Assessing the Contamination Risk of Private Well Water Supplies in Virginia

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(ABSTRACT)

When well water becomes contaminated to the extent that is does not meet EPA drinking water quality standards, it is considered unsafe for consumption. Nitrate and total coliform bacteria are both health contaminants and are both regulated in public water systems. A nitrate concentration of 10 mg/L or higher is considered unsafe, as is the presence of total coliform bacteria. Well degradation, inadequate well construction, and aquifer contamination can all result in contamination of well water. Factors such as well type, well age, well depth, treatment devices, population density, household plumbing pipe materials, and nearby pollution sources may affect household water quality. The specific objective of this study was to determine which factors influence nitrate levels and total coliform presence/absence of household well water. If possible, these influencing factors would be used to develop a relationship that would allow household residents to predict the nitrate level and total coliform presence/absence of their well water. As a result, a means of predicting the contamination risk to a specific well water supply under a given set of conditions, in addition to increasing awareness, could provide the homeowner with a rationale for further investigating the possibility of contamination.

Existing data from the Virginia Cooperative Extension Household Water Quality Testing and Information Program were assembled for analyses in this project. The data consisted of 9,697 private household water supplies sampled from 1989-1999 in 65 Virginia counties. Initially, the entire state of Virginia was analyzed, followed by the five physiographic provinces of Virginia: the Blue Ridge, Coastal Plain, Cumberland Plateau, Ridge & Valley, and Piedmont. Ultimately, Louisa County was investigated to evaluate the possibility that better models could be developed using smaller land areas and, consequently, less geological variation. Least squares regression, both parametrically and non-parametrically, was used to determine the influence of various factors on nitrate levels. Similarly, logistic regression was used to determine the influence of the same parameters on nitrate categories, presence/absence of total coliform, and risk categories.

Using stepwise model-building techniques, based primarily on statistical significance (p-values) and partial coefficient of determination (partial-R^2), first and second-order linear models were evaluated. The best-fitting model only explained 58.5% of the variation in nitrate and none of the models fit well enough to be used for prediction purposes. However, the models did identify which factors were, in a statistical sense, significantly related to nitrate levels and total coliform presence/absence and quantified the strength of these relationships in terms of the percent of variation explained.

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CHAPTER 1.0 INTRODUCTION

1.1 Household Water Quality

Groundwater is a valuable resource in the United States, as well as in Virginia, and is a vital source of drinking water. Unfortunately, many people view groundwater as a limitless resource protected from human activity. Groundwater, however, is vulnerable to contamination and, in order to preserve its quality, must be protected. Unlike public wells, the Safe Drinking Water Act does not protect private household wells. Therefore, the responsibility for a home's well water quality lies with the user/owner. The quality of groundwater in Virginia is generally good although it does vary among physiographic provinces, largely due to natural influences (Weigman & Kroehler, 1990).

In groundwater there may be many constituents; no natural water is considered "pure." Of these constituents, some are considered to be health-risks while many are only nuisances (Weigman & Kroehler, 1990). Two health-related contaminants are nitrate and total coliform bacteria. Nitrate is considered to be a health-risk primarily to infants. Infants, upon ingesting too much nitrate, can develop methemoglobinemia, or"blue-baby syndrome," which can be fatal (Weigman & Kroehler). In order to protect infants, the Safe Drinking Water Act sets the nitrate standard at 10 ppm. Total coliform bacteria are considered to be a health-risk because they indicate the possible presence of pathogenic microorganisms. Pathogenic microorganisms can result in potentially serious illness and possibly death. To reduce the probability of being exposed to waterborne pathogenic microorganisms the drinking water standard for total coliform is set at zero.

Well water can become contaminated in one of two ways: 1) the aquifer from which the well draws water is contaminated or 2) contaminated surface water enters the well. Contaminated surface water often enters the well when the structure of the well is compromised. Consequently, well type, well age, and well depth are important factors when considering resultant water quality. There are three primary well types in Virginia: dug, bored, and drilled. Dug and bored wells are relatively shallow and usually draw water from the surficial aquifer. Drilled wells, however, are usually deeper and, therefore, draw water from a confined aquifer less likely to come into contact with contaminated surface water. Well age is usually correlated with well type and depth, in that older wells tend to be shallow, dug or bored wells (Baker et al., 1994), whereas newer wells tend to be deep, drilled wells (Glanville et al., 1997).

1.2 Objectives

This project examines the contamination risk of private well water supplies. Contamination risk is defined as the likelihood of nitrate and total coliform bacteria contamination. The higher the contamination risk, the greater the likelihood of high nitrate levels and presence of total coliform bacteria. Likewise, a lower contamination risk means a high likelihood of low nitrate levels and absence of total coliform bacteria.

Despite the value of good quality household water, many well owners are unaware of contamination issues and associated risks. They often neglect to even test their own drinking water for various reasons. Therefore, a prediction method for contamination risk of a specific well water supply situation, in addition to increasing awareness, could provide the homeowner with a rationale for further investigating the possibility of contamination. Further investigation might include, for example, obtaining a water test, and/or spending additional time and money on water supply improvements.

The goal of this project was to develop a statistical relationship that would allow household residents to predict the nitrate level and total coliform presence/absence in their household well water. Such a prediction model could provide the household resident with information that would advise him/her as to whether or not to invest in water testing and/or other investigations of their well water quality status and contamination risk.

Though it may not be possible to develop a prediction method it should be possible to determine which factors have the greatest effect on household well water quality. There are many factors that can affect the quality of household water including county and/or physiographic province in which the well is located, well characteristics (i.e. well type, well depth, and well age), installed treatment devices, housing density, plumbing materials, and surrounding activities on the land surface.

1.3 Hypotheses

HYPOTHESES

Installed treatment devices, plumbing materials, and potential pollution sources are not significant factors in explaining nitrate and total coliform bacteria contamination.

County and/or province in which a well is located, well characteristics, and housing density are significant factors in explaining nitrate and total coliform bacteria contamination.

NULL HYPOTHESES

Installed treatment devices, plumbing materials, and potential pollution sources are significant factors in explaining nitrate and total coliform bacteria contamination.

County and/or province in which a well is located, well characteristics, and housing density are not significant factors in explaining nitrate and total coliform bacteria contamination.

CHAPTER 2.0 LITERATURE REVIEW

2.1 Overview of the Nation's Groundwater

Groundwater is one of our nation's most valuable resources and is it's primary source of its drinking water (Aller et al., 1995). Ninety-seven percent of freshwater in the United States is groundwater (Amundson et al., 1988), and it supplies more than 90% of the nation's public water and 97% of its rural domestic water (Aller et al., 1995). Groundwater is usually an affordable household water source when one considers that it does not have to be transported over great distances and that one-cent worth of electricity of can lift 83.3 gallons of groundwater. Unfortunately, many individuals believe that groundwater is a limitless resource naturally protected from human activities. In fact, groundwater is vulnerable (Weigman & Kroehler, 1990), although often unhealthily regarded as "out of sight, out of mind" (IEN, 1992).

The United States Environmental Protection Agency estimates that 50 million people in the United States depend on private household water supplies. These individual water supply users are generally more concerned with water quantity than water quality. In fact, 40% of the private water supplies are polluted (Whitsell & Hutchinson, 1973). With regard to nitrate alone, 2.4% of the nation's private rural domestic wells are estimated to have nitrate levels greater than 10 mg/L (Fedkiw, 1991). No one area is immune to groundwater contamination because contamination has been reported in all states. Groundwater contamination can result in poor drinking water quality, loss of a water supply, high cleanup costs, high costs for an alternative water supply, and/or potential health problems (USEPA, 1993).

An individual concerned about his/her water supply should investigate further if any of these cases apply: 1) persistent illness of user(s) 2) open well, spring, or cistern 3) turbid water after rainstorm 4) dug well with jointed casing 5) well or spring located in an area subject to flooding 6) area of sinkhole, cavernous, or fractured rock geology or 7) crowded residential area or industrial development without community sewage facilities (Whitsell & Hutchinson, 1973). Unfortunately, it is difficult to detect groundwater contamination until the water is brought to the surface. In the case of surface water, a "dead fish" odor and discoloration are warning signs of pollution but these indicators do not always apply to groundwater. In fact, the most common contaminants occur in small amounts and are odorless and colorless (Weigman & Kroehler, 1990).

2.2 Groundwater of Virginia

Each day Virginians use 5.6 billion gallons of water from rivers, streams, lakes, and groundwater (Weigman & Kroehler, 1990). Forty-one percent of Virginia's population depends on groundwater for its water supply (Bruggeman et al., 1995). While, groundwater is a vital, valuable, and vulnerable resource in Virginia (Weigman & Kroehler, 1990; Meng et al., 1985), overall, the quality of groundwater in Virginia is thought to be good. Virginia also seems to have sufficient drinking water supplies (Weigman & Kroehler, 1990). A replacement for groundwater as a household water source or extensive groundwater treatment would be expensive or impractical (IEN, 1992; VGPSC, 1993).

The following counties draw a majority of their public water supply from groundwater: Augusta, Caroline, Charlotte, Faquier, Fluvanna, Grayson, Louisa, Madison, Nelson, Roanoke, Rockingham, Russell, Shenandoah, Smyth, Sussex, and Washington. These counties are completely reliant on groundwater for public water supplies: Accomack, Amelia, Appomattox, Bath, Bedford, Botetourt, Buchanan, Charles City, Craig, Cumberland, Dinwiddie, Essex, Floyd, Frederick, Giles, Gloucester, Greensville Henrico, Highland, Isle of Wight, James City, King & Queen, King George, King William, Lancaster, Mathews, Middlesex, New Kent, Northampton, Northumberland, Page, Powhatan, Prince George, Rappahannock, Richmond, Southampton, Surry, and Westmoreland (IEN, 1992).

Private wells in Virginia are not covered by the Safe Drinking Water Act's federal wellhead protection program (IEN, 1992). Additionally, the Virginia Department of Health focuses on protecting public health from ponding sewage but not on sewage making its way to groundwater. As a result, some septic systems have been permitted in highly permeable soils and/or those with high water tables. More than 70% of Virginia households dispose of their wastes using septic systems. Furthermore, one in ten homes in 16 Virginia counties have no plumbing and 20% of households in 14 Virginia counties rely on outhouses. In 1985, a total of 200,000 Virginia citizens in 79,000 households were estimated to utilize unsanitary water supply and waste disposal methods (Weigman & Kroehler, 1990).

As of 1990, the state code has authority to protect groundwater using planning and zoning powers (IEN, 1992; VGPSC, 1993). The Virginia Department of Health has set forth well design and construction criteria that must be adhered to after the effective date of September 1, 1990. Ultimately, public health and ground water resources, as affected by construction and location of private wells, are protected by the Virginia State Board of Health (VDH, 1992). The Virginia Department of Health is responsible for permitting public wells, monitoring the testing program, and enforcing compliance with the Safe Drinking Water Act (IEN, 1992). However, once a private well is constructed and inspected, no agency in Virginia can legally regulate its water quality (Weigman & Kroehler, 1990).

2.2.1 Geology of Virginia

There are five physiographic provinces in Virginia within which the geologic structure and climate are similar. These features, along with the unique quantity and quality conditions of groundwater in each of the provinces, are discussed below. The provinces, from west to east across Virginia, are the Cumberland Plateau, Valley & Ridge, Blue Ridge, Piedmont, and Coastal Plain (Weigman & Kroehler, 1990; IEN, 1992; Meng et al., 1985).

2.2.1.1 Cumberland Plateau

The groundwater of the Cumberland Plateau is considered to be of poor quality, and rich in sulfur and iron (Weigman & Kroehler, 1990). There is also a meager quantity of available groundwater (DCED, 1969). Sandstone, shale, and coal are the majority of sedimentary rocks making up this province. Where coal mining occurs, acid mine drainage may make the groundwater acidic and unsuitable for many uses (IEN, 1992).

2.2.1.2 Valley & Ridge

The Valley & Ridge, along with the Cumberland Plateau, is underlain by sequences of consolidated sedimentary rock (Meng et al., 1985). The Valley & Ridge has a very high pollution potential. In this province sinkholes provide direct conduits for contaminated surface water and runoff to recharge and potentially contaminate the province's aquifers (Weigman & Kroehler, 1990). In the Valley & Ridge lowlands, limestone and dolomite make up the most productive consolidated aquifers in Virginia. In the uplands, sandstone and shale are the rock types and yield only enough water for rural and domestic supplies. Streams often cross fault zones of recharging aquifers thereby directly connecting surface water and groundwater. Recharge also results from surface runoff entering via limestone sinkholes, which bypass filtration by the soil and may allow for contaminated surface water to enter the groundwater (IEN, 1992).

2.2.1.3 Blue Ridge

Crystalline rock predominantly underlies the Blue Ridge as well as the Piedmont (Meng et al., 1985). There is little available groundwater in the Blue Ridge and it is primarily limited to domestic well use (Weigman & Kroehler, 1990; IEN, 1992). In the Blue Ridge the bedrock lies very near the surface and the small amount of groundwater available is contained in joints, fractures, and faults within the bedrock (IEN, 1992). In this province the water quality is good except for a few areas high in iron. There is also a low pollution potential in the Blue Ridge (Weigman & Kroehler, 1990).

2.2.1.4 Piedmont

The Piedmont is the largest province in Virginia (IEN, 1992). Diverse subsurface geology in the Piedmont leads to the area’s varying groundwater quality and well yields. Generally this province has good water quality except a few areas where there are high iron levels and acidity. The pollution potential for the Piedmont is low to moderate (Weigman & Kroehler, 1990). Hard, crystalline igneous and metamorphic formations dominate the province with some areas of sedimentary rocks with sapprolite deposits over bedrock. As the depth increases, the number of fractures and faults for transmitting groundwater decrease (IEN, 1992).

2.2.1.5 Coastal Plain

The Coastal Plain is underlain by unconsolidated sediments (Meng et al., 1985; IEN, 1992). There is a vast quantity of groundwater in Coastal Plain (Weigman & Kroehler, 1990) and more groundwater is withdrawn from this province than any other in the state. There are two groundwater systems in this province, one shallow and one deep (IEN, 1992). The quality is good except for areas where saline water, iron, and hydrogen sulfide are found. Due to the permeable soils and high population density of this province there is a high pollution potential in the upper unconfined aquifer (Weigman & Kroehler, 1990; IEN, 1992).

2.3 Potential Pollution Sources

Both human activities and natural sources have been found to contaminate groundwater (USEPA, 1993; Hallberg, 1989; Powell et al., 1990). Human activities are recognized as having long term, negative effects on groundwater (Weigman & Kroehler, 1990). In dealing with potential pollution sources, there are numerous uncertainties (Glanville et al., 1997) and pinpointing the contamination source and removing contaminants from groundwater is difficult and, therefore, makes clean up very expensive (Weigman & Kroehler, 1990). Regardless of the distance, a potential pollution source should not be located uphill from a well (Gosselin et al., 1997). It should be remembered that well construction and well placement may allow nitrate contamination to occur, but are not the cause of contamination (Hallberg, 1989). A compilation of potential pollution sources resulting from human activities is presented in Table 2.1 and potential natural pollution sources are listed in Table 2.2.

Table 2.1 Potential Pollution Sources (IEN, 1992)

Agricultural Potential Contaminants	
*	improperly applied pesticides, fungicides, and fertilizers
*	leakage from storage containers
*	animal feedlots
*	livestock operations
Residential Potential Contaminants	
*	onsite septic systems
*	cesspools
*	sewer lines
*	fuel storage systems
*	household, lawn, automotive, and pool chemicals
*	urban runoff
*	abandoned wells
NOTE: Septic systems and underground storage tanks are major sources of wastes disposed into the ground	
Waste Management contaminants	
*	older landfills
*	unlined landfills
*	stormwater
Industrial Potential Contaminants	
*	chemicals
*	petroleum
*	cleaning supplies
*	machinery
*	metals
*	electronic products
*	asphalt
*	mining (surface & underground)
*	pipelines
*	storage tanks (above and underground)
*	operating and abandoned wells (e.g. gas, oil, water supply, injections, monitoring, and exploration)
*	septage lagoons and sludge
*	land application of sludge
Commercial Potential Contaminants	
*	auto repair shops
*	gas stations
*	road maintenance depots
*	de-icing operations
*	boat yards
*	railroad tracks and yards
*	airports
*	construction areas
*	dry cleaners
*	laundromats
*	medical institutions
*	research laboratories
*	photography establishments
*	printers

Table 2.2 Natural Potential Pollution Sources (Clawges & Vowinkel, 1996; Madison & Brunett, 1985; Weigman & Kroehler, 1990)

Natural Potential Contaminants	
*	soil nitrogen
*	nitrogen-rich geologic deposits
*	atmospheric deposition
*	bat guano
*	nitrogen-fixing bacteria
*	playas
*	decomposing organic material
*	precipitation
*	geologic deposits containing organic materials

2.3.1 Septic Systems

The United States Environmental Protection Agency reports that septic systems are the major source of groundwater contamination with the potential to release nitrates and bacteria into the groundwater (Weigman & Kroehler, 1990). The average nitrogen concentration of domestic sewage is 35 mg/L (Horsley, 1995) and has been found to be as high as 70 mg/L (Madison & Brunett, 1985). It is estimated that 60% of the 23 million residential septic tanks in the US are operating improperly. One-third of US households dispose of their almost trillion gallons of wastes using septic systems. The potential problem with septic systems is magnified because those who use them often rely on nearby wells for drinking water (Weigman & Kroehler, 1990).

The soil in which a septic system is located should absorb the effluent and provide a high level of treatment. Sand allows the wastewater to pass through too quickly while heavy clay inhibits wastewater movement. Like sandy, permeable soils, areas with fractures or solution channels allow for septic tanks to release nitrates directly into shallow groundwater. Difficulties also occur when septic systems are densely located because they may exceed the soil's capacity to filter impurities. Septic systems must be properly sited (at least 100 ft downhill from wells or springs), designed, and constructed in order to prevent contamination of groundwater (Weigman & Kroehler, 1990).

2.3.2 Fertilizers

The largest nonpoint source of nitrate is agricultural activity (Madison & Brunett, 1985). More specifically, the high concentration of nitrogen in fertilizer and high application rates of fertilizer, make commercial fertilizers likely to have the greatest impact on groundwater. Fertilizer use has increased from 20 million tons nationwide to 40 million tons since the early 1950s. In addition, the nitrogen content of fertilizer used in the United States has increased from an average of 6.1 to 20.4% in recent years (Weigman & Kroehler, 1990). Typically, only when fertilizers are applied in excess of the plant's requirements do they have the potential to contaminate groundwater (Madison & Brunett, 1985; Spalding & Exner, 1993). Evidence of this comes from studies conducted in North Carolina and the Southeast where properly fertilized fields did not affect nitrate levels even in wells down gradient from the fields (Spalding & Exner, 1993). Often, however producers shy away from practices that would protect and preserve groundwater resources due to economic risks (Schepers et al., 1991).

2.3.3 Underground Storage Tanks

It is estimated that there are 5 million underground storage tanks in the United States. When underground tanks are abandoned their location is not always known (USEPA, 1993) and leaking is often not detected until long after it has begun. Of the underground storage tanks in the United States it is estimated that one-third are leaking (USEPA, 1993; Weigman & Kroehler, 1990).

2.3.4 Landfills

Older landfills present more of a groundwater concern than newer landfills. Earlier landfills were usually sited on “low-quality land”. This “low-quality land” includes marshlands, abandoned sand and gravel pits, old strip mines, and limestone sinkholes. In many instances, “low-quality lands” are also groundwater recharge areas (Weigman & Kroehler, 1990). Unlike older landfills, new landfills are required to have liners (clay or synthetic) and leachate collection systems to protect groundwater. Groundwater can be protected from contamination by municipal solid waste landfills by location restrictions, stringent operating requirements and design standards, record keeping, closure and post closure procedures, and groundwater monitoring and corrective action (USEPA, 1993).

2.3.5 Abandoned Wells

Improperly constructed and abandoned wells are a threat to public safety and the most widespread means of groundwater contamination in Virginia. It is estimated that several million wells have been abandoned nationwide since colonization, and the locations of many are unknown. The contamination potential of abandoned wells is magnified when users view them as convenient sites for dumping wastes (Weigman & Kroehler, 1990).

2.3.6 Municipal and Industrial Wastes

There were 6.6 million people in 571 communities in the United States who used land-disposal methods for municipal effluent in 1972. The contribution of industrial wastes to nitrate contamination represents more of a local impact than a widespread one like agriculture. This is partly true since state and federal governments require that effluents applied to the land not make the groundwater nonpotable (Madison & Brunett, 1985).

Liquid wastes from commercial activities are not necessarily directly land applied, however, may be disposed of in surface impoundments. Seventy percent of these impoundments nationwide are considered to be located in hydrologically vulnerable areas. If surface impoundments are lined, contamination of groundwater can be largely prevented (Weigman & Kroehler, 1990).

