



Ground Water Quality Technical Report No. 11

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# Assessment of Sources of Elevated Nitrate in Ground Water in Northwest Ada County, Idaho, Using Environmental Isotopes

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Prepared in cooperation with the Idaho State Department of Agriculture

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Idaho Division of Environmental Quality  
Boise Regional Office  
November 1999

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By Robert B. Howarth

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IDEQ=Idaho Division of Environmental Quality  
ISDA= Idaho State Department of Agriculture  
IDWR=Idaho Department of Water Resources  
IWWRI=Idaho Water Resources Research Institute  
EPA=U.S. Environmental Protection Agency

## ABSTRACT

Ground water contamination consisting of elevated nitrate, volatile organic compounds (VOCs), and pesticides was investigated in a localized area of northwest Ada County, Idaho beginning in December 1997. The project was performed jointly by the Idaho Division of Environmental Quality (IDEQ) and the Idaho State Department of Agriculture (ISDA). The investigation included the collection and analysis of ground water, surface water, and municipal wastewater samples. Previous investigations established that the VOC and pesticide contamination is likely the result of non-point source agricultural impacts. In the project area, the unconfined aquifer system is vulnerable to nitrate, VOC, and pesticide impacts from land uses because of the sandy, permeable soils and a relatively shallow depth to ground water. Several potential sources of nitrate contamination exist including a rapid infiltration wastewater treatment facility (Eagle Sewer District or ESD), a cattle feedlot, domestic subsurface sewage disposal systems, land application of animal wastes, and inorganic chemical fertilizer.

A suite of laboratory analyses and data evaluation techniques were combined to assess the potential sources of elevated nitrate. Stable isotopes of nitrogen ( $^{15}\text{N}$ ), oxygen ( $^{18}\text{O}$ ), and hydrogen ( $^2\text{H}$ ), and radioactive tritium were analyzed in water samples along with major ions, nutrients, VOCs, pesticides, and caffeine. The use of stable isotopes represents the first such application for IDEQ and was partially intended to test the usefulness of the technology. The data were evaluated using a number of hydrogeochemical graphical techniques including trilinear (Piper) diagrams, composition plots (x-y scatter plots), and fingerprint (Schoeller) diagrams. Existing ground water and wastewater monitoring data collected monthly by the ESD were also used in the interpretations.

Ground water samples were collected from: three dedicated monitoring wells and one subsurface drainage sampling structure (called the underdrain) at the ESD facility; and from five private, domestic wells. Sample locations were chosen to represent areas with potentially different sources of nitrate contamination. The domestic wells selected for sampling have existing drillers' reports (except for one well), draw water from the uppermost unconfined aquifer, and have a history of nitrate and organic chemical contamination. Surface water samples were collected from the Farmers Union Canal near the northern boundary of the project area, from a drainage ditch (Foothill Ditch) near the southern project boundary, and from wastewater influent piping of the ESD (i.e., the water coming into the rapid infiltration facility from the primary treatment plant).

The depth to water was measured in each well and an elevation survey was performed in order to establish the direction of ground water flow across the project area. Measurements taken in December 1997, and March 1998, indicated that ground water flows from northeast to southwest with some influence to the flowpaths caused by recharge from the ESD rapid infiltration facility.

Nitrate, in surface water and ground water samples, was detected at levels ranging from less than 0.005 milligrams per liter (mg/l) to 53.0 mg/l. Four of the five domestic wells contained

nitrate above the drinking water maximum contaminant level of 10 mg/l. The same four wells contained 1,2,3-trichloropropane at concentrations ranging up to 11.8 micrograms per liter ( $\mu\text{g/l}$ ) and the herbicide dacthal ranging in concentration up to 53.0  $\mu\text{g/l}$ . One well also contained the herbicide atrazine at a concentration of 1.8  $\mu\text{g/l}$ . Caffeine was not detected in any sample above the laboratory detection limit of 0.8  $\mu\text{g/l}$ .

Tritium and the stable isotopes of hydrogen and oxygen were used in a qualitative manner to ascertain characteristics of the shallow ground water flow system. The tritium results indicate that the shallow ground water system contains relatively young water recharged primarily from the surface water irrigation network.

The nitrogen isotope analyses were performed in an attempt to differentiate the potential sources of nitrate contamination.  $^{15}\text{N}$  values ranged from 1.6 permil (‰) to 16.6 ‰. The smaller values represent potential impacts from inorganic chemical fertilizers, while the larger values represent impacts from human or animal waste. A lack of access to wells in critical locations and to wastewater lagoons prevented a direct evaluation of potential impacts from the feedlot. Feedlot wastewater is presently directed to four engineered lagoons. A review of modern and historic aerial photographs shows that wastewater ponded in different locations within the feedlot boundary in the past. These historic ponding areas may represent potential sources of more intense nitrate leaching than would typically exist on dry feedlot surfaces.

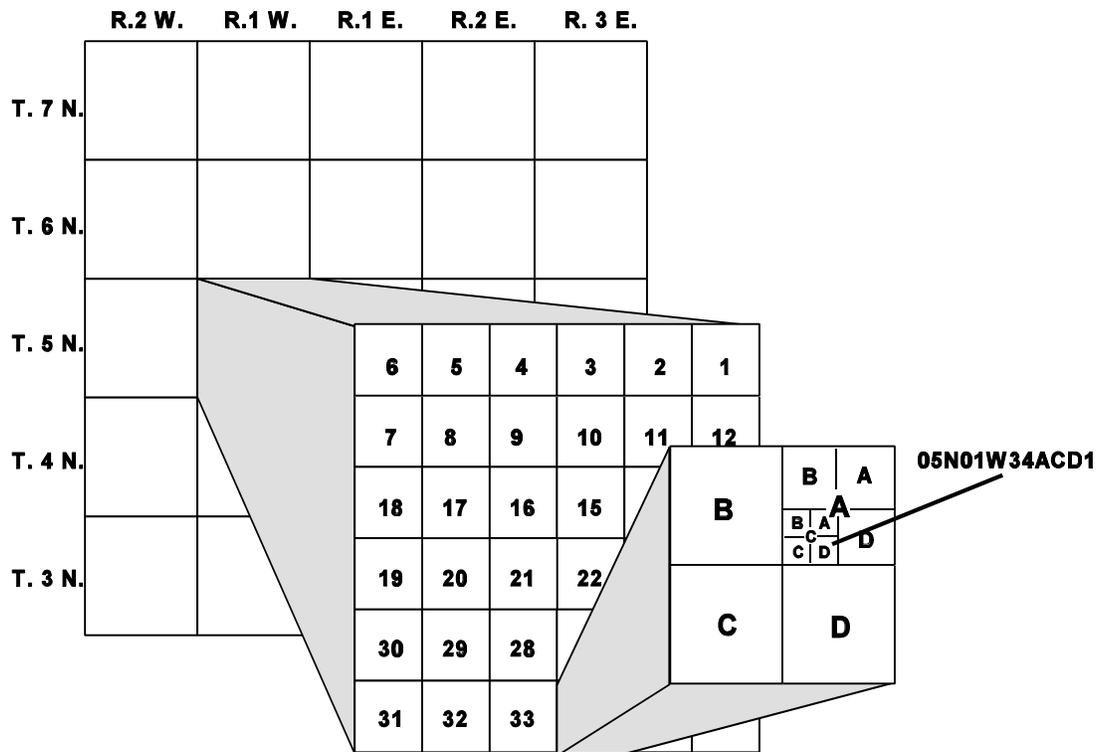
ESD has monitored nitrate in ground water since 1984. Laboratory analyses indicate extreme variability in nitrate concentrations over time. Recent, frequent monitoring for nitrate was conducted on samples collected from the ESD underdrain. These results indicate that the rapid infiltration system is presently operating at a high level of efficiency in terms of nitrogen removal.

Data collected for this study by IDEQ do not unequivocally distinguish feedlot ground water nitrate impacts from ESD ground water impacts. Hydrogeologic and hydrogeochemical data suggest that neither the feedlot nor the ESD facility is the source of elevated nitrate in domestic wells located north of these two facilities. Ground water flowing beneath much of the area may be impacted by a combination of non-point source agricultural activities that includes the application of animal waste (manure), inorganic chemical fertilizers, and pesticides. Domestic subsurface sewage disposal systems also potentially contribute to elevated nitrate concentrations; however, the nitrogen addition from these systems is minimal compared with other potential sources.

Nitrogen isotope ratio analyses helped distinguish certain sources of nitrate in this area. Further use of this technology is recommended. The results of this investigation will be presented to groups or technical forums with the responsibility for directing agricultural practices in Idaho. The goal is to use the results to support land use modifications that will improve ground water quality.

# SAMPLE LOCATION NUMBERING SYSTEM

The numbering system for identifying locations of wells and surface water sampling sites in this report is based on the common subdivision of land into townships, ranges, and sections (Figure 1). This subdivision of lands is called the public land survey system (PLSS). The location based on the PLSS is referenced to the Boise baseline and meridian. The first segment represents the township north of the Boise baseline, the second segment represents the range east of the Boise meridian, and the third is the section number. The three letters following the section number indicate the quarter-quarter-quarter section (10-acre tract) within the section. Quarter sections are labeled A, B, C, and D in counterclockwise order starting with the northeast quarter of the section. The number following the letters is a serial number assigned to wells within the 10-acre tract. An "S" following the number indicates that the sampling location is a surface water body rather than a well.



**Figure 1.** Sample location numbering system.

## INTRODUCTION

An area of concern due to ground water contamination has been identified northwest of Eagle, Ada County, Idaho (Figure 2). Initially, both an area resident and the Idaho Department of Water Resources (IDWR) Statewide Ambient Ground Water Quality Monitoring Program (Statewide Program) reported laboratory results of elevated nitrate levels and volatile organic compounds (VOCs). Several follow-up monitoring events were conducted by the Idaho Division of Environmental Quality (IDEQ) and the Idaho State Department of Agriculture (ISDA).

In April 1990, IDEQ conducted an evaluation of nitrate in an area of approximately seven square miles. The results showed nitrate levels ranging from below the laboratory detection limit of 0.05 milligrams per liter (mg/l) to 62 mg/l (Boyle, 1997) [The maximum level of nitrate allowed in public drinking water systems, also known as the maximum contaminant level (MCL), is 10 mg/l].

