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Drinking Water Quality in the Southern Willamette Valley.

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The purpose of this study was to; (1) determine the extent of well water
contamination with nitrate and pesticides, and to understand the relationships among
nitrate, pesticide, dissolved chloride, dissolved sulfate, well age, and well depth in the
southern Willamette Valley, Oregon; and, (2) to investigate local residents' perceptions
and opinions regarding water quality issues. Three data sets were used. First, the
Oregon Department of Environmental Quality (ODEQ) sampled untreated well water
for nitrate contamination from 500 households in the winter of 2000-2001. Second, a
100 household subset of the original 500 households was re-sampled in the summer of
2002 to be tested again for nitrate and further analyzed for pesticides, dissolved sulfate,
and dissolved chloride. The third data set included responses to a mail survey from a
stratified subset of residents of the original 500 households whose well water was
sampled by the ODEQ.

Concentrations of nitrate during the 2000-2001 sampling period had a mean of 4.0
mg/L, and ranged from .05 to 22.6 mg/L in 476 sample wells. Concentrations exceeded

the national standard of 10 mg/L in 7.4% of these samples, which increased to 9.3% in wells less than 45 ft. deep. The mean nitrate concentration for wells sampled in 2002 was 10.8 mg/L, with 48% exceeding the national standard. Eighty-one of the 100 wells tested were found to contain at least 1 pesticide. The most common pesticides found were atrazine (73% of the wells) and its breakdown product desethylatrazine (80% of the wells). No significant association was found between nitrates 2000-2001 levels and either well depth or well age. Well depth and well age were found to have a statistically significant inverse relationship. Dissolved sulfate and nitrate (2002 sampling period) were significantly associated. Nitrate concentrations were not significantly correlated with any of the other independent variables.

The response rate for the surveys was 51%. Seventy-two percent of the respondents do not use a water treatment device and 28% use treatment devices. There was no difference in the use of water treatment devices based on nitrate concentrations in the well water. Respondents who used activated charcoal treatment devices had significantly lower nitrate concentrations than respondents who used reverse osmosis treatment systems. There was no significant relationship between respondents' description of well water quality and nitrate concentrations. However, respondents who did not own agricultural land were more likely than those who owned agricultural property to indicate concern over agricultural fertilizer and pesticide use harming well water quality. No significant relationship was found between nitrate contamination levels and the frequency of septic tank pumping, the distance of the septic tank from the well head, or the distance from the septic tanks drain field. Nitrate contamination levels were found to be significantly different between geologic units. Nitrate levels in

geologic unit Qg_l were significantly higher than all other geologic units, with the exception of Qalc. Typically, households located in areas where the Holocene alluvium of the Willamette River and the Pleistocene sand and gravel post-Missoula flood deposits dominated the geologic structure were at greater risk of high nitrate contamination levels.

An Analysis of Well Water Quality and Local Residents' Perceptions of Drinking
Water Quality in the Southern Willamette Valley

By
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Aaron C. Kite-Powell, Author

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INTRODUCTION

Concerns over the sustainability of our water resources are a strong motivation for an effort to better understand the consequences of water quality and usage problems. Groundwater contamination is one of the leading areas of concern for many regions of the world, particularly those areas with limited supplies. In the United States it is estimated that 50% of the population uses groundwater for drinking water. This figure is typically as high as 90% in rural populations (Office of Technology Assessment, 1990). In Oregon, over 70% of the state's population uses groundwater at least some of the time, and 95% of the rural population is dependent on groundwater resources (Oregon Department of Environmental Quality, 2001). The number of people who rely on groundwater is expected to increase over time due to increases in the population of rural areas. Although much of the population is dependent on groundwater for their drinking water, the majority of Oregon's groundwater is used for irrigation of agricultural lands.

As a result of limited monitoring, very little is known about the quality Oregon's groundwater. As of 1999, Oregon's Department of Water Resources has evaluated 15% of the state's groundwater resources; in addition, only 6.4% of the state has had groundwater quality studies performed (Oregon DEQ, 1999). Some data exist from individuals selling property with a private well, because of legal requirements to test for nitrates and total coliform bacteria when selling a property.

Groundwater underneath areas of intense agricultural activity can be particularly susceptible to non-point source contamination from the widespread use of fertilizers and

pesticides in the agricultural industry. Some of the more stable chemicals can be dissolved in rain, or irrigation water, and carried into the underlying aquifer. Overall, groundwater moves very slowly, but depending on soil, geological, and chemical characteristics, the actual rate of groundwater flow will vary.

Contamination of groundwater with nitrate and pesticides is the focus of much attention throughout the country. In Oregon, the two most common groundwater contaminants are nitrate and pesticides, followed by volatile organic compounds and bacteria (Eldridge, 2002). Due to its water solubility and ability to persist and accumulate in the groundwater for decades, nitrate is one of the more problematic and widespread of the contaminants. Sources of nitrate contamination are nitrogen fertilizers, septic systems, animal feedlot operations and barnyards, and application of wastewater to the ground.

Nitrate was first found to be a cause for concern because of the harm it causes infants. When infants less than six months of age consume excessive amounts of nitrate in drinking water they are at risk of developing methemoglobinemia, or "blue baby syndrome." In the 1940s, Minnesota experienced a 30-month time period during which there were 144 recorded cases of infant methemoglobinemia, and of those, 14 were fatal (Johnson et al., 1990). More accurate estimates of methemoglobinemia incidence could be made if states' departments of health required mandatory reporting. Since the time groundwater contamination with nitrate was correlated with incidence of methemoglobinemia in the 1940s, its incidence in the United States has declined, although it is still a serious threat to areas in the developing world. Nitrate, or metabolic compounds derived from it, have more recently been associated with

prematurity and intrauterine growth restriction (Bukowski et al., 2001), recurrent respiratory tract infections (Gupta et al., 2000), non-Hodgkin's lymphoma (Weisenberger 1991), bladder cancer (Weyer et al., 2001), hypertrophy of the thyroid (van Maanen et al., 1994), gastric cancer (Cuello et al., 1976), spontaneous abortions (MMWR, 1996), and the formation of mutagenic compounds.

In 2000–2001 the Oregon Department of Environmental Quality (DEQ) selected an area in the southern Willamette Valley between north Eugene and Albany, Oregon, as part of an extended look at groundwater contamination. The boundaries of the study area include the Cascade Range to the east, the Oregon Coast Range to the west, the Salem Hills to the north, and the city of Eugene's urban growth boundary to the south. This area roughly approximates the limits of the Quaternary alluvium in the southern Willamette Valley, which is also known to contain a sensitive aquifer (Eldridge, 2002). In this study they collected approximately 500 groundwater samples from domestic wells and tested them for nitrate. While reviewing this data, the DEQ chose to resample 100 of the initial 500 wells because they exhibited higher than expected contamination levels in relation to the other wells sampled. This second sampling event took place during the spring and summer of 2002. In addition to retesting for nitrate, these wells were also tested for, dissolved chloride, dissolved sulfate, and a variety of pesticides.

Purpose of the Study

The purpose of the study was twofold: (1) to research the concentrations and associations between nitrate, selected pesticides, dissolved chloride, dissolved sulfate well depth, and well age in residential wells from an area within the southern Willamette Valley; and, (2) to survey the residents whose wells were sampled to

determine their attitudes and perceptions of drinking water quality. The region in the Willamette Valley between north Eugene and Albany has been under intensive agricultural production for many decades. This area also has many older homes that rely on well water, and often the wells are shallow (< 75 ft. deep). Current data indicate extensive groundwater pollution from nitrate in some areas within this region.

Research Questions

1) What water treatment devices, if any, have participants installed in order to treat contaminated well water?

2) Is there a relationship between participants' concerns about their drinking water quality, and levels of contamination in their drinking water?

3) Is there a relationship between the frequency of septic tank pumping and contamination with nitrate?

4) What is the spatial relationship between nitrate contamination and geologic units?

Research Hypotheses

1) There is no relationship between the nitrate levels found in the 2000-2001 study and the following independent variables: well depth, and well age.

2) There is no relationship between the nitrate levels found in the 2002 study and the following independent variables: dissolved chloride, dissolved sulfate, atrazine, well age, and well depth.

Significance of the Study

The contamination of the groundwater with nitrate is an ongoing problem, especially in agricultural areas. The majority of residents in rural agricultural areas depend on clean groundwater supplies as their primary source of drinking water. Within the southern Willamette Valley there have been a limited number of large-scale surveys that follow high quality control/quality assurance standards to assess drinking water quality, and there have never been questionnaires sent to area residents to ascertain this population's knowledge, perceptions, and drinking water practices. Due to the potential for adverse impacts on the population's health from well water contamination, it is important to understand the contamination levels, their distributions, changes in these parameters in comparison to previous studies, and the relationship among contaminants in well water. This data would likely improve the scientific basis for making future policy decisions.

Assessments of natural resources often focus on the technical aspects of a particular situation. An integrative approach to the management of groundwater resources should also include an assessment of the affected population's knowledge, perceptions, and drinking water practices. Past studies have shown that there is not always a concordance between actual risks and the publics' perception of that risk (Burger et al., 1997). This study was designed to measure participants' perceptions of well water quality, the influence of land use on well water quality, the performance of various parties in the management of well water quality, and personal water use practices. Gaining a better understanding of the population's perspective will help management agencies to make better decisions on public education, manage potential

conflicts of opinion among stakeholders, build consensus, and help guide their approach to forming future water quality regulations.

Delimitations

1) The analysis of well-water samples focused on the region in the southern Willamette Valley between north Eugene and Albany.

2) The participants selected to complete the questionnaire represented a subset of those individuals whose well-water was sampled by the Oregon Department of Environmental Quality.

Definition of Terms

Aquifer: An underground layer of porous rock, sand, or gravel that is saturated with water and capable of yielding water to a well or spring.

Groundwater: Water that occurs in an underground layer of porous rock, sand, or gravel.

Methemogloin (metHb): A type of hemoglobin that contains an oxidized form of iron incapable of combining with and transporting oxygen.

Non-point source: A reference to the origin of a pollutant or contaminant; a source that has a diffuse origin, not any one place.

N-nitroso compounds: Category of chemical compounds formed by the reaction of nitrates, nitrites, or nitrogen-oxide precursors with amides or amines to produce nitrosamines and nitrosamides; compounds that are found in the environment and which have been shown to be formed in animal bodies, including humans. N-nitroso compounds are known to cause cancers in many animal species and are suspected of causing cancers in humans.

Southern Willamette Valley: The lowlands of the Willamette Valley extending from Eugene to Albany in Lane, Benton, and Linn Counties. It is bounded on the east by the Cascade Range, to the west by the Oregon Coast Range, to the north by the Salem Hills, and to the South by the city of Eugene's urban growth boundary.

Alluvium: sediment deposited by flowing water, as in a riverbed, flood plain, or delta.

Quaternary: of, belonging to, or designating the geologic time, systems of rocks, and sedimentary deposits of the second period of the Cenozoic Era from the end of the Tertiary Period through the present, characterized by the appearance and development of human beings and including the Pleistocene Epoch and the Holocene Epoch.

Fluvial: of, relating to, or inhabiting a stream or river.

Lacustrine: of or relating to lakes.

Clast: a rock fragment or grain resulting from the breakdown of larger rocks.

Facies: a rock or stratified body distinguished from others by its appearance or composition.

LITERATURE REVIEW

This next section includes the background and context necessary to have a full understanding of the research topic. It is organized into the following sections: (1) a brief history the area, (2) the geology and hydrogeology of the region under study, (3) land use patterns, (4) understanding the nitrogen cycles and nitrate contamination in the soil and groundwater, (5) human exposure to nitrate, (6) the health effects of nitrate exposure, (7) and the use of public opinion surveys for groundwater issues.

History of Land Use Patterns in the Willamette Valley

Settlement of the Willamette Basin by non-Native Americans began with the establishment of an over-land route by Meriwether Lewis and William Clark in 1806. Native Americans made the Willamette Valley their home before then primarily because of the mild climate, and the abundance of water, game, and trees (Woodward et al., 1998). In 1806, Captain William 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). In 1825, Dr. John McLoughlin (sometimes referred to as the father of Oregon) and a party of Hudson Bay fur trappers built a trading outpost near the confluence of the Columbia and Willamette rivers. Soon after in 1829, Dr. McLoughlin allowed a group of French Canadian settlers to travel further south down the Willamette River to establish farms nearby what is today names St. Paul (Uhrich et al., 1999). Word of the long growing season, a wide variety of cultivatable crops, the level to gently rolling terrain, and rich soil, spread fast. By 1860 about

53,000 had started the long journey westward to Oregon via the 2,000 mile Oregon Trail (Uhrich et al., 1999).

The central contributor to the Oregon frontier development was the agricultural industry, and by the mid-1800s the Willamette Valley had begun to develop distinct regions of agricultural production. The northern Willamette Valley supported a variety of vegetable crops, potatoes, perishable produce, and dairy products. In the lowlands of the central Willamette Valley, grain crops, such as wheat and oats, were some of the largest and most important crops grown anywhere in the valley. Beef and swine were second largest agricultural product in this region (Uhrich et al., 1999). Farther south the farms were smaller and not as well established; the most common products included potatoes, grains, livestock, and swine. Aside from the agricultural industry, both forestry and mining also played a role in the later development of Oregon, and the Willamette Basin.

Geology and Hydrology of the Study Area

The southern Willamette Valley is a broad alluvial plain situated in northwestern Oregon. It is bounded to the west by early Tertiary marine sedimentary and volcanic rocks of the Coast Range, and to the east by Tertiary and Quaternary volcanic and volcaniclastic rocks of the Cascade Range (O'Connor et al., 2001). Within this area many tributaries and perennial streams drain the adjacent mountain ranges and valley into the Willamette River. As it flows northward on its way to the Columbia River, the Willamette River winds through an extensive lowland, typically below 150 m above sea level, that is approximately 18 to 30 miles wide (O'Connor et al., 2001).

Over extensive tracts of geologic time, the basins of the Willamette Valley have undergone significant change. Changes which have most influenced the dynamics of groundwater in today's southern Willamette Valley began with the agglomeration of roughly 500 m of Neogene and Quaternary fill from the surrounding mountains and the Columbia River Basin, and periods of tectonic lowering of the valley (O'Connor et al., 2001). Today this fill underlies the main valley and lowland floors, and contains most of the groundwater used in the Willamette Valley today. Generally, the valley sediments include fine-grain Miocene and Pliocene fluvial-lacustrine deposits at the bottom of the basins, and in the upper 0 to 100 m there are coarse-grained fluvial deposits of the Quaternary age, which originated from the Cascade Range and Missoula Flood sediment (O'Connor et al., 2001). As a result of the sequence of geological events and the processes of time, four major units of Quaternary-age sediment, which can be further divided into five distinct surficial geologic units, underlie the southern Willamette Valley. Each of these deposits has unique characteristics that can have a substantial influence over groundwater flow and soil characteristics. The following section will discuss the characteristics associated with the geological and hydrogeological units that are present in the southern Willamette Valley.

The Pleistocene sand and gravel was deposited during two separate periods, one before the Missoula Floods (Qg_2) and one after (Qg_1). Both periods of sediment deposition can be characterized as having channel instability, high sediment supply, having sediment derived from the Cascade and Coastal Ranges (O'Connor et al., 2001). In the southern Willamette Valley these coarse-grain proximal alluvial fan and braided stream deposits make up the majority of today's Willamette aquifer. The deposits are

typically located within the upper 10 to 50 m of fill throughout the lowland. In the valleys of major Cascade Rivers emptying into the Willamette lowland, the deposits are up to 100 m thick (O'Connor et al., 2001). How the groundwater moves through this geologic unit, as well as all others, is primarily a function of clast size and how the sediments have been sorted. The composition of these deposits varies from cobbly, sandy gravel in the tributary valleys to silt and sand in the distal portions of the valley lowlands (O'Connor et al., 2001). Secondary influences affecting hydrogeologic properties are the processes of compaction and cementation of the deeper and older deposits. Of the two Pleistocene deposits, unit Qg_1, which was deposited after Qg_2, is generally the more permeable of the two, because it has experienced less weathering and compaction (O'Connor et al., 2001).

The Missoula Flood deposits generally referred to as the Willamette Silt hydrological unit, also influence groundwater dynamics in the southern Willamette Valley. They are a result of multiple catastrophic floods from the Glacial Lake Missoula between 15 and 12.7 thousand years ago. This deposit is composed of bedded clay, silt, and sand that cover the central Willamette Valley in as much as 35 m of fine-grained sediment, but thins toward the margins and in the southern Willamette Valley where the deposits are less than 10 m (Woodward et al., 1998). The city of Harrisburg, Oregon is located near the southernmost section of this deposit; south of this location the geologic unit has little influence over groundwater flow. Where the Willamette Silt does exist, its thickness plays a significant role in groundwater recharge, discharge, and flow. Due to its fine-grained sediment, it forms a poorly drained, low-permeability hydrogeologic unit, which acts as a leaky confining layer above the sand and gravel it

overlays (Woodcock, 2002). Any precipitation, or for that matter irrigation, percolates through the top layers of soil, but then is slowed and held in large quantities for future discharge into surface waters and the Willamette Aquifer (Woodcock, 2002). It is only a minor source of groundwater for the valley population, but the clay and silt left behind by these ancient floods provide a rich substrate for agriculture (O'Connor et al., 2001).

The final geologic unit relevant to this study in the southern Willamette Valley is the floodplain deposit of the Willamette River and its major tributaries (Qalc). Along the lowland bottoms, and on either side of the Willamette River up to a width of ~ 6 km, the Willamette Silt unit has been eroded away, and in its place is the Holocene alluvium of sand, silt, and gravel (O'Connor et al., 2001). As with the Pleistocene sand and gravel units discussed earlier, Qg_1 and Qg_2, the Holocene alluvium of the floodplain constitutes a major portion of the Willamette Aquifer. This geologic unit is also governed by similar hydrogeologic characteristics; however, because it is much younger than Qg_1 or Qg_2, compaction and cementation have not had a major influence on groundwater dynamics. Generally, the coarse-grained facies are well sorted, loose, and can be expected to be quite permeable (O'Connor et al., 2001).

Modern Land Use Practices

Today agriculture production accounts for 22% of the land use in the Willamette Basin, second only to forested land (70%). In 1993 the Willamette Basin accounted for approximately 50% of the gross farm sales, which stemmed from approximately 200 different agricultural commodities (Uhrich et al., 1999). Agricultural commodities produced within the Willamette Valley are some of the most diverse in the United States. Oregon produced more grass seed, Christmas trees, blackberries, boysenberries,

loganberries, black raspberries, hazelnuts, and peppermint in 1992 than any other state in the Nation (Uhrich et al., 1999). Within the study area most of the crops are irrigated, and include grains, hay mint, hops, grass and vegetable seeds, fruits, nuts, and nursery crops. Even though the majority of the land in the Willamette Basin is covered in forest, significantly, 68% of the agricultural land is underlain by alluvial geologic units, which are generally expected to have moderate to high permeability (Hinkle, 1997). Livestock production is also common in the study area, and includes 33 confined animal feeding operations (CAFOs) permitted by the Oregon Department of Agriculture (Eldridge, 2002). The production of timber in Oregon has surpassed that of any other state in the nation since 1938, and the majority of this has come from within the bounds of the Willamette basin (Uhrich et al., 1999). Before World War II the extraction of minerals also played a significant role in the Oregon economy. However, today the only ore produced in the Willamette Basin is a small amount of gold. Most mining in the basin today is that of sand, gravel, and crushed rock, with a total of 28 million tons (3 million tons from waterways) (Uhrich et al., 1999). In comparison with the rest of the State, this makes up 53% of the total mineral production.

Fundamentals of Nitrate in the Environment

Nitrates make up a group of ubiquitous chemicals in the environment. These chemicals include ammonia (NH_3), ammonium ion (NH^+_4), nitrogen gas (N_2), nitrite ion (NO^-_2), and nitrate ion (NO^-_3). They exist in the air, soil, and water, are an integral component of proteins, and are essential to the normal growth of plants and animals. Nitrogen's movement and change in chemical form through the biosphere is called the nitrogen cycle. In the gaseous form, nitrogen makes up approximately 79% of the

atmosphere. For this gaseous form to be useful to plants and animals it must undergo a process called nitrogen fixation. Nitrogen fixation involves combining either an oxygen or hydrogen molecule with nitrogen to form organic nitrogen. The bacterium, *Rhizobium sp.*, lives in a symbiotic relationship inside certain plants' root systems and is responsible for performing this chemical process, which provides an organic form of nitrogen to plants (Nadakavukaren, 2000). Other types of nitrogen fixation include atmospheric fixation by lightening, and industrial fixation with fertilizer. Also an important aspect of nitrogen transformation is the decomposition of animal wastes, and dead plant or animal matter, which is the beginning of ammonification. This refers to the change from organic nitrogen to a mixture of ammonia and ammonia ion (Canter, 1997). The ammonia is then assimilated by plants and is utilized to form proteins. Ammonium ions are further transformed via a biological oxidation process called nitrification. This is a 2-step process; the first step involves the formation of nitrites – which are oxidized again to form nitrates. Nitrates are either taken up by plants to help form plant proteins, or are broken down (denitrification) by the actions of heterotrophic bacteria in the presence of an organic carbon source to form nitrogen gas that returns to the atmosphere (Canter, 1997).