2.3.7 Other Pollution Sources

There are many other potential pollution sources, one of which is mining. Toxic byproducts, lowered water tables, disrupted aquifers, impacted movement and recharge of groundwater, land subsidence, and altered landscapes can result from mining (Weigman & Kroehler, 1990; IEN, 1992). Additionally, open dumps, although illegal in Virginia, are still in use throughout the state (Weigman & Kroehler, 1990).

2.4 Treatment Options

Instead of drinking contaminated water one can drink bottled water or treat one's water with a point-of-use or home water system (Weigman & Kroehler, 1990). Either option may be necessary, particularly in the case of natural constituents, or in the event that the problem, if caused by non-natural contaminants, cannot be otherwise corrected. While, private rural well water is often untreated (Amundson et al., 1988), point-of-use treatment devices are more common today since individuals have become more aware of drinking water quality issues (Bell et al., 1984). One must also keep in mind that high technology or complex designs may not be superior to simple designs (Regunathan et al., 1983). In the case of nitrate and some other contaminants, however, it may be easier to find a new source of water since the existing technology for nitrate removal is limited and difficult to implement (Spalding & Exner, 1993). These processes are often costly and may not be feasible for treating large volumes of water (Madison & Brunett, 1985). Table 2.3 shows the variety of treatment options and the contaminants that each process removes.

Table 2.3 Treatment Options (Weigman & Kroehler, 1990)

Treatment process	**Removed/Killed contaminants**
chlorination	microorganisms
ultra-violet radiation	microorganisms
activated carbon filters	some organic chemicals and many pesticides
adsorption filters	asbestos fibers and other particles
distillation units	toxic metals, radiological contaminants, and some organics
water softeners	calcium and magnesium
reverse osmosis	dissolved minerals, toxic metals, and radiological contaminants
anion exchange	nitrate
limestone chip filters	raise pH and reduce corrosivity

2.4.1 Chlorination

Chlorination is the most common treatment method for killing bacteria and certain viruses. The water temperature, pH, general water quality, and contact time influence the effectiveness of chlorination. Higher levels of turbidity allow the bacteria to "hide" and thus increase the contact time. The dosage of chlorine should be increased when other constituents, such as, iron, manganese, hydrogen sulfide, and ammonia are present because they "use up" chlorine by combining with the chlorine. Trihalomethanes (THMs) are formed when chlorine combines with organic matter and can be detrimental to one's health. Therefore, if the water being treated contains high levels of organic matter, chlorination as a treatment method should be carefully considered (Wagenet et al., 1995).

2.4.2 Activated Carbon

Granular activated carbon beds are the most common treatment device and are used to address common taste and odor problems, turbidity to some degree, and to remove excess chlorine, many organic contaminants (Regunathan et al., 1983; Fiore & Babineau, 1977), and chemical compounds produced by microorganisms (Geldreich & Reasoner, 1990). Finished water may contain a variety of microbes and the types and numbers of microbes are not affected by activated carbon filters, even in the case of coliforms. Microbes have been found to colonize activated carbon filter units and pose a potential health hazard. Activated carbon filters are not intended to be microbial filters and appear to be neutral to microbial treatment (Fiore & Babineau, 1977). It is not uncommon for activated carbon point-of-use devices to become microbial colonized by adventitious organisms shortly after installation (Snyder et al., 1995; Geldreich & Reasoner, 1990). The heterotrophic bacteria colonizing the filters feed on the organic materials trapped by the activated carbon (Snyder et al., 1995). This could be due to indigenous tap water bacteria surviving and multiplying in a carbon bed and offering competition to coliforms (Fiore & Babineau, 1977). The microbial populations increase during dormancy periods and decrease when the system is flushed and/or used regardless of the presence or absence of an activated carbon cartridge (Fiore & Babineau, 1977; Geldreich & Reasoner, 1990).

2.4.3 Media/Mesh Filters

Turbidity, particulate materials, and certain types of colloidal color are removed from water by mechanical filtration devices (Geldreich & Reasoner, 1990). However, unlike activated carbon units, mechanical filters are not recommended for removing organic chemicals (Wagenet et al., 1995). Home water filters can lead to increased microbial levels but so can unfiltered standing water. Unfiltered water did not show lower levels of coliforms than water passed through a filter system (Fiore & Babineau, 1977). To remove those organisms that resist disinfection, *Giardia* and *Cryptosporidium,* filtration may be the only option (Wagenet et al., 1995).

2.4.4 Ultra-violet Radiation

Ultra-violet (UV) radiation is a physical process that works without adding chemicals, without producing trihalomethanes, without changing taste, and without removing beneficial or inconsequential minerals. This process also works with carbon filtration, water softeners, and reverse osmosis to obtain complete treatment solutions (Carrigan, 1990). Ultra-violet radiation destroys bacteria, viruses, and some cysts (not including cysts of *Giardia* and *Cryptosporidium*) by penetrating the cell and rearranging the genetic information so that reproduction cannot take place (Carrigan, 1990; Wagenet et al., 1995). Suspended solids (turbidity), UV absorption, and the quartz sleeve coating of the lamp influence the effectiveness of UV. Shadows created by suspended solids prevent UV from reaching all the microbes. Microbes within particles are unreachable with enough light intensity to inactivate them. Calcium, magnesium, manganese, and iron may also affect the UV disinfection process over time, even when at recommended potable water levels or less, by precipitating onto the lamp sleeve and reducing the UV intensity. The only way to insure that an ultra-violet radiation system is working properly is to test for microbes (Carrigan, 1990).

2.4.5 Ozone

Ozone is the most powerful oxidant and can be used to disinfect water and can stand alone for water treatment. Ozone is effective for many purposes including bacterial disinfection and oxidizing nitrites. The nitrite ion is quickly oxidized to the soluble nitrate ion, which is further ozonated. When ozone is used to treat water containing iron, manganese, arsenic, and some organics, filtration must follow because the reaction between ozone and these elements produces insoluble materials (Rice, 1989).

2.4.6 Other Treatment Options

Exchange resins can be used to soften water by exchanging sodium ions for calcium, magnesium, and iron ions. These ion exchange resins may also free the water of mineral cations and anions and thus nitrates and sulfates (Geldreich & Reasoner, 1990; Wagenet et al., 1995). When it is necessary to remove all pathogens a water purifier would be used. Water purifiers are combinations of one or more treatment methods such as, small-pored membrane filters, silver impregnated granular activated carbon, halogen based disinfectants, ultraviolet exposure or ozone contact (Geldreich & Reasoner, 1990). Reverse osmosis can be used to lower total dissolved solids (dissolved ions, molecules, and solids), some organic chemicals, and organisms (Geldreich & Reasoner, 1990; Wagenet et al., 1995). However, the use of reverse osmosis for removing organisms is not recommended because of small tears and pinholes that can develop in the membrane and allow the passage of the organisms (Wagenet et al., 1995). Volatile impurities, including toxic metals, some organic and inorganic chemicals, and microorganisms, are vented off distillation units (Geldreich & Reasoner, 1990; Wagenet et al., 1995). *Giardia* and *Cryptosporidium* can be removed by distillation units (Wagenet et al., 1995).

2.4.7 Testing to Determine Treatment Option

Public water supplies are regulated, monitored, and regularly tested by qualified laboratories as required by federal and/or state regulations (Powell et al., 1990). Surface water supplies are required to be monitored annually and groundwater supplies triennially (Fedkiw, 1991). Private water supplies are only voluntarily tested by the landowner or user (Powell et al., 1990). Well owners are encouraged to routinely test their well water since it is difficult to predict nitrate concentrations (Fedkiw, 1991). In some localities the water is required to be tested when ownership of property changes (Powell et al., 1990). It should be kept in mind that one well sample is not sufficient to determine whether or not a well is regularly safe or contaminated at intervals (Fedkiw, 1991), thus the need for regular testing. Before taking any sample, the system should be flushed regardless of the presence or absence of a point-of-use device because of the increased bacterial populations that occur during static periods (Snyder et al., 1995; Bell et al., 1984; Geldreich & Reasoner, 1990).

2.5 Cause of Contamination

2.5.1 Wellhead or Aquifer Contamination

Due to percolation through the upper soil mantle, groundwater has long been considered a safe and reliable source of water (Amundson et al., 1988). This percolation allows the soil to adsorb, filter out, and degrade contaminants (Powell et al., 1990). However, it is possible that wells providing a direct conduit to the groundwater are contributing to its pollution. Therefore, a contaminated well does not necessarily indicate the aquifer water is the source of the contamination (Richards et al., 1996; Baker et al., 1994). It is entirely possible that poor well construction, well deterioration, and/or point source pollution are more to blame for well contamination than local geologic conditions (Glanville et al., 1997).

2.5.2 Aquifers

2.5.2.1 What is an Aquifer?

An aquifer is a formation where groundwater is found. Within the soil profile, there is an unsaturated zone and a saturated zone. The unsaturated zone is also known as the zone of aeration and contains both air and water in the void spaces. Within the saturated zone, all void spaces are filled with water and this water is known as groundwater (Weigman & Kroehler, 1990). A regional aquifer system is comprised of a surficial aquifer and an artesian aquifer (Hubbard & Sheridan, 1989). The surficial aquifer is considered unconfined while the artesian aquifer is confined (IEN, 1992).

The difference between unconfined and confined aquifers is how the water moves in and out of the aquifer (IEN, 1992). Aquifers are recharged via infiltration, percolation, and solution features such as sinkholes (Hubbard & Sheridan, 1989). Sinkholes, subsurface cracks, and underground rivers are characteristic of karst areas and not only recharge aquifers but also facilitate the movement of surface water and contaminants to enter the groundwater (Amundson et al., 1988; Fedkiw, 1991).

The artesian aquifer or confined aquifer is filled with water, under pressure, and surrounded by confining units (Weigman & Kroehler, 1990). Aquifers are also consolidated, solid rock formations or unconsolidated, uncemented formations with interspersed layers of silt, sand, and gravel (IEN, 1992). One type of rock that can comprise an aquifer is sedimentary rock, which is an unconsolidated deposit. Water flows between the sand grains of sedimentary rock. Another rock, metamorphic rock, is a crystalline formation where water flows between grains and in fractures. Lastly, there are crystalline formations or igneous rocks where water flows only in fractures, faults, and cracks. The geology of an aquifer affects the quantity and quality of the groundwater within. Therefore, there is no such thing as naturally pure water (Weigman & Kroehler, 1990).

2.5.2.2 Recharge, Movement, and Storage of Groundwater

The storage and movement of groundwater depends on the porosity of the aquifer (Weigman & Kroehler, 1990). Soils with large openings allow rapid infiltration and movement of water (Powell et al., 1990; USEPA, 1993). When groundwater moves at a slower rate, long-term effects can occur (Weigman & Kroehler, 1990) and contaminated groundwater can go undetected for years or even decades (IEN, 1992; USEPA, 1993). For example, groundwater within half a mile below the surface is an average of 200 years old while water greater than half of a mile of the surface is an average of 10,000 years old (Weigman & Kroehler, 1990).

2.5.2.3 Aquifer Characteristics and Contamination

Ideally, an aquifer should have high storage capacity, high specific yield, high hydraulic conductivity, and good water quality. Unfortunately, high permeability makes an aquifer vulnerable to contamination (Weigman & Kroehler, 1990). Contaminated surface water can contaminate an aquifer (USEPA, 1993). In addition, sinkholes, abandoned wells, mine shafts, and cesspools provide a direct link to groundwater (Powell et al., 1990).

Some features make groundwater more susceptible to contamination (Amundson et al., 1988). Unconfined aquifers of high permeability materials are vulnerable to direct access from surface sources (Fedkiw, 1991). Water supplies in unconsolidated formations are more likely to be contaminated than those in consolidated formations (Whitsell & Hutchinson, 1973). Shallow surficial aquifers, floodplain alluvial aquifers, and solution limestone aquifers are the most prone to contamination. Generally, confined aquifers are less prone to pollution (Hubbard & Sheridan, 1989).

Recharge areas for aquifers are hydrogeologically connected to an aquifer and help to recharge the aquifer. Therefore if a recharge area contains pollution sources, the groundwater of the aquifer is at risk (IEN, 1992). As the recharge of an aquifer increases, the magnitude of dilution increases in addition to the transport efficiency of pollutants to the water table (Robins, 1998). In areas where the soil mantle is thick and comprised of medium to fine textured soil or areas where there is a thick unsaturated zone, contamination of the groundwater may result and go unnoticed for years (Hallberg, 1989).

Sinkholes provide not only the possibility of groundwater contamination in general but nitrate contamination in particular. Nitrate concentrations vary within an aquifer and “hot spots,” where nitrate is greater than 10 mg/L, can be found. High nitrate concentration pockets are often associated with unconfined aquifers or karst settings (Fedkiw, 1991). Unlike nitrate, bacterial concentrations are generally higher at the soil surface and decline as depth increases. The more interconnected the macropores, the easier it is for bacteria to move through the soil (Conboy & Goss, 2000).

2.5.3 Wells

2.5.3.1 Wellhead Protection Areas

A wellhead protection area is defined as the land around a public water supply that is protected so that pollution is prevented from entering the groundwater (IEN, 1992). The defining of this term allows for land uses and activities near public water supply wells to be managed and for planning to prevent problems before they occur (VGPSC, 1993;IEN, 1992). The concept of wellhead protection is to prevent drinking water contamination as opposed to relying on remediation (USEPA, 1993). Wellhead protection areas can be protected using zoning limitations, performance standards for handling potential contaminants, and plans for handling an accident (VGPSC, 1993). The size of a wellhead protection area depends on the hydrogeology in the vicinity of a well, withdrawal rate, current or future activities near the well, and possible replacement options if the well becomes polluted (IEN, 1992; VGPSC, 1993). Therefore, the size of a wellhead protection area can vary from a few acres to several square miles or larger (IEN, 1992). It is possible that within a wellhead protection area, groundwater flow may take longer than 10 years to move from the edge to the center, where the well is located (Horsley, 1995).

2.5.3.2 Well Regulations

Few states have modern well construction codes and even fewer require that they be followed (Whitsell & Hutchinson, 1973). When private well construction regulations exist for a state, they must be complied with. The are several instances in Virginia where well construction permits are voided: 1) site conditions change from those on the application 2) site conditions change from those on the construction permit 3) more than 54 months have passed since the permit was issued (VDH, 1992).

2.5.3.3 Well Characteristics and Contamination

Well water quality problems can often be linked to construction deficiencies, improper site selection, and/or the presence of fractured, channeled, and cavernous formations. Many experts feel that faulty construction is the primary reason (Whitsell & Hutchinson, 1973). If well characteristics are more to blame for contamination than the aquifer itself, then private well water construction regulation should be improved (Glanville et al., 1997) along with wellhead practices being implemented (Reichenberger, 1990). Well construction is of great importance because when flaws occur it is very possible for surface water to directly enter the well (Richards et al., 1996; Baker et al., 1994). Relationships between faulty well construction and nitrate contamination have been determined in previous studies (Hallberg, 1989). Due to the possible major influence that poor well construction and/or maintenance have on well water quality, water from wells does not necessarily represent aquifer or groundwater conditions (Fedkiw, 1991). Wells of insufficient depth or poor construction (allowing preferential flow) call for improved well design and construction (Glanville et al., 1997). Once a well is improved, then the nitrate and bacteria problems should be resolved (Fawcett & Lym, 1992; Gosselin et al., 1997).

The problems that can exist with individual wells include: 1) insufficient and substandard well casing 2) inadequate sealing 3) poor welding of joints 4) lack of sanitary cover 5) use of unsealed, jointed casing 6) reliance on dug wells and 7) use of well pits to protect from freezing (Whitsell & Hutchinson, 1973). One well feature, grouting, is intended to prevent polluted surface water from getting into the annular space between the casing and well bore. This annular space can be a principal avenue by which contamination enters a well (VDH, 1992). Well casing, grouting (Tuthil et al., 1998), and lining all combine to help prevent contamination from entering a well (Conboy & Goss, 2000). To protect a well from contamination, it should be deep and cased by two or more linings (Amundson et al., 1988). To assure safe drinking water the well should be properly located and constructed, as well as tested regularly (Powell et al., 1990).

2.6 Contaminants

Nitrate and bacteria are both major contaminants resulting from human activity (Powell et al., 1990) and serve as indicators of well water contamination largely due to surface water intrusion. Nitrate contamination is both a health and an environmental concern (Hubbard & Sheridan, 1989). Groundwater vulnerability and agricultural pollution may be indicated by nitrate pollution (Bruggeman et al., 1995), of which concentrations in groundwater tend to remain the same over time (Glanville et al., 1997). Surface water can be contaminated with cyst organisms, enteric viruses, and bacterial organisms including coliforms (Rice, 1989). If coliform bacteria are found in water from a well, it is generally indicated that surface water is entering the well, often through inadequate construction (Fedkiw, 1991; Fawcett & Lym, 1992). Since surface water can contain contaminants, including pathogens, the presence of coliform bacteria can indicate the possible presence of pathogens and other harmful pollutants (Corzatt, 1990; Whitsell & Hutchinson, 1973; Wikstrom, 1989). Potential contaminants must be kept from reaching groundwater (IEN, 1992; USEPA, 1993). The prevention of contamination is best since the cleanup of groundwater is expensive and difficult (Powell et al., 1990). If contamination does occur, the only realistic solution may be to obtain a new water source or treat the water before use (Powell et al., 1990; Weigman & Kroehler, 1990; IEN, 1992).

2.6.1 Nitrate

Nitrate is easily taken up by plants but also easily leached through the soil because it is very soluble and very mobile (Hallberg, 1989; Clawges & Vowinkel, 1996). The leaching of nitrate is greatest in sandy soils (Hubbard & Sheridan, 1989). Nitrate leaching must be controlled in order to protect or improve water quality (Schepers et al., 1991). At high concentrations, nitrate is a hazardous pollutant in drinking water (Madison & Brunett, 1985). Nitrate is the most common contaminant in numerous aquifers (Clawges & Vowinkel, 1996; Madison & Brunett, 1985) and is a worldwide concern (Schepers et al., 1991). Within the world's aquifers, the levels of nitrate are increasing (Spalding & Exner, 1993; Madison & Brunett, 1985). The increase in nitrate levels is likely linked to rapid population growth (Madison & Brunett, 1985).

There may be a correlation between ingesting nitrate in drinking water and hypertension, increased infant mortality, central nervous system birth defects, certain cancers (including stomach cancer and non-Hodgkin's lymphoma), (Spalding & Exner, 1993) subclinical neurosystem damage, reproductive or development effects, and congenital malformations (Fedkiw, 1991 and Weigman & Kroehler, 1990). Of primary concern are infants six months old or younger who may develop methemoglobinemia or "blue-baby syndrome," caused by ingesting excessive nitrate. "Blue-baby syndrome" occurs less frequently today than 30 - 40 years ago because of awareness and water system improvements (Weigman & Kroehler, 1990). High levels of nitrate are not only dangerous to humans but also animals.

There are many parameters that can affect the resultant concentration of nitrate in groundwater. These include the amount of nitrogen available, amount of infiltrating water, hydraulic conductivity of the medium, depth to the water table, and potential for denitrification (Hallberg, 1989). Natural processes such as vegetative uptake and denitrification can reduce nitrate levels (Spalding & Exner, 1993; Fedkiw, 1991). Denitrification can be implemented with sewage effluent in order to reduce the nitrogen loading rates (Tuthil et al., 1998). For denitrification to take place, the soil must be saturated or wet (so that oxygen is absent) and plenty of carbon must be present. Water table management is being considered as a best management practice to increase denitrification and eliminate or reduce leaching of nitrogen (Fedkiw, 1991). In addition to denitrification it may be possible to sequester nitrates from a septic system by planting a buffer strip of trees between the septic system and wells located down gradient (Tuthil et al., 1998). Wells of proper depth are protected by sorption, degradation, and aquitard shielding (Glanville et al., 1997). These natural processes have a better chance of eliminating or reducing contamination when the distance between the pollution source and groundwater source is increased (USEPA, 1993).

The movement of nitrate in groundwater depends on climate, hydrology, geology, agricultural management, soils, and landform (Hubbard & Sheridan, 1989). Areas with higher amounts of rainfall have lower nitrate concentrations in the groundwater because of dilution (Robins, 1998). Agricultural management includes the quantity, method, and timing of nitrogen applications, cropping sequences, and irrigation water management. The movement of nitrate in groundwater is a major concern in the southeastern United States because of 1) sandy soils and high nitrogen inputs, 2) high average annual rainfall and runoff, and 3) increased irrigated acreage in recent years (Hubbard & Sheridan, 1989).