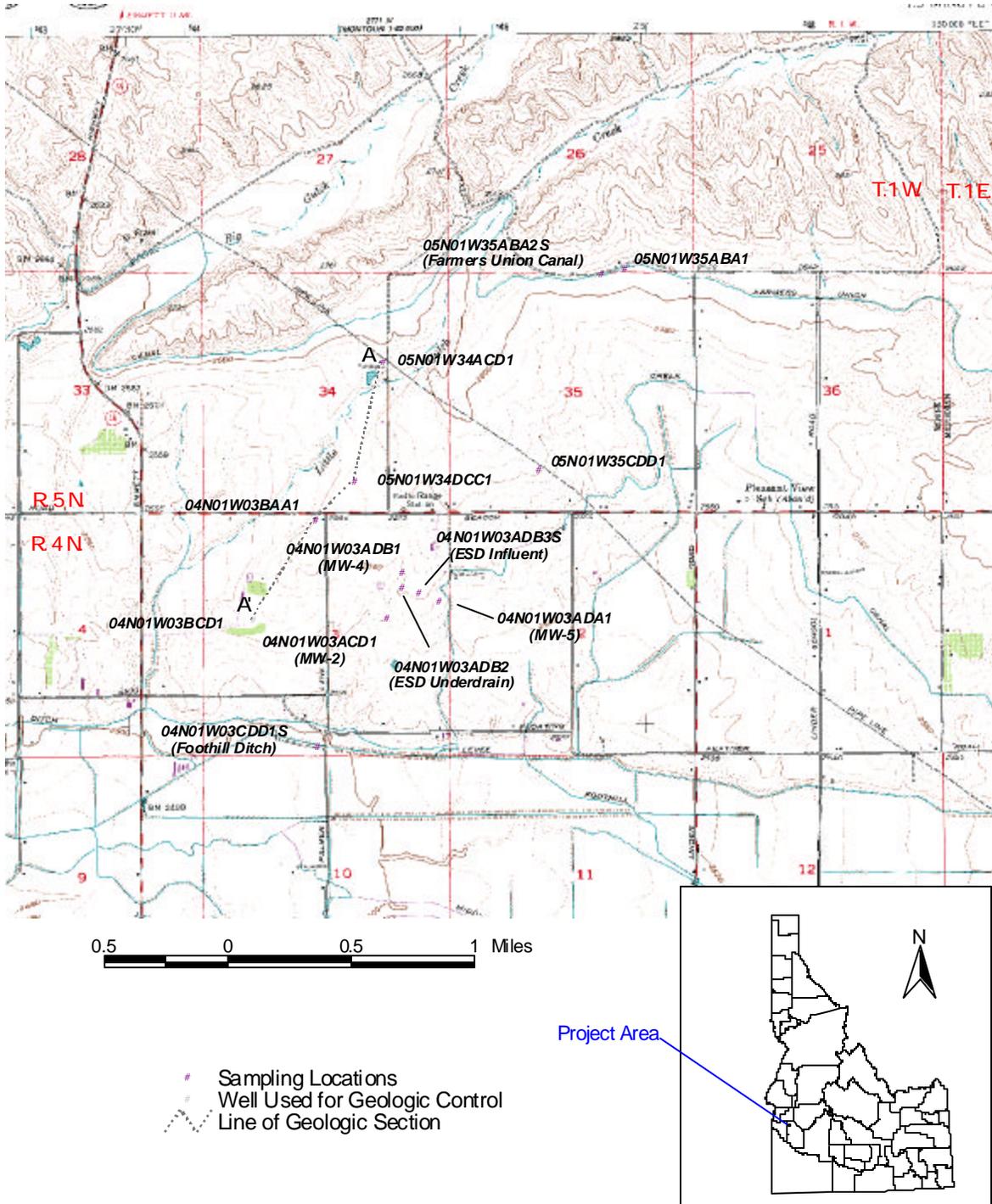
In July 1991, the IDWR Statewide Program detected the VOCs 1,2-dichloropropane (1,2-DCP) and 1,2,3-trichloropropane (1,2,3-TCP) in a private well near Beacon Light and Linder Roads. The detections were confirmed by IDWR through additional sampling conducted in August 1991. The average concentrations of 1,2-DCP and 1,2,3-TCP were 18 and 7 micrograms per liter ( $\mu\text{g/l}$ ), respectively. Later in the same year, IDEQ sampled an adjacent well revealing 1,2-DCP at a concentration of approximately 20  $\mu\text{g/l}$ . The MCL for 1,2-DCP is 5  $\mu\text{g/l}$  but an MCL for 1,2,3-TCP has not been established. ISDA has recognized these VOCs as being present in certain insecticidal fumigants (Whitney et al., 1992).

ISDA sampled eight wells within a one-mile radius around the well with the original VOC detection in December 1991, and again in February 1992. To further define the horizontal and vertical extent of contamination, ten additional wells were sampled in June, 1992. 1,2-DCP was detected in six wells at concentrations ranging up to 7  $\mu\text{g/l}$ . 1,2,3-TCP was detected in five wells at concentrations ranging up to 29  $\mu\text{g/l}$ . The highest level of nitrate detected in these wells was 12.7 mg/l.

ISDA sampled thirty-nine wells in the area in 1995. These results indicate that 18 wells had pesticide detections, with 16 of these 18 also containing detectable VOCs (Boyle, 1997).

Some wells in this area were also sampled in 1995 as part of a cooperative regional sampling project conducted by IDEQ and the United States Geological Survey (USGS). Certain samples collected in this area were the only ones collected in Ada and Canyon Counties to contain a combination of elevated nitrate, the herbicide dacthal, 1,2-DCP, and 1,2,3-TCP (Boyle, 1997).

Finally, in 1997, IDEQ and ISDA sampled an additional ten wells with previously unknown water quality. Four of these wells had nitrate above 10 mg/l along with detections of pesticides and VOCs.



**Figure 2.** Project area location map (portion of the USGS Star 7.5 minute topographic quadrangle).

These previous ground water monitoring projects have produced a large database of water quality information distributed among several agencies. The elevated nitrate, pesticide, and VOC detections are restricted to a specific area. Within this area, agriculture is the primary land use, and there are no discrete pesticide disposal areas. Therefore, the source of agricultural pesticides and pesticide-related VOCs is probably caused by non-point source agricultural activities.

The source of elevated nitrate is more difficult to identify. Potential sources include: subsurface sewage disposal systems (septic systems), residential and agricultural chemical fertilizer use, a cattle feedlot, and a municipal wastewater high-rate (rapid infiltration) land application system operated by the Eagle Sewer District (ESD). Nitrogen isotope ratio analysis was selected to help identify the source of elevated nitrate within the study area. In addition, other hydrogeological investigation tools included: (1) stable isotope ratio analysis of hydrogen (deuterium) and oxygen, (2) analysis of the radioactive isotope of hydrogen (tritium), (3) the analysis of caffeine as an indicator of human waste, and (4) laboratory analyses of common inorganic constituents, pesticides, and VOCs. These analyses were performed on water samples collected from nine ground water and three surface water locations. In addition, monthly ground water and wastewater monitoring data collected by the ESD were reviewed and incorporated into the interpretation contained in this report.

The purpose of this report is twofold: (1) discuss the utility of using nitrogen isotope ratio analysis in environmental ground water studies and (2) provide recommendations regarding improvement of water quality conditions in the study area.

## **Literature Review**

For the study area, previous ground water monitoring results are cited in the Introduction section of this report. Literature describing the use of nitrogen isotopes in environmental studies is extensive. The following summaries of available literature represent examples of the application of nitrogen and other isotopes in environmental studies:

- < Mengis et al. (1999) investigated nitrate-reducing processes occurring in ground water within a riparian zone in an agricultural watershed. Their investigation included the analysis of nitrogen and oxygen isotopes in nitrate. Mengis et al. concluded that nitrogen and oxygen isotope analyses provided strong evidence that nitrogen consumption from ground water in riparian zones is occurring due to microbial denitrification.
- < Aravena and Robertson (1998) discussed the use of nitrogen and oxygen isotopes in evaluating the denitrification occurring in ground water in the vicinity of a septic system servicing a campground in southern Ontario, Canada. They concluded that the process of denitrification affected the signature of both nitrogen and oxygen isotopes measured in the ground water.

- < Fogg et al. (1998) evaluated the horizontal and vertical variability in nitrogen isotope ratios in thick vadose zones beneath agricultural fields. This study sought to assess how nitrogen transformations in the vadose zone might affect nitrogen isotope ratios measured in underlying ground water samples. Fogg et al. suggested that little horizontal or vertical variation exists in nitrogen isotope ratios in soil water beneath the agricultural fields tested.
- < Rupert (1997) included analyses of nitrogen, oxygen, and hydrogen isotopes in a regional and local-scale evaluation of nitrate in ground water in the upper Snake River basin of Idaho and western Wyoming.
- < Seiler (1996) reviewed methods of identifying nitrate contamination in ground water in Washoe County, Nevada, that included the use of nitrogen isotopes. His report emphasized the need to use a combination of chemical analyses to reduce ambiguity in interpreted results.
- < Nitrogen and oxygen isotopes were used by Wassenaar (1995) to evaluate the origin of nitrate in the Abbotsford aquifer of southwestern British Columbia, Canada. The primary sources evaluated were poultry manure and synthetic ammonia-based fertilizers.
- < Exner and Spalding (1994) used nitrogen isotopes to evaluate nitrate contamination in wells near the towns of Sidney and Oshkosh, Nebraska. Commercial fertilizers and animal wastes were the primary sources discussed.
- < Gellenbeck (1994) demonstrated the successful application of nitrogen isotope analyses in differentiating sources of nitrate in ground water in the western Salt River Valley, near Phoenix, Arizona. The potential nitrate sources considered by Gellenbeck were dairies and feedlots, sewage treatment plants, agricultural activities, and natural sources such as decomposition of vegetation and nitrogen fixation by desert legumes.
- < Hendry et al. (1984) evaluated the distribution and origin of nitrate in ground water beneath a region of southern Alberta, Canada. They interpreted that zones of high nitrate are a result of the oxidation of naturally-occurring ammonium present within weathered tills.
- < Gormly and Spalding (1979) used nitrogen isotopes in a regional-scale ground water study in Nebraska. Commercial fertilizer was found to be the primary source of contamination in most wells with animal wastes responsible for contaminating a smaller number of wells.

Literature related to the geology and hydrogeology of the area includes a surficial geologic map of the Boise Valley (Othberg and Stanford, 1992). The geologic map indicates that the area of investigation is situated on Quaternary sediments described as sands of incised alluvial

fans and sandy alluvium of side-stream valleys and gulches. A thorough description of the geology and geomorphic history of the Boise Valley is found in an accompanying report by Othberg (1994).

Thomas and Dion (1974) discuss ground water and surface water resources, including geologic characteristics, of the Boise Valley along the Boise River corridor from Lucky Peak reservoir to its confluence with the Snake River. They evaluated the distribution of surface and ground water resources resulting from the construction of three main storage reservoirs and a system of irrigation diversions. Their investigation included the measurement of water levels in 86 wells near the Boise River resulting in a ground water flow map based on 1971 conditions.

A report by the consulting firm of Anderson & Kelly (1981) describes work done to evaluate ground water conditions in the area for the ESD. They concluded that a shallow unconfined aquifer exists to a depth of about 50 or 60 feet below the land surface. Clay and shale zones at this depth result in confined aquifer conditions for water bearing zones below 60 feet. Water level measurements indicated that the ground water flow direction was from northeast to southwest.

Neely and Crockett (1998) presented ground water quality information from a statewide ambient ground water quality monitoring network in the Treasure Valley of southwestern Idaho. They also provided an initial trend analysis for ground water quality changes occurring from 1991 through 1998. This analysis consisted of 137 sampling sites from a shallow aquifer system and 144 sites from a deeper aquifer system. Neely and Crockett (1998) found that water chemistry is different in the shallow versus the deep aquifer systems in the Treasure Valley. Eighty-three percent of the shallow sites and 49 percent of the deep sites had at least one constituent with a concentration that suggests impacts by human land use activities. The following constituents (related to human activity) were detected at concentrations exceeding applicable MCLs, or at levels that may otherwise be of concern to human health or the environment: ammonia, bacteria, nitrate, pesticides, phosphorus, and VOCs.