Beginning in the early 20th century human intervention, through industrial nitrogen fixation, has played a significant role in changing the nitrogen cycle. The most influential human activities include vast cultivation of nitrogen fixing leguminous crops such as soybeans and alfalfa, and the industrial nitrogen fixation for fertilizer production (Nadakavukaren, 2000). The burning of fossil fuels further contributes to the amount of nitrogen released into the atmosphere.

Nitrate Contamination of the Groundwater

The occurrence of nitrate in the groundwater is most often associated with the following four sources, or combinations of them: 1) Waste water disposal/septic systems, 2) natural geological sources, 3) row crop agriculture, and 4) irrigated agriculture (Cantor, 1997). Non-crop agriculture such as concentrated livestock operations can also contribute large amounts of nitrate infiltrate to the groundwater. Agricultural sources of nitrate contamination of groundwater far exceed the overall amount of nitrate released from natural sources and septic system leakage (Puckett, 1994). Since the early 1950s green revolution agricultural practices have transformed traditional agricultural practices into large monoculture crops that rely heavily on agrichemicals. As a result, farm yields have increased dramatically, but at the cost of having to use large amounts of fertilizer, and pesticides. By 1960s the amount of fertilizer being applied by farmers in the U.S. had reached approximately 2.5 million tons, and by 1981 this figure had risen to as high as 11.9 million tons of fertilizer (Berry, 1994). After peaking at 12.6 million tons in 1994, fertilization rates actually decreased to 11.7 million tons in 1995.

Actual plant uptake of the nitrogen applied to agricultural lands varies considerably depending on the crop planted. Generally, for arable crops the percent that reaches the plants ranges from 40 to 60%, under current agricultural practices. In grasslands this percentage can reach as much as 80% recovery of nitrate (Thornton et al., 1999). This implies that as much as 50% of the nitrogen applied as fertilizer on agricultural lands will remain in the soil system, and is likely available to be leached into the groundwater. Since nitrate has a negative charge it does not easily bind to soil

particles, and instead moves through the soil with water. As a result, the time of year with the highest rainfall and/or irrigation is the period when unused nitrogen from the last summer crop is most likely to percolate into the underlying soil and groundwater (Feaga et al., 2002). Some studies conducted in the last decade have shown that significant reductions in fertilizer rates can be made without endangering crop yields (Hallberg, 1991). In 1993 the Board on Agriculture of the National Research Council of the National Academy of Sciences reviewed the issue of excessive fertilization rates and concluded that each year in the U.S. there are six to nine million tons more nitrogen fertilizer added to crops than can actually be utilized (EWG, 1996). In light of this, it is tempting to apply standard rates of fertilization that will maximize plant growth and minimize environmental contamination, however; natural processes and seasonal variations make this approach difficult (Feaga et al., 2002). A comprehensive formula for calculating nitrogen efficiency in a given crop should sum the sources of nitrogen, including fertilizer N, residual mineral N, mineralization of organic N, and N from irrigation or rainfall, which is then be divided by total N in a the mature crop (Feaga et al., 2002). All of these factors should be included because up to a half of available nitrogen can come from sources other than nitrogen fertilizer. For instance, after harvest, broccoli, hops, and grass seed crops leave more nitrogen in the crop residue than is taken in the harvest (Feaga et al., 2002). The difficulty is in accurately measuring the other sources of nitrogen all ready in the soil so that fertilization rates can be properly adjusted.

As a result of these problems, more attention is being paid to sustainable agricultural practices that account for the protection of groundwater quality. Some

agricultural practices that could be used to reduce the amount of nitrate reaching the groundwater include, no autumn nitrogen application, crop rotation, stream buffers, control of invasive species, nitrification inhibitors and slow release nitrogen, improvement in irrigation system performance and management, prevention of aquifer contamination at the wellhead, irrigation scheduling, the establishment of realistic yield goals, frequent testing of soil, adjusting nitrogen fertilization rates to account for existing soil nitrogen, and plant tissue testing (OSU Department of Bioengineering). More information on best management practices is available in Appendix E.

Of all the forms of nitrogen, nitrate is the most soluble, and leaches easily into the groundwater. The downward movement of nitrate through the soil strata is influenced by a number of factors and agricultural practices. These include, hydrogeological factors, the physical structure of the soils (fine-grained vs. coarse-grained), chemical structure of the soils (redox potential), amounts of precipitation in the region, irrigated verses non-irrigated crops, and the type of crop (Thornton et al., 1999). These factors may help explain the spatial and temporal variability in contamination patterns. The risk of groundwater contamination is generally higher when regional characteristics include irrigated agricultural land use, a permeable soil structure (coarse grained soils), and the presence of an unconsolidated aquifer. However, the absence of one or more of these factors may alter the rate of nitrate movement through the soil, and delay or prevent the contamination of underlying groundwater reserves. A study of shallow groundwater quality in the Willamette Basin found that water underlying a large cumulative thickness of clay soil might be representative of water that was recharged longer ago. Water in this area was

associated with lower nitrate concentrations, which is likely to be related to lower nitrate fertilization rates in the past, and/or the soil's ability to reduce nitrate into nitrogen gas that escapes into the atmosphere (Hinkle, 1997). Depending on the depth of the well tested, it is also possible that the vertical flow of the nitrate is very slow, which has delayed the contamination of groundwater in that area. Some studies have also suggested that shallower wells are associated with increased levels of well water contamination (Squillace et al., 2002, Kross et al., 1993, Mitchell et al., 1996). Research conducted by Squillace et al. (2002) has found a consistent relationship between shallower well depths, unconfined aquifers, and the occurrence of volatile organic compounds, pesticides, and anthropogenic nitrate, in domestic wells throughout the United States.

Nitrates are often not the only contaminant in groundwater. Pesticides are used extensively in agricultural areas, and are significant sources of non-point source groundwater contamination. Along with the increased use of pesticides for both agricultural and nonagricultural purposes, the last few decades has shown an increase in the detection of pesticides in groundwater. Nationwide, about 143 pesticides and 21 pesticide byproducts have been detected (Barbash et al., 1994). Pesticides that have been detected most frequently are typically those used in the greatest amounts, and include the triazine and acetanilide herbicides (atrazine, simazine, alachlor, and metolachlor). Others that are known to be widespread groundwater contaminants include aldicarb and its byproducts, DBCP, and ethylene dibromide (Barbash et al., 1994).

Some of the factors that increase the likelihood of nitrate contamination are also influencing the occurrence of pesticides, such as; high agrochemical use on surrounding land, high groundwater recharge by precipitation or irrigation, high soil permeability, and unconfined aquifers (Williamson et al., 1998).

Groundwater studies typically use nitrate as an indicator for groundwater quality due to its stability and solubility in water. Nitrate concentrations above 3 mg/L in the groundwater are representative of anthropogenic sources (Madison et al., 1985). A few studies have noted a relationship between the detection of nitrates and the occurrence of pesticides in well-water samples. In a United States Geological Survey (USGS) study of groundwater quality in the Willamette Basin, it was found that nitrate concentrations in samples that also contained pesticides were statistically greater than nitrate concentrations in samples without pesticides (Hinkle, 1997). Another study conducted by the Washington State Department of Health and the USGS also looked at nitrate and pesticide co-occurrence, and found a correlation between nitrate concentrations at or above 2.7 mg/L and pesticide detection (Williamson et al., 1998). In this study, pesticides were detected in 58% of the wells with a nitrate concentration of 2.5 mg/L or more, whereas pesticides were found in only 28% of the wells with nitrate concentrations less than 2.5 mg/L (Williamson et al., 1998). Conversely, the Illinois State Water Survey assessed the extent to which nitrates and pesticides were contaminating wells in agricultural areas, and found no correlation between the elevated nitrate levels and the presence of pesticides (Charbeneau, 1995).

In another study conducted by the USGS it was found that volatile organic compounds and pesticides were detected without the presence of nitrate in 43% of the

samples analyzed (Squillace et al., 2002). Squillace et al. (2002) raise the point that commonly found pesticides in a particular region may be a better screening tool than nitrate. The example suggests that the presence of atrazine or desethylatrazine predicts the presence of other pesticides up to 82% of the time (Squillace et al., 2002). The differences in these findings are probably related to unique characteristics associated with the regions the studies were conducted, and should not be indicative of other regions. Complicating factors that could modify these findings include the type of pesticides used in the regions, the relative amounts dispersed on the land, and their chemical behavior in the soil system. If nitrate contamination were found to consistently predict the presence of pesticides at certain concentrations, it would reduce the costs of having to analyze for both nitrates and pesticides in domestic well-water analyses. Similarly, testing for one pesticide commonly used in the region may also be an efficient means of screening for more general pesticide contamination.

Correlations among nitrates, dissolved chloride, and dissolved sulfate will also be analyzed. It has been suggested that nitrate, dissolved sulfate, and dissolved chloride would occur together because they have some common sources, nitrogen-based fertilizers (ammonium sulfate) and chloride from the application of potassium chloride (Hinkle, 1997). Poorly maintained septic systems and animal wastes might also contribute to levels of both nitrate and chloride. Dissolved sulfate in the groundwater may be from natural sources; however, many nitrogen-based fertilizers are combined with sulfate to produce ammonium sulfate (IDEQ, 2001).

Human Exposure to Nitrate

Exposure to nitrate occurs through three primary paths, which include ingestion with contaminated drinking water, ingestion with food, and from endogenous synthesis; and, as a result exposure is highly variable and predominantly dependent on the safety of the water source and dietary patterns. Nitrate is one of the most commonly detected pollutants in water systems. It has been estimated that as many as 4.5 million people in the United States consume water that has been contaminated with nitrate at levels exceeding the EPA's 10 mg/L standard (Nolan et al., 1998). In northeastern Oregon a study was conducted that assessed the population's exposure to various levels of nitrate in drinking water. The results of the study found that 57% of the population was exposed to nitrate concentrations between 0.2 and 4.9 mg/L nitrate-N, and 23% were exposed to concentrations from 10.0 to 40.0 mg/L nitrate-N (Mitchell et al., 1996). The Environmental Working Group (EWG) reviewed 150,000 test results for nitrate at the community water level, and found 1,077 water systems where the source of drinking water exceeded 10 mg/L since 1993. These wells served approximately 12.4 million people (EWG, 1996). The majority of these detections occurred in community water system wells that were located in areas with large amounts of agricultural activity. Groundwater samples from 1255 domestic wells distributed across the U.S. were taken by the USGS as a part of the National Water-Quality Assessment (NAQWA) from 1992 to 1999. The results of this study indicate that 11% of the domestic wells tested above the EPA's 10 mg/l limit for nitrate-N (Squillace et. al., 2002). Since the 1980s Iowa's state laboratory has tested 10,000 to 12,000 water samples per year for nitrate, with most of the samples coming from private wells. Throughout this time period analyses

have consistently found that 15% to 24% of all well samples have exceeded the recommended health advisory for nitrate. A statewide study of 104 wells in Kansas also found that 28% of the nitrate levels exceeded the 10 mg/l health advisory (Kross et. al., 1993). The most recent assessment of groundwater quality (following high quality control standards) in the Willamette Basin, Oregon was conducted in the summer of 1993 by the USGS. Seventy domestic wells less than 75 ft. deep were chosen throughout the Willamette Basin using a random process, with the majority of the wells located in agricultural areas. The results of the study indicate that 9% of the wells exceed the EPA's health advisory for nitrate (Hinkle, 1997).

Dependent on how food is grown or processed, it may also be a significant source of nitrate/nitrite. Vegetables, including spinach, beets, collards, kale, and Chinese red and white cabbage, can be significant sources of nitrates in the diet. These vegetables also contain antioxidant vitamins and pigments that serve to reduce the amounts of potentially harmful levels of nitrate or nitrite consumption.

Before the addition of nitrites was prohibited, meats were a particularly common source of nitrites in the diet. Nitrite is added to processed meat products in order to maintain the reddish color of the product, to maintain the texture of a product with a long shelf life, and to inhibit the growth of anaerobic bacteria (Epley et al., 1992).

Nitrates can also be formed endogenously. One study shows that excretion of nitrate in humans exceeded the amount of ingested nitrate (Tannenbaum et al., 1978). Some of the absorbed nitrate from foods and water is transported to the salivary glands were it is secreted in the saliva. Of the amount of nitrate excreted in the saliva, some is then reduced to nitrite. It is estimated that 80% of the nitrite that enters the stomach

comes from reduced salivary nitrate. Although, it is considered less significant than dietary intake of nitrite because it does not consistently increase the gastric nitrite levels when nitrosatable compounds are available (van Loon et al., 1998).

Human Health Risk Associated with Exposure to Nitrate

The predominant health concern associated with excess nitrate intake is methemoglobinemia, or "blue baby syndrome". This condition usually affects infants less than 6 months old due to unique physiological factors in that age group. These factors include a higher pH in their digestive system that allows increased numbers of bacteria to convert nitrate to nitrite. Also, infants lack the enzyme methemoglobin reductase that reduces the methemoglobin to hemoglobin in the blood (Knobeloch et al., 2000). As levels of methemoglobin in the blood increase, the amount of oxygen delivered to the tissues decreases. This conversion of hemoglobin to methemoglobin usually begins to occur when 10% of the available hemoglobin is converted (Canter, 1997). To help reduce incidence of methemoglobinemia, water quality standards for nitrate were set at 10 mg/L. This is based on the observation that increases in methemolgobin levels in the blood begin to occur at levels of 10 to 20mg/l nitrate. Since these standards have been implemented it seems that fewer cases of methemoglobinemia have been reported. However, it is not required that methemoglobinemia be reported to state or federal health agencies, so it is difficult to be sure. Some researchers have also suggested that illness or death due to nitrate-induced methemoglobinemia often goes unrecognized or even misdiagnosed as congenital heart disease or sudden infant death syndrome (Johnson et al., 1990).

Surprisingly little is known about the chronic or reproductive health outcomes resulting from the ingestion of nitrates, even though 2 million U.S. families are exposed to levels higher than 10 mg/L (EWG, 1996). Some researchers suggest that pregnant women should be advised not to drink contaminated water. This is in response to a study in Indiana that found high nitrate levels in wells used by pregnant women who experienced miscarriages (MMWR, 1996). Consumption of nitrates has also been associated with the incidence of gastric, bladder, non-Hodgkin lymphoma, brain and central nervous system cancers, and ovarian cancer (Xu et al., 1992; Morales-Suarez-Varela et al., 1995; Yang et al., 1998; van Maanen et al., 1996; Mueller et al., 2001; Weyer et al., 2001). Due to particular study designs, conflicting studies, and lack of consistent reproducibility, there is significant uncertainty in the interpretation of these results. The proposed mechanism in these instances is related to the simultaneous ingestion of nitrite or nitrate and amines, which results in the formation of nitrosamines in the stomach. The most potent of the nitrosamines are dimethyl- and dithethylnitrosamine, both of which have caused liver and kidney tumors in rats (Shibamoto et al., 1993).

Endogenous nitrosation has been shown in human populations by using the NPRO test. This test has shown a consistent association between nitrate intake and endogenous nitrosation of proline, particularly in area with high rates of gastric cancer (Ohshima et al., 1981; Møller et al., 1989). Studies in which food frequency questionnaires have been used have shown a small protective effect of estimated nitrate intake and gastric cancer (van Maanen et al., 1996). It is assumed that this is due to the presence of antioxidants in the diets of the study population. Studies of populations

exposed to high levels through their well water, without concurrent high antioxidant intake from foods, have shown neoplastic changes in the stomach tissue (Xu et al., 1992). Another study evaluated the use of the HPRT (hypoxanthine-guanine phosphoribosyltransferase) variant frequency (VF) test in lymphocytes as a biomarker for genetic risk of humans consuming different levels of nitrates in their drinking water. This study concluded there was a genetic risk associated with drinking water contaminated with high levels of nitrate (van Maanen et al., 1996).

So far the majority of the studies have focused only on exposure to nitrates, even though part of the difficulty in interpretation of some of these studies is that nitrates are typically not the only contaminant present in groundwater. Often groundwater in agricultural areas is contaminated with pesticides as well. An ecologic study in Ontario, Canada evaluated the relationship between atrazine and nitrate in the drinking water and incidence of gastric cancer. This study found an association between atrazine and colon cancer, but no relationship with nitrates and/or gastric cancer (Van Leeuwen et al., 1999). The authors acknowledge that the limited number of samples studied may have confounded the outcome, and that there was no direct testing of the water supplies or individuals. Another study tested endocrine, immune, and behavioral effect of aldicarb (carbamate), atrazine (triazine), and nitrate mixtures at groundwater concentrations. The animals used were wild deer mice. Researchers found that doses of single compounds at the MCL had no effect, but found significant changes when various mixtures were tested (Porter et al., 1999). The authors give "special significance" to any mixture containing nitrates with one or both of the pesticides in relation to aggression scores, effects on body mass, effects on thyroid hormone balance, effects on

antibody production, and effects on final spleen weight (Porter et al., 1999). Currently there is little known about the biological effects of commonly found pesticide and fertilizer mixtures, especially in human populations.

Public Opinion Surveys and Well Water Quality

Few published surveys address the specifics of participant's opinions and perceptions of well water quality issues. Most reports are designed for a broader set of environmental concerns, water quality concerns and/or natural resource management issues. A number of national surveys of public attitudes about health and the environment by the Roper Association Inc. in 1990 found a slow but consistent increase in the consumption of bottled water as a substitute for tap water (Baxter, 1990). The reported concern in these surveys was over the purity and safety of their tap water, and not the taste of the bottled water. The nonprofit organization, "Public Voice for Food and Health Policy", conducted a national telephone survey in 1993 that surveyed American opinions concerning agrichemicals. Their results suggest that Americans' concern over agrichemicals negatively impacting the environment and public health is very strong and widespread, even exceeding recent publicity over food safety problems with bacterial contamination of meats (Morris et al., 1993). When asked their level of concern about agrichemicals contaminating water supplies, 71% of participants responded as being very concerned (Morris et al., 1993). Similarly, a 1996 survey of students and staff at Rutgers University studied participants' level of concern and perceived risk of a broad range of environmental issues. The environmental issues could be broken into a number of categories, including general ecological problems (cutting down of rainforests, polluting groundwater, trash along coasts, lead in drinking

water, and acid rain), radon and nuclear waste, fertilizers and pesticides, and electromagnetic waves (Burger et al., 1997). An overall ranking of the results placed concern of groundwater pollution as the most pressing issue; however, concern over fertilizers/pesticides were ranked among the three lowest (Burger et al., 1997). According to a national survey conducted by the Water Quality Association in 1999, a national trade association, nearly three-quarters of Americans are concerned about their water supply's safety. This association also reports a 28% increase in the use of household water treatment systems between the years 1995 and 1999, and no concurrent increases in bottled water use (Water Quality Assoc., 1999).

Studies in Canada have also indicated an increasingly concerned public with regard to drinking water quality. A study in 1981 by the Environmental Health Directorate of Health and Welfare Canada found 14% of 970 participants were not satisfied with their water quality (Auslander et al., 1993). A more recent version of this survey in 1988 only showed a 4% increase in concern over water quality. In Toronto, Canada, studies in 1983 and 1988, conducted by the Department of Public Health, showed an increase in daily bottled water use from 6% to 14% respectively, and an increase in point-of-use treatment devices from 1% to 11% (Auslander et al., 1993). In both studies the predominant reason given for the use of alternative water sources was attributed to concern over the healthfulness of the water.

One study in the state of Wisconsin used a survey that was particularly similar to survey questions used in this study. The purpose of the study was to ascertain the public response to elevated nitrate levels in drinking water wells in Wisconsin. The study found that families living on farms using older and shallower wells were most

susceptible to being exposed to higher levels of nitrate in their drinking water (Schubert et al., 1999). Also an important finding was that a majority of the families continued to use the nitrate contaminated well water as their primary source of drinking water, and they used it without implementing any measures to reduce their nitrate exposure (Schubert et al., 1999). The greatest percentage of families who did take some action to reduce their level of nitrate exposure made up the lowest income group (i.e., < $25,000/y).