2.6.1.1 Nitrate Standards

The only true standard for nitrate is the drinking water standard, established by the Safe Drinking Water Act, of 10 mg/L (Horsley, 1995; Spalding & Exner, 1993; Hubbard & Sheridan, 1989). When nitrate levels exceed 10 mg/L, doctors recommend using bottled water (Fedkiw, 1991; Weigman & Kroehler, 1990). Infants under three months are nitrate sensitive (Fedkiw, 1991) and are the primary reason for the nitrate standard since those under six months may suffer from methemoglobinemia if they ingest nitrate from drinking water (Spalding & Exner, 1993). For infants less than six months old a 10 mg/L, 10 day health advisory level is set while for adults the 10 mg/L level is the lifetime health advisory level (Fedkiw, 1991).

In order to set a standard for an evaluation of the extent of nitrate contamination, the natural background level must be known (Gosselin et al., 1997). Although it is known that low concentrations of nitrate occur naturally (Kross et al., 1993), due to human activities no natural nitrate concentration has been clearly defined (Madison & Brunett, 1985; Gosselin et al., 1997). In one study, the background concentration was assumed to be 0.2 mg/L (Bruggeman et al., 1995). In other studies, the natural nitrate background level has been defined as 1 mg/L (Clawges & Vowinkel, 1996; Fedkiw, 1991), 2 mg/L (Fedkiw, 1991), 3 mg/L (Spalding & Exner, 1993; Fedkiw, 1991), and even 5 mg/L (Gosselin et al., 1997). However, 3 mg/L is generally assumed to be a level that clearly indicates the influence of human activity (Clawges & Vowinkel, 1996; Madison & Brunett, 1985; Hallberg, 1989; Gosselin et al., 1997; Baker et al., 1994; Kross et al., 1993). The level of 3 mg/L may be conservative since half the samples from the United States show nondetectable levels (Spalding & Exner, 1993).

2.6.2 Total Coliform

Viruses, bacteria, fungi, algae, and protozoa are all microorganisms. Of these microorganisms, there are a wide variety of pathogenic microbes that can cause waterborne diseases (Carrigan, 1990). The presence of bacteria in water not only can cause objectionable odors but also may indicate a breakdown in the disinfection system (Corzatt, 1990). One type of microorganism, coliform bacteria, is the primary microbiological parameter used to evaluate water quality (Tuthil et al., 1998) and is considered to be a human health concern (Corzatt, 1990). Total coliforms do not positively indicate contamination of fecal origin (Amundson et al., 1988). Only fecal bacteria can positively indicate contamination by feces of humans or other warm-blooded animals (Weigman & Kroehler, 1990).

When a septic system contaminates a water supply, outbreaks of waterborne contagious diseases can occur. A septic system does not necessarily need to be nearby because it is possible for some of the pathogenic organisms to travel long distances and live for extended periods outside a host (Weigman & Kroehler, 1990). Possible sewage pollution is indicated by the presence of coliform bacteria, which may be confirmed by further testing for fecal bacteria, such as fecal coliform or E. coli (Tuthil et al., 1998). Climatic conditions, land use patterns, vegetative cover, topography, soil and geologic characteristics, well condition, location of potential pollution sources, and agricultural management practices can affect the transport and contamination of groundwater by bacteria. Various factors affect the microbiological quality of groundwater. In areas where the depth to bedrock is shallow, there is little interaction with the soil and, therefore, contaminants are not effectively removed (Conboy & Goss, 2000). It is possible for the soil to filter and adsorb bacteria and viruses as the water infiltrates the soil (Conboy & Goss, 2000; Tuthil et al., 1998). In some cases, 97% of bacteria applied to the soil were removed by the first centimeter of soil (Conboy & Goss, 2000).

In most states, public well water systems are required to be disinfected before use (Wikstrom, 1989). It is not uncommon for indigenous organisms to multiply in potable water systems when water is held stagnant overnight or longer. Bacterial growth commonly occurs on walls of pipes, valves, pipe fittings, aerators, faucets, and surface of media in point-of-use products (Regunathan et al., 1983). The bacterial quality of water varies with the time of day, water temperature, filter replacement frequency, and treatment device (Geldreich & Reasoner, 1990). Regardless, it is best to take samples for bacteriological analyses after running water for several minutes (Regunathan et al., 1983). It is also suggested that bacteriological tests be done yearly on private well water (Weigman & Kroehler, 1990).

2.6.2.1 Total Coliform Standards

Although coliform bacteria do not cause disease they do indicate the possible presence of pathogenic organisms (Gosselin et al., 1997) which can cause hepatitis, cholera, or giardiasis (USEPA, 1993). As a general rule, if a water sample contains more than four total coliforms per 100 mL then the water supply can be considered unsatisfactory (Wikstrom, 1989). The current standards (Maximum Contaminant Level Goal) are zero for both fecal and total coliform (USEPA, 1995). If no coliform bacteria are present, a well water supply is considered safe (Gosselin et al., 1997). However, from a more liberal standpoint, if a 100 mL sample contains three or fewer total coliforms, the sample is generally considered to not be significantly contaminated (Whitsell & Hutchinson, 1973).

2.7 Relationships and Trends

2.7.1 Contamination versus Well Characteristics

Since most nitrate sources are at or near the land surface, one would expect shallow aquifers to be more prone to contamination than deep aquifers (Madison & Brunett, 1985). For the most part, confined aquifers are less vulnerable to surface contamination than unconfined aquifers (IEN, 1992). Within an aquifer, contaminant concentrations are generally higher towards the top of an aquifer (Spalding & Exner, 1993). The shallow depth of a well may make it vulnerable to contamination (Hallberg, 1989; Powell et al., 1990) and this difference may be due to the properties of unconfined versus confined aquifers (Bruggeman et al., 1995) or the transition from alluvial material to bedrock (Baker et al., 1994). Improperly constructed wells and point sources of pollution were found to be the main degradation factors with respect to well water quality (Gosselin et al., 1997; Reichenberger, 1990). Drilled wells are usually low risk (Conboy & Goss, 2000). Springs are more prone to contamination than drilled wells because springs are shallower and more susceptible to surface contamination (Snyder et al., 1995). In addition, dug and driven wells are more prone to contamination than drilled wells (Baker et al., 1994). Drilled wells are also likely to be safer than bored wells (Whitsell & Hutchinson, 1973). Old, shallow, poorly constructed wells located close to nitrate sources are the most susceptible to contamination (Fedkiw, 1991). Deep, drilled wells and shallow, dug wells can be vulnerable to contamination by poor location. High-risk wells are typically dug or bored and an average of 29 years older than low risk wells (Conboy & Goss, 2000). In general, poor well siting and poor well construction increases susceptibility to contamination (Fedkiw, 1991).

2.7.2 Nitrate versus Well Characteristics, Pollution Sources, Location/Housing Density, Time

There was generally an inverse relationship noted between nitrate concentration and depth (Hallberg, 1989; Clawges & Vowinkel, 1996; Glanville et al., 1997). This relationship is a function of time and rates. A similar trend was also observed between depth and other contaminants originated on the surface (Hallberg, 1989). Although Glanville et al. (1997) found there to be a strong correlation between nitrate and depth, Baker et al., 1994 found that well depth did not appear to influence nitrate contamination. Well depth, well age, pH, and temperature were all factors found to be related to nitrate detection (Bruggeman et al., 1995). Older and shallower wells tend to have more nitrate problems (Baker et al., 1994; Richards et al., 1996). Age was found to have an influence on nitrate contamination while well type was not found to influence nitrate (Glanville et al., 1997). Shallow depth, substandard well construction, and poor well siting were correlated with higher nitrate levels (Fedkiw, 1991; Spalding & Exner, 1993). Most cases of nitrate contamination occur due to activities near the well or poor well construction (Fawcett & Lym, 1992). Like well construction, well siting also influences nitrate concentrations (Fawcett & Lym, 1992; Richards et al., 1996; Baker et al., 1994). Age, depth, type, and potential pollution sources may influence nitrate contamination (Richards et al., 1996). In Ohio, well age and depth were found to influence nitrate levels more than proximity to nitrate sources (Fedkiw, 1991). There are many factors affecting the concentration of nitrate, including depth, location, and time, all of which interact (Hallberg, 1989). Potential pollution sources, in some studies, yielded illogical relationships to nitrate levels (Glanville et al., 1997; Richards et al., 1996). Increased levels of nitrate in shallow drainage water are usually in direct proportion to amount of nitrogen fertilizer applied. Inorganic nitrogen concentrations have been found to be directly related to amount of agriculture in a watershed. Inorganic nitrogen is primarily nitrate-nitrogen (Hallberg, 1989). Areas with higher agricultural marketing have been shown to have more wells with nitrate levels greater than 10 mg/L than other areas. In Washington, a correlation between nitrate density and residential density was found (Fedkiw, 1991). Urban-residential and agricultural areas have higher nitrate concentrations than undeveloped areas because of human activities (Clawges & Vowinkel, 1996). Nitrate contamination can be caused by nonpoint source pollution (Fawcett & Lym, 1992). Soils, geology, and land use can explain patterns of nitrate contamination in a particular area (Baker et al., 1994). Nitrate contamination varies greatly between regions (Richards et al., 1996).

2.7.3 Coliform versus Well Characteristics

There have been a number of studies looking at which parameters influence and what factors affect bacterial contamination, although no consensus has been reached. The relationship between depth and coliform densities was found, in one instance, to be of no significance. However, it was shown that the frequency and number of coliforms was greater in shallower wells. The reason for this difference is probably explained by preferential flow. It was also found that no notable correlation existed between well age and coliform levels (Glanville et al., 1997). Another study found that well depth was not a factor in increased coliform bacteria levels in wells but rather improper well construction (Tuthil et al., 1998). In another case, well type, well depth, and soil hydrologic group were found to be significant in determining bacterial contamination (Conboy & Goss, 2000). Conversely, another study showed well age, depth, appearance or construction to have no apparent correlation to bacterial contamination (VDH, 1983).

2.7.4 Interactions among Well Characteristics

There is some interaction and correlation between well type, depth, and age along with construction features. Age is often considered a single variable but more likely encompasses construction features and well condition. Newer wells tend to be deeper (Glanville et al., 1997). Dug wells tend to be very shallow and old (Baker et al., 1994). Bored wells are usually less than 50-75 ft deep and because of this shallow depth can be easily contaminated by surface activities (Weigman & Kroehler, 1990). Bored wells are sometimes preferred because they are cheaper than drilled wells, mainly because of their shallow depth (VDH, 1983). Many improperly constructed and poorly sited wells are old, dug wells (Spalding & Exner, 1993). Older wells are likely not to be grouted and thereby allow surface water to directly enter and contaminate the well (VDH, 1983).

2.8 DRASTIC

DRASTIC is a mapping system for assessing the relative vulnerability of an aquifer to contamination (IEN, 1992). DRASTIC was developed for the purpose of:

1. functioning as a management tool
2. being simple and easy-to-use
3. utilizing available information
4. being useable by various people of with a wide range of expertise (Aller et al., 1995)

The purpose of DRASTIC is to evaluate the groundwater pollution potential of any hydrogeologic setting in the United States with existing information (Aller et al., 1995). DRASTIC is a planning tool used to determine pollution potential but not intended to predict actual pollution (Richards et al., 1996). DRASTIC is also not meant to replace on-site evaluations but rather to compare different areas with respect to potential groundwater pollution. In other words, it is a screening tool but not a site assessment method. DRASTIC allows for areas to be evaluated for groundwater contamination vulnerability due to pollution sources that may or may not be actually present (Aller et al., 1995).

There are seven factors that contribute to DRASTIC methodology and are the basis for the name. They are: **D**epth to water, **R**echarge, **A**quifer media, **S**oils, **T**opography, **I**mpact of vadose zones, and hydraulic **C**onductivity (IEN, 1992; Aller et al., 1995). Within Virginia, DRASTIC maps have been created for Amherst, Augusta, Botetourt, Carroll, Greene, Henrico, Louisa, Middlesex, Nelson, Prince William, Rappahannock, Rockbridge, Rockingham, Shenandoah, Southampton, and Warren counties (IEN, 1992).

2.9 Previous Study in Virginia

There is a lack of comprehensive information concerning the quality of private drinking water throughout Virginia. The study described below was the only available source of extensive, spatial water supply data representing all regions of Virginia and a wide variety of household conditions. Under the Virginia Cooperative Extension Household Water Quality Testing and Information Program, 9,697 samples have been collected and analyzed from 65 Virginia counties, from 1989-1999. The results from these sample analyses were summarized for each physiographic province, including nitrate and total coliform (Poff & Ross, 2000). Several interesting trends should be noted from this particular study.

The percentage of tap water samples exceeding the nitrate drinking water standard for the state and each province, by source, is shown in Table 2.4.

Table 2.4 Percent of tap water samples exceeding the 10 ppm Nitrate standard (Poff & Ross, 2000)

Area	All sources	All wells	Drilled wells	Dug/Bored wells
Virginia	1.9	1.9	1.5	3.4
Cumberland Plateau	0.0	0.0	0.0	0.0
Valley & Ridge	2.6	2.9	2.8	5.9
Blue Ridge	1.3	1.3	0.6	0.0
Piedmont	1.5	1.4	1.1	2.3
Coastal Plain	2.3	2.1	0.7	5.0

From this information, similar trends among provinces and sources are noted. Some areas, and sources, are obviously more prone to nitrate contamination than others are. Nitrate concentrations greater than 3 ppm, as indicative of surface water contamination was also examined. From Table 2.5, an even greater variation resulted.

Table 2.5 Percent of tap water samples exceeding 3 ppm - Nitrate (Poff & Ross, 2000)

Area	**All sources**	**All wells**	**Drilled wells**	**Dug/Bored wells**
Virginia	14.4	14.5	12.4	23.4
Cumberland Plateau	1.4	1.6	1.1	5.0
Valley & Ridge	20.4	22.1	20.9	40.0
Blue Ridge	9.7	11.2	9.5	19.1
Piedmont	12.8	12.7	11.1	17.8
Coastal Plain	12.7	12.5	4.2	30.4

In this table, it can be seen that areas such as the Valley & Ridge are much more prone to contamination than, for example, the Cumberland Plateau. One could also conclude that dug/bored wells pose a greater contamination risk than drilled wells, with respect to nitrate.

Total Coliform is also a health-related concern and a summary of these results is shown in Table 2.6.

Table 2.6 Percent of tap water samples exceeding the zero Total Coliform standard (Poff & Ross, 2000)

Area	**All source**	**All wells**	**Drilled wells**	**Dug/Bored wells**
Virginia	43.8	40.3	33.6	68.8
Cumberland Plateau	59.0	50.1	48.5	80.0
Valley & Ridge	49.9	43.2	41.4	67.5
Blue Ridge	25.1	17.4	14.3	33.3
Piedmont	43.7	41.1	30.2	74.6
Coastal Plain	35.8	35.7	25.2	60.9

Compared to nitrate, a much larger number of samples exceeded the total coliform standard. A variation is also noted among the provinces. Once again, the dug/bored wells appear more prone to contamination. The Cumberland Plateau had the fewest samples exceeding the nitrate standard, however, the most samples exceeding the total coliform standard.

The results of this study are intriguing. Nitrate exceeds the standard (10 mg/L) in a small percentage of the samples but a much greater percentage appears to be influenced by human activities on the land surface, as indicated by the 3 mg/L threshold. From the standpoint of human safety, well water supplies showing nitrate levels greater than 3 mg/L may be as much of a concern as those exceeding 10 mg/L because, as the pollution on the land surface increases so may the nitrate level in the well. It would be valuable to be able to predict the level of nitrate in well water supplies, so that those with greater than desired levels could be corrected and pollution prevented. Similarly, it is undesirable for coliform bacteria to be present in a well water supply. This study showed large percentages of the samples exceeding the zero total coliform standard, which is, a cause for concern. Again, being able to predict the presence/absence of total coliform bacteria could lead to prevention of pollution and treatment of the problem.

CHAPTER 3.0 METHODS

3.1 Source of the data

The data for analysis were provided by the Virginia Cooperative Extension Household Water Quality Testing and Information Program (Ross, 1989-1999). The program was comprised of voluntary sampling of private water supplies. From 1989-1999, a total of 9,697 household water samples were collected and analyzed from 65 counties throughout Virginia. These counties are listed in Table A.1, Appendix A and are shown in Figure A.1, Appendix A. Each sample was tested for: iron, manganese, hardness, sulfate, chloride, fluoride, total dissolved solids (TDS), pH, saturation index (Langlier), copper, sodium, nitrate, total coliform bacteria, and E. coli bacteria. The bacterial results were of a presence/absence nature except for four recently sampled counties (Augusta, Rockingham, Accomack, and Northampton). The information gathered with each sample included: supply source type (well, spring, or cistern), well characteristics such as well type, well age, and well depth, treatment device(s), housing density, household plumbing pipe materials, water conditions (i.e. taste, color, odor problems, etc.), and nearby pollution sources which are listed by county in Table B.1, Appendix B (Ross, 1989-2000).

3.2 Preparation of the Data for Analysis

In order to analyze the nitrate levels and the presence/absence of total coliform bacteria of a homeowner's well water, the data set first had to be reduced to only include those samples from wells, both dug/bored and drilled. Upon eliminating the springs, cisterns, and undefined well types, from the data set, 7,814 samples remained. Of these, 189 samples were from the Blue Ridge province, 1,521 from the Coastal Plain, 402 from the Cumberland Plateau, 3,265 from the Piedmont, and 2,437 from the Ridge & Valley. Each sample was then checked, as described below, with regard to potential pollution sources, treatment devices, and pipe material.

A total of 26 different potential pollution sources were defined for Virginia, however, only certain ones were originally inquired about in each county. Each pollution source had to be validated for every county and, if needed, amended, to provide an answer in each case as follows. For each county, true or false should appear when a given potential pollution source was identified and only blank entries could appear for a pollution source that was not included. The data set originated in DBXL, an older database software package, in which blank entries indicated false responses. There were only a certain number of potential pollution source headings available in the database and the headings were changed to suit a given the county. When the data were modified to MS Excel and ultimately JMP formats, a statistical software package, 26 headings were available since all counties were being analyzed at once and blank data was interpreted as missing or unavailable data. Therefore, blank cells indicating false responses had to be modified to contain a"false" entry.

Unlike potential pollution sources, no blank entries could appear for treatment devices. Again the data originated in DBXL, where a blank entry implied a false response. The same list of treatment devices was provided for each county so no blank entries resulted. Blank data simply meant that a particular treatment device was not in use. In those cases where no treatment devices were specified, a true response should have appeared under the choice of "none."

Similar to treatment devices, the same list of possible pipe materials was provided for each county. Blank entries, like before, implied a false response. In this instance blank entries meant that pipe material was not installed. Where no pipe material was declared, a "true" response should appear under the option of "unknown." All blank responses under pipe material were changed to unknown.

3.3 Utilized Statistical Software

To conduct the analyses, JMP was utilized. The reason for choosing JMP over another statistical software package, such as SAS, was ease of use. Additionally, JMP is SAS based, therefore, the calculations are trustworthy. JMP has a windows set up complete with pull-down menus and avoids the user having to remember the order and format of command lines. Lastly, JMP is designed for interactive exploratory data analysis. Overall, JMP is easy-to-use, simple to understand, and user-friendly in nature.

3.4 Explanatory Variables of the Statistical Models

Initially, the state of Virginia, as a whole, was analyzed using several different response variables. Based on the results of these models, each of the five physiographic provinces (Blue Ridge, Coastal Plain, Cumberland Plateau, Piedmont, and Ridge & Valley) were then analyzed. To further explore the possibility of improving the coefficient of determination (R^2), Louisa County, which has a large number of observations and is relatively homogeneous in geologic terms, was analyzed to determine if a county level, rather than a statewide or provincial level, would result in further improvement.

For each of the models, the explanatory variables, and their possible values or units, are listed in Table 3.1.

Table 3.1 Explanatory Variables of the models

	Parameter	Possible values or units
	County	*
	Province	1- Blue Ridge, 2- Coastal Plain, 3- Cumberland Plateau, 4- Piedmont, 5- Ridge & Valley
Well Charact-eristics	Well type	1- dug or bored, 2- drilled
	Well depth+	unit = feet
	Well age+	unit = years
Installed Treatment Devices	None	true, false
	Softener	true, false
	Iron filter	true, false
	Chlorinator	true, false
	Neutralizer	true, false
	Sediment filter	true, false
	Activated carbon	true, false
	Other	true, false
	Location++	1- on a farm, 2- on a remote, rural lot, 3- in a rural community, 4- in a housing subdivision
	Pipe material	1- copper, 2- lead, 3- galvanized steel, 4- plastic, 5- other, 6- don't know
Potential Pollution Sources	Septic	true, false
	Privy	true, false
	Cemetery	true, false
	Oil tank	true, false
	Stream	true, false
	Sinkhole	true, false
	Marsh	true, false
	Compost	true, false
	Landfill	true, false
	Dump	true, false
	Active quarry	true, false
	Old quarry	true, false
	Gas tank	true, false
	Golf course	true, false
	Marina	true, false
	Orchard	true, false
	Field crop	true, false
	Animal	true, false
	Plant	true, false
	Active surface mine	true, false
	Old surface mine	true, false
	Active deep mine	true, false
	Old deep mine	true, false
	Sewage plant	true, false
	Tobacco	true, false
	Commercial farm	true, false

* See list of counties examined in this study
\+ These variables were actually entered in the model as log transformed variables
++ Location is linked to housing density

In Table 3.1 it should be noted that both the well depth and the well age are entered into the models as log transformed. This was done because the distributions of both well depth (ft) and well age (years) were positively skewed as shown in Table 3.2.