Several sample locations utilized for this project were located on property occupied by the ESD. ESD operates a municipal wastewater treatment facility in the study area employing a technology known as high-rate land application or rapid infiltration. In this report the identification labels associated with these sample locations were kept consistent with the ESD identification scheme.

## **Project Area**

The project area is located in Ada County, northwest of Eagle, Idaho, and is roughly nine square miles in size (Figure 2). The project area is situated on permeable sand and gravel alluvial fan deposits. The presence of agricultural pesticides in the shallow ground water indicates an impact from agricultural practices. Other potential contributors to ground water contamination include septic systems, residential use of chemicals, a feedlot, and the rapid infiltration municipal wastewater treatment system.

## **Land Use**

Land use is dominated by crop and animal production. The crops produced include wheat, barley, oats, corn, dry beans, mint, alfalfa hay, and pasture (USDA Soil Conservation Service, 1980). A large cattle feedlot with a capacity of about 16,000 head currently operates in the area. This facility may have started as a sheep raising operation in the 1940's or 1950's (Michael Ingham, IDEQ, 1998, personal communication). Approximately 200 acres of adjacent land is used for the application of manure and liquid waste from the feedlot. Other more distant farmland also receives applications of manure from the feedlot, although the frequency of these applications is not known to IDEQ. Approximately 40 acres of land are utilized by ESD for the rapid infiltration wastewater treatment system. Like many other areas in southwestern Idaho, agricultural land in the project area is being developed into home sites. An increased rate of home development will likely occur into the foreseeable future.

## **Water Use**

The Farmers Union Canal originates from the Boise River east of the project area and provides the surface water irrigation supply for the cropland of the area. Ground water wells also supply irrigation water to some of the cropland, but the extent to which ground water is utilized for irrigation is not known. Residents in the area all rely on wells for domestic water supplies.

## **Climate**

The climate in the area is dry and temperate with cool, wet winters and warm, dry summers (Dion, 1972). Snow cover is characteristically thin and melts rapidly. The mean annual temperature in Boise is 51<sup>n</sup> Fahrenheit (F). January has the lowest mean monthly temperature (29<sup>n</sup> F) and July has the warmest mean monthly temperature (75<sup>n</sup> F). Mean annual precipitation is about 11 inches with August having the lowest (0.16 inch) and February the highest (1.33 inch) mean monthly precipitation.

## **Soils**

The following general soil classifications and descriptions are from the *Soil Survey of Ada County Area, Idaho* (USDA Soil Conservation Service, 1980). The general classifications are based on a distinctive pattern of soils, relief, and drainage. Two general soil units exist in the project area: the Quincy-Lankbush-Brent and the Cashmere-Tindahay. The former class is described as a nearly level to steep, excessively drained and well drained, very deep soil; it occurs on foothills. The latter class is described as a nearly level to steep, well drained and somewhat excessively drained, very deep soil; it occurs in drainageways and on alluvial fans on foothills.

Soils in the project area are described as follows.

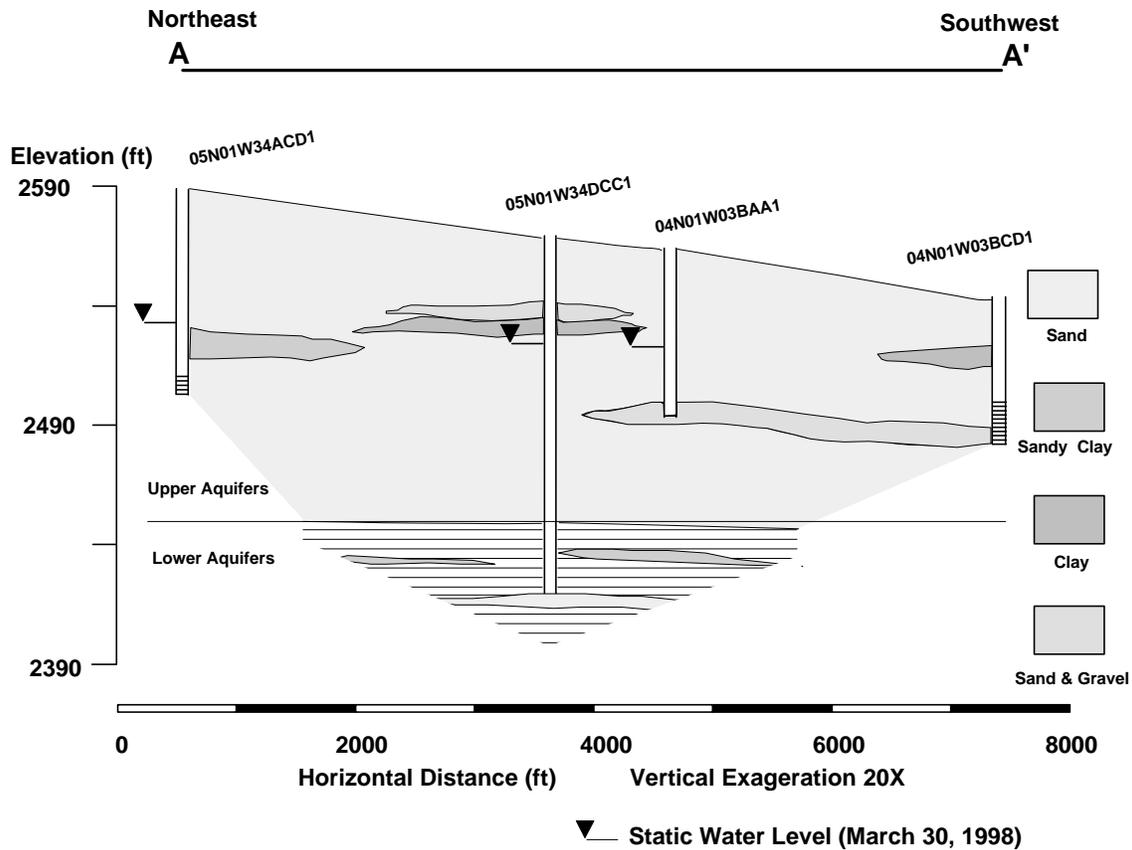
- < *Feltham loamy sand* (sandy, mixed, mesic Xeri Torriorthents); 0-12% slopes; formed in alluvium modified by wind; very deep and somewhat excessively drained.
- < *Jenness fine sandy loam* (coarse-loamy, mixed, nonacid, mesic Xeric Torriorthents); 0-2% slopes; very deep and well drained; formed in acid igneous material on alluvial fans and low alluvial terraces.
- < *Power silt loam* (fine-silty, mixed, mesic Xerollic Haplargids); 4-12% slopes; very deep and well drained; formed in loess or silty alluvium that is underlain by mixed alluvium; found on low alluvial terraces and basalt plains.
- < *Purdam silt loam* (fine-silty, mixed, mesic Haploxerollic Durargids); 0-8% slopes; moderately deep to a hardpan and well drained; formed in loess or silty alluvium; found on low alluvial terraces.

## **Hydrogeology**

For the project area, all subsurface information is interpreted from water well drillers' reports and published literature. Wells in the area range in depth from 60 to 300 feet; most are less than 150 feet deep. Approximately 30 drillers' reports were analyzed in the project area. The drillers' reports typically show that the general hydrogeology of the area consists of an upper and lower aquifer each composed of alternating layers of clay and sand, separated by a thick clay layer. Such a stratigraphic sequence may be formed by fluvial deposition (e.g., Miall, 1996). The lower aquifer is part of the Tertiary Glens Ferry Formation of the Idaho Group, whereas the upper aquifer includes Quaternary older terrace gravel, younger terrace gravel, and recent alluvial deposits (Thomas and Dion, 1974; Figure 3).

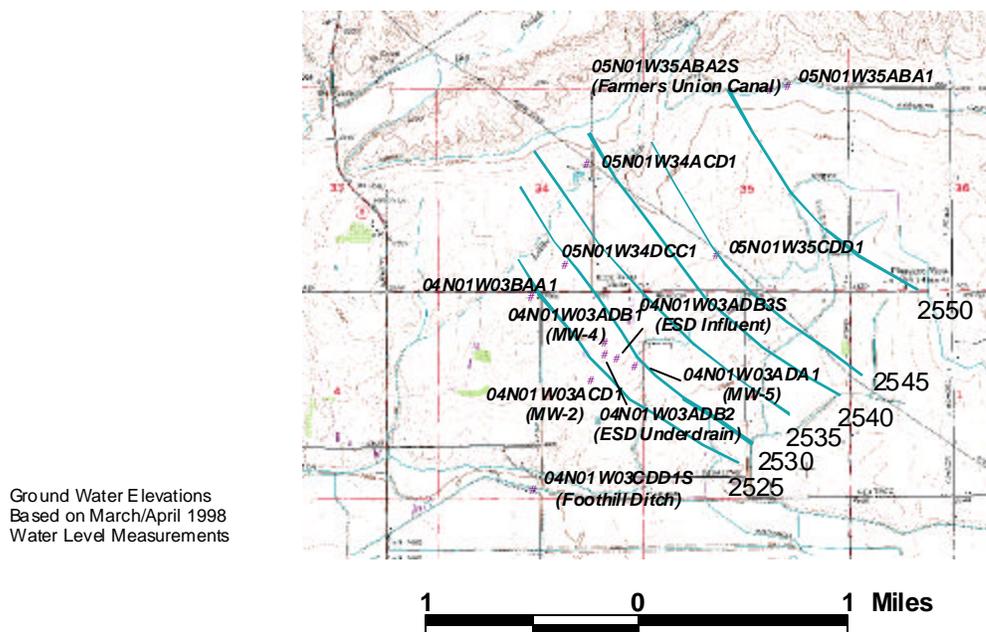
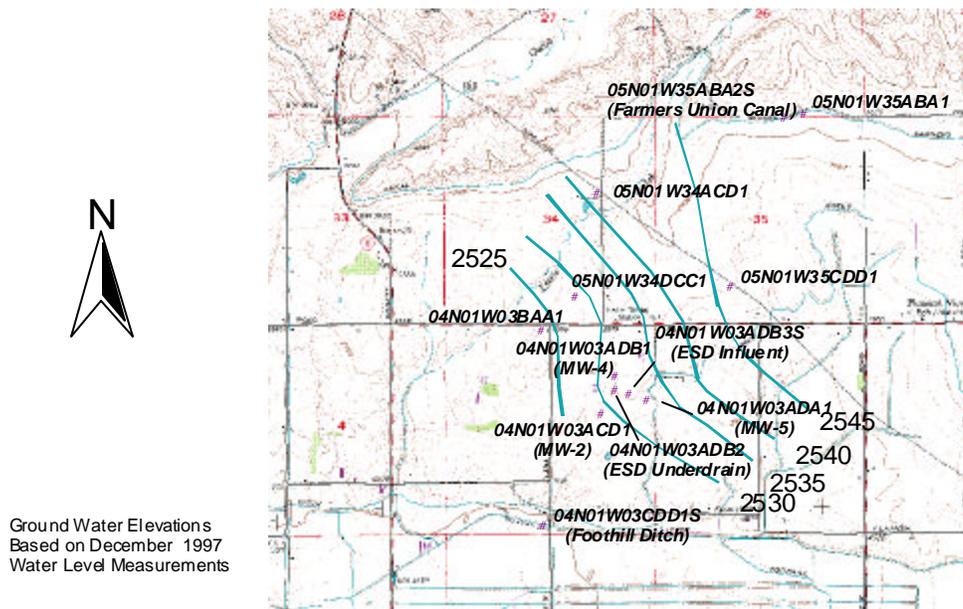
The ground water in the upper aquifer occurs under unconfined conditions and is encountered at depths ranging from five to 30 feet. This upper layer consists of a thick sequence (total thickness of 100 to 150 feet) of clayey sand, sand, and gravel which is underlain by a 10 to 20-foot thick clay layer.

