124	4.11	41.7	0.3	0.418	8.02	16.04
110	4.04	16.30	8.39	84	2.77	29.6	0.2	0.268	7.79	18.99
111	6.17	21.36	14.42	92	2.92	29.3	0.2	0.354	7.71	16.15
112	3.55	8.90	16.49	104	3.58	37.4	0.2	0.375	8.05	17.44
113	13.23	11.17	7.57	48	4.16	40.2	0.2	0.306	7.38	13.53
114	4.93	14.41	6.50	84	4.02	38.7	0.2	0.253	7.82	14.04
115	6.07	30.94	6.93	96	4.62	46.1	0.2	0.328	7.98	15.11
116	0.00	1.83	3.92	40	2.83	27.4	0.1	0.092	7.34	14.03
117	0.70	2.11	4.35	28	3.1	29.5	0.1	0.108	7.3	13.37
118	0.00	0.00	4.10	88	1.63	15.8	0.1	0.18	8.04	14.58
119	0.00	2.59	38.15	88	2.25	25	0.2	0.307	8.37	21.5
120	7.47	11.26	11.15	80	2.15	23	0.2	0.269	7.59	18.69
121	2.18	12.54	5.72	116	3.2	32.4	0.2	0.24	8.36	15.95
122	3.47	4.76	5.96	60	3.4	31.2	0.1	0.208	7.43	13.6

Well No	Latitude	Longitude	Year of well	Age of well	Well Depth	Geology Code	Land Use Code	Soil Code
1	44.25222	-123.22622	1983	20	39	3	4	2
2	44.26498	-123.20938	1977	26	29	3	2	2
3	44.20612	-123.21792	1982	21	60	4	1	2
4	44.23788	-123.19603	NA	NA	NA	3	4	5
5	44.23172	-123.16610	1977	26	26	1	3	4
6	44.18345	-123.17093	1991	12	37	3	3	2
7	44.18272	-123.16885	1997	6	39	3	3	5
8	44.25820	-123.21665	2001	2	49	3	1	6
9	44.21312	-123.19042	1993	10	50	3	4	6
10	44.16963	-123.16295	1993	10	39	3	3	5
11	44.13197	-123.15085	1998	5	40	3	4	2
12	44.22832	-123.19928	1988	15	27	3	2	2
13	44.22058	-123.21577	1997	6	50	3	1	NA
14	44.24058	-123.21277	1989	14	29	3	1	2
15	44.31283	-123.12742	1991	12	70	2	3	3
16	44.20810	-123.21783	NA	NA	28	4	4	2
17	44.33052	-123.12887	NA	NA	NA	2	0	3
18	44.23708	-123.20470	1994	9	39	3	3	2
19	44.22550	-123.18897	1979	24	32	3	1	2
20	44.30047	-123.22140	1991	12	47	1	3	NA
21	44.18475	-123.12350	1990	13	50	1	4	4
22	44.16677	-123.15972	1992	11	58	3	3	5
23	44.23712	-123.20292	1972	31	32	3	4	2
24	44.15767	-123.17952	1997	6	70	4	1	2
25	44.20683	-123.18763	1987	16	42	3	1	2
26	44.19387	-123.19908	NA	NA	40	3	3	6
27	44.36010	-123.07140	1998	5	58	2	3	1
29	44.14927	-123.15610	1995	8	66	3	0	2
30	44.17085	-123.16312	1978	25	45	3	3	5
31	44.16510	-123.16145	2002	1	38	3	3	2
32	44.21397	-123.17827	NA	NA	NA	3	4	5
33	44.31673	-123.17805	1981	22	40	2	3	1