METHODS

Subject Selection

This study used information from three data sets. The first data set consisted of 500 households in the southern Willamette Valley (parts of Linn, Benton, and Lane counties) that had their drinking water wells sampled by the Oregon Department of Environmental Quality (ODEQ) in 2000-2001 for nitrate concentrations and well depth. These wells were chosen by the ODEQ using a type of convenience sample called judgment-sampling (Lohr, 1998), indicating that the households were chosen based on previous research that suggested there was a well water contamination problem in this area. While this will tend to bias the data toward higher nitrate contamination, the overall spatial distribution of wells sampled within this region is broad.

The second data set consisted of a re-sampling of 100 households chosen from the original 500. These households were re-sampled because higher than expected values of nitrate were found in the original sampling event. The data included in the re-sampling were nitrate levels, pesticide levels, dissolved chloride, and dissolved sulfate.

The third data set consisted of responses to a mail questionnaire from residents of the original 500 households whose water was sampled by the ODEQ. The households were separated into three groups based on the level of nitrate contamination. The groups include low nitrate (0 – 2.99 mg/l), medium nitrate (3 – 9.99 mg/l), and high nitrate (10 – 28 mg/l). Of the entire list of households, 228 were grouped into the low nitrate group, 214 were grouped into the medium nitrate group, and 34 were grouped into the high nitrate group. Due to cost constraints the total number of questionnaires

sent to participants was limited to 200 households. This total was separated into a random sample of 83 low nitrate households, and 83 medium households. All 34 households included in the high nitrate group were sent a questionnaire. All data sets originate from the initial 500 wells in the southern Willamette Valley sampled using judgment-sampling methods.

Sample size calculations ensuring 95% confidence for the questionnaire indicate the minimum number of returned questionnaires must be 85 out of 200 questionnaires. Before sending the survey the list of 500 households were verified for any invalid entries.

Materials: Survey Development

Knowledge, concerns, and practices regarding well water quality were measured using a questionnaire developed for use in this study. A review of the literature did not find an existing instrument that could be used to measure these parameters in relation to well water quality. As a consequence, a variety of instruments that measured public opinion in relation to other natural resource issues were reviewed, and questions were adapted to address the specific concerns of well water quality in the southern Willamette Valley. The mail questionnaire collected information regarding population demographics, socioeconomic status, participant's association with the area under study, participant concerns regarding drinking water quality, participant's opinions of water resource management by certain sectors of society, and specific information on the participant's water system and usage practices. This survey was developed with the help of the Oregon State University Survey Research Center, senior hydrologists from the ODEQ, an O.S.U. extension water quality specialist, and the groundwater

coordinator in the Department of Human Service's Drinking Water Program (Appendix A). In order to improve the instrument's validity and reliability, the survey was pilot tested by 10 Corvallis area residents who rely on well water for their drinking water. Suggestions recommended by the participants were incorporated into the final survey questionnaire. This included the deletion of 2 questions, and the rewording of an additional 2 questions to increase their clarity. The Institutional Review Board for the Protection of Human Subjects approved the study.

A letter to introduce the participant to the survey was sent one week prior to the survey mailing (Appendix B). Included with the survey mailing was a detailed letter explaining the nature of the study, indicating how their households were selected, and informing them that their participation was voluntary, and that their answers would be kept confidential (Appendix C). A reminder letter asking participants to complete the survey if they have not already completed it was sent out one week after the initial mailing (Appendix D).

Sampling Equipment and Protocol

All field sampling and laboratory analysis, including sampling procedures, sample documentation and custody, sample transport, laboratory data QA/QC, equipment calibration and maintenance, performance audits, and confirmatory sampling requirements were conducted according to the standard procedures outlined in Oregon's Statewide Groundwater Monitoring Program Master Plan (Eldridge, 2002). All laboratory analysis, with the exception of pesticide analysis, was performed in the ODEQ laboratory in Portland, Oregon. Pesticide analysis was conducted in the Oregon Department of Agriculture laboratory.

The ODEQ field staff and I conducted the following tests: Temperature, conductivity, and pH were analyzed using the YSI-conductivity and temperature meter; and, Beckman-ϕ 200 pH meter and thermometer. Both of these measurement tools use EPA approved methods, and were calibrated before each sampling event. All water samples were taken from the wellhead or from the spigot nearest to the wellhead 5 minutes after purging the water system from previous usage. Identical methods were used in the 2000-2001 and 2002 sampling periods.

Data Analysis

The data collected from the initial 500 well water samples, the subsequent re-sampling of 100 wells, and the questionnaire data was analyzed using descriptive statistics, probability plots, the Levene test of homogeneity of variance, and the Kolmogorov-Smirnov statistic to determine the distributional characteristics of the data. Descriptive statistics showed means, medians, proportions, frequency distributions, and cross tabulations.

Prior to analyzing each research question and research hypothesis the distributional characteristics of the data were considered in order to determine whether parametric or nonparametric tests were most appropriate. The statistics used for analyzing the research questions included the Mann-Whitney U test, Kruskal-Wallace test, one-way analysis of variance, and the chi-square test of independence. The strength of the relationship for the Kruskal-Wallace test is measured by an index known as epsilon-squared, and to determine the nature of the differences a Mann-Whitney U test was used. To measure the strength of the relationship for the chi-square test of

independence, the Cramer's statistic was used. Analyses using an analysis of variance test were followed by a Tukey's HSD to discern where the differences are.

The statistic used in the analysis of 2000-2001 and 2002 well water variables, including research hypotheses 1 and 2, was the Pearson's correlation coefficient (r). To improve the distributional characteristics of the data, all variables in this analysis were transformed using a natural log base e transformation.

To measure the differences in nitrate contamination levels in households that have had both a winter nitrate test and a summer test to look for seasonal variation, the paired samples t-test was used.

All statistical analyses were conducted using SPSS v.11 (SPSS Inc., 2001). A two-tailed alpha level of 0.05 was used to evaluate the significance of all statistical tests. A spatial representation of nitrate levels and area geological/hydrogeological units was created using Arview GIS 3.2a software (Esri Inc., 1996).

RESULTS

This chapter discusses the results of the study. It is divided into an introductory section on descriptive statistics of the well water sampling parameters, survey population descriptive statistics, and followed by the results to the research questions and hypotheses.

Descriptive Statistics of Well Water Parameters

From 12/00 to 04/01 participants from 500 households in the southern Willamette Valley (S.W.V.) allowed the Oregon Department of Environmental Quality (ODEQ) to test their well water for nitrate. Information on well depth was also collected for 279 of the wells tested. Of the 500 households 476 water samples yielded valid results. The data indicate that 47.7% of the samples had nitrate levels that were less than 3 mg/L nitrate-N, 45% of the samples fell between 3 and 10 mg/L nitrate-N, and 7.4% of the samples exceed the national standard of 10 mg/L nitrate-N. The percentage of nitrate levels exceeding 10 mg/L increases to 9.3% in wells 45 ft. deep or less. The mean nitrate-N level for this sampling period was 4.08 mg/L, and detection levels ranged from 0.01 to 22.60 mg/L. The mean well depth was 52 ft., and ranged from 8 ft. to 325 ft. In this study, wells less than 75 ft. deep were classified as shallow wells, which accounted for 86% of the wells in the study.

A second sampling period that included 100 households, 90 of which were a part of the first sampling period, occurred from 05/02 through 07/02. These well water samples were analyzed for nitrate, pesticides, dissolved chloride, and dissolved sulfate. Table 1 provides descriptive statistics for the most commonly found parameters measured during both sampling periods. Data from the second sampling period

	Total N	Mean	Median	Min.	Max.	Std. Dev.	Health Standard
Nitrate-N 2000-2001 (mg/L)	476	4.1	3.3	.05	22.6	3.9	10.00 mg/L
Nitrate-N 2002 (mg/L)	100	10.8	9.9	.05	27.8	4.7	10.00 mg/L
Atrazine (ppt)	59	38.2	23.0	Present	192	39.5	3,000 (MCL)
Desethylatrazine (ppt)	65	102.1	57.0	Present	776	140.1	3,000 (MCL)
Malathion (ppt)	12	38.1	29.5	Present	118	30.0	N/A
Metribuzin (ppt)	4	135.0	122.0	56	240	83.0	N/A
Simazine (ppt)	19	55.3	32.0	Present	238	55.9	4,000 (MCL)
Bromacil (ppt)	4	151.8	152.0	30	273	124.4	0.1 Rfd (mg/kg/ day)
Triclopyr (ppt)	1	22.0	22.0	22	22	-	N/A
Terbacil (ppt)	7	119.4	131.0	Present	308	102.6	0.01 Rfd (mg/kg/ day)
Metolachlor (ppt)	7	20.0	15.0	Present	44	12.3	0.1 Rfd (mg/kg/ day)
P,p' DDE (ppt)	5	12.2	4.0	Present	44	17.8	N/A
3,4-dichloranaline (ppt)	6	50.0	31.0	18	156	52.6	N/A
Diazinon (ppt)	1	72.0	72.0	72	72	-	0.00009 Rfd (mg/kg/ day)
Dissolved Chloride (mg/l)	93	15.7	8.9	2.3	190	24.7	250 mg/L
Dissolved Sulfate (mg/l)	93	18	15.2	.71	62.6	10.7	250 mg/L
Well Depth (ft.)	279	52	40.0	8.0	325	37.5	N/A

Table 1. Descriptive statistics for all substances measured during the 2000-2001 and 2002 sampling periods.

indicate that 6% of the samples had nitrate levels less than 3 mg/l nitrate-N, 46% of the

samples were between 3 and 10 mg/ nitrate-N, and 48% of the samples exceeded the

national standard of 10 mg/L nitrate-N. For these households the mean nitrate-N level was 10.8 mg/l, and detection levels ranged from .10 to 27.8 mg/L. Eighteen wells of the 90 wells common to both sampling periods increased to levels exceeding the 10 mg/l standard in the second sampling period. Sixty-two of the wells in the second sampling period had data collected on well depth. The mean well depth was 45 ft. deep, and ranged from 15 ft. to 94 ft. deep. Most wells, 90.3%, were less than 75 ft. deep.

Pesticides were detected in 81 of the 100 wells tested. The number of pesticides found per well ranged from 1 to 7, as is shown in Table 2. All pesticide detections were measured at the parts per trillion levels (ppt). Not all of the pesticides detected in this study have federal limits, established as Maximum Contaminant Levels (MCL), but for those that do, none exceeded the national standard. Four of the pesticides (atrazine, simazine, bromacil, metolachlor) are classified as Group C, possible human carcinogens, based on the Environmental Protection Agency's *Guidelines for Carcinogen Risk Assessment* (EPA, 2002). The other eight pesticides detected are classified as either Group D (not classified as to human carcinogenicity) or Group E (evidence of noncarcinogenicity for humans) (EPA, 2002). The two most commonly found pesticides were atrazine and its breakdown product desethylatrazine.

		Frequency	Valid Percent
Pesticide Detects	1	9	11.1
	2	29	35.8
	3	15	18.5
	4	16	19.8
	5	7	8.6
	6	3	3.7
	7	2	2.5
	Total	81	100.0
Total number of wells tested		100	

Table 2. The frequency of pesticide combinations.

Survey Population Demographics

The response rate for the survey mailed in the winter of 2003 was 102 responses

out of 200 participants, or 51% of deliverable surveys. Eleven surveys were returned as

undeliverable. Response rates were very similar after stratifying participants into low

(< 3 mg/L), medium (3-10 mg/L), and high nitrate (> 10 mg/L) categories, see Table 3.

	# Of Non-Response	# Of Responses	Total
Low nitrate (< 3 mg/L)	42	41	83 (49%)
Medium nitrate (3-10 mg/L)	38	45	83 (54%)
High nitrate (> 10 mg/L)	18	16	34 (47%)
Total	98	102	200 (51%)

Table 3. Questionnaire response rates stratified by nitrate level.

The age distribution of the survey participants is shown in Figure 1. The mean

age was 61 years old, and the age range of participants was 24 to 86 years.
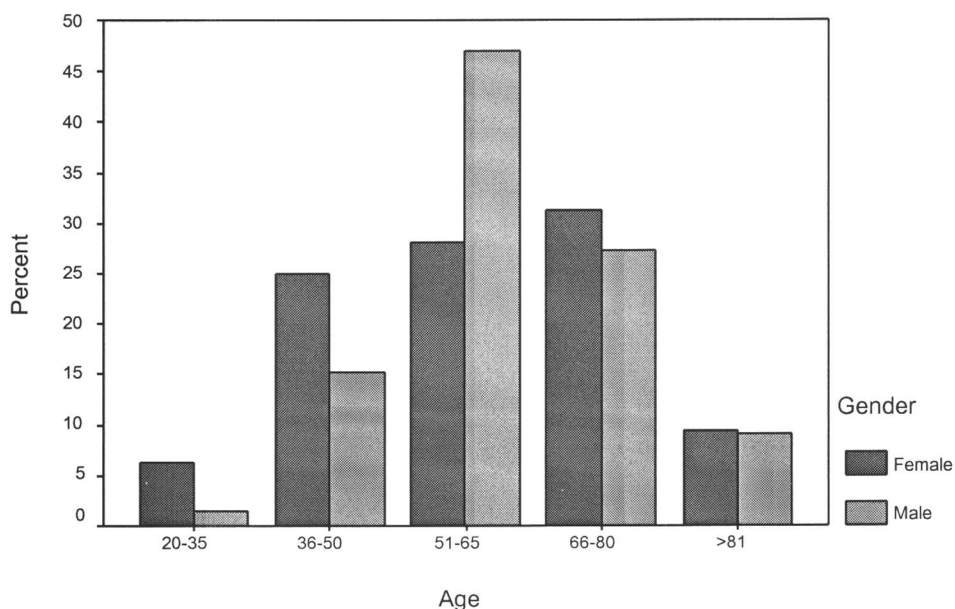
Figure 1. Age distribution of survey participants

Thirty-one percent of the population was >70 years old, while those less than 35 years old made up 3% of the participant population. Participants in the youngest age category, 20-35 years old, and the most likely to have young children, did not have wells that were classified as high nitrate (> 10 mg/L). The participants in the age category 51-65 had the greatest exposure to medium and high nitrate levels in their well water (Figure 2).
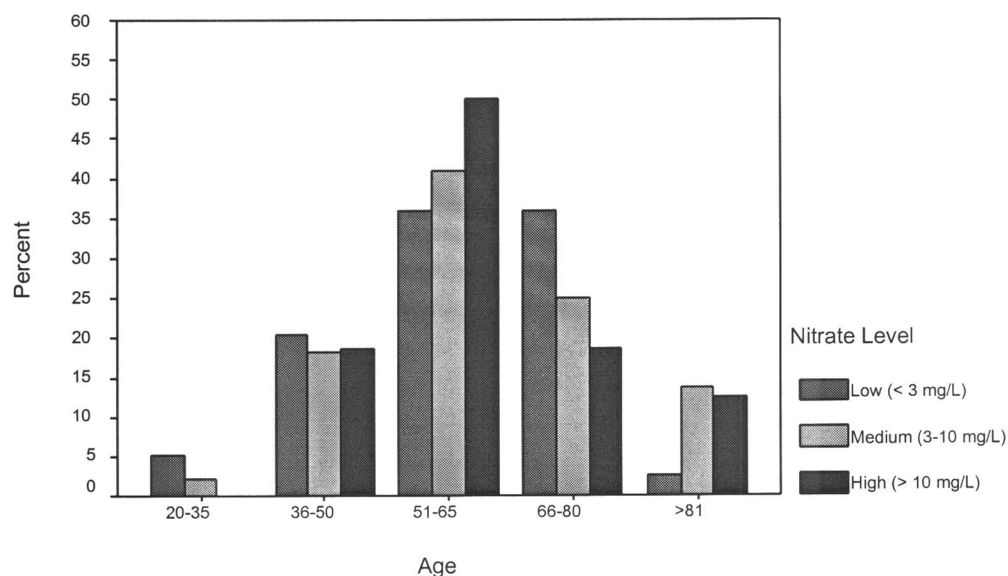
Figure 2. Age distribution relative to nitrate level

The proportion of male (66%) and female (33%) participants disproportionately favored males. The directions included in the survey mailing requested that the individual with the most knowledge of the household's water system and usage practices should complete the survey, which may be reflected by the differences in gender response rates.

The mean length of residence for survey participants in the S.W.V. is 40 years, and 91% have lived in the S.W.V. for 10 years or more. Most of the participants, 86%, state they own residential property, while 2% rent property. The remainder own

agricultural property, but not residential property in the S.W.V., or commute to their place of employment in the S.W.V. Fifty-three percent of the respondents reported owning agricultural land, and the remaining 47% owned residential property.

Household income distribution, representing 90 of the 102 reporting households, is shown in Figure 3. Twelve households (13%) had yearly incomes of ≤ $20,000, and 43 households reported incomes ≤ $40,000 per year. A quarter of the households reported annual incomes of $50,000 to 74,999 per year, whereas 8 households (9%) reported incomes in excess of $100,000 per year.
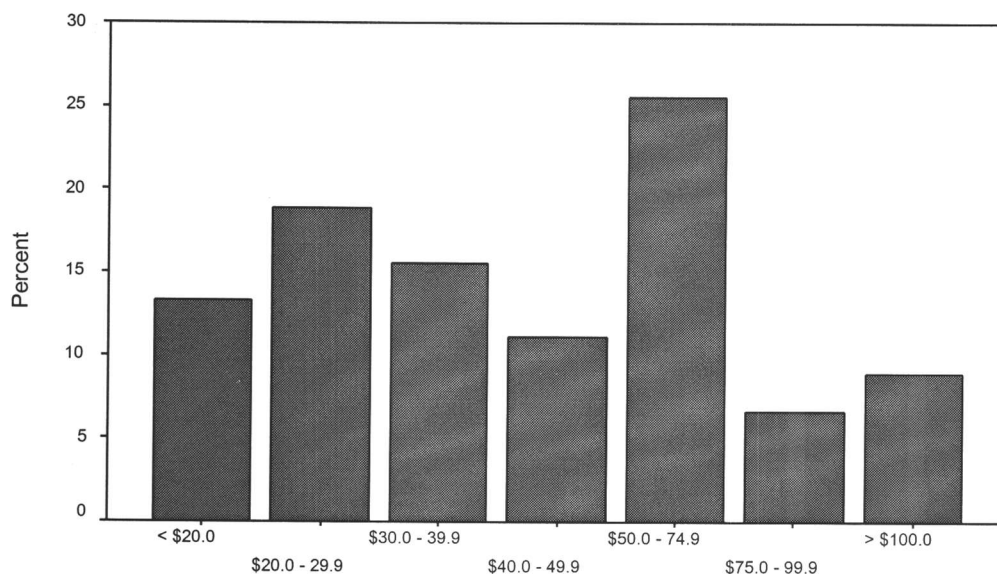
Figure 3. Household income distribution (thousands)

Survey participants were also asked about their highest level of education completed (Figure 4). A quarter of the participants have not completed more than a high school level education, and just over a quarter (29%) had completed some college. Forty-one percent of the participants have completed at least an Associate of Arts degree.
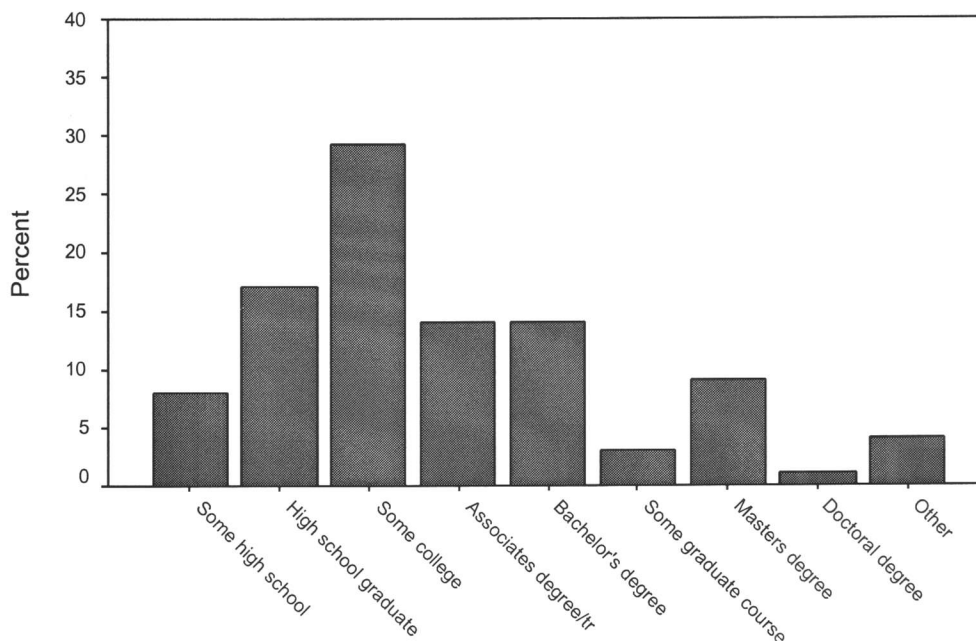
Figure 4. Participants' education level

The source of drinking water for 89% of the survey participants is water from a domestic well. Another 6% reported drinking exclusively bottled water, and 4% had drinking water delivered to their home from another source. One individual had their home attached to the local city water service since the water sampling had been performed.