The direction of ground water flow in the upper aquifer is to the southwest, towards the Boise River (Thomas and Dion, 1974). The local shallow ground water flow direction and gradient are probably influenced by agricultural irrigation, high rate wastewater land application, and canal seepage. The direction of ground water flow in the lower aquifer is unknown but postulated to be similar to the upper aquifer. ESD conducted three aquifer pumping tests in the upper unconfined aquifer in wells located in Section 3, T4N, R1W. Hydraulic conductivity ranged from 250 to 550 feet per day.



**Figure 3.** Geologic cross-section oriented in a direction parallel to the ground water flow direction.

For this project, measurements to determine depth to water were made with a steel tape or an electronic water level probe, in the eight wells that were sampled, to establish current ground water flow directions. These measurements occurred in December 1997, when the sampling took place and again in March/April 1998. Wellhead elevations were already established for the three ESD monitoring wells. For the private domestic wells, wellhead elevations were surveyed by ISDA engineers. Maps of the elevation of the shallow aquifer water table surface are shown on Figure 4.



Ground Water Elevation (ft above sea level)  
# Sampling Locations

Figure 4. Shallow aquifer potentiometric surface measured in December 1997 and March/April 1999.

## MATERIALS AND METHODS

This investigation included the collection and analysis of ground water, surface water, and municipal wastewater samples. Most of the samples were collected from December 1 through December 5, 1997. A sample preservation mistake required that a new sample be collected from location 04N01W03BAA1 on January 5, 1998, for re-analysis of certain inorganic compounds. Samples had to be collected from the Farmers Union Canal on October 21, 1997, because the flow to the canal was going to be shut off for the season prior to the planned December sampling event. Existing ground water and wastewater monitoring data collected monthly by the ESD were also used to aid in interpretations.

Nine ground water samples were collected from three dedicated monitoring wells and one subsurface drainage sampling structure (called the underdrain) at the ESD rapid infiltration facility, and from five private, domestic wells. Sample locations were chosen to represent areas with potentially different sources of nitrate contamination. The domestic wells selected for sampling draw water from the uppermost unconfined aquifer, have a history of nitrate and organic chemical contamination, and most have existing well drillers' reports (Appendix A). Surface water samples (three total) were collected from the Farmers Union Canal near the northern boundary of the project area, from a drainage ditch (Foothill Ditch) near the project area southern boundary, and from the ESD wastewater influent piping (i.e., the water coming into the rapid infiltration facility from the primary treatment plant).

Domestic wells were purged prior to sample collection. Adequate purging was based on the stabilization of the field parameters pH, temperature, and specific conductance taken at the sampling location. Field parameter measurements were considered stable when three successive measurements taken at intervals of five minutes or more differed by less than the following amounts:

specific conductance	5%
pH	0.1 unit
temperature	0.2° Celsius (C).

Dissolved oxygen measurements were also taken; however, this parameter often fluctuates and was not considered a part of the stabilization criteria. Sampling was conducted from outdoor plumbing fixtures in all but one case. A flow-through chamber was used that allowed well water to pass over the probe of the field meter at a uniform flow rate. One well was sampled from a kitchen faucet. In this case, a uniform flow was diverted through a small bucket which held the probe of the field meter.

For monitoring well sampling, the wells were purged with a decontaminated submersible pump and field measurements were recorded as water was diverted through the flow-through chamber. When purging was completed, samples for inorganic and isotopic analyses were collected using the submersible pump. Samples destined for organic analyses were collected with dedicated disposable polyethylene bailers.

Surface water samples (grab samples) were collected directly from flowing stretches of the Farmers Union Canal and the Foothill Ditch. The field meter probe was submersed directly in the water bodies. A wastewater sample coming into the ESD rapid infiltration facility was collected in a decontaminated long-handled polyethylene dipper from the pump discharge system and transferred directly to the laboratory containers. Samples were collected from the ESD underdrain system directly into the laboratory containers via gravity flow through an existing valve. A limited amount of water in the underdrain system prohibited the measurement of field parameters. No field parameter measurements were made of the ESD wastewater due to concerns about properly decontaminating the field meter after immersion in domestic wastewater.

All samples were analyzed for common inorganic constituents found in water: calcium, magnesium, sodium, potassium, iron, manganese, arsenic, chloride, sulfate, alkalinity, total dissolved solids, total phosphorus, ammonia, nitrate, and total Kjeldahl nitrogen. Each sample was also analyzed for the stable isotopes of oxygen ( $^{18}\text{O}/^{16}\text{O}$ ), hydrogen ( $^2\text{H}/^1\text{H}$ ), and nitrogen ( $^{15}\text{N}/^{14}\text{N}$ ). Nitrogen isotope analyses were performed on nitrogen found on dissolved nitrate molecules, except in the few samples where ammonia represented the predominant nitrogen form. A majority of the samples were also analyzed for caffeine and a few were analyzed for chlorinated acid pesticides (U.S. Environmental Protection Agency (EPA) method 515.1) and nitrogen and phosphorus pesticides (EPA method 507). Table 1 provides information about the analyses performed on the water samples.

**Table 1.** Chemical Constituents Analyzed in Water Samples.

Parameter	Method	Container	Preservation	Holding Time
* $^{15}\text{N}^{\dagger}$	SIRA <sup>†</sup>	Plastic, 4 l	0.75 ml/l conc. HCL	No Limit
* $^2\text{H}$ , * $^{18}\text{O}$ $^3\text{H}$ (tritium)	SIRA/ Direct Counting	Glass, 100 ml	Cool, 4° C	No Limit
Calcium	EPA 215.1	Plastic, 1 l	Cool, 4° C	60 days
Magnesium	EPA 242.2	Plastic, 1 l	Cool, 4° C	60 days
Sodium	EPA 273.1	Plastic, 1 l	Cool, 4° C	60 days
Potassium	EPA 258.1	Plastic, 1 l	Cool, 4° C	60 days
Chloride	EPA 325.3	Plastic, 1 l	Cool, 4° C	28 days
Alkalinity	EPA 310.1	Plastic, 1 l	Cool, 4° C	14 days

**Table 1, continued**

Parameter	Method	Container	Preservation	Holding Time
Sulfate	EPA 375.4	Plastic, 1 l	Cool, 4° C	28 days
Total Dissolved Solids	EPA 160.1	Plastic, 1 l	Cool, 4° C	28 days
Arsenic	EPA 200.9	Plastic, 1 l	3ml/l 1:1 dil. HNO <sub>3</sub> Cool, 4° C	60 days
Iron	EPA 236.1	Plastic, 1 l	3ml/l 1:1 dil. HNO <sub>3</sub> Cool, 4° C	60 days
Manganese	EPA 243.1	Plastic, 1 l	3ml/l 1:1 dil. HNO <sub>3</sub> Cool, 4° C	60 days
Total Kjeldahl Nitrogen	EPA 351.2	Plastic, 1 l	2 ml/l conc. H <sub>2</sub> SO <sub>4</sub> Cool, 4° C	28 days
Nitrate	EPA 353.2	Plastic, 1 l	2 ml/l conc. H <sub>2</sub> SO <sub>4</sub> Cool, 4° C	28 days
Ammonia	EPA 350.1	Plastic, 1 l	2 ml/l conc. H <sub>2</sub> SO <sub>4</sub> Cool, 4° C	28 days
Phosphorus, Total	EPA 365.4	Plastic, 1 l	2 ml/l conc. H <sub>2</sub> SO <sub>4</sub> Cool, 4° C	28 days
Volatile Organic Compounds	EPA 502.2	Glass, 40 ml	Cool, 4° C	14 days
Pesticides, chlorinated acid	EPA 515.1	Glass, 1 l	Cool, 4° C	7 days; 90 days for extract
Pesticides, nitrogen and phosphorus	EPA 507	Glass, 1 l	Cool, 4° C	7 days; 90 days for extract
Caffeine	EPA 8270 (modified)	Glass, 1 l	Cool, 4° C	7 days; 90 days for extract

†Results of stable isotope analyses are reported in delta notation with the symbol “\*”; see page 18.

‡Stable Isotope Ratio Analysis

## Quality Assurance Objectives

A quality assurance project plan was developed to guide the sampling team and to help maintain the reliability and integrity of the data. Table 2 provides the quality assurance objectives for this project. The laboratories involved in this project have verified that appropriate internal quality control checks were performed in accordance with standard operating protocols and that accuracy goals (where applicable) prescribed by the analytical methods were achieved.