Well No	Latitude	Longitude	Year of well	Age of well	Well Depth	Geology Code	Land Use Code	Soil Code
34	44.14963	-123.15452	NA	NA	60	3	3	2
35	44.21443	-123.17988	NA	NA	NA	3	3	5
36	44.21498	-123.17697	NA	NA	30	3	1	5
37	44.15600	-123.07098	1991	12	35	4	2	2
38	44.21743	-123.21880	1991	12	39	3	1	2
39	44.23573	-123.21012	1997	6	49	3	2	2
40	44.34588	-123.19755	1986	17	42	2	3	1
41	44.22112	-123.21617	1970	33	35	3	2	NA
42	44.15237	-123.10067	1992	11	50	1	4	2
43-A	44.26307	-123.19677	NA	NA	NA	1	2	NA
43-B	44.21788	-123.21940	2002	1	39	3	4	NA
44-A	44.15617	-123.07083	NA	NA	NA	4	2	NA
44-B	44.20055	-123.22078	1992	11	39	4	3	NA
45	44.20527	-123.21872	2001	2	73	4	3	2
46	44.16455	-123.16700	2002	1	40	3	3	2
47	44.21920	-123.21558	1984	19	40	3	1	NA
48	44.16460	-123.16575	2002	1	46	3	3	2
49	44.21890	-123.22312	2001	2	39	3	4	6
50	44.24050	-123.22533	1980	23	48	3	2	2
51	44.27747	-123.21898	1979	24	40	1	2	5
52	44.21330	-123.20947	2003	0	39	3	1	NA
53	44.14917	-123.18965	1988	15	38	4	3	2
54	44.14982	-123.17987	1999	4	72	4	0	2
55	44.23678	-123.20942	1994	9	40	3	1	2
56	44.24113	-123.21130	1977	26	29	3	4	6
57	44.20187	-123.21853	1976	27	33	4	3	2
58	44.20575	-123.21903	1999	4	58	4	3	2
59	44.13398	-123.07805	1984	19	55	1	4	5
60	44.14562	-123.08802	1976	27	60	1	3	5
61	44.18287	-123.11988	1988	15	39	1	3	1
63	44.14217	-123.09657	NA	NA	NA	1	2	5
64	44.14228	-123.09737	1978	25	48	1	2	5

Well No	Latitude	Longitude	Year of well	Age of well	Well Depth	Geology Code	Land Use Code	Soil Code
65	44.14317	-123.09743	1996	7	39	1	2	4
66	44.15607	-123.07223	1993	10	49	4	0	2
67	44.15980	-123.07273	1991	12	39	4	3	2
68	44.18170	-123.07262	2001	2	60	4	3	2
69	44.32443	-123.20487	1980	23	37	2	3	2
70	44.31983	-123.20580	1981	22	39	2	3	1
71	44.31445	-123.13808	1989	14	36	2	3	1
72	44.31682	-123.13272	2002	1	44	2	3	2
73	44.31695	-123.09240	1995	8	40	2	3	3
75	44.27262	-123.21108	1995	8	52	1	4	5
77	44.22650	-123.19627	1971	32	20	3	3	2
78	44.21922	-123.17692	1988	15	25	1	3	5
79	44.22153	-123.17260	1993	10	59	1	3	2
80	44.21868	-123.17182	1976	27	45	1	4	2
81	44.18108	-123.17628	1988	15	34	3	2	2
82	44.18092	-123.17833	1992	11	29	3	1	2
83	44.18203	-123.17757	1994	9	36	3	1	2
84	44.25802	-123.22633	1999	4	56	3	2	2
85	44.16158	-123.15695	1978	25	22	3	3	5
86	44.16922	-123.15642	1979	24	29	3	1	5
87	44.17063	-123.15198	1984	19	30	1	3	4
88	44.17155	-123.15060	1995	8	28	1	0	5
89-B	44.27310	-123.22647	2003	0	50	NA	NA	NA
90	44.13257	-123.13123	1999	4	68	3	4	5
91	44.18635	-123.17583	1988	15	47	3	3	2
92	44.18585	-123.17860	1998	5	60	3	1	2
93	44.22460	-123.22460	1992	11	43	3	1	2
94	44.20800	-123.20800	1996	7	60	3	1	6
95	44.20402	-123.17272	1989	14	44	3	4	6
96	44.19950	-123.17155	1994	9	49	3	1	5
97	44.18888	-123.17350	1988	15	29	3	3	5
98	44.13972	-123.13765	1999	4	39	3	3	5