Research Question 1

The first research question sought to determine what water treatment devices, if any, participants installed in order to treat contaminated well water. Ninety-nine of the 102 survey respondents replied to the question of whether they used a water treatment device, with 72% answering "No" and 28% answering "Yes." Those who responded "No" had a slightly higher mean nitrate level than those who responded "Yes" (Table 4). A Mann-Whitney *U* test compared the difference in mean ranks of nitrate levels for participants who answered either "No" or "Yes." The mean ranks (53 for "No" and

Do you use a water purification system?	N	Mean (mg/L)	Std. Deviation	95% Confidence Interval
No	71	5.8	4.5	4.9- 6.7
Yes	28	4.5	5.1	3.5 – 5.5

Table 4. Mean nitrate levels for participants relative to their use of water purification devices.

42 for "Yes") were not significantly different, $Z = -1.71$, $p > .08$. This means that there were no differences in the use of water treatment devices based on concentration of nitrate in the well water. This question was followed by asking those participants who responded "Yes" to indicate the type of treatment device(s) they used on their well water (see Figure 5).
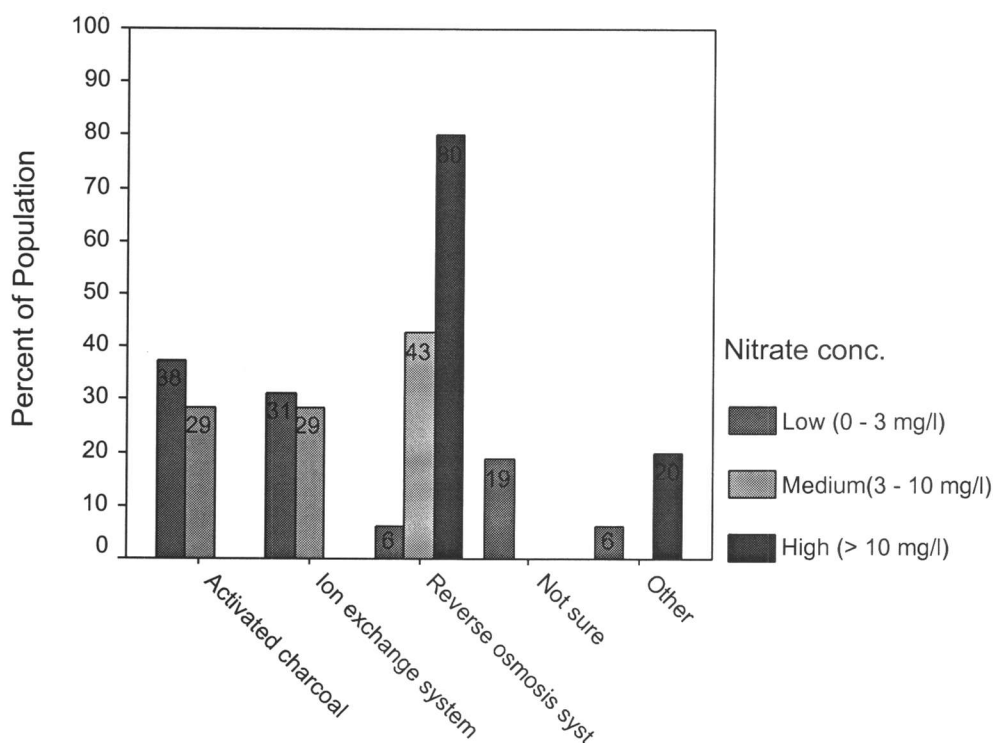
Figure 5. The type of purification system used in relation to nitrate concentration. (Total n = 28)

The largest percentage of participants with high nitrate levels used a reverse osmosis water purification system. As Figure 6 illustrates, respondents with low nitrate

contamination levels typically used activated charcoal (38%) and ion exchange systems (31%). Forty-three percent of the respondents categorized in the medium nitrate concentration range used reverse osmosis systems, 29% used activated charcoal, and 29% used ion exchange systems. A Kruskal-Wallis test was used to see if differences in nitrate 2000-2001 levels were significantly different between respondents who used activated charcoal systems (n = 8; mean rank = 9.4), ion exchange systems (n = 7; mean rank = 9.6), and reverse osmosis systems (n = 8; mean rank = 16.8). The result was found to be statistically significant, χ^2 (2, N = 23) = 6.05, p < .04. The strength of the relationship, as indexed by epsilon-squared, was .28. The Mann-Whitney U test was used as a follow up to determine which variables were significantly different. This comparison found that nitrate levels for respondents using activated charcoal systems (mean rank = 5.9) were significantly lower than nitrate levels for respondents using reverse osmosis systems (mean rank = 11.1), Z = -2.21, p < .03.

Research Question 2

The second research question analyzed the association between participants' concerns about their drinking water quality and levels of nitrate contamination in their drinking water. Sixty-nine percent of the survey respondents reported that they believed the quality of their well water was either "good" or "excellent" (Table 5). An analysis of variance test sought to determine if there was a difference between mean

How would you describe the quality of your well water?	N	Mean mg/L	Std. Deviation	95% Confidence Interval for the Mean	ANOVA
Excellent	35 (35%)	4.4	3.9	3.1 – 5.7	$F = .86$ $(p > .46)$
Good	34 (34%)	5.3	4.3	3.8 – 6.8	
Fair	23 (23%)	6.4	5.5	4.0 – 8.8	
Poor	8 (8%)	5.6	6.4	.30 – 10.9	
Total	100	5.3	4.6	4.4 – 6.2	

Table 5. Participants' responses to description of water quality relative to nitrate concentration.

nitrate contamination levels and the response variables (excellent, good, fair, and poor). No significant differences were found, $F (3, 96) = .86$, p > .46; however, it was apparent that respondents' descriptions of well water quality became less favorable as levels of nitrate contamination gradually increased.

Respondents were also asked several questions related to their concern over agricultural fertilizer use negatively impacting their well water quality, agricultural pesticide use negatively impacting their well water quality, and poorly maintained septic systems negatively impacting their well water quality. Fifty-five percent of the respondents either "strongly agreed" or "agreed" with the statement, "I am concerned that agricultural fertilizer use in the southern Willamette Valley will increase the level of nitrate in my home's well water" (Table 6). An analysis of variance was used to determine the relationship between mean nitrate levels and the response variables (strongly agree, agree, disagree, strongly disagree, and not sure). This test was found to be statistically significant, $F (4, 97) = 2.97$, p < .02. A post hoc Tukey HSD test indicated that the mean nitrate levels for those who responded "strongly agree"

Table 6. Respondent's concern over agricultural fertilizer use relative to nitrate contamination level.

I am concerned that ag. fertilizer use in the s.W.V. will increase nitrate levels in my home's well water.	N	Mean mg/L	Std. Deviation	95% C.I. for the Mean	ANOVA	Tukey HSD
Strongly Agree	22 (22%)	8.1	5.2	5.7 – 10.4	$F = 2.97$ ($p < .02$)	.03[a] .03[b]
Agree	34 (33%)	4.4	3.9	3.0 – 5.8		
Disagree	19 (19%)	4.9	5.5	2.2 – 7.6		
Strongly Disagree	8 (7%)	5.4	3.9	2.1 – 8.7		
Not Sure	19 (19%)	3.9	3.1	2.4 – 5.4		
Total	102	5.3	4.6	4.3 – 6.2		

[a] Tukey HSD significance value for "strongly agree" by "agree."
[b] Tukey HSD significance value for "strongly agree" by "not sure."

(M = 8.1, SD = 5.3) was significantly greater than the mean for those who responded "agree" (M = 4.4, SD = 3.9) and for those who responded "not sure" (M = 3.9, SD = 3.1). Notably, 19% of the respondents reported not being sure if they believed agricultural fertilizers were negatively impacting their well water quality. The same question of concern over agricultural fertilizer use having negative impacts on well water was cross-tabulated with ownership of agricultural property and analyzed using a chi-square test of independence (Table 7). In this analysis the possible responses were condensed to "agree" or "disagree", because 20% of the expected frequencies were less than 5. The chi-square test was found to be statistically significant, χ^2 (1, N = 84) = 14.91, p < .00. As indexed by the Cramer's statistic, the strength of the relationship was .42. Respondents who do not own agricultural property are more likely to agree with

the statement "I am concerned that agricultural fertilizer use in the southern Willamette Valley will increase the level of nitrates in my well water" than those respondents who do own agricultural property (Figure 6).
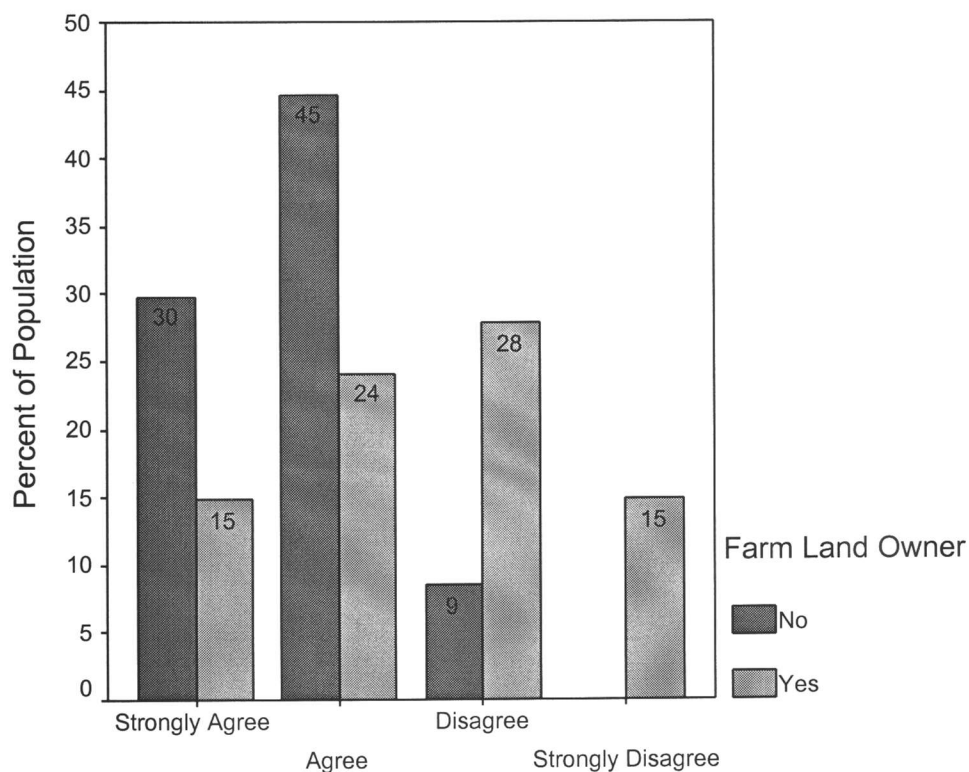
Figure 6. Concern over agricultural fertilizer harming well water quality.

Thirty-six percent of the respondents either "strongly agreed" or "agreed" to the statement, "I am concerned that agricultural pesticide use in the southern Willamette Valley is having a negative impact on the quality of my home's well water" (Table 7). Survey participants were not matched to households with pesticide detections; as a result no analysis was conducted on the levels of pesticide per well and survey response variables. However, respondents' concern over agricultural pesticide use in the

Table 7. Participants' responses to concern over agricultural fertilizer, pesticide, and septic systems impacting well water quality.

	Strongly Agree	Agree	Disagree	Strongly Disagree	Not Sure	χ-square
I am concerned that ag. fertilizer use in the s.W.V. will increase nitrate levels in my home's well water.	22 (22%)	34 (33%)	19 (19%)	8 (7%)	19 (19%)	14.91[1,2] (p < .00)
I am concerned that ag. pesticide use in the s.W.V. is having a negative effect on my home's well water.	13 (13%)	24 (24%)	30 (29%)	14 (14%)	21 (20%)	8.55[2,3] (p < .00)
I am concerned that poorly maintained septic systems will have a negative impact on my home's well water.	17 (17%)	58 (57%)	13 (13%)	5 (5%)	9 (9%)	1.93[2,4] (p < .19)

[1] A cross-tabulation between concern over agricultural fertilizer use negatively impacting well water and ownership of agricultural land.
[2] Participants' responses were condensed to "agree" and disagree."
[3] A cross-tabulation between concern over agricultural pesticide use negatively impacting well water and ownership of agricultural land.
[4] A cross-tabulation between concern over septic systems negatively impacting well water and ownership of agricultural land.

southern Willamette Valley was cross-tabulated with ownership of agricultural

property, and analyzed using a chi-square test of independence. This analysis also

condensed the responses to "agree" or "disagree" because 20% of the expected

frequencies were less than 5. The chi-square test was found to be statistically

significant, χ^2 (1, N = 81) = 8.55, p < .00 (Table 7). The Cramer's statistic found the

strength of relationship to be .33. Twenty percent of the respondents reported not being

sure if agricultural pesticides were negatively impacting their well water quality. Respondents who do not own agricultural property are more likely to agree with the statement, "I am concerned that agricultural pesticide use in the southern Willamette Valley is having a negative impact on the quality of my home's well water", than are respondents who do own agricultural property (Figure 7).
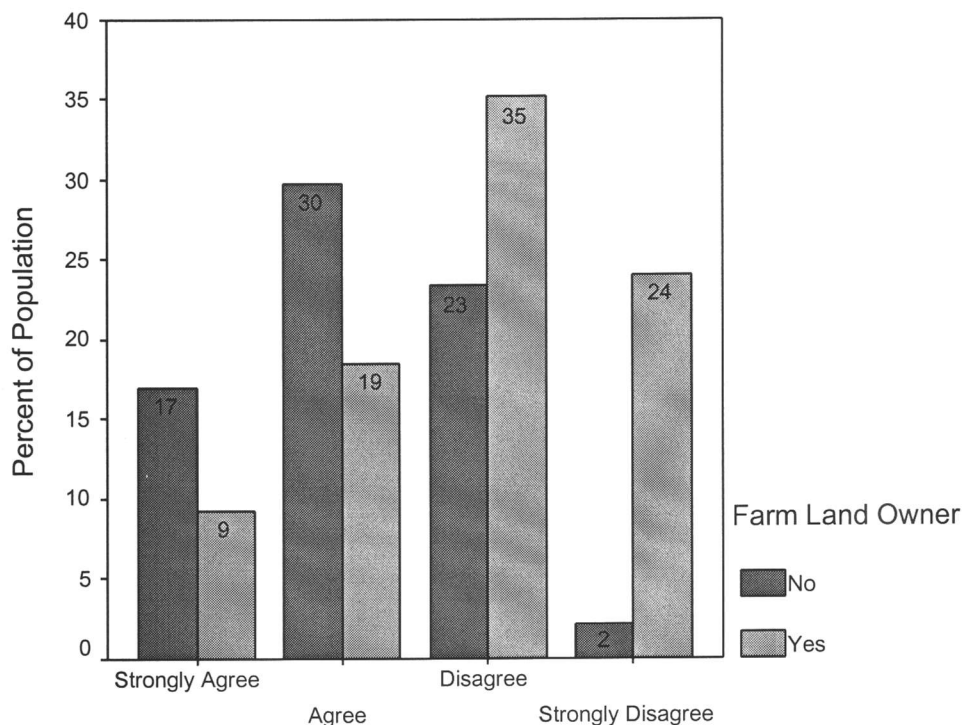
Figure 7. Concern over agricultural pesticide use harming well water quality.

Following up on the two previous questions concerning respondents' concern over agricultural fertilizer and pesticide use, respondents were asked their opinion on how well certain types of landowners were managing their land in the southern Willamette Valley to ensure good water quality. First, two questions were cross-tabulated: 1) How well are farmers managing their land in the southern Willamette Valley to ensure good water quality; and, 2) I am concerned that agricultural fertilizer

use in the southern Willamette Valley will increase the level of nitrate in my home's well water. A chi-square test of independence was used for this analysis, and it was found to be statistically significant, χ^2 (4, N = 84) = 24.39, p < .00 (Table 8). As indexed by the Cramer's statistic, the strength of the relationship was .54. Respondents who believe farmers are doing an unfavorable job in managing their land to ensure good water quality are more likely to "strongly agree" with concerns over agricultural fertilizer use having a negative impact on well water quality than expected, and visa versa. A similar result was found when comparing respondents' opinions of farmers' management of water quality on their land with concern over agricultural pesticide use in the southern Willamette Valley negatively impacting well water quality. A chi-square test of independence showed a statistically significant relationship, χ^2 (4, N = 84) = 9.92, p < .04 (Table 8). Cramer's statistic was .34. Respondents who believe farmers are doing an unfavorable job in managing their land to ensure good water quality are more likely to "strongly agree" with concerns over agricultural pesticide use negatively impacting their well water quality.

	χ – square test of independence
How well are farmers managing their land – BY – concern over agricultural fertilizer use negatively impacting well water quality.	24.39 (p < .00)
How well are farmers managing their land – BY – concern over agricultural pesticide use negatively impacting well water quality.	9.92 (p < .04)

Table 8. Cross-tabulation of participants concerns over agricultural chemical use and how well farmers are managing their land to ensure water quality.

These same cross-tabulations were conducted using private residents as the landowner whose responsibility it is to ensure good water quality. Neither chi-square test result was found to be statistically significant at an alpha level of .05.

Seventy-four percent of the respondents either "strongly agreed" or "agreed" with the statement, "I am concerned that poorly maintained residential septic systems will have a negative impact on my home's well water". An analysis of variance was used to determine the relationship between mean nitrate levels and the question's response variables (strongly agree, agree, disagree, strongly disagree, and not sure). This test was not statistically significant, $F(4, 97) = .89$, p > .47. This question was then cross-tabulated with ownership of agricultural property and analyzed using a chi-square test of independence. The possible responses were collapsed to "agree" or "disagree" because 20% of the expected cell frequencies were less than 5. The chi-square test was not statistically significant, $\chi^2 (1, N = 92) = 1.93$, p > .19 (Table 7).

Research Question 3

The third research question sought to determine the relationship between frequency of septic tank pumping, as reported by survey participants, and levels of nitrate contamination. Seventy-one percent of the participants reported having their septic systems pumped within the last 5 years, and only 6% reported pumping their septic systems more than 10 years ago, or never at all. The ranked data on frequency of septic tank pumping was correlated with the 2000-2001 nitrate contamination levels using Spearman's rank-order correlation. The observed correlations were not statistically significant, $r_s (100) = .006$, p > .953. Further analysis using a Spearman's rank-order correlation tested the relationship between the distance of the septic tank

from the well head and nitrate contamination levels, and the distance of the septic tanks'

drain field from the household well head and nitrate contamination levels. The

observed correlations were not statistically significant, r_s (91) = -.11, p > .30, and r_s (89)

= -.15, p > .17, respectively.

Research Question 4

The fourth research question sought to determine the spatial relationship

between nitrate contamination levels and geologic units in the region, and to determine

if mean nitrate contamination levels were different between geologic units. In the study

area there are 10 different geologic units. Five of these geologic units are especially

important in this study because they contain 90% of the study's households. These

units are: 1) Holocene alluvium of the Willamette River and its major tributaries (Q_{alc}),

2) Holocene alluvium of the Willamette River's minor tributaries (Q_{alf}), 3) Missoula

flood deposits (Q_{ff2}), 4) Pleistocene sand and gravel post-Missoula flood (Q_{g1}), and 5)

Pleistocene sand and gravel pre-Missoula flood (Q_{g2}). A spatial analysis of the

distribution of nitrate contamination is provided in Figures 8, 9, 10, and 11.