**Table 2.** Quality Assurance Objectives.

<i>Parameter</i>	<i>Matrix</i>	<i>Method</i>	<i>Detection Limit</i>	<i>Accuracy</i>	<i>Precision</i>	<i>Completeness</i>
* <sup>15</sup> N	Water	SIRA	NA†	NA	+/-0.8‰	95%
* <sup>2</sup> H	Water	SIRA	NA	NA	+/-2‰	95%
* <sup>18</sup> O	Water	SIRA	NA	NA	+/-0.2‰	95%
<sup>3</sup> H (tritium)	Water	Direct counting	2 tritium units	NA	Dependent upon tritium activity	95%
Calcium	Water	EPA 215.1	0.01 mg/l	80-120%	+/-10%	95%
Magnesium	Water	EPA 242.1	0.01 mg/l	80-120%	+/-5%	95%
Sodium	Water	EPA 273.1	0.01 mg/l	80-120%	+/-5%	95%
Potassium	Water	EPA 258.1	0.01 mg/l	80-120%	+/-5%	95%
Alkalinity	Water	EPA 310.1	10 mg/l	80-120%	+/-5%	95%
Chloride	Water	EPA 325.3	0.9 mg/l	80-120%	+/-15%	95%
Sulfate	Water	EPA 375.4	4.0 mg/l	80-120%	+/-15%	95%
Total Dissolved Solids	Water	EPA 160.1	6.0 mg/l	75-125%	+/-20%	95%
Arsenic	Water	EPA 200.9	0.01 mg/l	80-120%	+/-15%	95%
Iron	Water	EPA 236.1	0.01 mg/l	80-120%	+/-15%	95%
Manganese	Water	EPA 243.1	0.01 mg/l	80-120%	+/-10%	95%
Total Kjeldahl Nitrogen	Water	EPA 351.2	0.05 mg/l	80-120%	+/-30%	95%
Nitrate	Water	EPA 353.2	0.005 mg/l	80-120%	+/-10%	95%

**Table 2, continued**

<i>Parameter</i>	<i>Matrix</i>	<i>Method</i>	<i>Detection Limit</i>	<i>Accuracy</i>	<i>Precision</i>	<i>Completeness</i>
Ammonia	Water	EPA 350.1	0.005 mg/l	80-120%	+/-10%	95%
Phosphorus, Total	Water	EPA 365.4	0.05 mg/l	80-120%	+/-10%	95%
Volatile Organic Compounds	Water	EPA 502.2	0.21 µg/l	80-120%	+/-20%	95%
Pesticides, chlorinated acid	Water	EPA 515.1	Sample and analyte dependent	60-140%	+/-25%	95%
Pesticides, nitrogen and phosphorus	Water	EPA 507	Sample and analyte dependent	60-140%	+/-25%	95%
Caffeine	Water	EPA 8270 (modified)	0.8 µg/l	60-140%	+/-25%	95%

<sup>†</sup>Not applicable

## Environmental Isotopes

Isotopes are atoms of the same element with variations in the number of neutrons that accompany an invariable number of protons. They can be written by adding the number of protons and neutrons at the upper left corner of the symbol of the element (e.g., <sup>1</sup>H= common hydrogen with one proton and zero neutrons; <sup>3</sup>H= tritium with one proton and two neutrons). Environmental isotopes are the most abundant isotopes of elements occurring naturally in our hydrological, geological, and biological systems. The isotopic abundances of certain elements varies slightly in different natural materials. Environmental isotopes, both stable and radioactive species, are used to complement geochemistry and physical hydrogeology data. The stable isotopes of hydrogen, carbon, nitrogen, oxygen, and sulfur serve as tracers of water, carbon, nutrient, and sulfur cycling. Radioactive isotopes decay at a measurable rate. Therefore, knowledge of the decay rate of radioactive environmental isotopes, such as tritium, provides a measure of time that can be used to estimate the age and thereby interpret the rate and direction of movement of the ground water (Clark and Fritz, 1997).

Elements, and molecules of which they are a part, have different masses (atomic weights) due to variations in the number of neutrons in the element. The usefulness of environmental isotopes in hydrogeologic studies is brought about because molecules with different weights have different chemical and physical reaction rates which leads to isotope *partitioning* or *fractionation* (Clark and Fritz, 1997). Stable environmental isotopes are measured as the ratio of the two most abundant isotopes of a given element. For oxygen (O), the measurement involves the ratio of <sup>18</sup>O to <sup>16</sup>O. The <sup>18</sup>O/<sup>16</sup>O ratio is approximately 0.00204 since <sup>18</sup>O and <sup>16</sup>O have terrestrial abundances of about 0.204% and 99.796%, respectively. Small variations to

this ratio, for any compound containing oxygen, are caused by fractionation. These variations are only seen in the fifth or sixth decimal place. Isotopic concentrations are expressed as the difference between the measured ratios of a sample and a known reference over the measured ratio of the known reference. The mathematical expression of this methodology is given in delta ( $\delta$ ) notation:

$$\delta^{18}\text{O}_{\text{sample}} = \left[ \frac{m(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - m(^{18}\text{O}/^{16}\text{O})_{\text{reference}}}{m(^{18}\text{O}/^{16}\text{O})_{\text{reference}}} \right]$$

A key to isotopic analysis is that by using the reference ratio in this mathematical form, the measurement error ( $m$ ) (introduced by using different laboratory equipment, or using the same equipment at different times) is eliminated. Measurement error affects the isotopic ratio of the sample and the reference standard, resulting in an apparent ratio rather than the true ratio of the isotopes. Fortunately, the apparent ratio, (i.e., the sample isotopic ratio compared to the reference standard) is the useful measurement. Since fractionation only imparts minor variations in the isotopic concentrations,  $\delta$ -values are expressed as parts per thousand or permil (‰) difference from the reference. The equation above is then reduced to:

$$\delta^{18}\text{O}_{\text{sample}} = \left[ \left( \frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}}}{(^{18}\text{O}/^{16}\text{O})_{\text{reference}}} - 1 \right) \right] @1000$$

A  $\delta$ -‰ value that is positive, for example, +10‰, has 10 parts per thousand (one percent) more  $^{18}\text{O}$  than the reference. A positive  $\delta$ -‰ value is said to be “enriched” or “heavy” while a negative  $\delta$ -‰ value is said to be “depleted” or “light.” The reference standard used for the analysis of isotopic concentrations of  $^{18}\text{O}/^{16}\text{O}$  and deuterium-hydrogen ( $^2\text{H}/^1\text{H}$ ) in this project is standard mean ocean water (SMOW). The reference standard for the stable isotopes of nitrogen ( $^{15}\text{N}/^{14}\text{N}$ ) is atmospheric nitrogen (Clark and Fritz, 1997).

## Oxygen-Deuterium

Stable isotopes in water ( $^{18}\text{O}$  and  $^2\text{H}$ ) are affected by meteorological processes that provide a characteristic fingerprint of their origin (Clark and Fritz, 1997). The isotopes  $^{18}\text{O}$  and  $^2\text{H}$  are partitioned among different freshwater reservoirs by various hydrologic processes such as evaporation from the oceans, rainout, re-evaporation from terrestrial basins, snow and ice accumulation, and runoff. As water evaporates, the lighter isotopes,  $^{16}\text{O}$  and  $^1\text{H}$ , are preferentially removed and the remaining reservoir becomes enriched in the heavier isotopes,  $^{18}\text{O}$  and  $^2\text{H}$ . Condensation of water vapor causes the reverse effect. The heavier molecules condense more efficiently leaving the residual vapor in the cloud depleted in  $^{18}\text{O}$  and  $^2\text{H}$ . Craig (1961) showed that  $^{18}\text{O}$  and  $^2\text{H}$  behave predictably and that  $\delta^{18}\text{O}$  and  $\delta^{2}\text{H}$  in fresh waters correlate on a global scale. He developed a “global meteoric water line” that defines the worldwide fresh surface water relationship between  $^{18}\text{O}$  and  $^2\text{H}$  by the equation:

$$\delta^{2}\text{H} = 8\delta^{18}\text{O} + 10\text{‰ SMOW}$$

Craig’s (1961) observation only has application globally because it represents an average of many local and regional meteoric water lines, which are individually affected by varying

climatic and geographic factors. A local meteoric water line, based on analyses of surface water samples across southern Idaho, is provided by Wood and Low (1988) and is represented by the equation:

$$^2\text{H} = 6.4 \cdot ^{18}\text{O} - 21\text{‰ SMOW}$$

The use of  $^{18}\text{O}$  and  $^2\text{H}$  isotopes in this project is limited to simple comparisons between isotopic ratios at the various sampling locations. All water samples collected during this project were analyzed for stable isotope ratios of  $^{18}\text{O}/^{16}\text{O}$  and  $^2\text{H}/^1\text{H}$  by Geochron Laboratories in Cambridge, Massachusetts, using mass spectrometry. A quantitative evaluation of the origin and mixing relationships between the various waters sampled was not attempted.

### Nitrogen Isotopes

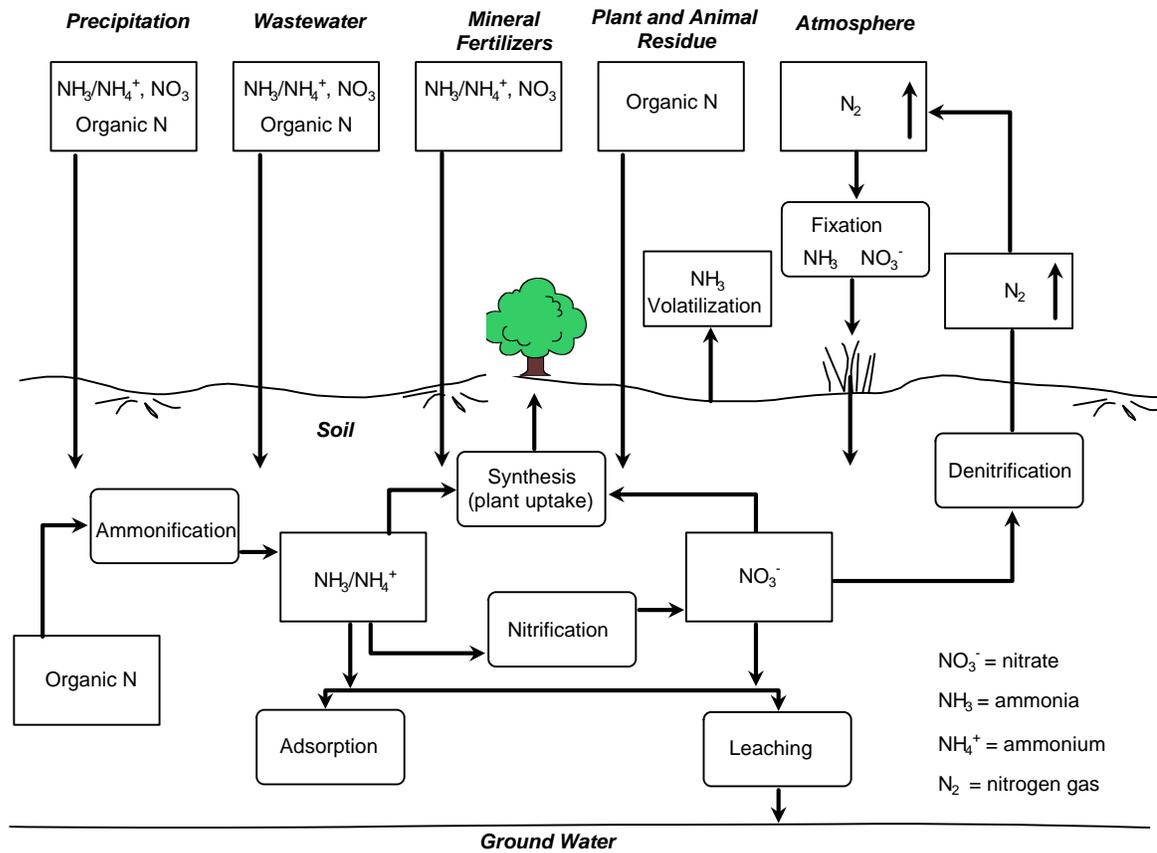
The stable isotopes of nitrogen,  $^{15}\text{N}$  and  $^{14}\text{N}$ , are often useful in distinguishing sources of nitrogen contamination. Nitrogen isotope fractionation occurs during several steps in the nitrogen cycle (Figure 5). Volatilization of ammonia results in the remaining ammonia source becoming isotopically enriched or heavier. Denitrification of a source material also causes isotopic enrichment in the remaining source material. The usefulness of nitrogen isotopes in hydrogeological studies is because certain major potential sources of nitrogen contamination have distinguishable isotopic signatures (i.e.,  $^{15}\text{N}/^{14}\text{N}$  ratios). Table 3 presents typical values of  $^{15}\text{N}$  values for important sources of nitrogen contamination.