Well No	Latitude	Longitude	Year of well	Age of well	Well Depth	Geology Code	Land Use Code	Soil Code
99	44.13462	-123.14515	1988	15	34	3	3	6
100	44.15138	-123.15272	1999	4	58	3	3	2
101	44.20750	-123.17277	1993	10	50	3	3	5
102	44.27282	-123.19112	2002	1	39	1	4	2
103	44.27207	-123.20123	1994	9	52	1	3	4
104	44.27350	-123.21990	2000	3	70	1	3	5
105	44.27268	-123.21975	1992	11	39	1	3	2
106	44.14313	-123.09787	2002	1	49	1	2	4
107	44.15188	-123.09625	2001	2	39	1	3	2
108	44.26838	-123.16745	1975	28	38	2	2	1
109	44.26553	-123.15750	1978	25	50	2	2	1
110	44.25205	-123.09987	1992	11	36	2	4	2
111	44.35978	-123.13973	1992	11	38	2	4	2
112	44.38662	-123.19038	1983	20	25	2	3	2
113	44.13515	-123.09478	1981	22	50	1	2	5
114	44.19375	-123.07488	2001	2	49	4	3	2
115	44.16063	-123.09777	1962	41	55	4	3	2
116	44.18140	-123.13168	1979	24	35	1	3	1
117	44.18107	-123.13387	1988	15	39	1	0	NA
118	44.38165	-122.98618	1978	25	43	2	3	2
119	44.37248	-123.01182	1991	12	46	2	0	6
120	44.22622	-123.20005	1996	7	42	3	2	2
121	44.14022	-123.20235	1996	7	60	4	3	2
122	44.27313	-123.19192	2003	0	39	1	4	2

## Appendix B: Signature Well Chemistry Results

Sample	P (ppm)	K (ppm)	S (ppm)	Ca (ppm)	Mg (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Al (ppm)
S-1	NA	110	NA	172	42	NA	NA	NA	NA	NA	NA
S-2	NA	139	NA	334	82.8	NA	NA	NA	NA	NA	NA
S-3	NA	248	NA	266	57.6	NA	NA	NA	NA	NA	NA
S-4	NA	449	NA	250	79.2	NA	NA	NA	NA	NA	NA
S-5	NA	309	NA	174	60	NA	NA	NA	NA	NA	NA
S-6	NA	206	NA	184	39.6	NA	NA	NA	NA	NA	NA
S-7	NA	248	NA	230	56.4	NA	NA	NA	NA	NA	NA
S-8	NA	246	NA	206	74.4	NA	NA	NA	NA	NA	NA
S-9	NA	239	NA	194	122.4	NA	NA	NA	NA	NA	NA
S-10	NA	286	NA	172	60	NA	NA	NA	NA	NA	NA
F-1	<1	<1	9	22	12	<0.04	<0.1	<0.1	<1	<0.1	<1
F-2	<1	<1	6	23	8	<0.04	<0.1	<0.1	<1	<0.1	<1
F-3	<1	1	4	15	5	<0.04	<0.1	<0.1	<1	<0.1	<1
F-4	<1	<1	8	19	8	<0.04	<0.1	<0.1	<1	<0.1	<1
F-5	<1	<1	13	29	18	<0.04	<0.1	<0.1	<1	<0.1	<1
F-6	<1	1	9	31	14	<0.04	<0.1	<0.1	<1	<0.1	<1
F-7	<1	<1	24	45	19	<0.04	<0.1	<0.1	<1	<0.1	<1
F-8	<1	1	7	39	19	<0.04	<0.1	<0.1	<1	<0.1	<1
F-9	<1	2	10	30	11	<0.04	<0.1	<0.1	<1	<0.1	<1
F-10	<1	2	65	31	22	0.04	<0.1	<0.1	<1	<0.1	<1
W-1	<1	<1	5	23	10	<0.04	<0.1	<0.1	<1	<0.1	<1
W-2	<1	<1	8	30	17	<0.04	<0.1	<0.1	<1	<0.1	<1
W-4	<1	1	10	31	18	<0.04	<0.1	<0.1	<1	<0.1	<1
W-9	<1	<1	8	27	10	<0.04	<0.1	<0.1	<1	<0.1	<1
W-12	<1	<1	5	23	10	<0.04	<0.1	<0.1	<1	<0.1	<1
W-13	<1	<1	2	17	5	<0.04	<0.1	<0.1	<1	<0.1	<1
W-18	<1	<1	5	25	9	<0.04	<0.1	<0.1	<1	<0.1	<1
W-21	<1	1	7	24	15	<0.04	<0.1	<0.1	<1	<0.1	<1
W32	<1	<1	7	29	17	<0.04	<0.1	<0.1	<1	<0.1	<1
W-37	<1	1	3	17	9	<0.04	<0.1	<0.1	<1	<0.1	<1
W-44	<1	2	4	21	10	<0.04	<0.1	<0.1	<1	<0.1	<1