Table 3.2 Distributions of well depth and well age for the state of Virginia

Statistic		Variable	
		well depth (ft)	**well age (years)**
Minimum		0.0	2.0
Median		150.0	20.0
Mean		188.81	22.87
Maximum		4000.0	276.0
Skewness			
	untransformed	4.25	2.89
	transformed	-0.363	-0.412

The explanatory variables "county" and "province" were not originally included in the regression runs. They were added later to see if there was a spatial influence on the response variables. Ultimately there did appear to be an influence so these factors were left in the models for evaluation.

3.5 Explanatory Variable Selection

The statistical model building strategy used was *backward elimination*. All explanatory variables were entered into the model and then eliminated one by one, starting with the highest p-value greater than 0.10, as observed under the "Effect Tests" of the JMP fit-model platform. If the p-value was between 0.05 and 0.10, the change in R^2 was observed to determine whether the parameter should be an explanatory variable or not. If the change in R^2 was less than 0.05, then the parameter was eliminated from the model. A change of greater than 0.05 indicated that the parameter explained more than five-percent of the total variation in the response variable. Once the individual effects to the model were defined, all interactions, if appropriate, were explored as possible effects. In addition to evaluating the interactions of individual effects, second order relationships were examined. The interactions and second order relationships were then eliminated in the same fashion as before with the first order terms.

3.6 Model Response Variables

The response variables described below were modeled for the state and each of the provinces and included $\log_{10}(NO_3)$, Nitrate-Ranks, Nitrate Code, Nitrate Code (2 cats), Coliform Code, Risk

Category, and Risk Category (4 cats) described below. For Louisa County, only the $\log_{10}(NO_3)$ response variable was explored. The $\log_{10}(NO_3)$ response variable was simply the log-transformed values of nitrate. The log transformed values of nitrate were used because of the positively skewed nature of nitrate, as seen in Table 3.3.

Table 3.3 Distribution of nitrate

Statistic		**Variable**
		Nitrate (mg/L)
Minimum		0.0
Median		0.35
Mean		1.45
Maximum		55.35
Skewness		
	untransformed	5.55
	transformed	-0.39

Nitrate-Ranks was the response variable created to deal with the non-normality of the $\log_{10}(NO_3)$ empirical distribution. Nitrate-Ranks was the rank of NO_3, using the average rank for ties.

Nitrate Code was an ordinal variable putting the nitrate values into one of three categories. Those values less than 3 mg/L were considered to be of category 10, those between 3 and 10 mg/L of category 20, and those greater than 10 mg/L of category 30. The 3 mg/L breakpoint was used because it was assumed that this level indicates surface impacts on water quality. The drinking water standard is 10 mg/L and thus the reason for this breakpoint. Nitrate Code (2 cats) was also an ordinal variable and grouped nitrate values into only two categories. Category 10 contained nitrate values of less than 3 mg/L and category 20 contained nitrate values greater than 3 mg/L.

The Coliform Code response variable classified the total coliform data into true/false or presence/absence categories. The total coliform data were already in this format, with the exception of the four most recently sampled counties, providing the reason for the creation of this variable. It was possible that instead of exploring total coliform as a response variable E. coli could have been used. However, E. coli data were not available for every county of the study. Also, E. coli is more subject to weather variations and it is possible that the data were not representative. Lastly, total coliform bacteria were considered to indicate pathogenic organisms whereas E. coli bacteria only indicate the presence of bacteria from the feces of warm-blooded animals.

The final two response variables combined the nitrate and total coliform data into a single ordinal variable. The categories for Risk Category are shown in Table 3.4.

Table 3.4 Categories of the Risk Category Response Variable

Category	Nitrate Level (mg/L)	Total Coliform
10	< 3	absent
11	< 3	present
20	3 – 10	absent
21	3 – 10	present
30	> 10	absent
31	> 10	present

The categories for Risk Category (4 cats) are shown in Table 3.5.

Table 3.5 Categories of the Risk Category (4 cats) Response Variable

Category	Nitrate Level (mg/L)	Total Coliform
10	< 3	absent
11	< 3	present
20	> 3	absent
21	> 3	present

3.7 Model Evaluation

To model the response variables, $\log_{10}(NO_3)$ and Nitrate-Ranks, least squares regression was used. Least squares regression was chosen because it not only shows the influence of the factors but also provides coefficients that can be used to develop an equation and predict the responses. After determining the significant effects for the $\log_{10}(NO_3)$ model, the predicted values and residuals were saved. The residuals of the model were then evaluated for their skewness and normality. Such analysis of residuals was not needed for the Nitrate-Ranks model because it is a nonparametric method and, therefore, is not required to fulfill any normality assumption.

The least squares regression yields an R^2 value which can be used to compare each of the models across each of the regions and to determine how suitable the model is. The coefficient of determination, R^2, is the percent of total variation in the response variable, in this case nitrate, that is explained by the explanatory variables in the model. For each of the parameters entered into the model, and found to be significant, there is also a partial-R^2 value that can be generated. This value is the sequential sum of squares for each of the factors divided by the total sum of squares. The partial-R^2 value reveals the contribution of each parameter to the model. The model R^2 value is the sum of the partial-R^2 values.

The other five response variables were categorical variables and therefore analyzed using logistic regression. With logistic regression there are no distributional assumptions to be satisfied while, at the same time, there is no coefficient of determination for determining the suitability of the model. There is also no way to determine the influence of individual parameters to the model. Logistic regression simply allows us to determine which factors significantly affect the categorical response variables.

3.8 Case Study: DRASTIC

3.8.1 Development of Source Data

The objective of this case study was to determine if there is a correlation between DRASTIC scores and actual and predicted nitrate values. For this case study, Louisa and Middlesex counties were used. These two counties were selected because of their location in a non-karst area and the availability of data, including DRASTIC maps (Thomas Jefferson Planning District Commission, 1991 and Virginia Water Control Board, 1988). Considering that DRASTIC only evaluates the surficial aquifer, the maximum depth of shallow wells in each county had to be established. It was assumed that those wells less than 75 feet in Louisa and those less than 65 feet in Middlesex were shallow wells (Ross, 2001). For each of these shallow wells, a DRASTIC score then had to be obtained. This was done by locating the wells on the county maps and then transcribing these locations over to the DRASTIC maps. The DRASTIC scores, although numeric, are ordinal in nature. Moreover, they are relative within each county/area and not comparable between counties. DRASTIC scores order the degree of pollution within a county, but do not order pollution levels between counties because equal DRASTIC scores in different counties do not necessarily imply equal levels of pollution. The lower the DRASTIC score the lower the pollution potential. Conversely, higher DRASTIC scores indicate a higher pollution potential.

3.8.2 Model Response Variables

For both counties, the predicted values from the $\log_{10}(NO_3)$ model of the corresponding province were used to evaluate any correlation with the DRASTIC scores. The predicted values from the $\log_{10}(NO_3)$ model of the state of Virginia were not used because these values were not predicted by the model for the samples used in this case study. The correlation between the actual nitrate values and the DRASTIC scores were also evaluated. Because DRASTIC scores are ordinal, Spearman's rank correlation was used to quantify the relationship. The reported p-values test the null hypothesis that the rank correlation is zero, i.e. no relationship, versus the alternative hypothesis that the rank correlation is different from zero, i.e., there is a relationship.

3.9 Case Study: Total Coliform Colony Forming Units

3.9.1 Source Data

The objective of this case study was to determine if it was worthwhile to evaluate total coliform CFUs rather than presence/absence data. Only those counties with the number of total coliform colony forming units provided were evaluated. These counties were Augusta, Rockingham, Accomack, and Northampton. The same factors evaluated in the previous models were also used in this case. The response variables evaluated for this case study were Total Coliform, Transformed Total Coliform, Coliform Code, and Transformed Coliform Code.

3.9.2 Model Response Variables

Both the Total Coliform and Transformed Total Coliform response variables are numeric and continuous variables presenting the number of total coliform colony forming units. The difference between the two is that the Transformed Total Coliform variable attempts to eliminate those samples that may have been contaminated inadvertently. For example, the contamination may have resulted from mishandling the sample or picking up bacteria from the mouth of the faucet, and not from surface water contaminating the well. Based on previous research (Whitsell & Hutchinson, 1993) and frequency analysis of the data, those samples with three or fewer total coliform colony forming units were assumed to be inadvertently contaminated and the values should be set to zero. In changing the total coliform data for the Transformed Total Coliform response variable, 71 samples out of a total 671 samples were switched from values of one, two, or three CFUs to zero CFUs. These variables were modeled using least squares regression and therefore the residuals were subject to the same normality assumption as before.

The Coliform Code and Transformed Coliform Code are numeric, ordinal response variables. In the case of these two variables, "zero" defined those instances where the numbers of colony forming units were zero and "one" defined those instances where the numbers of colony forming units were greater than zero. Coliform Code uses Total Coliform as the guide while Transformed Coliform Code uses Transformed Total Coliform. These two variables, being ordinal in nature, required modeling by logistic regression. Like the previous logistic regression models, there are no distributional assumptions to be satisfied and no coefficient of determination.

3.10 Summary

The data for this project were obtained from the Virginia Cooperative Extension Household Water Quality Testing and Information Program. Each sample was tested for a variety of constituents and the homeowner provided information regarding the source and water system. The data were then prepared by eliminating all springs, cisterns, and unknown well supplies. The potential pollution sources, treatment devices, and pipe materials were then validated. To conduct the analyses on the data, JMP, a statistical software package, was utilized. The county and/or the province in which the well is located, well characteristics, installed treatment devices, housing density, plumbing material, and potential pollution sources were the potential explanatory variables of the model. Analyses were first conducted on the state of Virginia as a whole and then, based on the results, conducted on each of the five physiographic provinces. To explore the possibility of higher coefficients of determination the same explanatory variables were investigated in Louisa County. Explanatory variables were determined to be significant if the p-value was less than 0.10. If the p-value was between 0.05 and 0.10, then the change in R^2 determined if the variable was to be retained. Changes in R^2 greater than 0.05, called for the variable to be retained as an explanatory variable of the model. In addition to individual parameters being investigated, interactions among variable and second order relationships were explored. The response variables included the log transformed values of nitrate, ranks of nitrate, nitrate categorical variables, total coliform categorical variable, and two response variables combining nitrate and total coliform data into a single parameter. The models were evaluated based on p-values and R^2 value, if available. Influence of each of the parameters was shown with the partial R^2 values.

The DRASTIC case study looked at shallow wells of Louisa and Middlesex counties. The response variables included the actual and predicted nitrate values and DRASTIC scores of both counties. Spearman's rank correlation was used to quantify the relationships, if any.

The total coliform case study looked at the total coliform colony forming units of Augusta, Rockingham, Accomack, and Northampton counties. Two response variables were developed to look at the influence of actual colony forming units while two other response variables were created to examine the influence of total coliform presence/absence. The significant factors to these response variables were determined using least squares regression.

CHAPTER 4.0 RESULTS AND DISCUSSION

4.1 Overview

The output from JMP, for each of these regressions, can be seen in Appendix C. The results for each of the response values are summarized in Tables D.1 - D.7, Appendix D. The response variables in Table D.3 - D.7 were evaluated using logistic regression and, therefore, there are no R^2 or partial-R^2 values to show. Each of the response variables was first evaluated for the state of Virginia. The highest model R^2 value generated was 0.206 (Appendix C), implying that only 20% of the total variation in nitrate was accounted for by the explanatory variables.

Next, each of the five physiographic provinces were modeled for each of the response variables. For the Cumberland Plateau, the response variables, Nitrate Code and Nitrate Code (2 cats) were not modeled because none of the samples exceeded 10 mg/L. The range of the R^2 values for the provinces was from 0.139 (Table D.2, Appendix D) to 0.585 (Table D.1, Appendix D) and higher than the R^2 for the state in most cases.

To determine if improved R^2 values could be obtained, a model was developed at the county level for Louisa County, which was modeled for the $\log_{10}(NO_3)$ response variable. Louisa County is in the Piedmont province, which yielded an R^2 value of 0.310 (Appendix C) for the $\log_{10}(NO_3)$ response variable. When modeled as an individual county, the $\log_{10}(NO_3)$ response variable yielded an R^2 value of 0.187 (Appendix C). This value was almost half of that for the Piedmont province.

4.2 Nitrate Models

Tables D.1-D.4, Appendix D present the summary tables for the analyses done on nitrate values. Tables D.3 and D.4 summarize the results of the ordinal response variables Nitrate Code and Nitrate Code (2 cats) and, therefore, these tables only reveal the significant parameters of the models. Both the $\log_{10}(NO_3)$ and Nitrate-Ranks response variables, summarized in Tables D.1 and D.2, Appendix D, were examined using least squares regression and, therefore, can be compared by their R^2 values. Of the 12 total regressions performed using these two variables, the highest R^2 value was found to be 0.585 (Table D.1, Appendix D) while the lowest R^2 was

0.139 (Table D.2, Appendix D). The highest R^2 value explains only 58.5% of the total variation of nitrate, which is not considered sufficiently high enough to use the model for prediction.

In addition to the low R^2 values, only the Piedmont province, using the $\log_{10}(NO_3)$ response variable, showed a non-skewed, normal distribution. The R^2 of the Piedmont province was 0.310, which explains less than 50% of the total variation. The distributions of the residuals showing the skewness and the normality are shown in Appendix C, following the corresponding model output.

Comparison of the $\log_{10}(NO_3)$ and Nitrate-Ranks response variables (Tables D.1-D.2, Appendix D) shows that the same four explanatory variables (location, activated carbon, county, and $\log_{10}$(age)) were significant in more than half of the areas explored. For the $\log_{10}$(NO3) response variable, the county in which the well was located, well characteristics, installed treatment devices, housing density, plumbing material, and potential pollution sources were all identified as significant parameters in one or more of the models. However, only the county in which the well was located, $\log_{10}$(age), activated carbon treatment device, and housing density were significant parameters in more than half of the areas. Areas include the state of Virginia and each of the five physiographic provinces explored.

The Nitrate-Ranks response variable resulted in the same parameters to be significant, with the exception of plumbing material. Like the $\log_{10}$(NO3) response variable, the county in which the well was located, $\log_{10}$(age), activated carbon treatment device, and housing density were found to be significant in more than half of the areas explored. If only those factors that were significant in over half of the areas explored are considered, then the results are in some agreement with the hypothesis. It was expected that the county and/or province in which the well is located, well characteristics, and housing density would be the only factors to influence household well water quality with respect to nitrate and total coliform. These three factors did influence the household well water quality but so did installed treatment devices. Installed treatment devices were hypothesized to have no effect on nitrate levels and total coliform presence/absence.

4.3 Most Important Explanatory Variables of the $\log_{10}$(NO3) Response Variable

The most definitive conclusion that can be drawn is that of 1) identifying which factors significantly and substantially affect the response variable and, 2) quantifying the effects. For the $\log_{10}(NO_3)$ response variable, the location factor was significant in most models and was one of the three most important variables (i.e., highest partial-R^2 value) in three of the six areas (state of Virginia and each of the five physiographic provinces) studied. Location also appeared in the most models using the Nitrate-Ranks response variable. However, it was one of the three most important variables in only two of the six areas. The three most important explanatory variables, based on the partial-R^2 values, for each of the six areas and each of the response variables, are shown in Tables 4.1 and 4.2.

Table 4.1 Three most important explanatory variables for $\log_{10}(NO_3)$ response variable

Area	Top Three Most Important Explanatory Variables
Virginia	county, $\log_{10}$(age), $\log_{10}$(depth)
Blue Ridge	location, oil tank, gas tank
Coastal Plain	well type, county, $\log_{10}$(depth)
Cumberland Plateau	softener, location, pipe material
Piedmont	county, $\log_{10}$(age), location
Ridge & Valley	county, $\log_{10}$(age), iron filter

Table 4.2 Three most important explanatory variables for Nitrate-Ranks response variable

Area	Top Three Most Important Explanatory Variables
Virginia	county, $\log_{10}$(age), location
Blue Ridge	location, oil tank, $\log_{10}$(depth)
Coastal Plain	well type, county, county*$\log_{10}$(depth)
Cumberland Plateau	softener, $\log_{10}$(age)*softener, old surface mine
Piedmont	county, $\log_{10}$(age), county*$\log_{10}$(age)
Ridge & Valley	county, $\log_{10}$(age), iron filter

Only the Ridge & Valley province showed the same top three most important explanatory variables under both the $\log_{10}(NO_3)$ and Nitrate-Ranks response variables. The state of Virginia, Blue Ridge, Coastal Plain, and Piedmont provinces all had two of the top three most important explanatory variables present under both of the response variables. The Cumberland Plateau province was the only area in which only one of the factors was the same for both response variables.

The most important variables are the factors that have the greatest influence on nitrate levels in the provinces. For the Blue Ridge, Coastal Plain, and Piedmont provinces, certain variables explained 10% or more of the total variation in nitrate. For the Blue Ridge, location explained 11.9% of the total variation in nitrate levels. The mean nitrate levels by location are shown in Table 4.3. Location explains greater than 10% of the total variation in nitrate only in the Blue Ridge province, probably due, in part, to the Blue Ridge province having the highest percentage of initial samples retained, among all provinces, for model analysis.

Table 4.3 Mean Nitrate levels by location in Blue Ridge

Location	n	Mean Nitrate (mg/L)	95% Confidence Limits	
			lower	upper
farm	60	0.579	0.086	3.88
remote rural lot	22	0.113	0.015	0.842
rural community	59	0.487	0.073	3.247
housing subdivision	6	0.102	0.010	1.001

The locations in Table 4.3 are listed in order of increasing housing density. The lowest housing density and second highest housing density show the highest nitrate levels while the second lowest and highest housing densities show the lowest nitrate levels. A possible reason for farms having the highest mean nitrate levels is the quantities of animal waste and nitrate-containing fertilizer in the vicinity of the well. Remote, rural lots are likely spaced at distances great enough so that potential pollution sources do not affect the nitrate levels in the well water and they are isolated from farming activities. Rural communities generally consist of older homes located close together whereby potential pollution sources such as septic systems may affect well water quality. Like rural areas, housing subdivisions are not in close proximity to agricultural activities. In general, housing subdivisions have a higher housing density than rural communities but did not have higher mean nitrate levels. This may have been because water supplies are sometimes shared or treatment technology may be improved in these areas so that the measured nitrate level may not be representative of actual groundwater nitrate levels. Additionally, homes are generally newer and the residents more affluent.

In the Coastal Plain, county and well type combined, explained 41.8% of the total variation of nitrate. The mean nitrate levels by county are shown in Table 4.4 and by well type in Table 4.5.

Table 4.4 Mean Nitrate levels by county in Coastal Plain

County	n	Mean Nitrate (mg/L)	95% Confidence Limits	
			lower	upper
Accomack	81	0.0226	0.0106	0.0480
Essex	36	0.454	0.208	0.991
Gloucester	79	0.101	0.0495	0.207
Isle of Wight	33	0.0608	0.0246	0.151
King & Queen	27	0.533	0.226	1.25
King William	71	0.0799	0.0393	0.162
Lancaster	27	0.265	0.110	0.636
Mathews	79	0.0399	0.0200	0.0797
Middlesex	68	0.125	0.0614	0.254
Northampton	62	0.120	0.0580	0.247
Northumberland	66	0.447	0.221	0.903
Prince George	192	0.453	0.235	0.872
Richmond	52	0.373	0.180	0.772
Southampton	31	0.103	0.0447	0.239
Westmoreland	34	0.264	0.118	0.591

The differences in mean nitrate levels between counties are not explained by the location of the county. The education level and/or the income level of the residents may better explain the differences in mean nitrate levels. In general, those residents with higher education and greater income are more likely to take actions to protect and insure the quality of their well water. Also, some counties may have more shallow wells than others. Table 4.5 implies that counties with shallow wells have higher nitrate levels.