**Table 3.** Typical  $^{15}\text{N}$  Values.

Potential Contaminant Source	$^{15}\text{N}$ (‰)
Commercial fertilizer	-4 to + 4
Animal or human waste	Greater than + 10
Precipitation	-3
Organic nitrogen in soil	+ 4 to + 9

(after Seiler, 1996)

Seiler (1996) reported the results of eight case studies in which nitrogen isotopes were evaluated in an attempt to differentiate sources of nitrogen. In several cases, the investigators were successful in distinguishing human or animal waste nitrate from commercial fertilizer or naturally-occurring nitrate. Unfortunately, human versus animal sources of nitrate could not be distinguished from each other with an acceptable degree of certainty (Seiler, 1996).



**Figure 5.** The nitrogen cycle.

Isotope fractionation can occur after the nitrogen source is deposited; this obscures the signatures of the source materials. Also,  $^{15}\text{N}$  signatures may reflect mixing from multiple sources. Predicting these changes is difficult. Therefore, using nitrogen isotopes alone for determining sources is often insufficient. To correct this, several studies promote the use of stable isotopes of oxygen on nitrate to reduce the ambiguity in source determinations (e.g., Wassenaar, 1995). The oxygen used to manufacture commercial fertilizer comes from the atmosphere and is enriched in  $^{18}\text{O}$ . Nitrate produced by nitrification of animal wastes in subsurface waters gets two of the three oxygen atoms from the local water. Oxygen found in local meteoric water is isotopically light and should enable one to distinguish commercial fertilizer nitrate from nitrate derived from nitrification of animal wastes. Unfortunately, a laboratory with the capability to analyze oxygen isotopes on nitrate could not be identified for use in this project.

All water samples collected during this project were subjected to stable isotope ratio analysis of  $^{15}\text{N}/^{14}\text{N}$  on dissolved nitrate (or ammonia when nitrate did not exist). The analyses were performed by Coastal Science Laboratories in Austin, Texas, using mass spectrometry.

## **Tritium**

Tritium,  $^3\text{H}$ , is a radioactive isotope of hydrogen with a half-life of 12.43 years. Tritium was introduced into the atmosphere primarily as a result of thermonuclear bomb testing from the period 1951 to 1980. Smaller amounts are also produced naturally by cosmic radiation reacting with nitrogen in the stratosphere. Natural and man-made tritium enter the hydrologic cycle through precipitation and become part of the water molecule. For this project, tritium concentrations are expressed in tritium units (TU). One tritium unit corresponds to one  $^3\text{H}$  atom per  $10^{18}$   $^1\text{H}$  atoms and is radioactively equivalent to 3.2 pico-Curies per liter (pCi/l) (Clark and Fritz, 1997).

In theory, the analysis of tritium is able to provide the “age” of ground water since it is part of the water molecule and not merely a physiochemically or biologically-controlled dissolved component. In practice, however, hydrodynamic mixing and the convergence of ground water flow paths from different recharge origins result in an integration of water with different “ages.” Thus, it is more accurate to think of tritium analyses as providing estimates of ground water mean residence times (Clark and Fritz, 1997).

Thermonuclear bomb tritium has been greatly reduced in the oceans since the cessation of the last major atmospheric weapons tests. Reduced levels of tritium in the environment have made quantitative interpretations of ground water ages difficult. For many recent hydrogeological investigations, including this one, tritium analyses are used qualitatively to provide broad estimates of ground water age. The following guidelines are for the qualitative use of tritium in ground water investigations (Clark and Fritz, 1997):

< 0.8 TU	Ground water recharged prior to 1952 (submodern)
0.8 to -4 TU	Mixture between submodern and recent recharge
5 to 15 TU	Modern (recharged between five and 10 years ago)
15 to 30 TU	Some “bomb” tritium present
> 30 TU	Considerable component of recharge from 1960s or 1970s
> 50 TU	Dominantly recharge from 1960s.

All water samples collected during this project were analyzed for tritium by Geochron Laboratories using a liquid scintillation counter.

## **Caffeine**

Caffeine analyses were performed on all water samples, except for the sample collected from the Farmers Union Canal. The analyses were performed by the State Laboratory using a gas chromatograph/mass spectrometer method with a detection limit of around 0.8 µg/l (Marybeth Sevier, State Lab, 1998, personal communication). Information obtained after the analyses were performed suggested that this detection limit may not be low enough.

Caffeine is a component of beverages, food products, and medications used specifically for human consumption. The most significant source of caffeine in ground water or surface water resources is domestic sewage effluent. Buska et al. (1994) found that caffeine persisted in surface water up to eight miles downstream from a treated wastewater discharge. Barber et al. (1995) described monitoring performed on the Mississippi River to assess organic contamination from municipal and industrial wastewater discharges. Caffeine, in the range of 0.01 to 0.1 µg/l, was found to be a characteristic component of the organic contamination associated with the wastewater discharges. Caffeine was detected in ground water samples taken from wells near Reno, Nevada, at concentrations as high as 0.23 µg/l (Seiler et al., 1999).

## **Pesticides and Volatile Organic Compounds (VOCs)**

Certain wells were selected for analysis of pesticides and VOCs due to the previous occurrence of these compounds in these wells. Costs prohibited the analysis of pesticides and VOCs on all samples collected. Wells selected for these analyses are located downgradient of agricultural fields. Pesticide analyses were performed on samples collected from four wells by the Analytical Sciences Laboratory at the University of Idaho. Two laboratory methods were used: EPA method 515.1 for chlorinated acid pesticides and EPA method 507 for nitrogen and phosphorus pesticides. VOC analyses were performed on samples from the same four wells by the State Lab via EPA method 502.2. Table 4 lists the pesticides and VOCs included in the analyses, and Table 2 lists the approximate detection limits for the analytical methods used.

**Table 4.** Pesticides and Volatile Organic Compounds Analyzed.

<b>Pesticides by EPA Method 507</b>				
Alachlor	Ametryn	Atraton	Atrazine	Bromacil
Butachlor	Butylate	Carboxin	Chloroprotham	Cycloate
Diazinon	Dichlorvos	Diphenamid	Disulfoton	Disulfoton sulfone
Disulfoton sulfoxide	EPTC	Ethoprop	Fenamiphos	Fenarimol
Fluridone	Hexazinone	Merphos	Methyl proaxon	Metolachlor
Metribuzin	Mevinphos	MGK 264	Molinate	Napropamide
Norflurazon	Pebulate	Prometon	Prometryn	Pronamide
Propazine	Simazine	Simetryn	Stirofos	Tebuthiuron
Terbacil	Terbufos	Terbutryn	Triademefon	Tricyclazole
Vernolate				
<b>Pesticides by EPA Method 515.1</b>				
Acifluorfen	Bentazon	Chloramben	2,4-D	Dalapon
2,4-DB	MCPA	Dicamba	3,5-Dichloroben. Acid	Dichloroprop
Dinoseb	DCPA	4-Nitrophenol	Pentachlorophenol	Picloram
2,4,5-T	2,4,5-TP	MCPP		
<b>Volatile Organic Compounds by EPA Method 502.2</b>				
Benzene	Bromobenzene	Bromochloromethane	Bromodichloromethane	Bromoform
Bromomethane	n-Butylbenzene	tert-Butylbenzene	Carbon tetrachloride	Chlorobenzene
Chloroethane	2-Chlorotoluene	4-Chlorotoluene	Dibromochloromethane	1,2-Dibromo-3-chloropropane
1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	Dichlorodifluoromethane	1,1-Dichloroethane
1,2-Dichloroethane	1,1-Dichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,2-Dichloropropane
1,3-Dichloropropane	2,2-Dichloropropane	1,1-Dichloropropene	trans-1,3-Dichloropropene	Ethylbenzene
Isopropylbenzene	p-Isopropyltoluene	Methylene chloride	Napthalene	n-Propylbenzene
Styrene	1,1,1,2-Tetrachloroethane	1,1,2,2-Tetrachloroethane	Tetrachloroethene	Toluene
1,2,3-Trichlorobenzene	1,2,4-Trichlorobenzene	1,1,1-Trichloroethane	1,1,2-Trichloroethane	Trichloroethene
Trichlorofluoromethane	1,2,3-Trichloropropane	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	Vinyl chloride
Xylenes				

## FIELD AND LABORATORY RESULTS

Table 5 presents the sample location description and results of parameter measurements taken in the field. Table 6 presents the laboratory analytical results for the inorganic constituents. Table 7 presents the results of the nutrient and trace element analyses. Table 8 presents the analytical results for pesticides, VOCs, and caffeine. Table 9 presents the results of the stable isotope ratio and the tritium analyses.

**Table 5.** Sample Location Information and Field Parameter Measurements.

Sample Location	Latitude (decimal degrees)	Longitude (decimal degrees)	Sample Date	Well Depth (feet)	Water Temp. (°C)	Specific Cond. (µs/cm)	pH (standard units)	Dissolved Oxygen (mg/l)
05N01W34ACD1	43.730	-116.439	12/01/97	85	12.8	559	7.54	7.92
05N01W35CDD1	43.724	-116.426	12/05/97	200	9.4	725	7.61	5.00
05N01W35ABA1	43.736	-116.419	12/04/97	120	14.2	345	7.49	6.74
05N01W34DCC1	43.723	-116.441	12/04/97	150	12.8	1080	7.00	5.87
05N01W35ABA2S (Farmers Union Canal)	43.735	-116.421	10/21/97	Surface Water	7.8	99	7.10	10.30
04N01W03BAA1	43.721	-116.444	12/01/97 01/05/98	70	15.2	883	7.78	6.60
04N01W03CDD1S (Foothill Ditch)	43.707	-116.444	12/04/97	Surface Water	9.6	580	7.90	9.10
04N01W03ADB2 (ESD Underdrain)	43.716	-116.437	12/04/97	10 †	NA*	NA	NA	NA
04N01W03ADB3S (ESD Influent)	43.716	-116.436	12/01/97	Waste- water	NA	NA	NA	NA
04N01W03ACD1 (ESD MW-2)	43.715	-116.438	12/01/97	47	16.5	1060	7.52	0.08
04N01W03ADB1 (ESD MW-4)	43.717	-116.437	12/01/97	63	11.7	1020	7.57	0.01
04N01W03ADA1 (ESD MW-5)	43.716	-116.434	12/01/97	53	13.9	678	7.48	3.04

†Well resampled for certain analyses due to sample preservation error

‡Samples collected from a vadose zone sampling device buried approximately 10 feet below the rapid infiltration basin

\*Not analyzed

**Table 6.** Laboratory Results of Inorganic Analyses.

Sample Location	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Chloride (mg/l)	Sulfate as SO <sub>4</sub> (mg/l)	Alkalinity total as CaCO <sub>3</sub> (mg/l)	Total Dissolved Solids (mg/l)
05N01W34ACD1	49.2	10.6	39	3.2	11.0	24.9	180	359
05N01W35CDD1	63.6	12.4	54	2.9	17.7	27.6	242	441
05N01W35ABA1	37.0	15.3	32	6.0	2.9	10.9	162	211