Sample	P (ppm)	K (ppm)	S (ppm)	Ca (ppm)	Mg (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Al (ppm)
W-50	<1	1	6	31	14	<0.04	<0.1	<0.1	<1	<0.1	<1
W-64A	<1	1	5	27	12	<0.04	<0.1	<0.1	<1	<0.1	<1
W-65	<1	1	5	24	11	<0.04	<0.1	<0.1	<1	<0.1	<1
W-70	<1	1	15	35	21	<0.04	<0.1	<0.1	<1	<0.1	<1
W-77	<1	<1	4	22	7	<0.04	<0.1	<0.1	<1	<0.1	<1
W-95	<1	<1	4	22	11	<0.04	<0.1	<0.1	<1	<0.1	<1
W-106	<1	1	5	25	14	0.05	<0.1	<0.1	<1	<0.1	<1
W-113	<1	2	7	29	17	<0.04	<0.1	<0.1	<1	<0.1	<1

Sample	As (ppm)	Ba (ppm)	Cd (ppm)	Co (ppm)	Mo (ppm)	Na (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Cr (ppm)	pH	18O (‰)	15N (‰)
S-1	NA	NA	NA	NA	NA	5.29	NA	NA	NA	NA	NA	NA	NA
S-2	NA	NA	NA	NA	NA	8.51	NA	NA	NA	NA	NA	NA	NA
S-3	NA	NA	NA	NA	NA	5.29	NA	NA	NA	NA	NA	NA	NA
S-4	NA	NA	NA	NA	NA	19.09	NA	NA	NA	NA	NA	NA	NA
S-5	NA	NA	NA	NA	NA	12.65	NA	NA	NA	NA	NA	NA	NA
S-6	NA	NA	NA	NA	NA	5.06	NA	NA	NA	NA	NA	NA	NA
S-7	NA	NA	NA	NA	NA	20.47	NA	NA	NA	NA	NA	NA	NA
S-8	NA	NA	NA	NA	NA	10.81	NA	NA	NA	NA	NA	NA	NA
S-9	NA	NA	NA	NA	NA	13.34	NA	NA	NA	NA	NA	NA	NA
S-10	NA	NA	NA	NA	NA	11.27	NA	NA	NA	NA	NA	NA	NA
F-1	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	NA	5.64	5.69
F-2	<0.1	<0.05	<0.01	<0.03	<1	9	<0.06	<0.04	<1	<0.02	NA	5.74	4.25
F-3	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	NA	NA	NA
F-4	<0.1	<0.05	<0.01	<0.03	<1	33	<0.06	<0.04	<1	<0.02	NA	NA	NA
F-5	<0.1	<0.05	<0.01	<0.03	<1	8	<0.06	<0.04	<1	<0.02	NA	4.86	7.62
F-6	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	NA	NA	NA
F-7	<0.1	<0.05	<0.01	<0.03	<1	23	<0.06	<0.04	<1	<0.02	NA	NA	NA
F-8	<0.1	<0.05	<0.01	<0.03	<1	12	<0.06	<0.04	<1	<0.02	NA	5.53	1.95
F-9	<0.1	<0.05	<0.01	<0.03	<1	10	<0.06	<0.04	<1	<0.02	NA	2.15	9.4
F-10	<0.1	<0.05	<0.01	<0.03	<1	93	<0.06	<0.04	<1	<0.02	NA	7.6	4.9
W-1	<0.1	<0.05	<0.01	<0.03	<1	5	<0.06	<0.04	<1	<0.02	7.5	6.36	3.56
W-2	<0.1	<0.05	<0.01	<0.03	<1	8	<0.06	<0.04	<1	<0.02	7.43	4.78	4.02
W-4	<0.1	<0.05	<0.01	<0.03	<1	8	<0.06	<0.04	<1	<0.02	7.41	3.82	3.35
W-9	<0.1	<0.05	<0.01	<0.03	<1	5	<0.06	<0.04	<1	<0.02	7.54	8.81	4.5
W-12	<0.1	<0.05	<0.01	<0.03	<1	6	<0.06	<0.04	<1	<0.02	7.47	NA	4.06
W-13	<0.1	<0.05	<0.01	<0.03	<1	10	<0.06	<0.04	<1	<0.02	7.74	NA	NA
W-18	<0.1	<0.05	<0.01	<0.03	<1	5	<0.06	<0.04	<1	<0.02	7.57	NA	4.38
W-21	<0.1	<0.05	<0.01	<0.03	<1	8	<0.06	<0.04	<1	<0.02	7.66	NA	5.55
W32	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	7.66	NA	4.96
W-37	<0.1	<0.05	<0.01	<0.03	<1	5	<0.06	<0.04	<1	<0.02	7.83	NA	NA
W-44	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	7.62	NA	NA