Nitrate levels in the S.W.V.
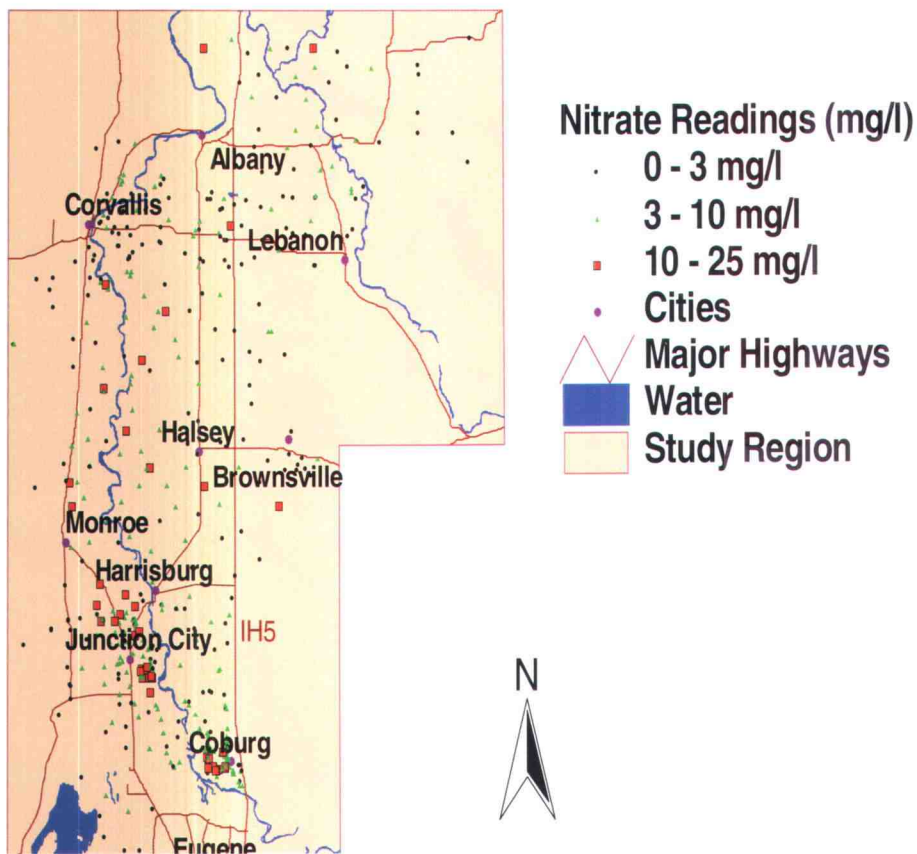
Figure 8. Nitrate levels in the S.W.V. in relation to landmarks.

Low Level Nitrate Readings
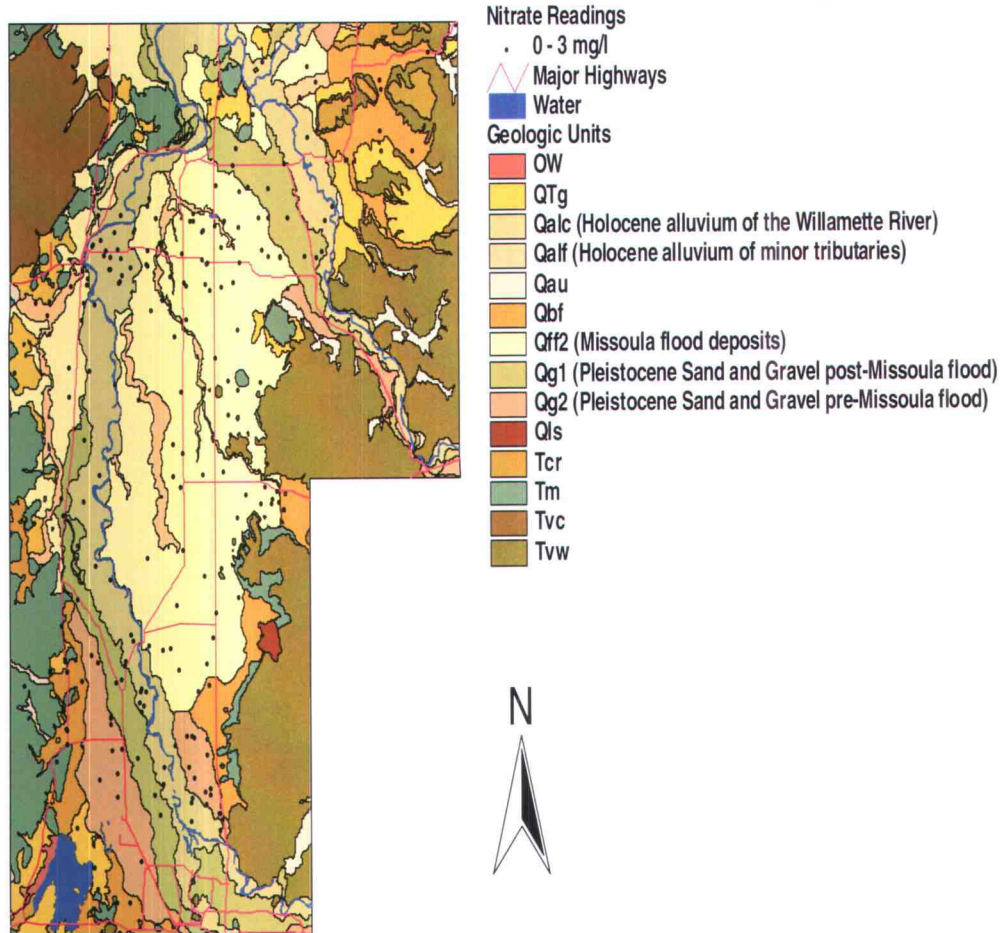
Figure 9. The spatial distribution of low nitrate contamination levels (0-3 mg/L) in relation to geologic units in the S.W.V. The legend provides the names of the 5 geologic units that are especially pertinent to this study (O'Connor, 2001).
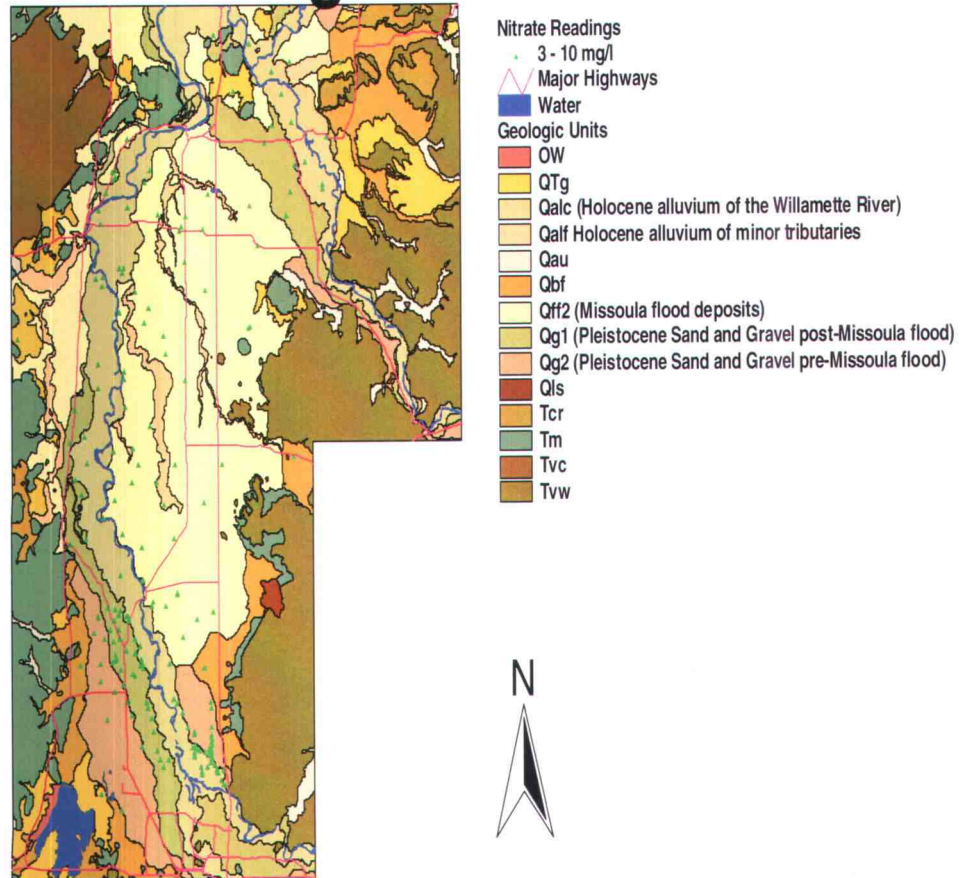
Figure 10. The spatial distribution of mid-range nitrate contamination levels (3-10 mg/L) in relation to geologic units in the S.W.V. The legend provides the names of the 5 of the geologic units that are especially pertinent to this study (O'Connor, 2001).

Highest Nitrate Levels
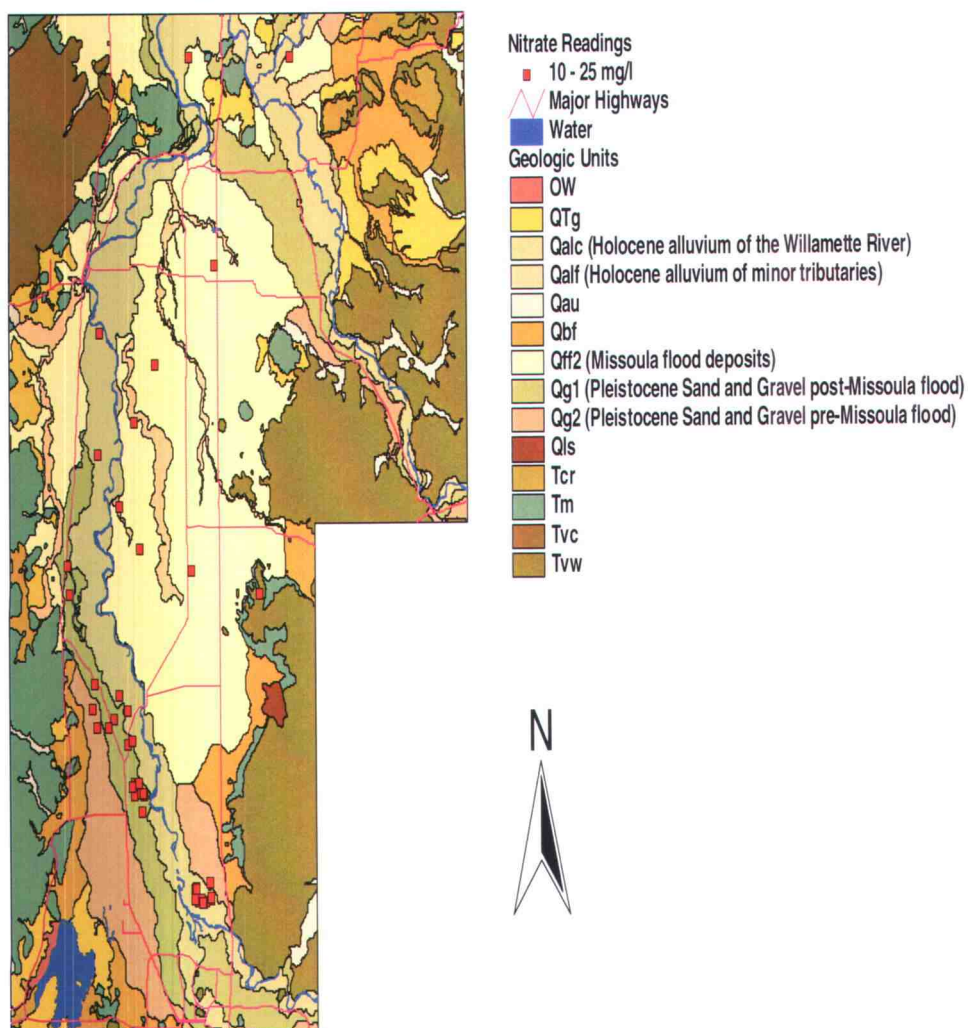
Figure 11. The spatial distribution of high nitrate contamination levels (> 10 mg/L) in relation to geologic units in the S.W.V. The legend provides the names of the 5 of the geologic units that are especially pertinent to this study (O'Connor, 2001).

The total number of households in each of the 5 geologic units evaluated in this study is presented in Table 5. The largest total number of households occurs within the Q_{ff2} geologic unit (n = 147). This unit also contains more households that are classified

as having low nitrate contamination (n = 87) than any other unit. The two units with the

largest number of households that are classified as having high nitrate contamination

		Frequency (%)
Geologic	Qalc	136 (32)
Unit	Qalf	13 (3)
	Qff_2	147 (34)
	Qg_1	72 (17)
	Qg_2	61 (14)
	Total	429

Table 9. The number of households within each geologic unit.

levels are Q_{alc} (n = 13) and Q_{g1} (n = 13) for a combined total of 26 households out of a

possible 35 total households in this category. Approximately 82% of households with

nitrate contamination levels $\geq$ 10 mg/l are located within or very near the Holocene and

Pleistocene sand and gravel deposits that are associated with the Willamette aquifer.
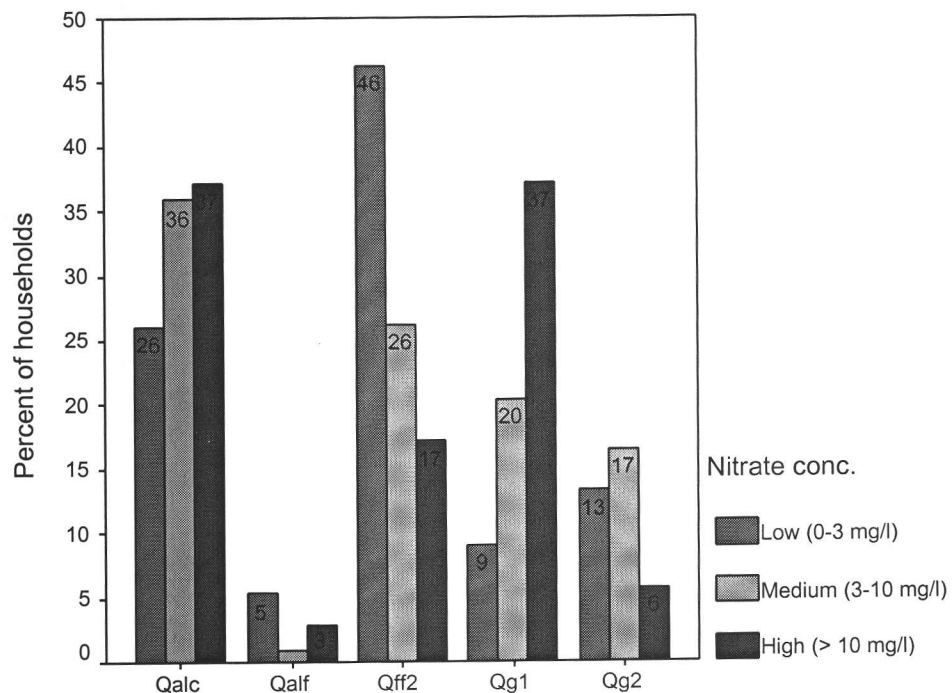
Figure 12. Households within geologic units relative to nitrate
concentrations

A Kruskal-Wallis test was conducted to evaluate the differences between mean nitrate rank contamination levels in 5 of the geologic units. The independent variable, geologic unit, had five levels: Q_{alc}, Q_{alf}, Q_{ff2}, Q_{g1}, Q_{g2}. The dependent variables were the nitrate concentrations conducted in 2000-2001. The test, which was corrected for tied ranks, was significant, χ^2 (4, N = 429) = 56.1, p < 00. The strength of the relationship as indexed by epsilon-squared was .13, indicating the proportion of variability in the ranked dependent variable accounted for by geologic unit was 13%. A Mann-Whitney U test was conducted to evaluate pairwise differences among the five groups; results are presented in Table 10. The results indicate that mean nitrate ranks for geologic unit Q_{g1} were significantly higher than all other geologic units, with the exception of Q_{alc}. The geologic unit with the lowest mean nitrate ranks was Q_{ff2}.

Geologic Unit (i)	Geologic Unit (j)	Difference in Mean ranks (i-j)	Z-score	Sig. (2-tailed)
Qalc	Qalf	44.0	-3.51	.00
	Qff$_2$	53.0	-5.44	.00
	Qg$_1$	-16.3	-1.86	.06
	Qg$_2$	12.5	-1.42	.16
Qalf	Qff$_2$	-23.3	-1.74	.08
	Qg$_1$	-26.7	-3.59	.00
	Qg$_2$	-20.9	-3.17	.00
Qff$_2$	Qg$_1$	-51.9	-5.70	.00
	Qg$_2$	-30.8	-3.36	.00
Qg$_1$	Qg$_2$	19.2	-2.86	.00

Table 10. The pairwise results of a Mann-Whitney test of mean nitrate ranks between geologic units.

Research Hypothesis 1

The first research hypothesis stated that there was no relationship between

nitrate 2000-2001 contamination levels and the independent variables well depth and

well age. To improve the distributional characteristics of the data, a natural log

transformation was applied to nitrate 2000-2001 data, well age data, and to the well

depth data. Analysis of the scatterplot for nitrate 2000-2001 data and well depth

showed no linear relationship (Figure 13). However, the proportion of wells with

higher nitrate concentrations is greater in shallower wells. In wells that are ≤ 75 ft.

deep, nitrate concentrations exceed 10 mg/L 9.4% of the time; whereas, in wells that are

≥ 75 ft. deep, nitrate concentrations exceed 10 mg/L only 5.3% of the time.
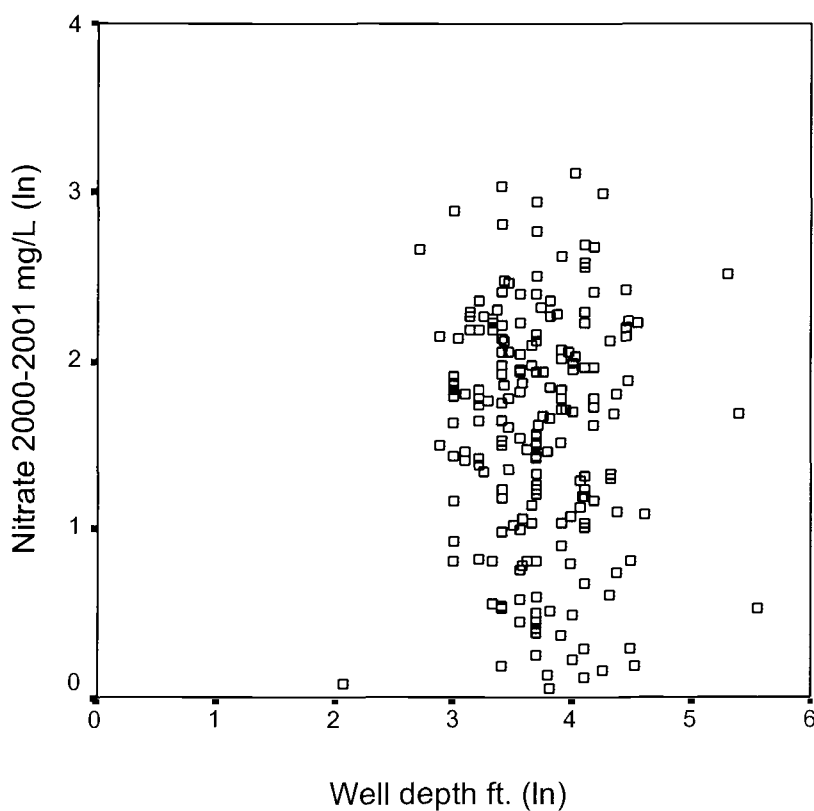
Figure 13. Scatterplot of well depth and nitrate 2000-2001 levels
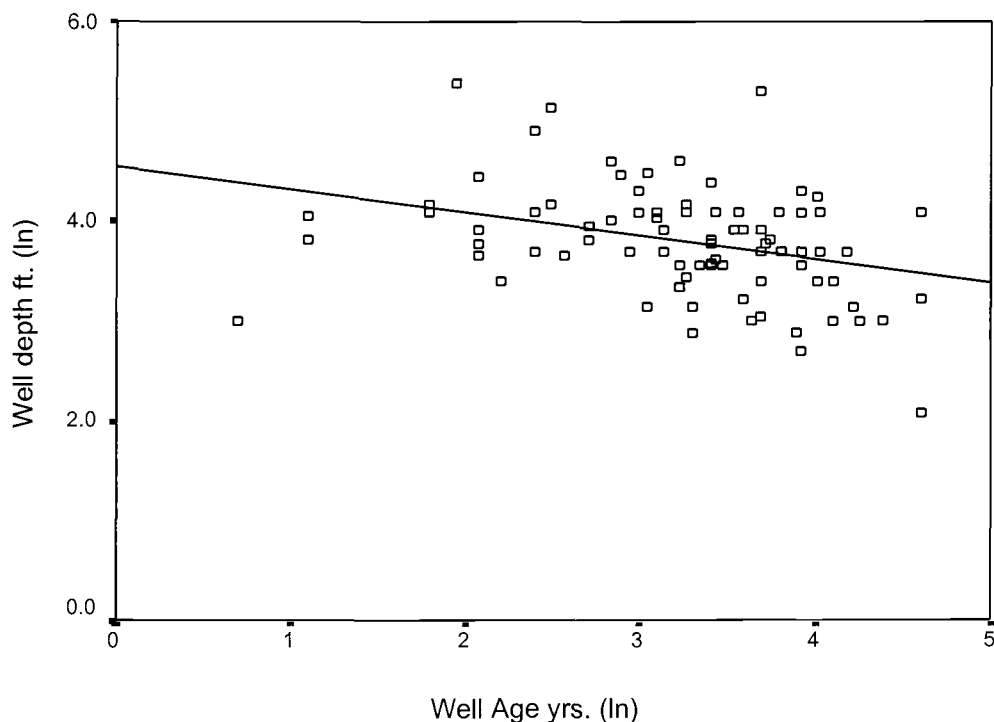
Figure 14. Scatterplot of well age and well depth

Pearson's correlation coefficients were computed to assess the relationship between nitrate 2000-2001 and well age, and well depth and well age. The correlation between nitrate 2000-2001 levels and well age was not statistically significant, r (88) = .19, p > .06. Although not part of the research hypothesis, well depth and well age were found to have a statistically significant inverse correlation, r (86) = -.33, p < .00. This indicates that the proportion of variability in well depth that can be explained by, or that is associated with, well age is .11 (11%) (Figure 14). Because there was no statistically significant association between nitrates 2000-2001 levels and either well depth or well age, we fail to reject the first hypothesis.