**Table 6, continued**

Sample Location	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Chloride (mg/l)	Sulfate as SO <sub>4</sub> (mg/l)	Alkalinity total as CaCO <sub>3</sub> (mg/l)	Total Dissolved Solids (mg/l)
05N01W34DCC1	111.5	24.1	58	4.6	69.9	60.7	200	730
05N01W35ABA2S (Farmers Union Canal)	9.9	1.3	4.8	0.7	<2.0	3.68	39	58
04N01W03BAA1	84.0	19.2	46	4.2	43.5	42.2	210	553
04N01W03BAA1 (Duplicate)	86.0	19.9	47	4.1	43.8	42.8	209	559
04N01W03CDD1S (Foothill Ditch)	54.0	15.6	34	2.8	11.9	20.5	237	355
04N01W03ADB2 (ESD Underdrain)	142.0	35.7	130	17.5	114.0	5.02	676	938
04N01W03ADB3S (ESD Influent)	33.6	6.7	96	11.5	96.2	40.5	247	559
04N01W03ACD1 (ESD MW-2)	74.6	27.8	102	4.8	104.0	43.2	339	673
04N01W03ADB1 (ESD MW-4)	92.5	25.3	82	3.9	96.0	39.3	339	640
04N01W03ADA1 (ESD MW-5)	81.2	22.5	15	3.2	22.9	14.7	274	411

**Table 7. Nutrient and Trace Element Results.**

Sample Location	Iron (mg/l)	Manganese (mg/l)	Arsenic (mg/l)	Phosphorus (total as P) (mg/l)	Ammonia as N (mg/l)	Total Kjeldahl Nitrogen as N (mg/l)	Nitrate as N (mg/l)
05N01W34ACD1	0.03	<0.001	0.011	0.300	0.006	<0.05	12.3
05N01W35CDD1	0.71	0.007	<0.010	0.234	<0.005	0.23	17.9
05N01W35ABA1	45.60	0.482	0.014	0.866	0.049	1.14	0.751
05N01W34DCC1	0.15	0.002	<0.010	0.193	0.014	0.18	53.0
05N01W35ABA2S (Farmers Union Canal)	0.41	0.015	<0.010	0.080	0.017	0.17	0.010
04N01W03BAA1	0.06	0.002	<0.010	0.145	<0.005	<0.05	23.2
04N01W03BAA1 (Duplicate)	0.05	0.002	<0.010	0.158	<0.005	<0.05	NR <sup>†</sup>
04N01W03CDD1S (Foothill Ditch)	1.28	0.091	0.015	0.295	0.048	0.46	5.29
04N01W03ADB2 (ESD Underdrain)	2.85	6.810	<0.010	4.920	0.214	1.74	0.005
04N01W03ADB3S (ESD Influent)	0.11	0.033	<0.010	4.210	17.6	23.5	<0.005
04N01W03ACD1 (ESD MW-2)	0.01	0.002	0.035	0.839	0.005	0.53	6.98
04N01W03ADB1 (ESD MW-4)	0.01	0.099	0.032	0.507	0.007	0.56	11.3
04N01W03ADA1 (ESD MW-5)	0.16	0.004	0.016	0.247	0.013	0.24	8.88

<sup>†</sup>Result not reported due to an error in sample preservation

**Table 8.** Volatile Organic Compound, Caffeine, and Pesticide Results.

Sample Location	1,2,3-trichloro-propane ( $\mu\text{g/l}$ )	Caffeine ( $\mu\text{g/l}$ )	Dacthal ( $\mu\text{g/l}$ )	Atrazine ( $\mu\text{g/l}$ )
05N01W34ACD1	2.21	<0.8	9.60	<0.13
05N01W35CDD1	5.36	<0.8	10.00	<0.13
05N01W35ABA1	NA	<0.8	NA	NA
05N01W34DCC1	11.8	<0.8	53.00	<0.13
05N01W35ABA2S (Farmers Union Canal)	NA	<0.8	NA	NA
04N01W03BAA1	3.58	<0.8	26.00	1.80
04N01W03BAA1 (Duplicate)	3.58	<0.8	NA	NA
04N01W03CDD1S (Foothill Ditch)	NA	<0.8	NA	NA
04N01W03ADB2 (ESD Underdrain)	NA	<0.8	NA	NA
04N01W03ADB3S (ESD Influent)	NA	<0.8	NA	NA
04N01W03ACD1 (ESD MW-2)	NA	<0.8	NA	NA
04N01W03ADB1 (ESD MW-4)	NA	<0.8	NA	NA
04N01W03ADA1 (ESD MW-5)	NA	<0.8	NA	NA

**Table 9.** Environmental Isotope Results.

Sample Location	$^2\text{H}$ (‰)	$^{18}\text{O}$ (‰)	$^{15}\text{N}$ (‰)	$^3\text{H}$ (tritium units)
05N01W34ACD1	-124	-16.4	1.6	11.0
05N01W35CDD1	-122	-15.9	5.0	9.2
05N01W35ABA1	-126	-17.0	1.8	7.8
05N01W34DCC1	-116	-15.4	6.4	14.1
05N01W35ABA2S (Farmers Union Canal)	-125	-16.6	insufficient nitrogen	5.2
04N01W03BAA1	-119	-15.6	6.3	18.0
04N01W03BAA1 (Duplicate)	-119	-15.8	5.5	14.3
04N01W03CDD1S (Foothill Ditch)	-125	-16.5	5.0	15.6
04N01W03ADB2 (ESD Underdrain)	-113	-13.8	8.6	10.5
04N01W03ADB3S (ESD Influent)	-121	-15.9	8.9	7.8
04N01W03ACD1 (ESD MW-2)	-115	-14.4	14.8	6.0

**Table 9 , continued**

Sample Location	<sup>2</sup> H (‰)	<sup>18</sup> O (‰)	<sup>15</sup> N (‰)	<sup>3</sup> H (tritium units)
04N01W03ADB1 (ESD MW-4)	-116	-15.1	16.6	6.7
04N01W03ADA1 (ESD MW-5)	-123	-16.5	7.8	8.5

## Quality Assurance Results

Duplicate samples were collected from well 04N01W03BAA1 and analyzed for inorganic constituents, VOCs, and isotopes. Only one constituent analyzed in the duplicate samples did not meet the precision goals (Table 2). Iron, found at a level close to the method detection limit, exceeded the precision criteria by five percent.

A cursory evaluation of analytical accuracy was accomplished by calculating the cation-anion balance for each sample (Table 10). The balance errors ranged from 0.5 to 13.3 percent and averaged 4.9 percent for the 12 inorganic analyses. The suggested allowable balance error varies depending on the ionic concentration of the samples. Total dissolved solids (TDS) concentration is a measure of the ionic concentration. As the ionic concentration increases, the allowable balance error decreases. TDS concentrations ranged from 58 to 938 mg/l which corresponds to allowable balance errors of 15 to four percent, respectively (Hem, 1985). Using this criterion, four of the 12 inorganic analyses exceed the generally accepted balance error. This indicates either a lack of accuracy in the analytical procedures, or that significant inorganic components of the water were not analyzed. The range of balance errors encountered in this project do not affect any interpretations that utilize the inorganic laboratory results.

**Table 10.** Cation-Anion Balance Errors. Bold font indicates those analyses that do not meet generally acceptable cation-anion balance criteria.

Sample Location	Total Cations (meq/l)	Total Anions (meq/l)	Balance Error (%)	Accepted Balance Error (%)	TDS (mg/l)
05N01W34ACD1	5.106	4.624	5.0	4 - 5	359
05N01W35CDD1	6.617	6.199	3.3	4 - 5	441
05N01W35ABA1	4.651	3.558	<b>13.3</b>	4 - 5	211
05N01W34DCC1	10.188	8.087	<b>11.5</b>	3 - 4	730
05N01W35ABA2S (Farmers Union Canal)	0.828	0.856	1.7	7 - 15	58
04N01W03BAA1	7.880	6.676	<b>8.3</b>	3 - 4	553
04N01W03CDD1S (Foothill Ditch)	5.529	5.584	0.5	4 - 5	355

**Table 10, continued**

<i>Sample Location</i>	<i>Total Cations (meq/l)</i>	<i>Total Anions (meq/l)</i>	<i>Balance Error (%)</i>	<i>Accepted Balance Error (%)</i>	<i>TDS (mg/l)</i>
04N01W03ADB2 (ESD Underdrain)	16.126	16.829	2.1	3 - 4	938
04N01W03ADB3S (ESD Influent)	6.698	8.493	<b>11.8</b>	3 - 4	559
04N01W03ACD1 (ESD MW-2)	10.570	10.720	0.7	3 - 4	673
04N01W03ADB1 (ESD MW-4)	10.364	10.483	0.6	3 - 4	640
04N01W03ADA1 (ESD MW-5)	6.638	6.571	0.5	4 - 5	411

## Data Evaluation

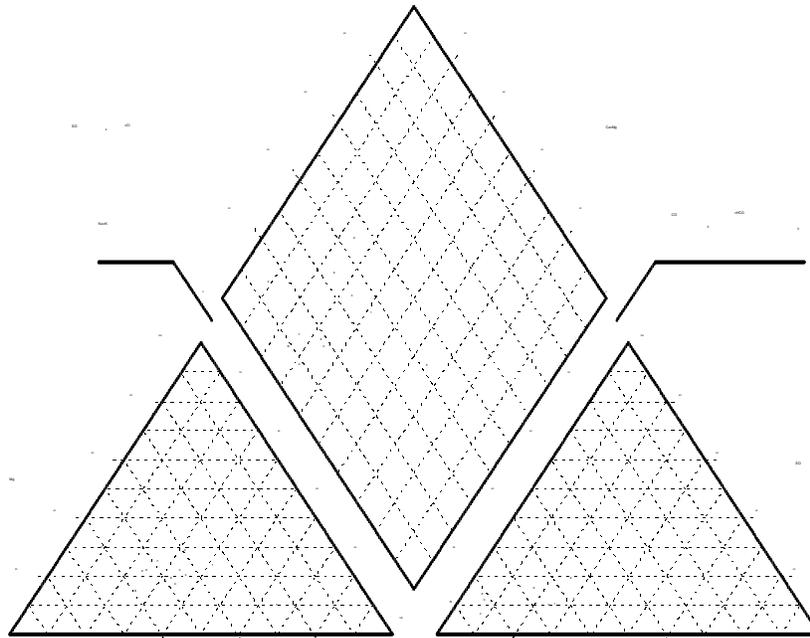
Hydrogeochemical data evaluation techniques were applied to the analytical results of 12 samples collected for general chemical parameters (i.e., cations, anions, and nutrients). These techniques helped assess the overall character of surface water and ground water in the study area, and helped determine whether water in certain areas had a common origin or migration history. The following evaluation tools were employed: a trilinear plot, composition plots (x-y scatter plots), and a fingerprint (Schoeller) diagram.