Table 4.5 Mean Nitrate levels by well type in Coastal Plain

Well Type	n	Mean Nitrate (mg/L)	95% Confidence Limits	
			lower	upper
dug/bored	344	0.992	0.511	1.93
drilled	594	0.0536	0.0291	0.0987

Table 4.5 shows that dug/bored wells have higher mean nitrate levels than drilled wells. Dug/bored wells, which are generally shallow, are, therefore, more readily exposed to the land surface and nitrate sources. Well type only explained little more than 10% of the total variation in nitrate levels in the Coastal Plain province because this was the only province in which well type appeared as a significant parameter. A possible reason for well type being a significant

parameter only in the Coastal Plain is that in the other provinces there is an uneven distribution of samples between the two well types.

The explanatory variable, county, explained 17.9% of the total variation in nitrate levels in the Piedmont. Mean nitrate levels, by county, are shown in Table 4.6. County was identified as a significant parameter in the Coastal Plain, Piedmont, and Ridge & Valley provinces but was only found to explain more than 10% of the total variation in nitrate in the Coastal Plain and Piedmont provinces. The reason for this is unknown.

Table 4.6 Mean Nitrate levels by county in Piedmont

County	n	Mean Nitrate (mg/L)	95% Confidence Limits	
			lower	upper
Albemarl	320	0.317	0.199	0.507
Amelia	69	2.01	1.14	3.56
Buckingham	59	1.98	1.09	3.63
Chesterfield	75	0.213	0.121	0.376
Cumberland	51	2.06	1.10	3.86
Dinwiddie	148	0.783	0.466	1.31
Fluvanna	32	0.562	0.280	1.13
Louisa	298	0.259	0.162	0.411
Nelson	37	1.87	0.932	3.77
Powhatan	88	0.442	0.260	0.750

As previously observed, when county was identified as a variable explaining more than 10% of the total variation, there does not seem to be any spatial reason for the difference in mean nitrate levels. Again the explanation may lie in the education and/or income level of the county residents.

4.4 Total Coliform and Risk Models

The response variables, Coliform Code, Risk Category, and Risk Category (4 cats), were analyzed using logistic regression. The results of these regressions are summarized in Tables D.5 – D.7, Appendix D. Like the Nitrate Code and Nitrate Code (2 cats) response variables, these regressions do not reveal much information. The only information gathered from these tables is which parameters significantly affect the response variable. Unlike the least squares regression models, no model R^2 or partial R^2 values are available. The p-values given in the tables show the significance of each parameter.

4.5 Explanations for Lack of Prediction Model

In explaining the inability to develop a prediction model, it should be noted that this study was observational and not experimental. Under an experimental study, a control must be present; since there are no controls in nature, the study is thus observational. In general, high R^2 values are rare when dealing with environmental data (Holtzman, 2001).

The data used in this study were considered reliable, however, due to the voluntary nature of the data, human error may have influenced and possibly biased the results. The participants who submitted private household water samples for testing were those individuals who had a well, spring, or cistern, learned of the program, and spent the time, money, and effort to voluntarily collect and deliver their sample to the proper location. In each county, samples were collected only from those areas in which private water supplies were in use as opposed to public water supplies. The participant group may have also been skewed to those with higher education and income levels who generally would have had more awareness and knowledge of water quality issues. Furthermore, homeowners were asked questions about their water supply, and although the answers provided were considered to be reliable, in some cases "unknown" was declared and, as a result, valuable data may have gone uncollected.

With respect to the quality of the data, the nitrate and total coliform results were determined in a laboratory where quality assurance and control are observed. Little inaccuracy was expected in the nitrate data. Similarly, little inaccuracy is expected with the total coliform data, however, mishandling of the sample, either when collected or in the laboratory, could have resulted in a small percentage of “false-positive” results.

Regardless, nitrate levels and presence/absence of total coliform could not be predicted, at least not when using the parameters of this study. The main reason for unsuccessful development of a prediction model may be the lack of parameters to explain the response. Additional parameters could include soil and geologic characteristics, additional potential pollution sources, distances to potential pollution sources, and well water supply use frequency. A model could possibly be developed taking into account a much wider range of variables and data, however, the simplistic nature of such an approach would vanish.

4.6 Case Study: DRASTIC

In this study, the correlation between the actual and predicted nitrate values and DRASTIC scores was examined. The JMP output tables of these analyses can be seen in Appendix E. The data for these analyses is shown in Table E.1, Appendix E, following the JMP output tables. Middlesex County showed the only statistically significant correlation for the comparisons of DRASTIC scores in which DRASTIC scores corresponded to certain nitrate levels. The correlation between the predicted nitrate values and DRASTIC scores was statistically insignificant ($p = 0.30$). The correlation between the actual nitrate values and DRASTIC scores showed a statistically significant ($p = 0.0087$) negative correlation with a Spearman's Rho value of -0.534. The plot of the actual nitrate values versus the DRASTIC scores is shown in Figure 4.1.

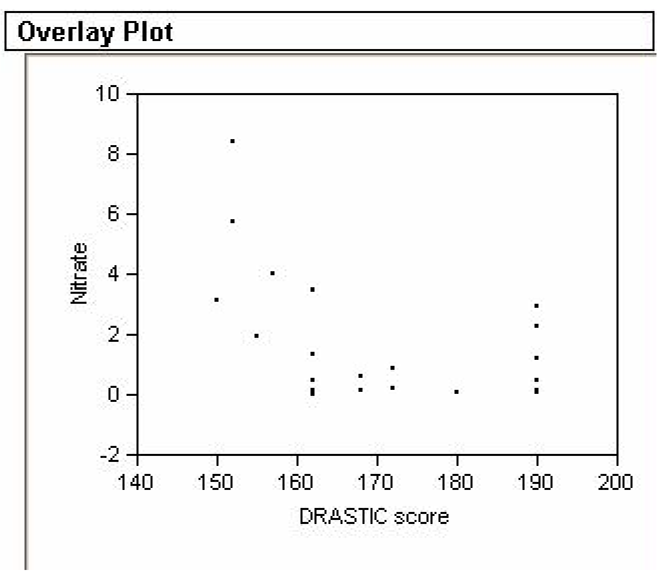

Figure 4.1 Actual Nitrate levels (mg/L) vs. DRASTIC scores of Middlesex County

This correlation indicates that higher DRASTIC scores mean lower nitrate levels. The expected correlation was a positive one in which high DRASTIC scores would be correlated with high nitrate levels.

Louisa County showed only statistically insignificant correlation ($p = 0.56$) between predicted nitrate values and DRASTIC scores. The correlation between the DRASTIC scores and the actual nitrate values was also statistically insignificant ($p = 0.13$). For Louisa County, the lack of a statistically significant correlation means that no conclusion can be drawn as to how nitrate levels and DRASTIC scores are related.

4.7 Case Study: Total Coliform Colony Forming Units

Least squares regression was attempted for both the Total Coliform and Transformed Total Coliform response variables. However, none of the variables entered into the model were found to be significant. Logistic regression was tried on the Coliform Code and Transformed Coliform Code response variables and only the regression on Coliform Code yielded statistically significant results. The output table from JMP for this regression is shown in Appendix F. The logistic regression on Coliform Code indicates that only $\log_{10}$(age), sediment filter, and marina contribute to the prediction of total coliform bacteria presence/absence.

CHAPTER 5.0 SUMMARY AND CONCLUSIONS

The objective of this study was to examine various factors potentially affecting nitrate levels and total coliform presence/absence in household well water. If possible, a prediction model would be developed. To determine the significant parameters and possibly the coefficients to be used in prediction, a backwards elimination statistical model building strategy was used. Upon completing the modeling process, a number of conclusions were reached.

- The small coefficients of determination for the models only allowed the influencing factors to be determined; no prediction method could be developed.
- Higher coefficients of determination were noted at the provincial level compared to the state as a whole, however, there was no improvement at the county level.
- In addition to the low model R^2 values the empirical distributions were, in all but one case, skewed and non-normal.
- The explanatory variables location, activated carbon, county, and $\log_{10}$(age) appeared significant in more than half of the six areas (state of Virginia and five physiographic provinces) explored.
- If only those factors that appear in more than half of the areas studied are considered to influence nitrate levels and total coliform presence/absence then, the hypotheses are generally correct.
    - County and/or province in which the well is located, well characteristics, housing density, and installed treatment devices were found to influence nitrate levels.
- The factors significantly and substantially affecting the response variable were defined.
    - Housing density appeared to have the greatest influence on nitrate levels.
- County, well type, and housing density were identified as explaining more than 10% of the total variation in three different provinces.

In addition, a case study involving the DRASTIC method was performed. The objective was to determine if DRASTIC scores were correlated with actual and/or predicted nitrate levels. To determine the relationship, if any, Spearman's rank correlation was used. After conducting the analyses, the following was observed.

- DRASTIC scores did not appear to be correlated with actual and/or predicted nitrate values.
    - The relationship between Middlesex actual nitrate values and DRASTIC scores was found to be the only significant relationship. However, this significant relationship was the reverse of that expected.

A second case study was conducted to examine any differences in the type of total coliform units. The objective of this study was to determine if there is value in total coliform colony forming units over total coliform presence/absence. Four response variables were developed to explore the possibility of colony forming unit data being more valuable than presence/absence data. These response variables were analyzed using least squares regression to identify the significant explanatory variables. Analyses of these variables resulted in the following:

- No significant parameters were found to explain total coliform colony forming units.
    - Without definition of significant parameters, it could not be determined whether or not all values greater than zero are the same

CHAPTER 6.0 RECOMMENDATIONS FOR FURTHER STUDY

The goal of this project was to develop a statistical relationship that would allow household residents and others to predict the nitrate level and total coliform presence/absence of their household well water. The data used for this study were reliable and improvement of the data would probably not improve the modeling results. If further studies are to be explored, the following considerations are suggested:

- Use of a scientific sampling procedure, in terms of private household well locations.
- Collection of the data by a qualified team and not the homeowners themselves, thus reducing the chance of human error.
- Use of other parameters, such as soil and geologic characteristics, additional pollution sources, distance to the pollution source, specific construction characteristics of the well (i.e. lining, grouting, etc.), and well water supply use frequency.
    - The addition of more parameters may make it possible to create better models, however, they would probably not be simplistic enough for a homeowner to utilize.
- Consider non-linear relationships other than those analyzed.
    - These non-linear relationships are difficult to describe, if they exist

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APPENDIX A Counties participating in Virginia Household Water Quality Testing and Information Program

Table A.1 Counties by Physiographic Province (Ross, 1989-2000)

Blue Ridge	**Cumberland Plateau**
Carroll	Buchanan
Floyd	Dickenson
Grayson	Wise
Coastal Plain	**Piedmont**
Accomack	Albemarl
Caroline	Amelia
Essex	Amherst
Gloucester	Appomattox
Isle of Wight	Bedford
King & Queen	Buckingham
King George	Campbell
King William	Chesterfield
Lancaster	Culpeper
Mathews	Cumberland
Middlesex	Dinwiddie
Northampton	Fluvanna
Northumberland	Franklin
Prince George	Goochland
Richmond	Greene
Southampton	Loudon
Westmoreland	Louisa
Ridge & Valley	Madison
Augusta	Nelson
Bland	Orange
Botetourt	Patrick
Clarke	Powhatan
Giles	Prince William
Lee	Rappahannock
Montgomery	Spotsylvania
Page	Stafford
Pulaski	
Rockbridge	
Rockingham	
Russell	
Scott	
Tazewell	
Warren	
Wythe	

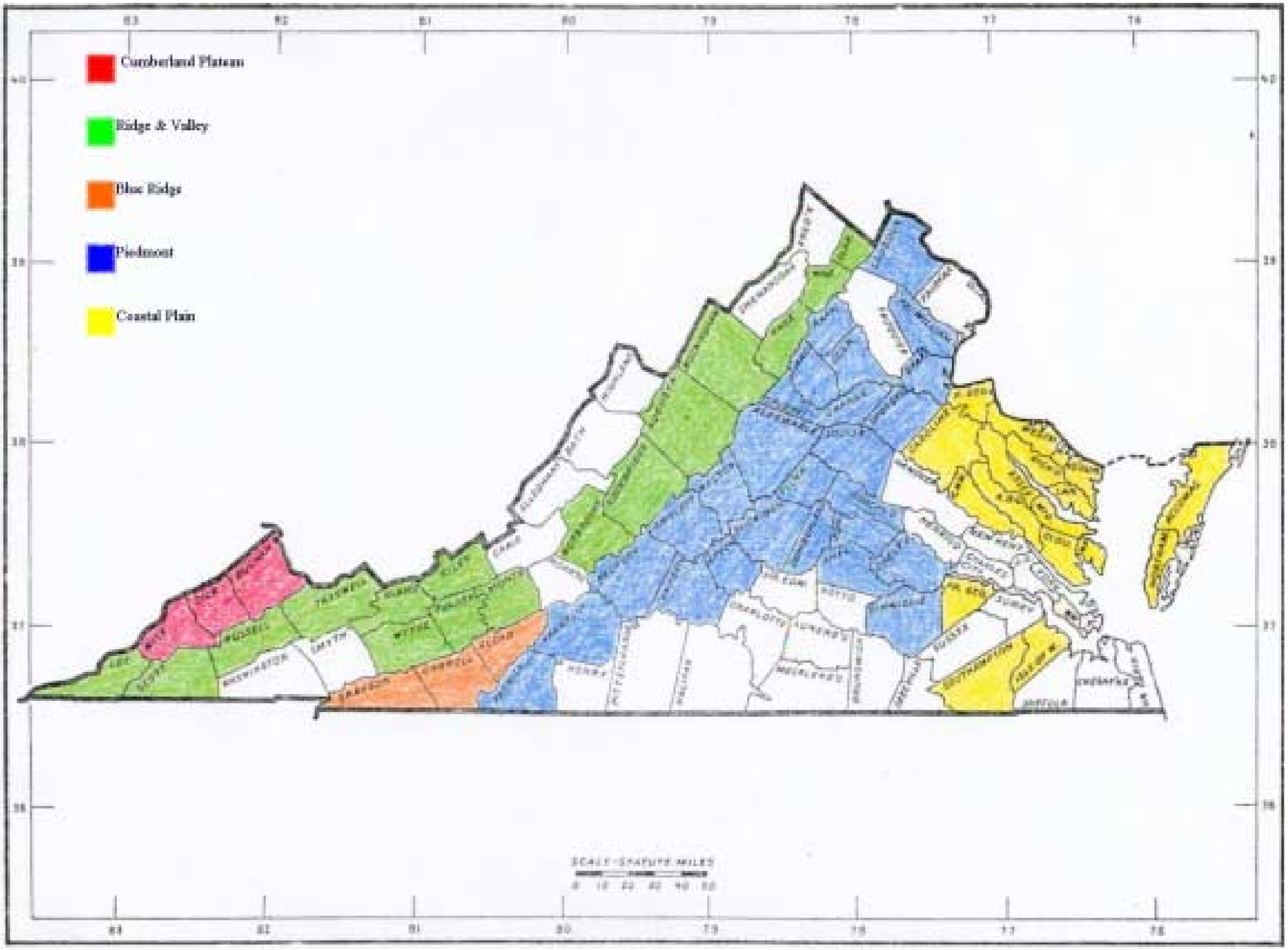


Figure A.1 Map of Counties Analyzed (Ross, 1989-2000)

APPENDIX B Potential pollution sources of Virginia Household Water Quality Testing and Information Program (Ross, 1989-200)

Table B.1 Potential Pollution Sources Inquired about for Each County (Ross, 1989-2000)

	SEPTIC	PRIVY	CEMETER	OIL TANK	STREAM	SINKHOLE	MARSH	COMPOST	LANDFILL	DUMP	ACTIVE QUARRY	OLD QUARRY	GAS TANK	GOLF	MARINA	ORCHARD	CROP	ANIMAL	PLANT	SEWAGE	TOBACCO	ACTIVE SURFACE MINE	OLD SURFACE MINE	ACTIVE DEEP MINE	OLD DEEP MINE	FARM
Warren	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Page	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Rappahannock	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Clarke	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Culpeper	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Madison	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Montgomery	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Greene	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Orange	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Gloucester	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Mathews	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Dickenson	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Wythe	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Scott	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Wise	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Loudoun	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*	*						
Franklin	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*		*					
Russell	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Tazewell	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Pulaski	*	*	*	*	*	*			*	*	*	*		*		*		*	*							
Lee	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Buchanan	*	*	*	*	*	*			*	*			*						*			*	*	*	*	*
Albemarl	*	*	*	*	*			*	*	*	*	*	*	*		*	*	*	*							
Goochland	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							

Table B.1 continued

	SEPTIC	PRIVY	CEMETER	OIL TANK	STREAM	SINKHOLE	MARSH	COMPOST	LANDFILL	DUMP	ACTIVE QUARRY	OLD QUARRY	GAS TANK	GOLF	MARINA	ORCHARD	CROP	ANIMAL	PLANT	SEWAGE	TOBACCO	ACTIVE SURFACE MINE	OLD SURFACE MINE	ACTIVE DEEP MINE	OLD DEEP MINE	FARM
Prince William	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Rockbridge	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Lancaster	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Northumberland	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Caroline	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
King George	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Spotsylvania	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Stafford	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Carroll	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Grayson	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Patrick	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Isle of Wight	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Southampton	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Chesterfield	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Fluvanna	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Botetourt	*	*	*	*	*	*			*	*	*	*	*	*		*		*	*							
Floyd	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Richmond	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Westmoreland	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Amherst	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Appomattox	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Bedford	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							
Campbell	*	*	*	*	*			*	*	*	*	*	*	*		*		*	*							

Table B.1 continued

	SEPTIC	PRIVY	CEMETER	OIL TANK	STREAM	SINKHOLE	MARSH	COMPOST	LANDFILL	DUMP	ACTIVE QUARRY	OLD QUARRY	GAS TANK	GOLF	MARINA	ORCHARD	CROP	ANIMAL	PLANT	SEWAGE	TOBACCO	ACTIVE SURFACE MINE	OLD SURFACE MINE	ACTIVE DEEP MINE	OLD DEEP MINE	FARM
Amelia	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Powhatan	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Buckingham	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Cumberland	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Nelson	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Dinwiddie	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Prince George	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Bland	*	*	*	*	*	*			*	*	*	*	*	*			*	*	*							
Giles	*	*	*	*	*	*			*	*	*	*	*	*			*	*	*							
Essex	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
King & Queen	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
King William	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Middlesex	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Louisa	*	*	*	*	*			*	*	*	*	*	*	*			*	*	*							
Augusta	*	*	*	*	*	*			*	*	*	*	*	*			*	*	*							
Rockingham	*	*	*	*	*	*			*	*	*	*	*	*			*	*	*							
Accomack	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							
Northampton	*	*	*	*	*		*		*	*	*	*	*		*		*	*	*							

APPENDIX C JMP Regression output tables and Residual distributions

Response log10(NO3)

Summary of Fit

RSquare	0.206362
RSquare Adj	0.190823
Root Mean Square Error	0.753171
Mean of Response	-0.26085
Observations (or Sum Wgts)	1407

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	27	203.40332	7.53346	13.2803
Error	1379	782.26002	0.56727	Prob > F
C. Total	1406	985.66334		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	1362	777.58021	0.570911	2.0739
Pure Error	17	4.67981	0.275283	Prob > F
Total Error	1379	782.26002		0.0383
				Max RSq
				0.9953

Effect Tests

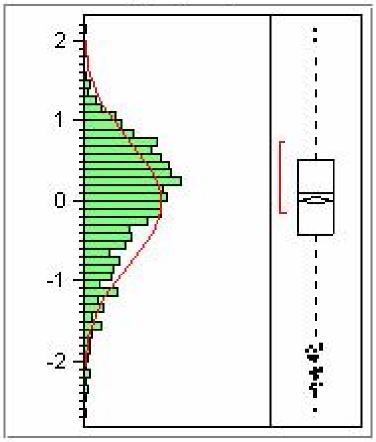
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	13	13	67.811768	9.1955	<.0001
log10(depth)	1	1	9.565845	16.8631	<.0001
log10(age)	1	1	27.346447	48.2074	<.0001
Iron Filter	1	1	12.243442	21.5832	<.0001
Activated Carbon	1	1	5.773022	10.1769	0.0015
Location	3	3	13.343333	7.8407	<.0001
Stream	1	1	10.143340	17.8811	<.0001
Sinkhole	1	1	4.335413	7.6426	0.0058
Animal	1	1	9.033797	15.9251	<.0001
log10(depth)*Location	3	3	5.885160	3.4582	0.0159
Iron Filter*Activated Carbon	1	1	3.134973	5.5265	0.0189