Research Hypothesis 2

The second research hypothesis stated that there is no relationship between nitrate 2002 contamination levels and the independent variables dissolved chloride, dissolved sulfate, atrazine, well depth, and well age. To improve the distributional characteristics of the data, natural log transformations were applied to all of the variables. Pearson's correlation coefficients were computed to assess the relationship among the variables (Table 11).

		Nitrate 2002 (ln)	Well age (ln)	Well depth (ln)	Dissolved sulfate (ln)	Dissolved chloride (ln)	Atrazine (ln)
Nitrate 2002 (ln)	Pearson Correlation	1					
	Sig. (2-tailed)	.					
	N	100					
Well age (ln)	Pearson Correlation	.17	1				
	Sig. (2-tailed)	.39	.				
	N	29	88				
Well depth (ln)	Pearson Correlation	-.23	-.33**	1			
	Sig. (2-tailed)	.07	.00	.			
	N	62	86	279			
Dissolved sulfate (ln)	Pearson Correlation	.47**	.49**	-.42**	1		
	Sig. (2-tailed)	.00	.01	.00	.		
	N	89	29	61	93		
Dissolved chloride (ln)	Pearson Correlation	.08	.25	-.15	.13	1	
	Sig. (2-tailed)	.45	.19	.24	.23	.	
	N	89	29	61	93	93	
Atrazine (ln)	Pearson Correlation	.15	.57**	-.09	.33**	.42**	1
	Sig. (2-tailed)	.25	.01	.60	.01	.00	.
	N	59	22	38	58	58	59

Table 11. Correlations for nitrate 2002 data
** Correlation is significant at the .05 level (2-tailed)

The correlation between nitrate 2002 contamination levels and dissolved sulfate was found to be statistically significant, r (89) = .47, p < .00, indicating the two variables are positively related. However, the scatterplot of nitrate contamination levels and dissolved sulfate shows much of the correlation to be due to some outliers from wells were both nitrate and dissolved sulfate are low (Figure 15). The proportion of variability in nitrate 2002 levels that can be explained by dissolved sulfate levels is .22 (22%). When analyzed without the outliers, the correlation between dissolved sulfate and nitrate 2002 contamination is reduced to a non-significant level, r (89) = .20, p > .06. No other significant correlations between nitrate 2002 contamination levels and the other variables were found. However, a Pearson's correlation and scatterplot analysis between atrazine and well age, and dissolved sulfate and well age exhibited linear relationships and were significantly correlated (Figures 16 and 17). Atrazine and well age are moderately correlated; as well age increases atrazine levels also increase. Dissolved sulfate levels were also moderately correlated with well age, as well age increased, dissolved sulfate levels increased too. Because there was a significant association between nitrate 2002 levels and dissolved sulfate, the second hypothesis was rejected.
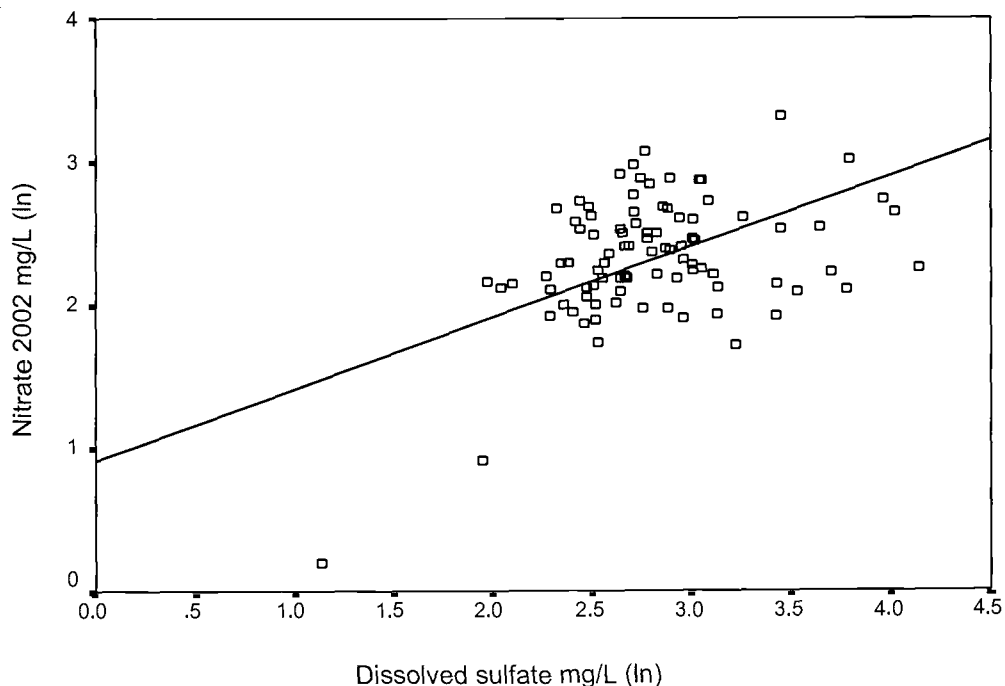
Figure 15. Scatterplot of dissolved sulfate and nitrate 2002.

Ninety households in the southern Willamette Valley have had two nitrate tests

performed. Of the 90 households' common to both studies, 64 of them (71%)

experienced increases in nitrate levels from the first sampling period in 2000-2001 to

the second sampling period in 2002, eighteen of which changed from below the health

standard to above the health standard of 10 mg/l nitrate. To evaluate the change in

nitrate levels from the first sampling period in the winter of 2000-2001 to the second

sampling period in the summer of 2002 the mean nitrate levels were compared using a

paired samples t-test. This test was found to be statistically significant, t (89) = -3.66, p

< .00, suggesting that mean nitrate levels for the summer 2002 sampling period (Mean =

11.3, SD = 4.3) are higher than mean nitrate levels for the winter 2000-2001 sampling

period (Mean = 9.9, SD = 3.3). The strength of the relationship between the mean

nitrate levels for the two sampling periods was .13, as indexed by eta^2. The 95%

confidence interval for the mean difference was -2.12 to -.63.
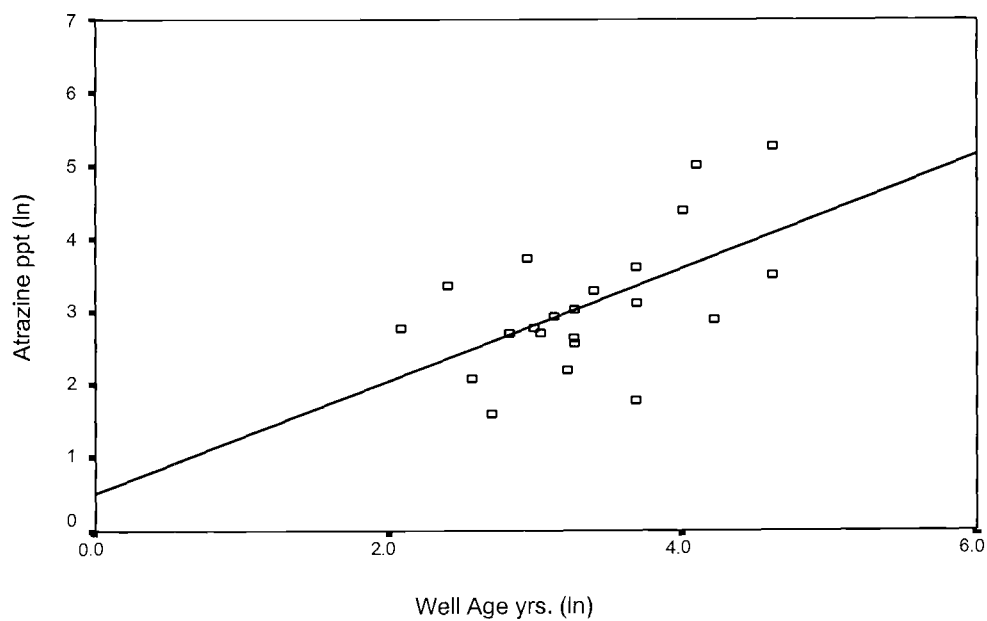
Figure 16. Scatterplot of well age and atrazine levels.
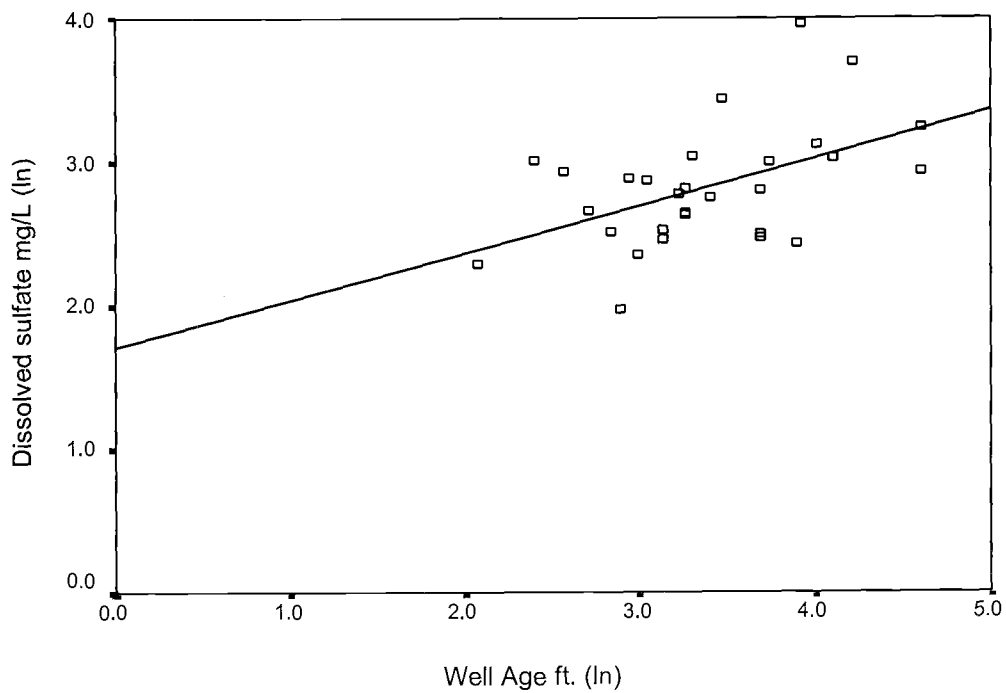
Figure 17. Scatterplot of well age and dissolved sulfate levels.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

The purpose of this study was twofold: (1) to research the concentrations and associations between nitrates, selected pesticides, dissolved chloride, dissolved sulfate, well depth, and well age in residential wells from an area within the southern Willamette Valley; and, (2) to survey the residents whose wells were sampled to determine their attitudes and perceptions of their drinking water quality. The region in the Willamette Valley between north Eugene and Albany has been under intensive agricultural production for many decades. This area also has many older homes that rely on well water, and often the wells are shallow (< 75 ft. deep). Current data indicate extensive groundwater pollution from nitrates in some areas within this region.

Extent of Nitrate Contamination in the southern Willamette Valley

In the southern Willamette Valley, concentrations of nitrate during the 2000-2001 sampling event had a mean of 4.0 mg/l, and ranged from <0.05 to 22.60 mg/l in 476 sample wells. Nitrate concentrations exceeded the U.S. Environmental Protection Agencies (USEPA) Maximum Contaminant Level (MCL) of 10 mg/l in 7.4% of these samples. In wells less than 75 ft. deep the percentage of nitrate concentrations exceeding the USEPA's MCL increased to 9%. This result is comparable to the results of a study conducted in the Willamette Basin in 1993, which also found 9% of wells less than 75 ft. deep to exceed the MCL (Hinkle, 1997). It is also comparable to results of a nationwide study in the mid-1990s that sampled rural wells throughout the U.S. and found 11% of the 1242 nitrate samples to exceed the national health standard of 10 mg/l (Squillace, 2002). Considerable monitoring of groundwater quality in agricultural areas

in mid-Western states has also found many wells with high nitrate concentrations. In Iowa, a sample representative of domestic wells statewide found an average of 18.3% of the samples exceeding the health standard for nitrate, and in wells less than 45 ft. deep this percentage increased to 35%. The percentage of nitrate concentrations above 10 mg/l could vary considerably within specific regions of the state, even as much as 29% in one instance.

Regional variability is also evident within the southern Willamette Valley. In sharp contrast to the 2000-2001 sampling period, the mean nitrate concentration for the 100 wells sampled in 2002 was 10.8 mg/l, with 48% of the wells exceeding the national standard. The majority of the variation in these findings is likely a result of re-sampling wells with higher overall nitrate levels during the 2002 sampling period; however, there is evidence of increased susceptibility to increasing nitrate concentrations in specific areas. Of the 90 households' common to both studies, 64 of them (71%) experienced increases in nitrate levels from the first sampling period in 2000-2001 to the second sampling period in 2002, eighteen of which changed from below the health standard to above the health standard of 10 mg/l nitrate. This may be a result of the different seasons in which sampling was conducted. The 2000-2001 sampling event took place from 12/00 to 3/01, and the 2002 sampling event took place from 5/02 to 7/02. These times of years have distinctly different precipitation patterns and irrigation practices, which may have influenced the rate and amount of nitrate entering the groundwater. Even though exposure to relatively high nitrate concentrations was widespread, with well water being the main source of drinking water for 89% of the participants, the likelihood of methemoglobinemia appears to be low because those exposed to high

nitrate concentrations (> 10 mg/l) were 50 years old or older. However, this risk may change in the future as the population within this region grows.

Ninety-one percent of the respondents have lived in this region for 10 years or more. Studies of long-term exposure to nitrate from contaminated well water are still inconclusive as to what risk this poses. A number of studies link nitrate ingestion to gastric cancer, bladder cancer, non-Hodgkin's lymphoma, ovarian cancer, and brain and central nervous system cancers (Xu et al., 1992; Morales-Suarez-Varela et al., 1995; Yang et al., 1998; van Maanen et al., 1996; Mueller et al., 2001; Weyer et al., 2001). Moreover, toxicological science has traditionally focused on individual exposures. As a result, very little is known about exposure to chemical combinations, such as nitrate and pesticides, and their effect on human health. One such study of chemical combinations tested endocrine, immune, and behavioral effects of aldicarb, atrazine, and nitrate mixtures at typical groundwater concentrations. The results, on wild deer mice, of the single compounds at each of their MCL found no effect, but found significant changes when various mixtures were tested (Porter et al., 1999). The authors give "special significance" to any mixture containing nitrates with one or both of the pesticides in relation to aggression scores, effects on body mass, effects on thyroid hormone balance, effects on antibody production, and effects on final spleen weight (Porter et al., 1999).

Many factors influence regional and local variation in nitrate concentrations, including cumulative soil thickness at the well, soil textures in the area surrounding the well, the depth of the well sampled, well construction, nitrate loading, poorly functioning septic systems near the well, groundwater flow, and the geology of the region. This study retrospectively assessed the relationship between nitrate 2000-2001

concentrations and the geologic unit in which households were located, with interesting findings. Results of this study are in agreement with the suggested theoretical differences in permeability of the 5 main geologic units in the region (O'Connor, 2001). The more permeable geologic units, Pleistocene sand and gravel post-Missoula flood (Q_{g1}) and Holocene alluvium of the Willamette River and its major tributaries (Q_{alc}), were much more likely to have nitrate concentrations ≥ 10 mg/l. In comparison, the less permeable Missoula flood deposits (Q_{ff2}), were less likely to have wells with nitrate concentrations ≥ 10 mg/l. Rather, this geologic unit had the largest percentage of wells with nitrate measurements between 0 and 3 mg/l. This suggests that there may be a need for more targeted monitoring of well water in specific geologic regions, and perhaps groundwater quality management policies that account for significant regional variability.

No significant linear correlation was found between nitrate 2000-2001 levels and either well depth or well age. However, a nonlinear relationship existed between well depth and nitrate concentrations for wells included in the 2000-2001 sampling period. Nitrate concentrations typically increased as the well depth decreased. This finding supports similar results of previous reports. A study representative of the state of Iowa found that wells greater than 45 ft. deep were very often less contaminated with nitrate than wells less than 45 ft deep (Kross et al., 1993). Another study in rural northeastern Oregon found wells less than 50 meters in depth to be more likely to have nitrate concentrations exceeding 10 mg/L (Mitchell et al., 1993). A study of drinking water wells in Wisconsin found that wells with greater than 12 mg/L nitrate were significantly shallower than wells with 0-2 mg/L nitrate (Schubert et al., 1999). These

findings were not evident for the nitrate 2002 data, but this is likely due to the bias toward high nitrate levels in this sampling. No relationship was found between well age and nitrate levels from either sampling period; however, well age and well depth were found to have a weak, but significant inverse relationship. Well depth typically increases with newer wells.

Evaluation of the nitrate 2002 data sought to gain a better understanding of the relationship among nitrates, dissolved chloride, and dissolved sulfide, and to discern a possible connection to a common source. High levels of dissolved chloride in the groundwater are often associated with leakage from poorly operating septic systems, or from confined livestock feeding operations where manure is the primary source. On the other-hand, dissolved sulfates may be indicative of agricultural fertilizer (ammonium sulfate) applications leaching into the groundwater. Natural sources of dissolved sulfates, however, may also exist. The only significant correlation between the three nutrients that appeared in this study was found with nitrate 2002 concentrations and dissolved sulfate. This finding may indicate that fertilizer use in the region is more likely to be the main source of nitrate in the well water, rather than contamination from septic systems or animal feedlots. The Idaho Department of Environmental Quality in a study of domestic well water also found similar relationships among these nutrients. This study was conducted on drinking water wells in the Ashton, Idaho area, and found a strong correlation between dissolved sulfates and nitrate levels, but no relationship between dissolved chloride and dissolved sulfate (IDEQ, 2001). The conclusion was that the elevated nitrate levels were most likely a result of one source. Additionally, the

age of the well was associated with levels of dissolved sulfates, which suggests older wells may be vulnerable to outside contamination.

Pesticides were also detected in the domestic wells sampled in 2002. A total of 81 of the 100 wells tested were found to contain at least 1 pesticide, and although pesticide detections were widespread, none of the pesticides exceeded their MCL. The most common pesticides found were atrazine (73% of wells) and its breakdown product desethylatrazine (80% of wells). The combinations of pesticides detected ranged from 1 to 7 per well, with as many as 35% of the wells containing at least 4 different pesticides in addition to high nitrate levels. The presence of atrazine in wells was associated with the age of the well, suggesting that older wells in the southern Willamette Valley may be more susceptible to pesticide contamination. Neither atrazine nor the numbers of pesticides found per well were correlated with nitrate levels in the 2002 sampling period. The study conducted by Hinkle et al., (1997) on groundwater in the Willamette Basin also found no correlation between atrazine and nitrates, but did find that median nitrate levels were higher in wells with pesticide contamination. A study in the Central Columbian Plateau, Washington and Idaho, also found an increasing occurrence of pesticides with increasing concentrations of nitrate (Williamson et al., 1998). The inability of the current study to find a similar relationship may be due to the bias towards high nitrate wells in the 2002 sampling period, and the inability to compare wells with relatively low levels of nitrate contamination.