Sample	As (ppm)	Ba (ppm)	Cd (ppm)	Co (ppm)	Mo (ppm)	Na (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Cr (ppm)	pH	18O (‰)	15N (‰)
W-49	<0.1	<0.05	<0.01	<0.03	<1	11	<0.06	<0.04	<1	<0.02	7.55	7.64	8.38
W-50	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	7.58	6.17	5.22
W-64A	<0.1	<0.05	<0.01	<0.03	<1	6	<0.06	<0.04	<1	<0.02	7.7	4.88	6
W-65	<0.1	<0.05	<0.01	<0.03	<1	7	<0.06	<0.04	<1	<0.02	7.27	4.58	6.81
W-70	<0.1	<0.05	<0.01	<0.03	<1	24	<0.06	<0.04	<1	<0.02	8.08	9.05	8.33
W-77	<0.1	<0.05	<0.01	<0.03	<1	3	<0.06	<0.04	<1	<0.02	7.48	3.07	2.88
W-95	<0.1	<0.05	<0.01	<0.03	<1	5	<0.06	<0.04	<1	<0.02	7.65	5.38	3.67
W-106	<0.1	<0.05	<0.01	<0.03	<1	8	<0.06	<0.04	<1	<0.02	7.77	6.16	7.91
W-113	<0.1	<0.05	<0.01	<0.03	<1	9	<0.06	<0.04	<1	<0.02	7.38	3.12	2.51



## Appendix C: Letters and Sampling forms

Dear Resident,

One of my graduate students, Chris Vick, is conducting his thesis research on groundwater in the southern Willamette Valley. For the study Chris needs water samples from wells in your area that are less than 75 feet in depth. Your well log, on file with the Oregon Water Resources Department, shows your well qualifies for this study.

Chris will be collecting water samples from as many wells as possible during weekdays from August 21<sup>st</sup> to September 19<sup>th</sup>, 2003. He will take a small sample of water and measure the depth of the water in the well.

After Chris collects the samples he will analyze the water for anions, which include nitrate, sulfate, chloride, flouride, and bicarbonate. By participating in the study, Chris will analyze your well water for free and mail the results to you upon completion of the analysis.

If you would like to ensure you are included in the study or to arrange a specific time for Chris to come to your home, please contact him toll free at **1-888-675-2588** or via email at **vickc@engr.orst.edu**, and leave a message with your name, address, phone number and what day/time you would like him to sample your well.

The results of the study will be published in a thesis, but you can be sure that your name, address and phone number will be kept fully confidential.

In advance, thank you for your time and participation.

Sincerely,

John Selker, Ph.D.  
Professor, Bioengineering

September 12, 2003

Jeff Tweedy  
420 Uncle Tupelo Rd.  
Coburg, OR 97302

Dear Mr. Tweedy,

Earlier this year, I sampled your private water well as part of a study of shallow groundwater in the southern Willamette Valley. Thank you for your participation and support of my research project. All of the lab results are presented on the next page. I have also included an information sheet on nitrate. Please remember that all results will be published in a thesis project, but will not include your name or address.