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	13	13	78.364610	10.6265	<.0001
log10(depth)	1	1	24.589905	43.3481	<.0001
log10(age)	1	1	32.861901	57.9303	<.0001
Iron Filter	1	1	17.235240	30.3830	<.0001
Activated Carbon	1	1	2.313660	4.0786	0.0436
Location	3	3	15.697524	9.2241	<.0001
Stream	1	1	9.700775	17.1009	<.0001
Sinkhole	1	1	4.215076	7.4305	0.0065
Animal	1	1	8.967101	15.8076	<.0001
log10(depth)*Location	3	3	6.322555	3.7152	0.0112
Iron Filter*Activated Carbon	1	1	3.134973	5.5265	0.0189

Distributions

Residual log10(NO3)



Normal(-5e-15,0.7459)

Quantiles

100.0%	maximum	2.1029
99.5%		1.4895
97.5%		1.1588
90.0%		0.8390
75.0%	quartile	0.5210
50.0%	median	0.1059
25.0%	quartile	-0.4181
10.0%		-1.0843
2.5%		-1.7361
0.5%		-2.3208
0.0%	minimum	-2.6279

Moments

Mean	-5.17e-15
Std Dev	0.745904
Std Err Mean	0.0198855
upper 95% Mean	0.0390091
lower 95% Mean	-0.039009
N	1407
Sum Wgts	1407
Sum	-7.28e-12
Variance	0.5563727
Skewness	-0.683459
Kurtosis	0.3832129
CV	-1.442e16

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	-5.17e-15	-0.039008	0.0390084
Dispersion	Sigma	0.7459040	0.7193269	0.7745352

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.957172	0.0000

Response Nitrate - Ranks

Summary of Fit

RSquare	0.19376
RSquare Adj	0.182206
Root Mean Square Error	1933.315
Mean of Response	4425.385
Observations (or Sum Wgts)	1629

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	23	1441715289	62683273	16.7705
Error	1605	5999017283	3737705.5	Prob > F
C. Total	1628	7440732571		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	1216	4525236936	3721412	0.9823
Pure Error	389	1473780347	3788638	Prob > F
Total Error	1605	5999017283		0.5916
				Max RSq
				0.8019

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	13	13	333961919	6.8730	<.0001
log10(age)	1	1	329763111	88.2261	<.0001
Iron Filter	1	1	106292944	28.4380	<.0001
Activated Carbon	1	1	30650202	8.2003	0.0042
Location	3	3	121125836	10.8022	<.0001
Stream	1	1	71821298	19.2153	<.0001
Sinkhole	1	1	34500810	9.2305	0.0024
Animal	1	1	82237868	22.0022	<.0001
log10(age)*log10(age)	1	1	53635812	14.3499	0.0002

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	13	13	491147622	10.1080	<.0001
log10(age)	1	1	351809813	94.1245	<.0001
Iron Filter	1	1	145980444	39.0562	<.0001
Activated Carbon	1	1	32399357	8.6682	0.0033
Location	3	3	189095173	16.8637	<.0001
Stream	1	1	68102420	18.2204	<.0001
Sinkhole	1	1	34232542	9.1587	0.0025
Animal	1	1	75312105	20.1493	<.0001
log10(age)*log10(age)	1	1	53635812	14.3499	0.0002

Ordinal Logistic Fit for Nitrate Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	122.34803	20	244.6961	<.0001
Full	773.27916			
Reduced	895.62719			

RSquare (U)	0.1366
Observations (or Sum Wgts)	1629

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	2522	643.97578	1287.952
Saturated	2542	129.30337	Prob>ChiSq
Fitted	20	773.27916	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	13	13	124.071964	0.0000
log10(age)	1	1	40.6841674	0.0000
Softener	1	1	8.9994544	0.0027
Location	3	3	24.1156983	0.0000
Sinkhole	1	1	9.80610959	0.0017
Animal	1	1	19.6826714	0.0000

Ordinal Logistic Fit for Nitrate Code (2 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	121.11634	22	242.2327	<.0001
Full	658.45582			
Reduced	779.57216			

RSquare (U)	0.1554
Observations (or Sum Wgts)	1629

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	1306	558.29363	1116.587
Saturated	1328	100.16219	Prob>ChiSq
Fitted	22	658.45582	0.9999

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	13	13	114.261683	0.0000
log10(age)	1	1	33.8268289	0.0000
Softener	1	1	1.16420926	0.2806
Location	3	3	25.6476056	0.0000
Septic	1	1	8.97771893	0.0027
Sinkhole	1	1	5.9635646	0.0146
Animal	1	1	15.925361	0.0001
Softener*Septic	1	1	3.92959496	0.0474

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	175.0220	51	350.0439	<.0001
Full	1699.2684			
Reduced	1874.2904			

RSquare (U)	0.0934
Observations (or Sum Wgts)	2823

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	1801	1099.4761	2198.952
Saturated	1852	599.7923	Prob>ChiSq
Fitted	51	1699.2684	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	23	23	118.848647	0.0000
Well Type	1	1	12.8341317	0.0003
log10(depth)	1	1	37.9791471	0.0000
None	1	1	10.6827902	0.0011
Activated Carbon	1	1	8.93657026	0.0028
Sinkhole	1	1	5.33334039	0.0209
County*log10(depth)	23	23	41.2971501	0.0109

Ordinal Logistic Fit for Risk Category

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	128.7638	25	257.5277	<.0001
Full	1651.1168			
Reduced	1779.8806			

RSquare (U)	0.0723
Observations (or Sum Wgts)	1494

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	7365	1640.0264	3280.053
Saturated	7390	11.0904	Prob>ChiSq
Fitted	25	1651.1168	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	13	13	102.04749	0.0000
Well Type	1	1	4.23810899	0.0395
log10(depth)	1	1	14.8694153	0.0001
log10(age)	1	1	0.23559578	0.6274
Softener	1	1	7.551991	0.0060
Sediment Filter	1	1	5.9294808	0.0149
Location	3	3	22.7353157	0.0000
Stream	1	1	4.39697413	0.0360
Sinkhole	1	1	10.9153272	0.0010
Animal	1	1	12.1965262	0.0005
log10(age)*Stream	1	1	8.03303743	0.0046

Ordinal Logistic Fit for Risk Category (4 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	129.6894	25	259.3788	<.0001
Full	1544.7210			
Reduced	1674.4104			

RSquare (U)	0.0775
Observations (or Sum Wgts)	1494

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	4403	1532.2444	3064.489
Saturated	4428	12.4766	Prob>ChiSq
Fitted	25	1544.7210	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	13	13	96.3671371	0.0000
log10(depth)	1	1	20.6877667	0.0000
log10(age)	1	1	0.02729732	0.8688
None	1	1	0.90946953	0.3403
Location	3	3	20.6817259	0.0001
Stream	1	1	4.2268346	0.0398
Sinkhole	1	1	3.61373715	0.0573
Animal	1	1	10.1096377	0.0015
log10(age)*log10(age)	1	1	4.8413088	0.0278
log10(age)*Stream	1	1	7.35256222	0.0067
None*Sinkhole	1	1	4.22404467	0.0399

Response log10(NO3)

Summary of Fit

RSquare	0.323863
RSquare Adj	0.284667
Root Mean Square Error	0.672755
Mean of Response	-0.4049
Observations (or Sum Wgts)	147

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	29.917100	3.73964	8.2626
Error	138	62.458625	0.45260	Prob > F
C. Total	146	92.375725		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	106	51.746464	0.488174	1.4583
Pure Error	32	10.712161	0.334755	Prob > F
Total Error	138	62.458625		0.1111
				Max RSq
				0.8840

Effect Tests

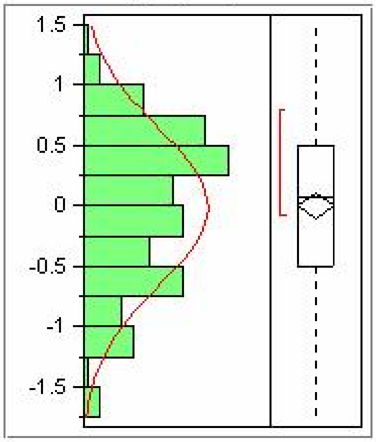
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
log10(depth)	1	1	2.6909303	5.9455	0.0160
Softener	1	1	2.1164024	4.6761	0.0323
Activated Carbon	1	1	2.9566157	6.5325	0.0117
Location	3	3	9.0884435	6.6935	0.0003
Oil Tank	1	1	4.5592775	10.0736	0.0019
Gas Tank	1	1	4.4884159	9.9170	0.0020

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
log10(depth)	1	1	3.168094	6.9998	0.0091
Softener	1	1	2.610994	5.7689	0.0176
Activated Carbon	1	1	3.197961	7.0658	0.0088
Location	3	3	11.003484	8.1039	<.0001
Oil Tank	1	1	5.448151	12.0375	0.0007
Gas Tank	1	1	4.488416	9.9170	0.0020

Distributions

Residual log10(NO3)



Quantiles

100.0%	maximum	1.4761
99.5%		1.4761
97.5%		1.0651
90.0%		0.7698
75.0%	quartile	0.5061
50.0%	median	0.0665
25.0%	quartile	-0.5032
10.0%		-0.9406
2.5%		-1.3536
0.5%		-1.7425
0.0%	minimum	-1.7425

Moments

Mean	5.075e-16
Std Dev	0.6540633
Std Err Mean	0.0539462
upper 95% Mean	0.1066174
lower 95% Mean	-0.106617
N	147
Sum Wgts	147
Sum	7.461e-14
Variance	0.4277988
Skewness	-0.37306
Kurtosis	-0.452691
CV	1.2887e17

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	0.0000000	-0.106616	0.1066164
Dispersion	Sigma	0.6540633	0.5868734	0.7387644

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.966920	0.0251

Response Nitrate - Ranks

Summary of Fit

RSquare	0.276971
RSquare Adj	0.235948
Root Mean Square Error	48.70127
Mean of Response	94.83333
Observations (or Sum Wgts)	150

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	128108.64	16013.6	6.7516
Error	141	334425.69	2371.8	Prob > F
C. Total	149	462534.33		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	109	276713.24	2538.65	1.4076
Pure Error	32	57712.46	1803.51	Prob > F
Total Error	141	334425.69		0.1340
				Max RSq
				0.8752

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
log10(depth)	1	1	17473.354	7.3671	0.0075
Softener	1	1	10206.713	4.3033	0.0399
Activated Carbon	1	1	10768.539	4.5402	0.0348
Location	3	3	37779.911	5.3096	0.0017
Oil Tank	1	1	20215.373	8.5232	0.0041
Gas Tank	1	1	14350.635	6.0505	0.0151

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
log10(depth)	1	1	18039.816	7.6059	0.0066
Softener	1	1	12425.034	5.2386	0.0236
Activated Carbon	1	1	12568.735	5.2992	0.0228
Location	3	3	47267.346	6.6429	0.0003
Oil Tank	1	1	23457.073	9.8899	0.0020
Gas Tank	1	1	14350.635	6.0505	0.0151

Ordinal Logistic Fit for Nitrate Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	8.166751	3	16.3335	0.0010
Full	59.626211			
Reduced	67.792962			

RSquare (U)	0.1205
Observations (or Sum Wgts)	189

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	7	2.639131	5.278261
Saturated	10	56.987081	Prob>ChiSq
Fitted	3	59.626211	0.6260

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Softener	1	1	5.41650888	0.0199
Oil Tank	1	1	4.85946175	0.0275
Landfill	1	1	4.45347883	0.0348

Ordinal Logistic Fit for Nitrate Code (2 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	2.902929	1	5.805858	0.0160
Full	60.919729			
Reduced	63.822658			

RSquare (U)	0.0455
Observations (or Sum Wgts)	189

Converged by Gradient

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Oil Tank	1	1	6.4876347	0.0109

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	7.843908	3	15.68782	0.0013
Full	76.502659			
Reduced	84.346567			

RSquare (U)	0.0930
Observations (or Sum Wgts)	189

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	2	3.551219	7.102438
Saturated	5	72.951440	Prob>ChiSq
Fitted	3	76.502659	0.0287

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	2	2	11.1038497	0.0039
Well Type	1	1	5.76426701	0.0164

Ordinal Logistic Fit for Risk Category

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	9.67929	4	19.35859	0.0007
Full	118.31508			
Reduced	127.99438			

RSquare (U)	0.0756
Observations (or Sum Wgts)	160

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	224	63.26613	126.5323
Saturated	228	55.04895	Prob>ChiSq
Fitted	4	118.31508	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
log10(age)	1	1	4.53269788	0.0333
Softener	1	1	7.31316194	0.0068
Landfill	1	1	4.72868605	0.0297
log10(age)*log10(age)	1	1	5.57754412	0.0182

Ordinal Logistic Fit for Risk Category (4 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	7.93113	3	15.86225	0.0012
Full	116.32258			
Reduced	124.25371			

RSquare (U)	0.0638
Observations (or Sum Wgts)	160

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	162	59.02429	118.0486
Saturated	165	57.29829	Prob>ChiSq
Fitted	3	116.32258	0.9962

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
log10(age)	1	1	4.90878131	0.0267
Softener	1	1	6.7497749	0.0094
log10(age)*log10(age)	1	1	5.22270022	0.0223

Response log10(NO3)

Summary of Fit

RSquare	0.584514
RSquare Adj	0.565502
Root Mean Square Error	0.66306
Mean of Response	-0.806
Observations (or Sum Wgts)	938

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	41	554.18268	13.5167	30.7442
Error	896	393.92553	0.4396	Prob > F
C. Total	937	948.10821		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	725	342.31568	0.472160	1.5644
Pure Error	171	51.60985	0.301812	Prob > F
Total Error	896	393.92553		0.0002
				Max RSq
				0.9456

Effect Tests

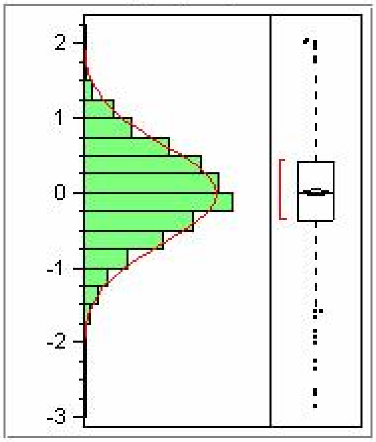
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	14	14	37.729787	6.1299	<.0001
Well Type	1	1	20.265370	46.0944	<.0001
log10(depth)	1	1	26.436832	60.1317	<.0001
Activated Carbon	1	1	2.053321	4.6704	0.0310
Location	3	3	6.626427	5.0240	0.0019
Cemetery	1	1	3.065698	6.9731	0.0084
Field Crop	1	1	4.809454	10.9393	0.0010
County*log10(depth)	14	14	29.282924	4.7575	<.0001
Well Type*log10(depth)	1	1	7.353678	16.7262	<.0001
log10(depth)*Location	3	3	10.332656	7.8340	<.0001
log10(depth)*log10(depth)	1	1	8.146123	18.5287	<.0001

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	14	14	182.51381	29.6525	<.0001
Well Type	1	1	213.32012	485.2055	<.0001
log10(depth)	1	1	87.54340	199.1211	<.0001
Activated Carbon	1	1	2.76677	6.2931	0.0123
Location	3	3	9.66680	7.3292	<.0001
Cemetery	1	1	2.37237	5.3961	0.0204
Field Crop	1	1	3.74184	8.5110	0.0036
County*log10(depth)	14	14	34.31953	5.5758	<.0001
Well Type*log10(depth)	1	1	1.21783	2.7700	0.0964
log10(depth)*Location	3	3	8.57408	6.5007	0.0002
log10(depth)*log10(depth)	1	1	8.14612	18.5287	<.0001

Distributions

Residual log10(NO3)



Normal(-4e-15,0.64839)

Quantiles

100.0%	maximum	2.0236
99.5%		1.9326
97.5%		1.2077
90.0%		0.7983
75.0%	quartile	0.4284
50.0%	median	-0.0001
25.0%	quartile	-0.3798
10.0%		-0.7819
2.5%		-1.3306
0.5%		-2.2978
0.0%	minimum	-2.8811

Moments

Mean	-3.81e-15
Std Dev	0.6483914
Std Err Mean	0.0211707
upper 95% Mean	0.0415482
lower 95% Mean	-0.041548
N	938
Sum Wgts	938
Sum	-3.57e-12
Variance	0.4204115
Skewness	-0.293048
Kurtosis	1.2337123
CV	-1.704e16

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	-3.81e-15	-0.041548	0.0415475
Dispersion	Sigma	0.6483914	0.6203196	0.6791441

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.981992	0.0240

Response Nitrate - Ranks

Summary of Fit

RSquare	0.556932
RSquare Adj	0.535886
Root Mean Square Error	297.6762
Mean of Response	704.8832
Observations (or Sum Wgts)	839

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	38	89106719	2344914	26.4630
Error	800	70888911	88611	Prob > F
C. Total	838	159995630		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	654	63192162	96624.1	1.8329
Pure Error	146	7696750	52717.5	Prob > F
Total Error	800	70888911		<.0001
				Max RSq
				0.9519

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	11	11	9630350.9	9.8801	<.0001
Well Type	1	1	2274393.6	25.6671	<.0001
log10(depth)	1	1	4583302.0	51.7238	<.0001
Neutralizer	1	1	586290.4	6.6164	0.0103
Activated Carbon	1	1	541771.2	6.1140	0.0136
Location	3	3	1669106.2	6.2788	0.0003
Marsh	1	1	1508900.7	17.0283	<.0001
County*log10(depth)	11	11	6005042.2	6.1608	<.0001
Well Type*Location	3	3	1027127.0	3.8638	0.0092
Well Type*Marsh	1	1	862847.8	9.7375	0.0019
log10(depth)*Location	3	3	757578.9	2.8498	0.0366
log10(depth)*Marsh	1	1	991237.3	11.1864	0.0009

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	11	11	25658471	26.3239	<.0001
Well Type	1	1	44606421	503.3952	<.0001
log10(depth)	1	1	4960171	55.9768	<.0001
Neutralizer	1	1	383643	4.3295	0.0378
Activated Carbon	1	1	580139	6.5470	0.0107
Location	3	3	1643496	6.1824	0.0004
Marsh	1	1	477625	5.3901	0.0205
County*log10(depth)	11	11	7325379	7.5153	<.0001
Well Type*Location	3	3	1261024	4.7437	0.0028
Well Type*Marsh	1	1	191865	2.1652	0.1416
log10(depth)*Location	3	3	1027249	3.8643	0.0092
log10(depth)*Marsh	1	1	991237	11.1864	0.0009

Ordinal Logistic Fit for Nitrate Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	188.56078	26	377.1216	<.0001
Full	374.19197			
Reduced	562.75274			

RSquare (U)	0.3351
Observations (or Sum Wgts)	1203

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	1880	326.42527	652.8505
Saturated	1906	47.76670	Prob>ChiSq
Fitted	26	374.19197	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	16	16	74.432642	0.0000
Well Type	1	1	4.71036073	0.0300
log10(depth)	1	1	39.5247611	0.0000
Location	3	3	8.666873	0.0341
Oil Tank	1	1	5.77442352	0.0163
log10(depth)*log10(depth)	1	1	15.6776379	0.0001
log10(depth)*Location	3	3	13.2490408	0.0041

Ordinal Logistic Fit for Nitrate Code (2 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	178.54665	24	357.0933	<.0001
Full	259.47792			
Reduced	438.02457			

RSquare (U)	0.4076
Observations (or Sum Wgts)	1112

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	864	230.60731	461.2146
Saturated	888	28.87061	Prob>ChiSq
Fitted	24	259.47792	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	14	14	65.1395614	0.0000
Well Type	1	1	9.20400852	0.0024
log10(depth)	1	1	32.6663919	0.0000
Location	3	3	5.10275752	0.1644
Field Crop	1	1	7.74230916	0.0054
log10(depth)*log10(depth)	1	1	10.527752	0.0012
log10(depth)*Location	3	3	16.0529543	0.0011

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	111.08833	35	222.1767	<.0001
Full	677.86257			
Reduced	788.95090			

RSquare (U)	0.1408
Observations (or Sum Wgts)	1202

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	609	370.63490	741.2698
Saturated	644	307.22767	Prob>ChiSq
Fitted	35	677.86257	0.0002

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	16	16	30.3314047	0.0164
Well Type	1	1	0.07737576	0.7809
log10(age)	1	1	3.78881974	0.0516
County*Well Type	16	16	35.4133408	0.0035
log10(age)*log10(age)	1	1	9.60079839	0.0019

Ordinal Logistic Fit for Risk Category

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	209.1760	56	418.3521	<.0001
Full	895.0568			
Reduced	1104.2328			