Use of Treatment Devices

A total of 28 out of 99 participants responded positively to the question concerning the use of water treatment systems. An disturbing finding is that 11 of the 16 participants (69%) classified as having high nitrate (>10 mg/l) levels in their well water responded "No" when asked if they use a water treatment device to purify their homes well water. None of these respondents were younger than 50 years old, and as a result, the risk of the most acute medical condition associated with ingesting nitrate, methemoglobinemia, is extremely low. Four of the participants in the high nitrate category (25%) that responded "Yes" to the use of water treatment devices chose a reverse osmosis system to remove the nitrate, and one of the participants reported having water delivered from an alternative source. Another three participants in the medium nitrate category (3-10 mg/L) reported using reverse osmosis systems, as did 1 participant in the low nitrate category. The majority of the respondents in the low and medium nitrate contamination categories reported using activated charcoal filters or ion exchange systems, neither of which is capable of removing nitrate. A survey of rural residents of northeastern Oregon found some similar results. Thirty percent of the survey's respondents reported using water treatment devices, with 32% of the respondents choosing a reverse osmosis treatment system (Mitchell et al., 1996).

Participants' Concerns Regarding Drinking Water Quality

Survey participants' description of their well water quality was on the whole quite favorable, as 69% described the quality of their well water as either "excellent" or "good." No significant differences in mean nitrate contamination levels between the question's response variables were found, but it was apparent that respondents'

descriptions of well water quality became less favorable as levels of nitrate contamination gradually increased.

Participants' responses to more specific questions regarding the influence they believed potential sources of contamination had on their well water quality exhibited interesting results. With regard to concern over agricultural fertilizer use harming well water quality, 55% either "strongly agreed" or "agreed." Those who "strongly agreed" with the statement were also those with significantly higher mean nitrate levels in comparison to those who "agree" or were "not sure." This suggests that individuals with the highest nitrate contaminations may be attributing the contamination to agricultural fertilizers. A smaller percentage of the participants agreed that agricultural pesticides were harming the quality of their well water (36%). In both cases respondents who did not own agricultural property, 47% of the survey population, were much more likely to express concern over the effect of fertilizers and pesticides negatively impacting their well water than respondents who did own agricultural property. The largest percentage of participants, 74%, expressed concern that septic systems were contaminating their well water, but there was no association between how the participants responded and nitrate contamination levels. Interestingly, respondents who reported owning agricultural property expressed more concern over septic systems having a negative impact on water quality than either agricultural fertilizer or pesticide use.

Septic System Pumping and Nitrate Contamination

Survey participants expressed some concern over septic systems having a negative impact on the quality of their well water, and appear to be taking proactive

measures to protect their water by having their septic tanks regularly pumped. In many instances nitrate contamination can result when septic systems are not maintained, or if the household wellhead is positioned too closely to the septic system's drain field. Densely packed communities that are not connected to a local wastewater treatment facility are especially at risk of nitrate contamination. To attempt to determine the influence septic systems pose to households in this survey, participants reported the frequency with which they pump their septic systems, the distance of their wellhead from the septic tank, and the distance of the wellhead from the drain field. No significant relationships or trends were found among these variables and levels of nitrate contamination in well water. Moreover, no relationships were found among these variables and dissolved chloride, also commonly found in areas where septic systems are causing water contamination problems.

Limitations of the Study

This study represents a judgment sample of household wells in an area chosen by the Oregon Department of Environmental Quality (ODEQ), and with a general knowledge that a nitrate contamination problem exists. The locations of household wells in this study were spread out over a broad spatial scale, as shown in Figures 8-11, but with some bias toward the Junction City and Coburg regions. Therefore, the findings of the study are limited to the study area only. The two water quality sampling periods occurred approximately a year and a half apart making correlations between nitrate 2000-2001 contamination levels and contaminants from the 2002 sampling period inappropriate. Thus the sampling period with the largest number of sample wells

(N = 476), 2000-2001 sampling period, could only be correlated with more static variables such as well depth and well age.

The list of participants for the mailed survey was drawn from the judgment sample of households sampled by the ODEQ, primarily so that comparisons could be made between well water contaminant levels in the households and the perceptions of the sampled residents toward well water quality issues. Response rates between low, medium, and high nitrate contamination categories were very similar, suggesting some similarity among the participants within the different categories. As is the case with most surveys, the responses provided by participants may be influenced by current events, or a participant's perception of some socially accepted behavior. The results are subject to sampling error, and as a result the conclusions drawn are only representative of the 476 households included in the ODEQ study area.

Conclusions

This study investigated well water contamination, primarily nitrate contamination, in household wells located in the southern Willamette Valley. Participants concerns over well water quality issues and their exposure mediating practice were also evaluated. The following list presents the major findings of the study:

1) For the 2000-2001 sampling period 47.7% of the samples had nitrate levels that were less than 3 mg/L nitrate-N, 45% of the samples were between 3 and 10 mg/L nitrate-N, and 7.4% of the samples exceeded the national standard of 10 mg/L nitrate-N.

2) For the 2002 sampling period 6% of the samples had nitrate levels less than 3 mg/L nitrate-N, 46% of the samples were between 3 and 10 mg/L nitrate-N, and 48% of the samples exceeded the national standard of 10 mg/L nitrate-N. Eleven percent of households (53%) combined from both sampling periods had wells with nitrate contamination levels above the public drinking water standard.

3) Pesticides were detected in 81 of the 100 wells tests.

4) There was no significant difference in the use of water treatment systems based on concentration of nitrate in the well water.

5) Respondents who used activated charcoal water purification devices had significantly lower nitrate levels than respondents who used reverse osmosis water purification devices.

6) There was no significant difference in respondents' description of well water quality based on concentration of nitrate in the well water. However, it was apparent that respondents' descriptions of well water quality became less favorable as levels of nitrate contamination gradually increased.

7) There was a significant difference in respondents' level of concern over agricultural fertilizers having a negative impact on well water quality based on nitrate contamination level. The mean nitrate levels for those who responded "strongly agree" was significantly greater than for those who responded either "agree" or "not sure."

8) Respondents who do not own agricultural property are more likely to agree with the statement "I am concerned that agricultural fertilizer use in the southern

Willamette Valley will increase the level of nitrates in my well water" than are respondents who do own agricultural property.

9) Respondents who do not own agricultural property are more likely to agree with the statement, "I am concerned that agricultural pesticide use in the southern Willamette Valley is having a negative impact on the quality of my home's well water", than are respondents who do own agricultural property.

10) Respondents who believe farmers are doing an unfavorable job in managing their land to ensure good water quality are more likely to "strongly agree" with concerns over agricultural fertilizer and agricultural pesticide use having a negative impact on well water quality.

11) The analysis of participants' attitudes, perceptions, and knowledge shows difference in opinion between agricultural landowners and residents of the area. Both types of residents expressed some concern over groundwater quality, but differences in opinion about sources of potential contamination were apparent. Agricultural landowners typically assign less importance to agricultural sources of contamination than other residents. This may difference may indicate a future cause of some conflict when solutions to groundwater contamination are proposed by state agencies.

12) There was no significant relationship found between nitrate contamination levels and the frequency of septic tank pumping, the distance of the septic tank from the well head, and the distance from the septic tanks drain field.

13) Nitrate contamination levels were found to be significantly different between geologic units. The nitrate levels in geologic unit Qg_1 were significantly higher

than all other geologic units, with the exception of Q_{alc}. Typically, households located in areas where the Holocene alluvium of the Willamette River and the Pleistocene sand and gravel post-Missoula flood deposits dominated the geologic structure were at greater risk of high nitrate contamination.

14) No significant association between nitrate 2000-2001 levels and either well depth or well age was found, resulting in a failure to reject the first research hypothesis.

15) A significant association existed between nitrate 2002 levels and dissolved sulfate, resulting in the rejection of the second research hypothesis.

16) Household nitrate levels in the 2002 sampling period were significantly higher than the nitrate levels in the 2000-2001 sampling period.

Even though exposure to relatively high nitrate concentrations was widespread, with well water being the main source of drinking water for 89% of the participants, the likelihood of methemoglobinemia appears to be low because those exposed to high nitrate concentrations (> 10 mg/l) were 50 years old or older. However, this risk may change in the future as the population within this region grows.

Ninety-one percent of the respondents have lived in this region for 10 years or more. Some participants are correctly using reverse osmosis treatment systems to remove nitrate from their drinking water, but others still do not perceive the need for any treatment. Studies of long-term exposure to nitrate from contaminated well water are still inconclusive as to what risk this poses. Moreover, toxicological science has traditionally focused on individual exposures, as a result very little is known about

exposure to chemical combinations, such as nitrate and pesticides, and their effect on human health.

Recommendations

The potential risk of methemoglobinemia warrants continued public education of the risks involved with drinking well water contaminated with nitrate at levels > 10 mg/L. Clear evidence of nitrate's long-term health effects is not conclusive, and until more is understood of nitrates role in the etiology of these chronic condition the consumption of water with high nitrate contamination should be as low as possible.

Efforts should be made to inform the areas residents of the well water contamination problems, and advice should be given on how best to reduce exposure. Local health departments, medical offices (especially OB-GYN and Pediatricians), and extension offices in the area may be reliable sources of information for area residents. These resources could distribute fact sheets that describe areas of contamination, sources of contamination, general knowledge about areas of higher risk, how best to reduce exposure to contaminated well water, and recommendations explaining the importance of testing well water. Having this information may encourage area residents to become more involved with local community meetings on groundwater management, and help agencies to craft policies that are inclusive of the regional stakeholders.

Future studies and continued monitoring of well water quality in the southern Willamette Valley should include variables that provide a measurement of soil type and thickness for each well sampled, sampling methods that stratify wells by geologic unit, and measurements of dissolved sulfate, dissolved chloride, and pesticides. Including these variables in a representative study of nitrate levels in the southern Willamette

Valley would provide a richer interpretation of their relationships in well water, and as a result may elucidate possible predictor variables for contaminated well water. Due to high nitrate levels, the current study suggests that monitoring of well water in specific geologic units is warranted.

Finally, measures should be taken to reduce the problem of nitrate contamination at the source. Exact sources of nitrate contamination, non-point source pollution in general, are difficult to ascertain, but in areas with high agricultural land use and permeable soil structures it is highly likely that agricultural fertilizers are a major source of contamination. Recognizing that there is a problem with the amount and distribution of well water nitrate contamination in the area suggests that there is a need for further research on strategies that reduce the amount of fertilizer needed, and reduce the amount lost from the soil. More evidence on the source of nitrate would change perceptions about the influence of specific land use practices, and may provide more incentive to change. Appendix E provides some of the strategies that could be used to protect groundwater from nitrate contamination. The voluntary adoption of best management practices is only one possible solution to reducing nitrate contamination in the region. Realistically, a number of strategies will be needed to influence change, including economic incentives and disincentives, zoning and land use restrictions, environmental regulations, and possibly bans on specific agricultural chemicals.

BIBLIOGRAPHY

Auslander, B., Langlois P. Toronto Tap Water: Perception of Its Quality and Use of Alternatives. *Canadian Journal of Public Health.* April 1993; vol. 84 (2); 99-102.

Barbash, J.E., Resek E.A. *Pesticides in the Groundwater: Distribution, Trends, and Governing Factors.* Ann Arbor Press, Inc., Chelsea MI. 1994.

Baxter R. Some Public Attitudes about Health and the Environment. *Environmental Health Perspectives.* 1990; vol. 86; 261-269.

Berry J.T., Commercial Fertilizers. Tennessee Valley Authority Environmental Research Center. Muscle Shoals, Al. 1994.

Bukowski J., Somers G., Bryanton J. Agricultural Contamination of Groundwater as a Possible Risk Factor for Growth Restriction or Prematurity. *Journal of Occupational and Environmental Medicine.* April 2001; 43 (4): 377-383.

Burger J., Martin M., Cooper K., Gochfeld M. Attitudes toward environmental hazards: Where do toxic wastes fit? *Journal of Toxicology and Environmental Health.* 51:109-121; 1997.

Canter, Larry W. *Nitrates in Groundwater.* CRC Press Lewis Publishers, New York; 1997.

Cuello C., Correa P., Haenszel W. Gastric caner in Columbia: Cancer risk and suspect environmental agents. *Journal of the National Cancer Institute.* Vol. 57: 1015-1020; 1976.

Eldridge, A. Upper Willamette Basin Groundwater Assessment: Final Sampling and Analysis Plan. Oregon Department of Environmental Quality, Groundwater Quality Protection Program; Water Quality Division. June, 2002.

Environmental Protection Agency. *2002 Edition of the Drinking Water Standards and Health Advisories.* Office of Water: EPA 822-R-02-038. 2002. Washington D.C.

Environmental Working Group. Pouring it on: Nitrate Contamination of Drinking Water. 1996: http://www.ewg.org/reports/Nitrate/NitrateContents.html

Eply RJ., Addis PB., Warthesen JJ. Nitrate in Meat. University of Minnesota: FS-00974. 1992. www.extension.umn.edu/distribution/nutrition/DJ0974.html

Feaga J., Dick R., Louie M., Selker J. Nitrates and Groundwater: Why Should We Be Concerned With Our Current Fertilization Practices? Draft paper; Oregon State University Department of Bioresource engineering. 2002.

Gupta S.K., Gupta R.C., Seth A.K., Gupta A.B., Bassin J.K., Gupta D.K., Sharma S. Epidemiological Evaluation of recurrent Stomatitis, Nitrates in Drinking water, and cytochrome b_5 Reductase Activity. *American Journal of Gastroenterology.* Vol. 94; No. 7. 1999: 1808-1812.

Hallberg A. A Progress Review of Iowa's Agricultural-Energy-Environmental Initiatives: Nitrogen Management in Iowa. *Technical Information Series 22.* Iowa Department of Natural Resources. Dec. 1991.

Hinkle, Stephen. Quality of Shallow Groundwater in Alluvial Aquifers of the Willamette Basin, Oregon, 1993-95. *U.S. Geological Survey: Water Resources Investigations.* Report 97-4082-B. 1997.

Idaho Department of Environmental Quality. *Groundwater Quality Investigation and Wellhead Protection Study City of Ashton, Idaho.* Groundwater Quality Technical Report No. 15: Technical Services Division; August 2001.

Johnson Carl J., Kross Burton C. Continuing Importance of Nitrate Contamination of Groundwater and Wells in Rural Areas. *American Journal of Industrial Medicine.* June 1990; 18:449-456.

Knobeloch L, Salna B, Hogan A, Postle J, Anderson H. Blue Babies and Nitrate-Contaminated Well Water. *Env Health Per* July 2000; 108 (7): 675-678.

Kross B.C., Hallberg G.R., Bruner R., Cherryholmes K., Johnson K. The Nitrate Contamination of Private Well Water in Iowa. *American Journal of Public Health.* February 1993; vol. 83:270-272.

Lohr, Sharon. *Sampling: Design and Analysis.* Brooks Cole Inc. Washington D.C. 1998.

Madison R.J., Brunett J.O. Overview of the occurrence of nitrate in groundwater of the United States: U.S. Geological Survy Water-Supply Paper 2275. 1985.

Mitchell, T.J., Harding, A.K. Who is Drinking Nitrate in Their Well Water? *Journal of Environmental Health.* October 1996; 59(3) 14-19.

MØller H, Landt J, Perdersen E, Jensen P, Autrup H, Jensen OM. Endogenous Nitrosation in Relation to Nitrate Exposure from Drinking Water and Diet in a Danish Rural Population. *Cancer Research.* June 1989; 49 (11): 3117-3121.

Morales-Suarez-Varela MM, Llopis-Gonzales A, Tejerizo-Perez ML. Impact of nitrates in drinking water on cancer mortality in Valencia, Spain. *European Journal of Epidemiology* 11(1):15-21 1995.

Morris P.M., Rosenfeld A., Bellinger M. What Americans Think about Agrichemicals: A nationwide survey on health, environment, and public policy. Washington D.C. Public Voice for Food and Health Policy. April 1993.

Mueller, BA, Newton K, Holly EA, Preston-Martin S. Residential water source and the risk of childhood brain tumors. *Env Health Per* June 2001; 109 (6): 551-556.

Nadakavukaren, Anne. Our Global Environment: A Health Perspective; 5th Edition. Waveland Press, Inc., Prospect Heights. 2000.

Nolan BT., Ruddy BC., Hitt KJ., Helsel DR. A national look at nitrate contamination of groundwater. *Water conditioning and purification.* 1998. 39 (12): 76-79.

O'Connor J., Sarna-Wojcicki A., Wozniak K., Polette D., Fleck R. Origin, Extent, and Thickness of Quaternary Geologic Units in the Willamette Valley, Oregon: U.S. Geological Survey Professional Paper 1620. 2001.

Office of Technology Assessment, "Beneath the Bottom Line: Agricultural Approaches to Reduce Agrichemical Contamination of Groundwater," OTA-F-418, November, 1990, U.S. Congress, U.S. Government Printing Office, Washington D.C., pp. 3-20. Oregon Department of Environmental Quality. "Groundwater Basics: For Drinking Water Protection." Water Quality Division Drinking Water Protection Program. Fact Sheet. 2001.

Oregon Department of Environmental Quality: Water Quality Division. "Report to the Legislative Assembly Groundwater Quality Protection in Oregon. January 1999.

Oregon State University. Department of Bioresource Engineering. Best Management Practices to Protect Groundwater From Nitrate Contamination. 2002.

Ohshima H. Bartsch H. Quantitative estimation of endogenous nitrosation in humans by monitoring N-nitrsoproline excreted in the urine. *Cancer Research.* September 1981; 41 (9): 3658-3662.

Porter WP, Jaeger JW, Carlson IH. Endocrine, immune, and behavioral effects of aldicarb (carbamate), atrazine (triazine) and nitrate (fertilizer) mixtures at groundwater concentrations. *Toxicology and Industrial Health* Jan-Mar 1999; 15 (1-2): 133-150.

Puckett, L.J. Nonpoint and Point Sources of Nitrogen in Major Watersheds in the United States. *U.S. Geological Survey Water Resource Investigations.* Report number 94-4001. Washington D.C. 1994.

Schubert C., Knobeloch L., Kanarek M., Anderson H. Public Response to Elevated Nitrate in Drinking Water Wells in Wisconsin. *Archives of Environmental Health.* July-August 1999; 54(4) 242-247.

Shibamota, Takayuki and Bjeldanes, Leonard F. *Introduction to Food Toxicology.* Academic Press Inc., New York, 1993.

Spontaneous abortions possibly related to ingestion of nitrate-contaminated well water—LaGrange County, Indiana, 1991-1994. MMWR 45(26): 569-572. 1996

Squillace, P.J., Scott J.C., Moran M.J., Nolan B.T., Kolpin D.W. VOCs, Pesticides, Nitrate, and Their Mixtures in Groundwater Used for Drinking Water in the United States. *Environmental Science and Technology.* Vol. 36; 1923-1930. 2002.

Tannenbaum SR., Fett D., Young VR., Land PD., Bruce WR. Nitrite and nitrate are formed by endogenous synthesis in the human intestine. *Science.* 1978. 200(4349): 1487-1490.

Thornton J.A., Rast W., Holland M.M., Jolankai G., Ryding S.O. *Assessment and Control of Nonpoint Source Pollution of Aquatic Ecosystems: A practical approach.* The Parthenon Publishing Group; Paris. 1999.

Uhrich, M., Wentz D. Environmental Setting of the Willamette Basin, Oregon. U.S. Geological Survey, Water-Resources Investigations Report 97-4082-A. 1999.

Van Leeuwen, J, Waltner-Toews D, Abernathy T, Smit B, Shoukri M. Associations between stomach cancer incidence nad drinking water contamination with atrazine and nitrate in Ontario (Canada) agroecosytems, 1987-1991. *International Journal of Epidemiology.* October 1999; 28 (5): 836-840.

van Maanen JMS, van Dijk A, Mulder K, de Baets MH, Menheere P, van der Heide D, Mertens P, Kleinjans, J. Consumption of drinking water with high nitrate levels causes hypertrophy of the thyroid. Toxicology Letter. 72:365-374. 1994

van Maanen JMS, Welle IJ, Hageman G, Dallinga JW, Mertens P, Kleinjans J. Nitrate contamination of drinking water: relationship with HPRT variant frequency in lymphocyte DNA and urinary excretion of *N*-Nitrosamines. *Env Health Per* May 1996; 104 (5): 522-528.

Water Quality Association press release. Consumer use of household water treatment. www.wqa.org. 1999.