It has been a wonderful experience meeting you and others in your community. If you have questions about the data, please contact me at my email address or phone number. If you are concerned about the levels of nitrate in your well and want more information, please contact OSU Extension Agent, Gail Andrews, at 541-737-6294 or [gail.glick.andrews@orst.edu](mailto:gail.glick.andrews@orst.edu).

Sincerely,

Chris Vick  
Graduate Student  
Department of Bioengineering  
Oregon State University  
[vickc@enr.orst.edu](mailto:vickc@enr.orst.edu)  
541-737-6311

## Well Chemistry

Address:

Well Identification Number:

Nitrate (mg/L):

Sulfate (mg/L):

Chloride (mg/L):

Bromide (mg/L):

Nitrite (mg/L):

Bicarbonate (mg/L):

Dissolved Oxygen: (mg/L):

Dissolved Oxygen (% Saturation):

Total Dissolved Solids (g/L):

Conductivity (mS/cm):

pH:

## 2003 OSU Extension Well Survey Form

Site Number: \_\_\_\_\_ Date: \_\_\_\_\_

Address: \_\_\_\_\_

Owner Name: \_\_\_\_\_

Phone Number: \_\_\_\_\_

---

### GPS Data:

Latitude (N): \_\_\_\_\_ Comments: \_\_\_\_\_

Longitude (W): \_\_\_\_\_

Elevation (m): \_\_\_\_\_

Land Use: \_\_\_\_\_

Visible Septic Field Y  N  If yes, distance from wellhead \_\_\_\_\_

Comments: \_\_\_\_\_

### Sampling:

IC Sample  Time: \_\_\_\_\_ Comments: \_\_\_\_\_

CAT Sample  Time: \_\_\_\_\_ Comments: \_\_\_\_\_

ISO Sample  Time: \_\_\_\_\_ Comments: \_\_\_\_\_

Temp \_\_\_\_\_ °C DO \_\_\_\_\_ mg/L TDS \_\_\_\_\_ g/L

Cond. \_\_\_\_\_ ms/cm pH \_\_\_\_\_

Time: \_\_\_\_\_ Comments: \_\_\_\_\_

Water Levels: Easy  OK  Difficult

Hangups: Y  N  at \_\_\_\_\_

Tools Needed: \_\_\_\_\_

Depth: \_\_\_\_\_ Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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General Comments: \_\_\_\_\_

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08/11/2003

## Leach Field Sampling

Sample # \_\_\_\_\_

Name: \_\_\_\_\_

Address: \_\_\_\_\_

Phone Number: \_\_\_\_\_

Date/Time: \_\_\_\_\_

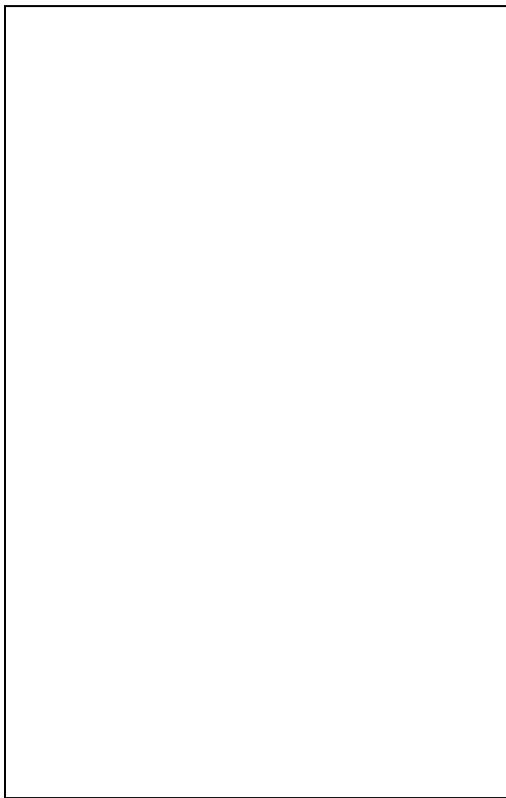
### GPS READING:

Lat:

Lon:

Elev:

Number of cores taken and locations:



Notes: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