RSquare (U)	0.1894
Observations (or Sum Wgts)	1016

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	4959	884.82947	1769.659
Saturated	5015	10.22731	Prob>ChiSq
Fitted	56	895.05677	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	16	16	32.2195912	0.0094
Well Type	1	1	0.27473883	0.6002
log10(depth)	1	1	11.7273116	0.0006
log10(age)	1	1	0.2001985	0.6546
Location	3	3	23.5303264	0.0000
Oil Tank	1	1	6.58033769	0.0103
log10(age)*log10(age)	1	1	6.77537449	0.0092
County*Well Type	16	16	46.3171259	0.0001
County*log10(depth)	16	16	45.465152	0.0001

Ordinal Logistic Fit for Risk Category (4 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	207.0727	56	414.1455	<.0001
Full	842.6097			
Reduced	1049.6824			

RSquare (U)	0.1973
Observations (or Sum Wgts)	1016

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	2953	832.38240	1664.765
Saturated	3009	10.22731	Prob>ChiSq
Fitted	56	842.60971	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	16	16	32.1008253	0.0097
Well Type	1	1	0.28866428	0.5911
log10(depth)	1	1	11.5560425	0.0007
log10(age)	1	1	0.09727598	0.7551
Location	3	3	22.7324128	0.0000
Oil Tank	1	1	6.39097209	0.0115
log10(age)*log10(age)	1	1	6.76940617	0.0093
County*Well Type	16	16	42.082413	0.0004
County*log10(depth)	16	16	39.5423001	0.0009

Response log10(NO3)

Summary of Fit

RSquare	0.205376
RSquare Adj	0.17455
Root Mean Square Error	0.600832
Mean of Response	-1.02012
Observations (or Sum Wgts)	242

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	21.64620	2.40513	6.6624
Error	232	83.75190	0.36100	Prob > F
C. Total	241	105.39810		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	160	57.839264	0.361495	1.0044
Pure Error	72	25.912640	0.359898	Prob > F
Total Error	232	83.751904		0.5014
				Max RSq
				0.7541

Effect Tests

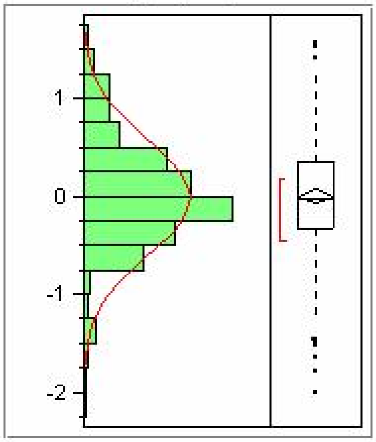
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
log10(age)	1	1	3.6855703	10.2093	0.0016
Softener	1	1	8.5159463	23.5899	<.0001
Location	3	3	4.8249369	4.4552	0.0046
Pipe Material	4	4	4.1326772	2.8620	0.0242

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
log10(age)	1	1	3.1605785	8.7551	0.0034
Softener	1	1	9.4594809	26.2036	<.0001
Location	3	3	4.8934624	4.5184	0.0042
Pipe Material	4	4	4.1326772	2.8620	0.0242

Distributions

Residual log10(NO3)



Quantiles

100.0%	maximum	1.5495
99.5%		1.5425
97.5%		1.2553
90.0%		0.8512
75.0%	quartile	0.3520
50.0%	median	-0.0205
25.0%	quartile	-0.3327
10.0%		-0.6060
2.5%		-1.4778
0.5%		-1.9654
0.0%	minimum	-2.0127

Moments

Mean	-2.22e-16
Std Dev	0.5895068
Std Err Mean	0.0378949
upper 95% Mean	0.0746485
lower 95% Mean	-0.074649
N	242
Sum Wgts	242
Sum	-5.37e-14
Variance	0.3475183
Skewness	-0.146603
Kurtosis	0.993774
CV	-2.655e17

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	-2.22e-16	-0.074648	0.0746476
Dispersion	Sigma	0.5895068	0.5412481	0.6472872

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.969153	0.0051

Response Nitrate - Ranks

Summary of Fit

RSquare	0.139041
RSquare Adj	0.12786
Root Mean Square Error	109.3604
Mean of Response	196.8978
Observations (or Sum Wgts)	313

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	594882.9	148721	12.4351
Error	308	3683589.9	11960	Prob > F
C. Total	312	4278472.7		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	133	1683921.2	12661.1	1.1080
Pure Error	175	1999668.6	11426.7	Prob > F
Total Error	308	3683589.9		0.2617
				Max RSq
				0.5326

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
log10(age)	1	1	17066.98	1.4270	0.2332
Softener	1	1	437404.93	36.5732	<.0001
Old Surface Mine	1	1	56651.06	4.7368	0.0303
log10(age)*Softener	1	1	61729.67	5.1615	0.0238

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
log10(age)	1	1	47343.25	3.9586	0.0475
Softener	1	1	429630.37	35.9232	<.0001
Old Surface Mine	1	1	56179.58	4.6974	0.0310
log10(age)*Softener	1	1	61729.67	5.1615	0.0238

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	18.06386	4	36.12772	<.0001
Full	218.84625			
Reduced	236.91012			

RSquare (U)	0.0762
Observations (or Sum Wgts)	342

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	208	120.38869	240.7774
Saturated	212	98.45756	Prob>ChiSq
Fitted	4	218.84625	0.0592

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	2	2	14.3815077	0.0008
log10(depth)	1	1	6.24193695	0.0125
Softener	1	1	11.338331	0.0008

Ordinal Logistic Fit for Risk Category

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	17.95277	4	35.90554	<.0001
Full	240.13784			
Reduced	258.09061			

RSquare (U)	0.0696
Observations (or Sum Wgts)	342

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	632	141.68028	283.3606
Saturated	636	98.45756	Prob>ChiSq
Fitted	4	240.13784	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	2	2	11.4931849	0.0032
log10(depth)	1	1	8.27248523	0.0040
Softener	1	1	12.9581075	0.0003

Ordinal Logistic Fit for Risk Category (4 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	17.95277	4	35.90554	<.0001
Full	240.13784			
Reduced	258.09061			

RSquare (U)	0.0696
Observations (or Sum Wgts)	342

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	632	141.68028	283.3606
Saturated	636	98.45756	Prob>ChiSq
Fitted	4	240.13784	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	2	2	11.4931849	0.0032
log10(depth)	1	1	8.27248523	0.0040
Softener	1	1	12.9581075	0.0003

Response log10(NO3)

Summary of Fit

RSquare	0.309891
RSquare Adj	0.293059
Root Mean Square Error	0.662442
Mean of Response	-0.31879
Observations (or Sum Wgts)	1177

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	28	226.21950	8.07927	18.4109
Error	1148	503.77684	0.43883	Prob > F
C. Total	1176	729.99635		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	799	342.14381	0.428215	0.9246
Pure Error	349	161.63303	0.463132	Prob > F
Total Error	1148	503.77684		0.8105
				Max RSq
				0.7786

Effect Tests

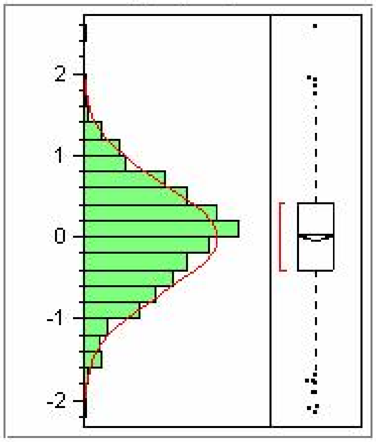
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	9	9	85.809841	21.7269	<.0001
log10(age)	1	1	0.152291	0.3470	0.5559
Location	3	3	14.923363	11.3357	<.0001
Septic	1	1	2.198736	5.0105	0.0254
Dump	1	1	3.259077	7.4267	0.0065
Gas Tank	1	1	5.779042	13.1692	0.0003
Field Crop	1	1	3.808345	8.6784	0.0033
County*log10(age)	9	9	17.752645	4.4949	<.0001
log10(age)*Gas Tank	1	1	3.642967	8.3015	0.0040
log10(age)*log10(age)	1	1	3.154349	7.1881	0.0074

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	9	9	130.64154	33.0782	<.0001
log10(age)	1	1	39.66821	90.3954	<.0001
Location	3	3	20.43753	15.5243	<.0001
Septic	1	1	2.20426	5.0230	0.0252
Dump	1	1	2.74605	6.2577	0.0125
Gas Tank	1	1	4.21524	9.6056	0.0020
Field Crop	1	1	4.33391	9.8761	0.0017
County*log10(age)	9	9	15.93500	4.0347	<.0001
log10(age)*Gas Tank	1	1	2.88341	6.5707	0.0105
log10(age)*log10(age)	1	1	3.15435	7.1881	0.0074

Distributions

Residual log10(NO3)



Normal(1e-14,0.65451)

Quantiles

100.0%	maximum	2.5699
99.5%		1.6360
97.5%		1.2281
90.0%		0.7955
75.0%	quartile	0.4271
50.0%	median	0.0422
25.0%	quartile	-0.4150
10.0%		-0.8663
2.5%		-1.4097
0.5%		-1.8204
0.0%	minimum	-2.1568

Moments

Mean	1e-14
Std Dev	0.6545087
Std Err Mean	0.0190778
upper 95% Mean	0.0374309
lower 95% Mean	-0.037431
N	1177
Sum Wgts	1177
Sum	1.178e-11
Variance	0.4283817
Skewness	-0.152881
Kurtosis	0.2342622
CV	6.542e+15

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	0.0000000	-0.03743	0.0374302
Dispersion	Sigma	0.6545087	0.6290951	0.6820778

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.988035	0.6901

Response Nitrate - Ranks

Summary of Fit

RSquare	0.360316
RSquare Adj	0.346377
Root Mean Square Error	733.4642
Mean of Response	1716.901
Observations (or Sum Wgts)	1267

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	27	375446406	13905422	25.8480
Error	1239	666544564	537969.79	Prob > F
C. Total	1266	1041990969		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	804	445192569	553722	1.0882
Pure Error	435	221351995	508855	Prob > F
Total Error	1239	666544564		0.1609
				Max RSq
				0.7876

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	9	9	164766454	34.0305	<.0001
log10(age)	1	1	14687	0.0273	0.8688
Iron Filter	1	1	10242598	19.0394	<.0001
Location	3	3	11623490	7.2021	<.0001
Gas Tank	1	1	11463980	21.3097	<.0001
Field Crop	1	1	3369374	6.2631	0.0125
County*log10(age)	9	9	26565009	5.4867	<.0001
log10(age)*Gas Tank	1	1	5120667	9.5185	0.0021
log10(age)*log10(age)	1	1	3467750	6.4460	0.0112

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	9	9	246228193	50.8554	<.0001
log10(age)	1	1	55607803	103.3660	<.0001
Iron Filter	1	1	12012109	22.3286	<.0001
Location	3	3	16994680	10.5301	<.0001
Gas Tank	1	1	7941167	14.7614	0.0001
Field Crop	1	1	3867777	7.1896	0.0074
County*log10(age)	9	9	25175940	5.1998	<.0001
log10(age)*Gas Tank	1	1	4150987	7.7160	0.0056
log10(age)*log10(age)	1	1	3467750	6.4460	0.0112

Ordinal Logistic Fit for Nitrate Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	54.68839	6	109.3768	<.0001
Full	448.39301			
Reduced	503.08140			

RSquare (U)	0.1087
Observations (or Sum Wgts)	1267

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	976	251.85679	503.7136
Saturated	982	196.53622	Prob>ChiSq
Fitted	6	448.39301	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Well Type	1	1	8.14539366	0.0043
log10(age)	1	1	15.4921055	0.0001
Location	3	3	27.2526098	0.0000
Field Crop	1	1	12.9991581	0.0003

Ordinal Logistic Fit for Nitrate Code (2 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	55.73422	7	111.4684	<.0001
Full	394.94529			
Reduced	450.67951			

RSquare (U)	0.1237
Observations (or Sum Wgts)	1267

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	484	204.47749	408.955
Saturated	491	190.46780	Prob>ChiSq
Fitted	7	394.94529	0.9943

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Well Type	1	1	7.2558874	0.0071
log10(age)	1	1	13.3929107	0.0003
Location	3	3	25.8847329	0.0000
Field Crop	1	1	16.3026718	0.0001
log10(age)*Field Crop	1	1	3.9474807	0.0469

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	385.0017	56	770.0035	<.0001
Full	1374.5752			
Reduced	1759.5769			

RSquare (U)	0.2188
Observations (or Sum Wgts)	2620

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	1607	903.2007	1806.401
Saturated	1663	471.3745	Prob>ChiSq
Fitted	56	1374.5752	0.0003

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	25	25	88.306782	0.0000
Well Type	1	1	0.48145444	0.4878
log10(depth)	1	1	0.19321204	0.6603
Iron Filter	1	1	6.42820295	0.0112
Neutralizer	1	1	11.3963868	0.0007
Sediment Filter	1	1	7.43602184	0.0064
County*log10(depth)	25	25	64.1459178	0.0000
Well Type*Iron Filter	1	1	4.35150885	0.0370

Ordinal Logistic Fit for Risk Category

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	327.9829	80	655.9658	<.0001
Full	2043.3005			
Reduced	2371.2834			

RSquare (U)	0.1383
Observations (or Sum Wgts)	2236

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	10790	2007.9364	4015.873
Saturated	10870	35.3641	Prob>ChiSq
Fitted	80	2043.3005	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	24	24	45.7187408	0.0048
Well Type	1	1	20.3537567	0.0000
log10(depth)	1	1	28.5876851	0.0000
log10(age)	1	1	32.9625765	0.0000
Iron Filter	1	1	9.07000036	0.0026
Neutralizer	1	1	6.09695515	0.0135
Sediment Filter	1	1	0.27174663	0.6022
County*log10(age)	24	24	53.40533	0.0005
County*Sediment Filter	24	24	41.5339936	0.0145
log10(depth)*Neutralizer	1	1	4.76698555	0.0290
log10(age)*log10(age)	1	1	4.91320171	0.0267

Ordinal Logistic Fit for Risk Category (4 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	344.1989	85	688.3977	<.0001
Full	1909.7404			
Reduced	2253.9392			

RSquare (U)	0.1527
Observations (or Sum Wgts)	2196

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	6413	1892.0584	3784.117
Saturated	6498	17.6820	Prob>ChiSq
Fitted	85	1909.7404	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	24	24	58.0981565	0.0001
Well Type	1	1	26.5121598	0.0000
log10(depth)	1	1	15.4482489	0.0001
log10(age)	1	1	12.9090066	0.0003
Iron Filter	1	1	8.69657806	0.0032
Sediment Filter	1	1	0.04785861	0.8268
Location	3	3	7.77745924	0.0508
log10(age)*log10(age)	1	1	9.94404168	0.0016
County*log10(depth)	24	24	46.7076076	0.0036
County*Sediment Filter	24	24	46.259238	0.0041
Well Type*log10(depth)	1	1	9.4598925	0.0021
Sediment Filter*Location	3	3	9.11976965	0.0277

Response log10(NO3)

Summary of Fit

RSquare	0.166985
RSquare Adj	0.151976
Root Mean Square Error	0.741307
Mean of Response	-0.16022
Observations (or Sum Wgts)	1131

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	20	122.27673	6.11384	11.1254
Error	1110	609.98534	0.54954	Prob > F
C. Total	1130	732.26207		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	740	391.14657	0.528576	0.8937
Pure Error	370	218.83877	0.591456	Prob > F
Total Error	1110	609.98534		0.8971
				Max RSq
				0.7011

Effect Tests

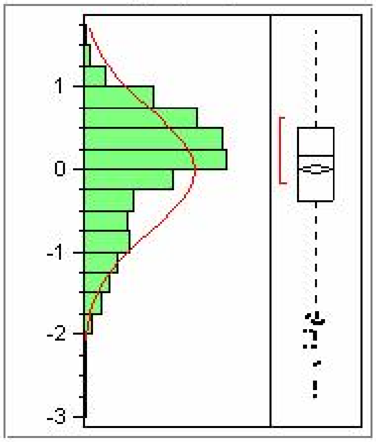
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	11	11	42.940776	7.1036	<.0001
log10(age)	1	1	23.896111	43.4841	<.0001
Iron Filter	1	1	17.524210	31.8891	<.0001
Activated Carbon	1	1	4.893736	8.9052	0.0029
Location	4	4	13.752091	6.2562	<.0001
Stream	1	1	5.777879	10.5141	0.0012
Sinkhole	1	1	4.256647	7.7459	0.0055

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	11	11	46.499339	7.6923	<.0001
log10(age)	1	1	26.695649	48.5785	<.0001
Iron Filter	1	1	20.118419	36.6098	<.0001
Activated Carbon	1	1	4.394437	7.9966	0.0048
Location	4	4	14.421623	6.5608	<.0001
Stream	1	1	5.890617	10.7192	0.0011
Sinkhole	1	1	4.256647	7.7459	0.0055

Distributions

Residual log10(NO3)



Quantiles

100.0%	maximum	1.6943
99.5%		1.3892
97.5%		1.1301
90.0%		0.7947
75.0%	quartile	0.5132
50.0%	median	0.1622
25.0%	quartile	-0.3933
10.0%		-1.0804
2.5%		-1.7003
0.5%		-2.3641
0.0%	minimum	-2.7618

Moments

Mean	9.361e-16
Std Dev	0.7347177
Std Err Mean	0.0218469
upper 95% Mean	0.0428657
lower 95% Mean	-0.042866
N	1131
Sum Wgts	1131
Sum	1.059e-12
Variance	0.53981
Skewness	-0.849648
Kurtosis	0.4805591
CV	7.8489e16

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	0.0000000	-0.042865	0.0428650
Dispersion	Sigma	0.7347177	0.7056378	0.7663158

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.936333	0.0000

Response Nitrate - Ranks

Summary of Fit

RSquare	0.198646
RSquare Adj	0.184061
Root Mean Square Error	630.9598
Mean of Response	1268.772
Observations (or Sum Wgts)	1008

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	18	97601020	5422279	13.6200
Error	989	393730997	398110	Prob > F
C. Total	1007	491332017		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	717	278864533	388932	0.9210
Pure Error	272	114866464	422303	Prob > F
Total Error	989	393730997		0.7987
				Max RSq
				0.7662

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
County	7	7	21306515	7.6456	<.0001
log10(age)	1	1	6367307	15.9938	<.0001
Iron Filter	1	1	8948536	22.4775	<.0001
Activated Carbon	1	1	3088660	7.7583	0.0054
Location	3	3	5478260	4.5869	0.0034
Stream	1	1	6733345	16.9133	<.0001
Sinkhole	1	1	3729049	9.3669	0.0023
Animal	1	1	5150846	12.9382	0.0003
log10(age)*Sinkhole	1	1	2090518	5.2511	0.0221
log10(age)*log10(age)	1	1	3746862	9.4116	0.0022

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
County	7	7	34711873	12.4559	<.0001
log10(age)	1	1	18053841	45.3489	<.0001
Iron Filter	1	1	13591052	34.1389	<.0001
Activated Carbon	1	1	3319568	8.3383	0.0040
Location	3	3	9479604	7.9372	<.0001
Stream	1	1	5926585	14.8868	0.0001
Sinkhole	1	1	2120250	5.3258	0.0212
Animal	1	1	4750547	11.9327	0.0006
log10(age)*Sinkhole	1	1	1900837	4.7747	0.0291
log10(age)*log10(age)	1	1	3746862	9.4116	0.0022

Ordinal Logistic Fit for Nitrate Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	90.92555	20	181.8511	<.0001
Full	518.06506			
Reduced	608.99061			

RSquare (U)	0.1493
Observations (or Sum Wgts)	1019

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	1254	334.57733	669.1547
Saturated	1274	183.48773	Prob>ChiSq
Fitted	20	518.06506	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	7	7	82.8920717	0.0000
log10(age)	1	1	21.6444121	0.0000
Softener	1	1	0.35706055	0.5501
Septic	1	1	8.43311577	0.0037
Sinkhole	1	1	4.71902254	0.0298
Animal	1	1	9.75453502	0.0018
County*log10(age)	7	7	15.1178079	0.0345
Softener*Septic	1	1	5.82828586	0.0158

Ordinal Logistic Fit for Nitrate Code (2 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	76.91826	18	153.8365	<.0001
Full	397.80648			
Reduced	474.72473			

RSquare (U)	0.1620
Observations (or Sum Wgts)	935

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	905	395.03389	790.0678
Saturated	923	2.77259	Prob>ChiSq
Fitted	18	397.80648	0.9975

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	7	7	67.1123343	0.0000
log10(depth)	1	1	5.75918149	0.0164
log10(age)	1	1	11.4813615	0.0007
Softener	1	1	0.07253572	0.7877
Location	3	3	8.13604083	0.0433
Septic	1	1	10.2083176	0.0014
Stream	1	1	4.12562551	0.0422
Sinkhole	1	1	4.6366237	0.0313
Animal	1	1	7.65773456	0.0057
Softener*Septic	1	1	4.3817881	0.0363