Weisenburger D. Environmental Epidemiology of Non-Hodgkin's Lymphoma in Eastern Nebraska. *American Journal of Industrial Medicine.* 18: 303-305. 1991

Weyer PJ, Cerhan JR, Kross BC, Hallberg GR, Kantamneni J, Breuer G, Jones MP, Zheng W, Lynch CF. Municipal drinking water nitrate level and cancer risk in older women: the Iowa women's health study. *Journal of Epidemiology* May 2001; 11 (3): 327-338

Williamson A.K., Munn M.D., Ryker R.J., Wagner R.J., Ebbert J.C., Vanderpool A.M. *Water Quality in the Central Columbia Plateau, Washington and Idaho, 1992-1995.* U.S. Geological Survey: Circular 1144. 1998.

Woodcock, D. Influence of the Willamette Silt on Groundwater Flow in Shallow Basin-Fill Sediments of the Willamette Valley, Oregon. *Cordillian Section 98th Meeting; Session No. 43:* Geological Society of America. 2002.

Woodward D., Gannet M., Vaccaro J. Hydrogeologic Framework of the Willamette Lowland Aquifer System, Oregon and Washington: U.S. Geological Survey, Professional Paper 1424-B. 1998.

Xu G, Song P, Reed PI. The relationship between gastric mucosal changes and nitrate intake via drinking water in a high-risk population for gastric cancer in Moping county, China. *European Journal of Cancer Prevention* May 1992; 1; 437-443

Yang CY, Cheng MF, Tsai SS, Hsieh YL. Calcium, magnesium, and nitrate in drinking water and gastric cancer mortality. *Jpn J Cancer Research* 89(2):124-130, 1998.

APPENDICES

APPENDIX A

Mail Survey Questionnaire

Exploring Drinking Water Quality Issues

in the
Southern Willamette Valley

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We are very interested in learning about how residents in the southern Willamette Valley view groundwater quality and groundwater usage issues. All of your answers and comments will be kept strictly confidential to the full extent of the law. **Thank You!**

FIGURE 1
Southern Willamette Basin Groundwater Assessment

Southern Willamette Basin Groundwater Assessment Study Area

The above graphic is meant to provide a visual representation of the area I refer to as the "southern Willamette Valley."

Q1. Please indicate approximately how long you have lived in the southern Willamette Valley? *(Please fill in the blank)*

_____ YEARS

Q2. Please indicate whether or not each of the following describes your association with the southern Willamette Valley. *(Please circle one number for each, and where appropriate indicate the approximate acreage)*

	NO	YES
a. I own residential property in the southern Willamette Valley......................	1	2 → If Yes, how many acres? _____
b. I own agricultural land in the southern Willamette Valley................................	1	2 → If Yes, how many acres?_____

c. Other *(specify)* _____

Q3. How would you describe the quality of your well water? *(Please circle one number)*

    1 EXCELLENT
    2 GOOD
    3 FAIR
    4 POOR
    5 NO OPINION

Q4. What is the <u>primary</u> factor influencing the opinion you have of your well water quality? *(Please circle one number)*

    1 A TEST OF MY WELL WATER
    2 THE TASTE OF MY WELL WATER
    3 INFORMATION FROM A FAMILY MEMBER
    4 OTHER *(Please specify)* _____

Q5. Listed below are different opinions that people may hold regarding the southern Willamette Valley. Given your experience from living in this area, indicate your level of agreement or disagreement with each of the following statements. *(Please circle one number for each question)*

	STRONGLY AGREE	AGREE	DISAGREE	STRONGLY DISAGREE	NOT SURE
a. Land use activities can have an effect on well water quality.....	1	2	3	4	5
b. I am concerned that agricultural fertilizer use in the southern Willamette Valley will increase the level of nitrates in my home's well water...........................	1	2	3	4	5
c. I am concerned that poorly maintained residential septic systems will have a negative impact on my home's well water.............	1	2	3	4	5
d. I am concerned that agricultural pesticide use in the southern Willamette Valley is having a negative impact on the quality of my home's well water................	1	2	3	4	5

cont'd.

	STRONGLY AGREE	AGREE	DISAGREE	STRONGLY DISAGREE	NOT SURE
e. Applying fertilizer in excess of crop needs is ok as long as no harm is done to the crop.........	1	2	3	4	5
f. If groundwater contamination exists, regulatory actions should be used to protect the groundwater quality in the southern Willamette Valley	1	2	3	4	5
g. I am concerned that the overuse of household chemicals, including pesticides and fertilizers may be contaminating groundwater........	1	2	3	4	5

Q6. The Department of Environmental Quality has been working on a project since 2001 to evaluate the southern Willamette groundwater quality conditions. This project has involved collecting water quality samples from selected private wells and holding public meetings and trainings for the residents of this area. Before you received this questionnaire, were you aware of this project? *(Please circle one number)*

       1 NO → PLEASE SKIP TO QUESTION 7
       2 YES → PLEASE GO TO QUESTIONS Q6a

             Q6a. If Yes, do you think this is a valuable project? *(Please circle one number)*

                    1 NO
                    2 YES
                    3 NO OPINION

Q7. In the last decade the United States Department of Agriculture (USDA), and some state land-grant universities, have begun researching ways to decrease the levels of agri-chemicals used in food production. Are you in favor of more research into techniques that may reduce the levels of agri-chemicals, or do you believe current agricultural techniques are adequate. *(Please circle one number)*

       1 I FAVOR MORE RESEARCH
       2 CURRENT TECHNIQUES ARE ADEQUATE
       3 UNDECIDED OR UNSURE

Q8. In your opinion, how well are each of the following types of landowners managing their land in the southern Willamette Valley to ensure good water quality? (*Please circle one number for each*)

	POOR	FAIR	GOOD	EXCELLENT	NOT SURE
a. Farmers....................	1	2	3	4	5
b. Private residents...........	1	2	3	4	5
c. Industries other than farms.........................	1	2	3	4	5
d. Golf courses................	1	2	3	4	5
e. Cities........................	1	2	3	4	5
f. State Gov. (parks, etc)........	1	2	3	4	5
g. Federal Gov. (Bureau of Land Management)............	1	2	3	4	5

The following series of questions will ask you to describe your household water system and your family's use of it. When I refer to "you" in the following questions, I am referring to those household members who are either full-time or part-time residents of your home.

Q9. What is your family's <u>main source</u> of drinking water? (*Please circle one number*)

1 TAP WATER FROM THE WELL
2 BOTTLED WATER FROM THE STORE
3 WATER HAULED FROM ANOTHER SOURCE
4 OTHER (*Please specify*): _____

Q10. Do you use a water purification system on your family's <u>main source</u> of drinking water? (*Please circle one number*)

1 NO → PLEASE GO TO QUESTION 11
2 YES → PLEASE GO TO QUESTION 10a

Q10a. If Yes, what type of water purification system do you use? (*Please circle one number*)

1 ACTIVATED CHARCOAL
2 WATER DISTILLATION SYSTEM
3 ION EXCHANGE SYSTEM (WATER SOFTENER)
4 REVERSE OSMOSIS SYSTEM
5 BOILING DRINKING WATER
6 NOT SURE
7 OTHER (*Please specify* _____)

Q11. **If there is a finding that the groundwater in the southern Willamette Valley has been impacted by residential and/or agricultural land uses, which of the following do you think are reasonable actions for homeowners/landowners to take?** *(Please circle one number for each question)*

	NO	YES	UNDECIDED
a. PUMP SEPTIC TANKS AT LEAST ONCE EVERY 3 YEARS...	1	2	3
b. TEST WELL WATER ON A YEARLY BASIS.............	1	2	3
c. USE LESS FERTILIZER ON LAWN OR GARDENS......	1	2	3
d. TEST SOIL TO DETERMINE APPROPRIATE FERTILIZER APPLICATION RATES........................	1	2	3
e. IMPLEMENT BEST MANAGEMENT PLANS FOR AGRICULTURAL FERTILIZER USE........................	1	2	3
f. ASK LOCAL AND STATE GOVERNMENT REPRESENTATIVES FOR ASSISTANCE IN HELPING CLEAN UP THE GROUNDWATER..............	1	2	3

Q12. **Approximately how many feet deep is your home's drinking water well?** *(Please fill in the blank)*

_____ Feet Deep

Q13. **Approximately how old is your home's drinking water well?** *(Please fill in the blank)*

_____ Years old

Q14. **Approximately how far is your home's drinking water well from the septic tank?** *(Please fill in the blank)*

_____ Feet

Q15. **Approximately how far is your home's drinking water well from the septic system's drain field?** *(Please fill in the blank)*

_____ Feet

Q16. **When was the last time your septic tank was pumped?** *(Please circle one number)*

1 LESS THAN 2 YEARS AGO
2 2-5 YEARS AGO
3 5-10 YEARS AGO
4 MORE THAN 10 YEARS AGO
5 NEVER
6 NOT SURE

Before finishing the survey, we would like to learn more about your background. Be assured that all of the information you provide in this survey will be kept confidential to the full extent of the law.

Q17. What is your gender? *(Please circle one number)*

    1 FEMALE
    2 MALE

Q18. How old were you on your last birthday? *(Please fill in the blank)*
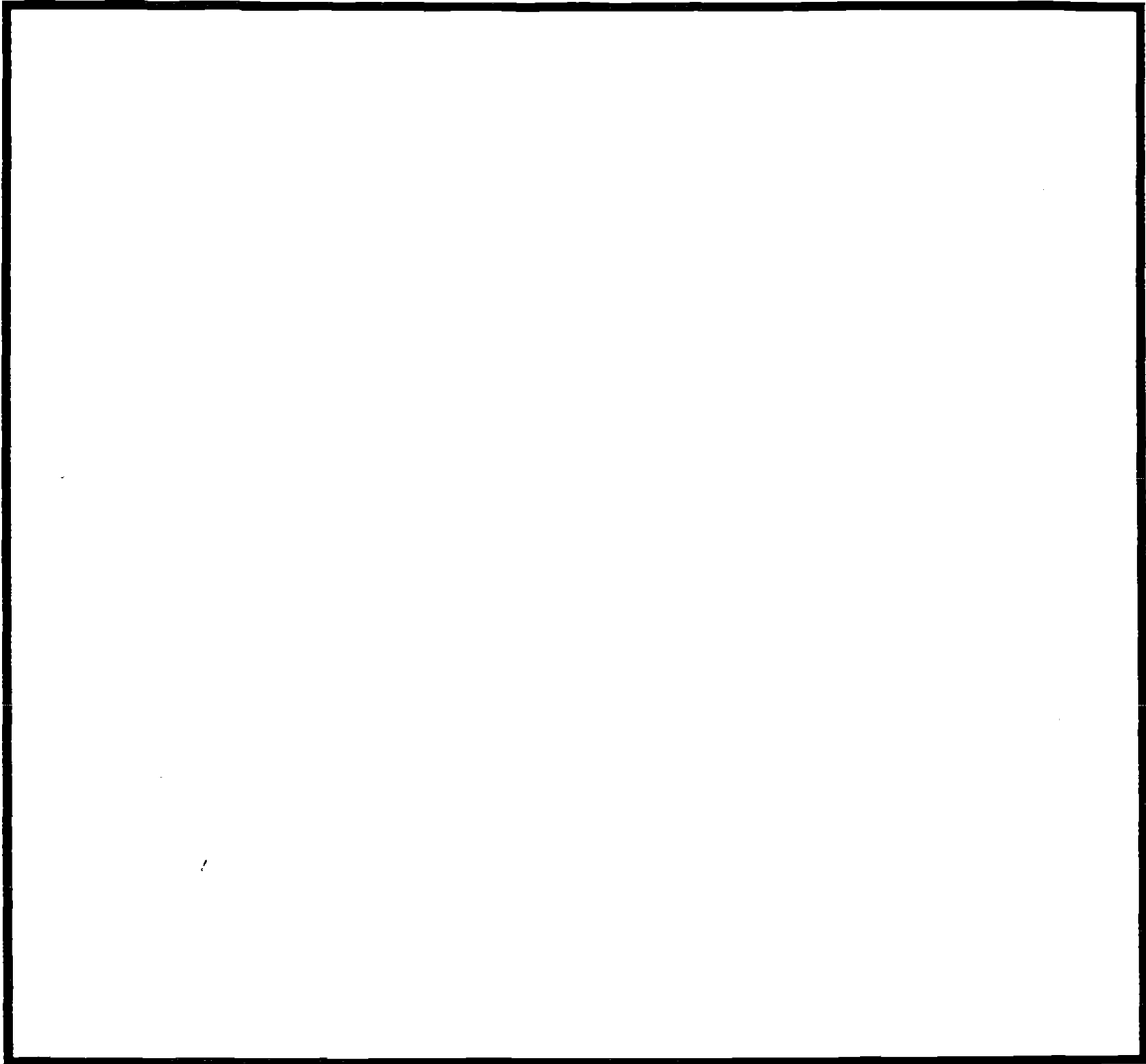
    _____ years

Q19. What is the highest level of education you have completed? *(Please circle one number)*

    1 SOME HIGH SCHOOL
    2 HIGH SCHOOL GRADUATE / GED
    3 SOME COLLEGE
    4 ASSOCIATES DEGREE / TRADE SCHOOL
    5 BACHELOR'S DEGREE
    6 SOME GRADUATE COURSEWORK
    7 MASTERS DEGREE
    8 DOCTORAL DEGREE
    9 OTHER *(Please specify)* _____

Q20. Which of the following categories best describes your total annual household income – before taxes – from all sources? *(Please circle one number)*

    1 UNDER $20,000
    2 $20,000 TO $29,999
    3 $30,000 TO $39,999
    4 $40,000 TO $49,999
    5 $50,000 TO $74,999
    6 $75,000 TO $99,999
    7 $100,000 AND OVER

Q21. We welcome any additional comments you may have concerning the issues raised in this questionnaire. *(Please use the space provided below for your comments)*

Thank you for taking the time to complete this survey and for sharing your opinions with us!

APPENDIX B

Letter of Introduction for Survey Questionnaire

01/20/2003

Dear Resident:

Within the next week you will receive a voluntary survey from the Department of Public Health at Oregon State University. This survey is a part of a graduate student's thesis work, and it will ask you for your opinions of groundwater and drinking water quality issues in the southern Willamette Valley. You are one of a group of randomly sampled residents in the southern Willamette Valley who has in the past been in contact with the Oregon Department of Environmental Quality, and who is being asked to give an opinion on these issues.

The information you provide will help in understanding local residents' understanding and perceptions of groundwater quality issues in this region. It may also in the future help to make some regionally appropriate policy decisions concerning the protection of groundwater. You can be sure that the opinions you provide on this survey will be kept fully confidential to the extent permitted by law.

In advance, thank you for your time and participation.

Sincerely,

Aaron Kite-Powell
Graduate Student, Environmental Health Manag.
(541) 737-1281
kitepowa@onid.orst.edu

Anna K. Harding Ph.D.
Chair and Associate
Professor
(541)737-3825

APPENDIX C

Letter that Accompanied the Survey Questionnaire

10/2002

Dear Resident:

Last week you were contacted by a graduate student, Aaron Kite-Powell, from Oregon State University's Department of Public Health regarding your participation in filling out a voluntary survey. The primary objective of the survey is to gain a better understanding of local residents' perceptions and understanding of drinking water quality issues in the southern Willamette Valley.

You are one of a group of randomly sampled residents in the southern Willamette Valley whose drinking water was tested by the Oregon Department of Environmental Quality (DEQ). In order for the survey results to truly represent the thinking of all those residents who have had their water tested by the DEQ, it is important that each survey is completed. Your responses, together with others, will be combined and used for statistical summaries only. Your participation in this study is voluntary and you may refuse to answer any question. Anyone in the household over 18 years of age may complete the survey. If you choose to participate, this will help to assess your views of drinking water quality in the region.

The answers you provide are **strictly confidential** to the extent permitted by law, and special precautions have been established to protect the confidentiality of your responses. The number on your survey will be removed once your survey has been returned. We use the number to contact those who have not returned their survey, so we do not burden those who have responded. Your survey will be destroyed once your responses have been tallied.

If you have questions about your rights as a participant in this study, please contact the Oregon State University Institutional Review Board (IRB) Coordinator at (541) 737-3437, or by email at IRB@oregonstate.edu. You may also call me at (541) 737-1281, or contact me by email at kitepowa@onid.orst.edu.

We would appreciate it if you would take about 15 minutes to respond to the enclosed survey and return it in the postage-paid envelope provided. The survey results will be presented as part of a masters thesis, and may be helpful in making future policy decisions concerning drinking water quality issues in the southern Willamette Valley.

Thank you very much for your help.

Sincerely,

Aaron Kite-Powell
Graduate Student, Env. Health Management

Anna K. Harding Ph.D.
Chair and Associate Professor

Enclosures

APPENDIX D

Reminder Letter for Survey Questionnaire

Last week a voluntary survey seeking your opinion about drinking water quality issues in the southern Willamette Valley was mailed to you by a graduate student from Oregon State University's Department of Public Health. You are a part of a small sample of residents who have in the recent past had drinking water samples taken by the Oregon Department of Environmental Quality.

If you have already completed and returned the questionnaire to us, please accept our thanks. If not, please do so today. This questionnaire has been sent to a small, but representative sample of residents, so it is extremely important that your answers are included as a part of the survey if the results are to accurately represent the opinions of all residents.

We appreciate your help.

Sincerely,

Anna K. Harding Ph.D.
Chair and Associate Professor

Aaron Kite-Powell
Grad. Student, Env. Hlth.

APPENDIX E

List of Agricultural Best Management Practices

Best Management Practices
To Protect Groundwater from Nitrate Contamination

(Adapted from Chris Vick - Department of Bioengineering)
Oregon State University

1. **No Autumn nitrogen application**
   Apply nitrogen when crops need it most (i.e. in the spring).
   Source: http://www.epa.gov.OWOW/NPS/Success319/OR.html

2. **Crop Rotation**
   Rotate nitrate leaching crops (i.e. onions) with nitrate scavenging crops (i.e. wheat and barley).
   Source: http://www.epa.gov.OWOW/NPS/Success319/OR.html

3. **Stream Buffers**
   Buffers are instrumental in removing pollutants entering as either sheetflow or shallow groundwater from outside areas.
   Source: http://www.forester.net/ec_0004_land.html

4. **Control of Invasive Plants**
   Timely control of invasive plants may reduce the need for pesticides later in the growing season.
   Source: http://www.deq.state.or.us/wq/WhpGuide/table3-7.htm

5. **Nitrification Inhibitors and Slow Release Nitrogen**
   Inhibit the production of nitrate from ammonia based fertilizers, and apply fertilizers that release nitrogen over long time periods.
   Source: http://www.dep.state.or.us/wq/WhpGuide/table3-7.htm

6. **Improve Irrigation System Performance and Management**
   Efficient irrigation makes the best use of available water by minimizing negative effects on water quality introduced from deep percolation and surface runoff. Good irrigation system performance is the result of carefully considered system design, prudent equipment maintenance, and proper irrigation water management. Knowing when and how much to irrigate is important for effective management.
   Source: http://biosys.bre.orst.edu/bre/docs/irrigation.htm

7. **Prevent aquifer contamination at wellhead**
   Aquifer contamination can occur because of movement of nutrients or other chemicals from the surface through or along a well casing. Activities near the wellhead may introduce contaminants, and those activities should be identified and curtailed.
   Source: http://biosys.bre.orst.edu/bre/docs/irrigation.htm

8. **Irrigation Scheduling**

Regular measurement of soil moisture is an accurate way of determining when to irrigate. Irrigation water must be applied uniformly and accurately. Adjust water application amounts to meet varying crop water movement beyond the root zone.

Source: http://www.ext.nodak.edu/extpubs/h2oqual/watgrnd/ae1116w.htm

9. **Establish Realistic Yield Goals**

If yield goals are overly optimistic, the recommended application rates of nitrogen will be too high, resulting in excess nitrogen in both soil and groundwater.

Source: 50 Ways Farmers Can Protect Their Groundwater

10. **Test the Soil**

Determine current nitrogen levels in the soil, applying only nitrogen necessary to satisfy crop demand.

Source: 50 Ways Farmers Can Protect Their Groundwater

11. **Credit other Nitrogen Sources**

Adjust nitrogen application rates to account for nitrogen supplied by legumes, manure, and other organic wastes.

Source: 50 Ways Farmers Can Protect Their Groundwater

12. **Plant Tissue Testing**

Analysis of the nutrient content of plant tissue, like soil testing, can provide growers with valuable management information. Tissue tests are useful for monitoring general plant nutrition levels and diagnostic problems.

Source: http://www.inform.umd.edu/EdRes/Topic/AgrEnv/ndd/agronomy/