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	76.2453	18	152.4906	<.0001
Full	1264.8305			
Reduced	1341.0758			

RSquare (U)	0.0569
Observations (or Sum Wgts)	2001

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	1064	654.3326	1308.665
Saturated	1082	610.4979	Prob>ChiSq
Fitted	18	1264.8305	<.0001

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	14	14	58.1879892	0.0000
log10(depth)	1	1	58.8147904	0.0000
Iron Filter	1	1	9.82809705	0.0017
Activated Carbon	1	1	9.55009372	0.0020
Sinkhole	1	1	4.44762819	0.0349

Ordinal Logistic Fit for Risk Category

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	74.7836	16	149.5671	<.0001
Full	1088.8475			
Reduced	1163.6311			

RSquare (U)	0.0643
Observations (or Sum Wgts)	935

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	4584	1077.7572	2155.514
Saturated	4600	11.0904	Prob>ChiSq
Fitted	16	1088.8475	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	7	7	70.5138694	0.0000
log10(depth)	1	1	9.71407412	0.0018
log10(age)	1	1	14.677913	0.0001
Softener	1	1	4.77922452	0.0288
Iron Filter	1	1	5.3363655	0.0209
Location	3	3	9.92399011	0.0192
Sinkhole	1	1	6.31743334	0.0120
Animal	1	1	5.07657553	0.0243

Ordinal Logistic Fit for Risk Category (4 cats)

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	82.7904	20	165.5808	<.0001
Full	1238.5974			
Reduced	1321.3878			

RSquare (U)	0.0627
Observations (or Sum Wgts)	1140

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	3310	1220.5756	2441.151
Saturated	3330	18.0218	Prob>ChiSq
Fitted	20	1238.5974	1.0000

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
County	11	11	78.4442296	0.0000
log10(depth)	1	1	11.0652477	0.0009
log10(age)	1	1	21.7859093	0.0000
Iron Filter	1	1	7.4748364	0.0063
Location	4	4	11.4594172	0.0219
Sinkhole	1	1	5.04346761	0.0247
log10(age)*log10(age)	1	1	5.90727164	0.0151

Response log10(NO3)

Summary of Fit

RSquare	0.186517
RSquare Adj	0.172729
Root Mean Square Error	0.804337
Mean of Response	-0.59208
Observations (or Sum Wgts)	301

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	43.75908	8.75182	13.5276
Error	295	190.85256	0.64696	Prob > F
C. Total	300	234.61165		<.0001

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	93	60.56504	0.651237	1.0097
Pure Error	202	130.28752	0.644988	Prob > F
Total Error	295	190.85256		0.4696
				Max RSq
				0.4447

Effect Tests

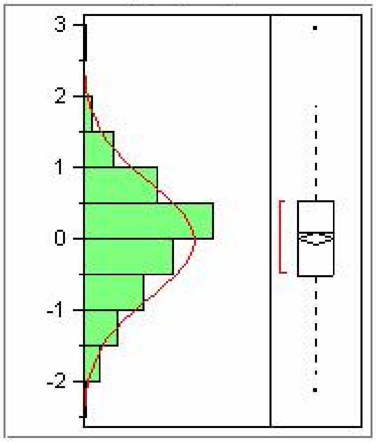
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
log10(age)	1	1	27.279276	42.1655	<.0001
Iron Filter	1	1	2.543283	3.9311	0.0483
Activated Carbon	1	1	2.791686	4.3151	0.0386
Active Quarry	1	1	2.654634	4.1033	0.0437
Animal	1	1	8.308216	12.8420	0.0004

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
log10(age)	1	1	28.646597	44.2789	<.0001
Iron Filter	1	1	2.507155	3.8753	0.0499
Activated Carbon	1	1	1.490230	2.3034	0.1302
Active Quarry	1	1	2.806886	4.3386	0.0381
Animal	1	1	8.308216	12.8420	0.0004

Distributions

Residual log10(NO3)



Quantiles

100.0%	maximum	2.9393
99.5%		2.3994
97.5%		1.4723
90.0%		0.9899
75.0%	quartile	0.5220
50.0%	median	0.0803
25.0%	quartile	-0.5289
10.0%		-1.0334
2.5%		-1.5745
0.5%		-2.0375
0.0%	minimum	-2.1663

Moments

Mean	-2.17e-16
Std Dev	0.7976059
Std Err Mean	0.0459732
upper 95% Mean	0.0904721
lower 95% Mean	-0.090472
N	301
Sum Wgts	301
Sum	-6.54e-14
Variance	0.6361752
Skewness	-0.02347
Kurtosis	0.0737351
CV	-3.671e17

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	-2.17e-16	-0.090471	0.0904709
Dispersion	Sigma	0.7976059	0.7385721	0.8669761

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.987397	0.8086

APPENDIX D Regression summary tables

Table D.1 $\log_{10}(NO_3)$ Response Variable

	Virginia (n = 1407)		Blue Ridge (n = 147)		Coastal Plain (n = 938)		Cumberland Plateau (n = 242)		Piedmont (n = 1177)		Ridge & Valley (n = 1131)	
source	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**
model	0.206	-----	0.324	-----	0.585	-----	0.205	-----	0.310	-----	0.167	-----
location	0.016	<.0001	0.119	<.0001	0.010	<.0001	0.046	0.0042	0.028	<.0001	0.020	<.0001
activated carbon	0.002	0.043	0.035	0.0088	0.003	0.012					0.006	0.0048
county	0.080	<.0001			0.193	<.0001			0.179	<.0001	0.064	<.0001
$\log_{10}$(age)	0.033	<.0001					0.030	0.0034	0.054	<.0001	0.036	<.0001
$\log_{10}$(depth)	0.025	<.0001	0.034	0.0091	0.092	<.0001						
field crop					0.004	0.0036			0.006	0.0017		
gas tank			0.049	0.0020					0.006	0.002		
iron filter	0.017	<.0001									0.027	<.0001
sinkhole	0.004	0.0065									0.006	0.0055
softener			0.028	0.018			0.090	<.0001				
stream	0.010	<.0001									0.008	0.0011
animal	0.009	<.0001										
cemetery					0.003	0.020						
dump									0.004	0.013		
oil tank			0.059	0.0007								
pipe material							0.039	0.024				
septic									0.003	0.025		
well type					0.225	<.0001						
$\log_{10}$(depth)*location	0.006	0.011			0.009	0.0002						
well type*$\log_{10}$(depth)					0.001	0.096						
county*$\log_{10}$(age)									0.022	<.0001		
county*$\log_{10}$(depth)					0.036	<.0001						
iron filter*activated carbon	0.003	0.019										
$\log_{10}$(age)*gas tank									0.004	0.011		
$\log_{10}$(age)*$\log_{10}$(age)									0.004	0.0074		
$\log_{10}$(depth)*$\log_{10}$(depth)					0.009	<.0001						

Table D.2 Nitrate-Ranks Response Variable

	Virginia (n = 1629)		Blue Ridge (n = 150)		Coastal Plain (n = 839)		Cumberland Plateau (n = 313)		Piedmont (n = 1267)		Ridge & Valley (n = 1008)	
source	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**	**partial R square**	**p-value**
model	0.194	-----	0.277	-----	0.557	-----	0.139	-----	0.360	-----	0.199	-----
location	0.025	<.0001	0.102	0.0003	0.010	0.0004			0.016	<.0001	0.019	<.0001
activated carbon	0.004	0.0033	0.027	0.023	0.004	0.011					0.007	0.004
county	0.066	<.0001			0.160	<.0001			0.236	<.0001	0.071	<.0001
$\log_{10}$(age)	0.047	<.0001					0.011	0.048	0.053	<.0001	0.037	<.0001
iron filter	0.020	<.0001							0.012	<.0001	0.028	<.0001
$\log_{10}$(depth)			0.039	0.0066	0.031	<.0001						
animal	0.010	<.0001									0.010	0.0006
gas tank			0.031	0.015					0.008	0.0001		
sinkhole	0.005	0.0025									0.004	0.021
softener			0.027	0.024			0.100	<.0001				
stream	0.009	<.0001									0.012	0.0001
field crop									0.004	0.0074		
marsh					0.003	0.021						
neutralizer					0.002	0.038						
oil tank			0.051	0.0020								
old surface mine							0.013	0.031				
well type					0.279	<.0001						
$\log_{10}$(age)*$\log_{10}$(age)	0.007	0.0002							0.003	0.011	0.008	0.0022
county*$\log_{10}$(age)									0.024	<.0001		
county*$\log_{10}$(depth)					0.046	<.0001						
$\log_{10}$(age)*gas tank									0.004	0.0056		
$\log_{10}$(age)*sinkhole											0.004	0.029
$\log_{10}$(age)*softener							0.014	0.024				
$\log_{10}$(depth)*location					0.006	0.0092						
$\log_{10}$(depth)*marsh					0.006	0.0009						
well type*location					0.008	0.0028						
well type*marsh					0.001	0.14						

Table D.3 Nitrate Code Response Variable

	Virginia (n = 1629)	Blue Ridge (n = 189)	Coastal Plain (n = 1203)	Cumberland Plateau	Piedmont (n = 1267)	Ridge & Valley (n = 1019)
	p-values					
county	0.0000		0.0000			0.0000
softener	0.0027	0.0199				0.5501
location	0.0000		0.0341		0.0000	
$\log_{10}$(age)	0.0000				0.0001	0.0000
animal	0.0000					0.0018
oil tank		0.0275	0.0163			
sinkhole	0.0017					0.0298
well type			0.0300		0.0043	
$\log_{10}$(depth)			0.0000			
field crop					0.0003	
landfill		0.0348				
septic						0.0037
county*$\log_{10}$(age)						0.0345
$\log_{10}$(depth)*location			0.0041			
$\log_{10}$(depth)*$\log_{10}$(depth)			0.0001			
softener*septic						0.0158

Table D.4 Nitrate Code (2 cats) Response Variable

	Virginia (n = 1629)	Blue Ridge (n = 189)	Coastal Plain (n = 1112)	Cumberland Plateau	Piedmont (n = 1267)	Ridge & Valley (n = 935)
	p-values					
location	0.0000		0.16		0.0000	0.043
county	0.0000		0.0000			0.0000
$\log_{10}$(age)	0.0000				0.0003	0.0007
animal	0.0001					0.0057
field crop			0.0054		0.0001	
$\log_{10}$(depth)			0.0000			0.016
septic	0.0027					0.0014
sinkhole	0.015					0.031
softener	0.28					0.79
well type			0.0024		0.0071	
oil tank		0.011				
stream						0.042
softener*septic	0.047					0.036
$\log_{10}$(age)*field crop					0.047	
$\log_{10}$(depth)*location			0.0011			
$\log_{10}$(depth)*$\log_{10}$(depth)			0.0012			

Table D.5 Coliform Code Response Variable

	Virginia (n = 2823)	Blue Ridge (n = 189)	Coastal Plain (n = 1202	Cumberland Plateau (n = 342)	Piedmont (n = 2620)	Ridge & Valley (n = 2001)
	p-values					
county	0.0000	0.0039	0.016	0.0008	0.0000	0.0000
$\log_{10}$(depth)	0.0000			0.013	0.66	0.0000
well type	0.0003	0.016	0.78		0.49	
activated carbon	0.0028					0.0020
iron filter					0.011	0.0017
sinkhole	0.021					0.035
$\log_{10}$(age)			0.052			
neutralizer					0.0007	
none	0.0011					
sediment filter					0.0064	
softener				0.0008		
county*$\log_{10}$(depth)	0.011				0.0000	
county*well type			0.0035			
$\log_{10}$(age)*$\log_{10}$(age)			0.0019			
well type*iron filter					0.037	

Table D.6 Risk Category Response Variable

	Virginia (n = 1494)	Blue Ridge (n = 160)	Coastal Plain (n = 1016)	Cumberland Plateau (n = 342)	Piedmont (n = 2236)	Ridge & Valley (n = 935)
	p-values					
county	0.0000		0.0094	0.0032	0.0048	0.0000
$\log_{10}$(depth)	0.0001		0.0006	0.0040	0.0000	0.0018
$\log_{10}$(age)	0.63	0.033	0.65		0.0000	0.0001
softener	0.0060	0.0068		0.0003		0.029
location	0.0000		0.0000			0.019
well type	0.040		0.60		0.0000	
animal	0.0005					0.024
iron filter					0.0026	0.021
sediment filter	0.015				0.60	
sinkhole	0.0010					0.012
landfill		0.030				
neutralizer					0.014	
oil tank			0.010			
stream	0.036					
$\log_{10}$(age)*$\log_{10}$(age)		0.018	0.0092		0.027	
county*$\log_{10}$(age)					0.0005	
county*$\log_{10}$(depth)			0.0001			
county*sediment filter					0.015	
county*well type			0.0001			
$\log_{10}$(age)*stream	0.0046					
$\log_{10}$(depth)*neutralizer					0.029	

Table D.7 Risk Category (4 cats) Response Variable

	Virginia (n = 1494)	Blue Ridge (n = 160)	Coastal Plain (n = 1016)	Cumberland Plateau (n = 342)	Piedmont (n = 2196)	Ridge & Valley (n = 1140)
	p-values					
county	0.0000		0.0097	0.0032	0.0001	0.0000
$\log_{10}$(age)	0.87	0.027	0.76		0.0003	0.0000
$\log_{10}$(depth)	0.0000		0.0007	0.0040	0.0001	0.0009
location	0.0001		0.0000		0.051	0.022
iron filter					0.0032	0.0063
sinkhole	0.057					0.025
softener		0.0094		0.0003		
well type			0.59		0.0000	
animal	0.0015					
none	0.34					
oil tank			0.012			
sediment filter					0.83	
stream	0.040					
$\log_{10}$(age)*$\log_{10}$(age)	0.028	0.022	0.0093		0.0016	0.015
county*$\log_{10}$(depth)			0.0009		0.0036	
county*sediment filter					0.0041	
county*well type			0.0004			
$\log_{10}$(age)*stream	0.0067					
none*sinkhole	0.040					
sediment filter*location					0.028	
well type*$\log_{10}$(depth)					0.0021	

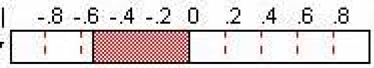
APPENDIX E JMP Multivariate output and data table

Multivariate

Correlations

	DRASTIC score	Nitrate
DRASTIC score	1.0000	-0.5204
Nitrate	-0.5204	1.0000

Nonparametric: Spearman's Rho

Variable	by Variable	Spearman Rho	Prob>|Rho|	
Nitrate	DRASTIC score	-0.5336	0.0087	

Multivariate

Correlations

	DRASTIC score	CP predicted - Nitrate
DRASTIC score	1.0000	-0.2072
CP predicted - Nitrate	-0.2072	1.0000

Nonparametric: Spearman's Rho

Variable	by Variable	Spearman Rho	Prob>|Rho|
CP predicted - Nitrate	DRASTIC score	-0.2259	0.2999

Multivariate

Correlations

	DRASTIC score	Nitrate
DRASTIC score	1.0000	-0.1088
Nitrate	-0.1088	1.0000

Nonparametric: Spearman's Rho

Variable	by Variable	Spearman Rho	Prob>|Rho|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
Nitrate	DRASTIC score	-0.1513	0.1271	

Multivariate

Correlations

	DRASTIC score	P predicted - Nitrate
DRASTIC score	1.0000	0.0414
P predicted - Nitrate	0.0414	1.0000

10 rows not used due to missing values.

Nonparametric: Spearman's Rho

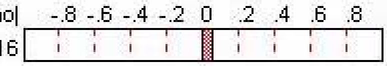
Variable	by Variable	Spearman Rho	Prob>|Rho|	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
P predicted - Nitrate	DRASTIC score	0.0610	0.5616	

Table E.1 DRASTIC scores, actual nitrate levels, predicted nitrate levels for Middlesex and Louisa counties

Middlesex			Louisa		
DRASTIC score	Nitrate	CP predicted - Nitrate	DRASTIC score	Nitrate	P predicted - Nitrate
150	3.070	0.737	104	7.246	0.445
152	5.679	1.000	108	0.008	0.301
152	8.398	0.520	108	0.008	
155	1.933	0.418	108	0.009	0.370
157	3.978	0.541	108	0.013	0.211
162	0.000	1.000	108	0.048	0.351
162	0.117	0.334	108	0.055	1.139
162	0.456	0.214	108	0.063	0.475
162	1.300	0.175	108	0.107	0.336
162	3.416	1.163	108	0.109	0.190
168	0.067	1.000	108	0.350	
168	0.595	0.429	108	0.391	0.261
172	0.177	0.807	108	0.483	0.603
172	0.853	0.328	108	0.502	0.380
180	0.064	0.196	108	0.517	0.130
190	0.019	0.249	108	0.531	1.501
190	0.062	0.608	108	0.763	0.927
190	0.065	0.188	108	0.830	1.178
190	0.107	0.290	108	0.895	0.473
190	0.455	1.210	108	0.962	0.481
190	1.144	0.418	108	0.998	1.254
190	2.266	0.757	108	1.031	0.705
190	2.894	0.277	108	1.078	0.702
			108	1.110	1.552
			108	1.184	0.172
			108	1.344	1.327
			108	1.356	0.757
			108	1.491	0.165
			108	1.797	0.233
			108	2.877	0.601
			108	3.438	0.528
			108	3.792	0.364
			108	3.956	0.481
			108	4.619	0.839
			108	4.788	0.663

			108	5.954	0.751
			108	6.332	0.280
			108	25.176	1.920
			109	0.005	0.165
			109	1.830	
			110	1.248	0.321
			112	0.208	0.311
			112	0.488	0.206
			112	1.268	0.437
			112	6.296	0.549
			114	0.014	0.588
			114	0.028	0.078
			114	0.034	0.275
			114	0.054	0.819
			114	0.058	0.554
			114	0.081	0.202
			114	0.100	0.339
			114	0.135	0.341
			114	0.151	0.482
			114	0.182	1.910
			114	0.194	0.464
			114	0.289	0.954
			114	0.299	0.324
			114	0.399	
			114	0.491	0.342
			114	0.756	0.444
			114	1.165	0.278
			114	4.284	0.479
			114	6.306	0.105
			115	0.025	0.846
			115	0.137	0.635
			118	0.877	1.141
			118	1.153	0.671
			119	0.075	0.513
			123	0.813	0.425
			131	1.041	1.467
			133	0.847	0.613
			133	1.746	1.672
			134	0.450	0.812
			135	0.065	0.635

			135	0.287	0.434
			135	0.370	0.481
			135	0.375	0.852
			135	0.424	0.550
			135	0.551	1.046
			135	0.568	0.415
			135	0.587	0.166
			135	0.600	
			135	1.154	1.090
			135	5.006	0.429
			184	0.049	0.146
			184	0.049	
			184	3.850	
			185	0.303	0.190
			185	0.400	0.137
			185	0.448	1.932
			185	0.448	0.542
			108	0.012	0.278
			108	0.139	
			108	0.274	1.219
			108	0.576	
			108	0.809	0.457
			109	1.050	
			114	0.110	0.599
			114	0.425	0.409
			127	2.739	1.252
			133	2.167	0.471
			135	0.405	0.453

APPENDIX F Total Coliform case study JMP Regression output table

Ordinal Logistic Fit for Coliform Code

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	8.31928	3	16.63856	0.0008
Full	126.35572			
Reduced	134.67500			

RSquare (U)	0.0618
Observations (or Sum Wgts)	232

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	61	39.33796	78.67592
Saturated	64	87.01776	Prob>ChiSq
Fitted	3	126.35572	0.0634

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
log10(age)	1	1	9.75699505	0.0018
Sediment Filter	1	1	4.50407956	0.0338
Marina	1	1	5.63999097	0.0176

VITA

Amanda C. Bourne

Amanda C. Bourne was born in Big Spring, Texas on June 1, 1977 to George and Beth Bourne. Throughout her childhood she lived in numerous locations since her father was an officer in the Air Force. In 1990 her parents divorced and she, her brother and her mother came to live in Tallahassee, Florida near her grandparents. In 1992 her mother became reacquainted with her high school sweetheart and would be remarried in October 1992. Her stepfather, Douglas Basham, encouraged her to seek a path in engineering and after graduating in 1995 from Cave Spring High School in Roanoke, Virginia she started down this path at Virginia Polytechnic Institute and State University in August of 1995. During her time at Virginia Tech she not only put forth full effort into her studies but also worked for various professors in the Biological Systems Engineering department. These professors were Saied Mostaghimi, Eldridge Collins, and Blake Ross. Four years later she received her Bachelor's of Science degree in Biological Systems Engineering. Only three short months later she began work on her graduate studies in Biological Systems Engineering under the supervision of Blake Ross. On August 13, 2001 Amanda will begin her career with PBS&J in Raleigh, NC.