### Trilinear Plot

Under natural conditions, the major ion composition of ground water is controlled by both the soluble minerals in the aquifer and the residence time of water in the aquifer. A general relationship is expected between the mineral composition of the natural water and the solid minerals with which the water has been in contact. This simple relationship can be complicated by the mixing of water from interconnected aquifers with different compositions, or from the mixing of flow paths within the same aquifer. The system may also be affected by chemical reactions such as cation exchange, adsorption of dissolved ions, and biological influences (Hem, 1985).

Figure 6 is a trilinear plot used to display major ion water chemistry (Piper, 1944). The plot shows concentrations in percent milliequivalents per liter (meq/l) of the major cations and anions for each water sample. The major cations of each water sample (calcium, magnesium, sodium, and potassium) are plotted on the left triangle. The major anions of each water sample (carbonate, bicarbonate, chloride, and sulfate) are plotted on the right triangle. The plotted points for each water sample are then projected to the upper diamond-shaped area to show cation and anion groups as a percentage of the sample. Water samples with similar chemistry plot in the same area on the plot.

The trilinear plot shows variability in the composition of the water samples. When compared to the other samples, wastewater flowing into ESD's rapid infiltration system (influent) exhibits a unique ionic composition owing primarily to high percentages of sodium and



1	04N01W03ACD1 (ESD MW-2)	7	04N01W03CDD1S (Foothill Ditch)
2	04N01W03ADA1 (ESD MW-5)	8	05N01W34ACD1
3	04N01W03ADB1 (ESD-MW-4)	9	05N01W34DCC1
4	04N01W03ADB2 (ESD underdrain)	A	05N01W35ABA1
5	04N01W03ADB3S (ESD influent)	B	05N01W35ABA2S ( Farmers Union Canal)
6	04N01W03BAA1	C	05N01W35CDD1

**Figure 6.** Trilinear plot.

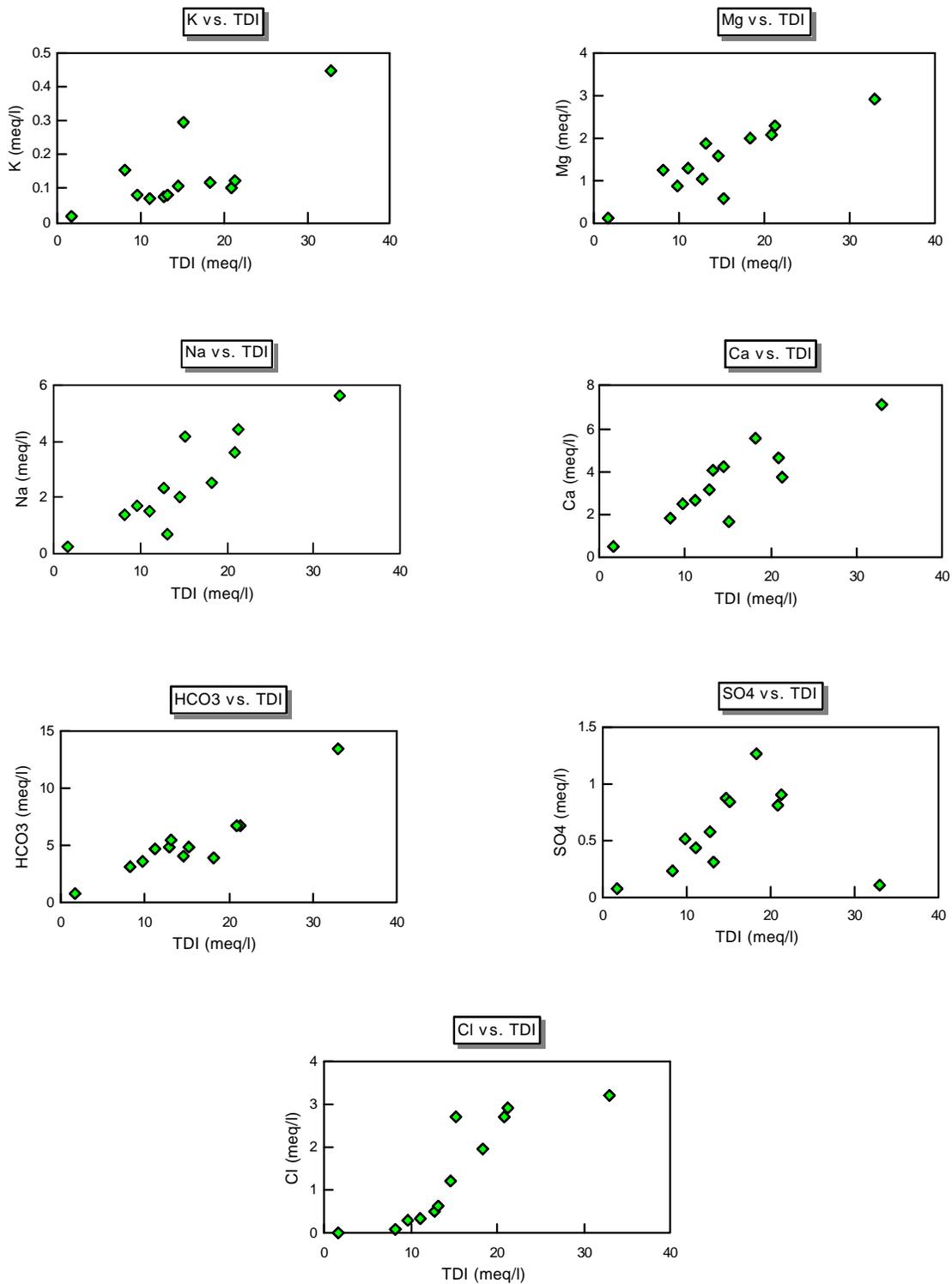
chloride. Upgradient monitoring well MW-5 also exhibits a distinctly different composition compared to downgradient well MW-2 and cross-gradient well MW-4. The rapid infiltration underdrain sample may have undergone significant geochemical changes from the time the water entered the rapid infiltration system. On a percentage basis, the water appears to have been depleted in sodium with a corresponding increase in calcium. Additionally, the underdrain sample exhibits different ionic characteristics than the sample from downgradient well MW-2. This suggests that the ground water flowing beneath the rapid infiltration system is not influenced significantly in terms of its chemical make up as it mixes with water percolating through the rapid infiltration basins.

The two surface water samples, Foothills Ditch and Farmers Union Canal, both exhibit a similar low percentage of chloride to well 05N01W35ABA1 (letter A on Figure 6), which is located very close to the canal. Wells 05N01W34ACD1 (#8 on Figure 6) and 05N01W35CDD1 (letter C on Figure 6) are similar in composition. Both contain elevated levels of nitrate along with detections of 1,2,3-TCP and dacthal. They also share a common geographical characteristic: they are located in the most hydraulically upgradient portion of the study area with respect to the other contaminated wells. The land use upgradient from these wells is primarily agricultural with a relatively low density of homes and livestock.

### **Composition Plots**

Figure 7 contains compositional plots of the major ions plotted against the total dissolved ions (TDI: the sum of major cations and anions). All axes represent concentrations in meq/l. Each symbol on the plots represents an individual water sample. These plots show whether there are compositional differences (water types) in the sample set. Data that plot in diagonal linear trends represent mixing of water with low dissolved ion concentrations and water with higher dissolved ion concentrations. Data that plot as more than one cluster indicate separate types of water that are not mixed. A random distribution of data indicates that many individual, unrelated water types exist or that the analytical quality of the data is poor (Mazor, 1991).

Linear trends are visible on most of the graphs in Figure 7, with the low and high TDI end members represented by the Farmers Union Canal sample and the underdrain sample, respectively. This linearity suggests that the shallow ground water emanating from different recharge areas or sources in the project area is mixing rather than maintaining the original character of the recharge water. One additional noteworthy characteristic is reflected on the sulfate ( $\text{SO}_4$ ) versus TDI graph: the concentration of sulfate in the underdrain sample (the point that plots at about 33 meq/l on the TDI axis) is very low. In all other graphs, the underdrain sample exhibits the highest TDI and specific ion concentration. This may be caused by reducing (anaerobic) conditions beneath the rapid infiltration basins, which results in a decrease in  $\text{SO}_4$  concentrations as reduced forms of sulfur (not measured) become more prevalent. Elevated iron and manganese (Table 7) in the underdrain sample also reflect the anaerobic conditions beneath the rapid infiltration system.

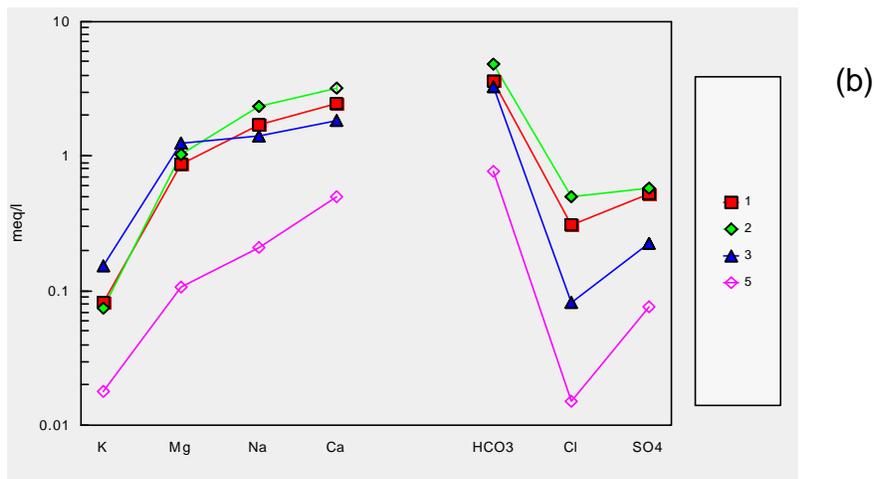
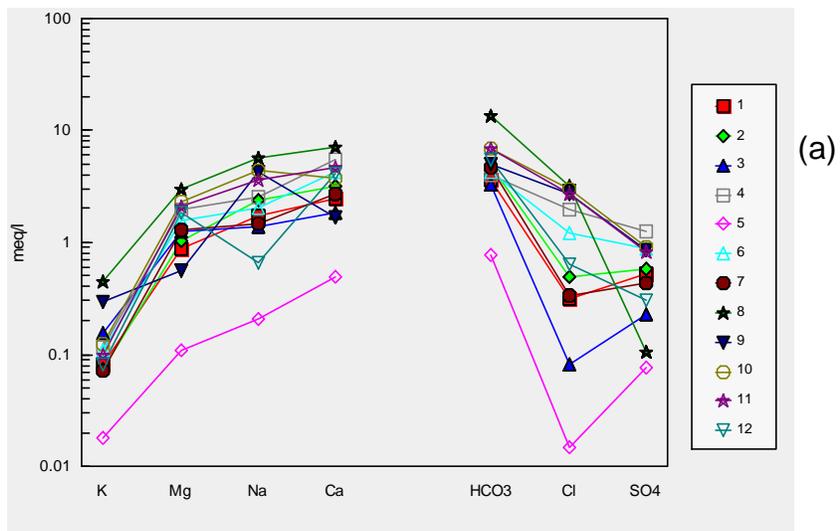


**Figure 7.** X-Y plots of major anions and cations versus the sum of the dissolved ions for all water samples taken in the study area.

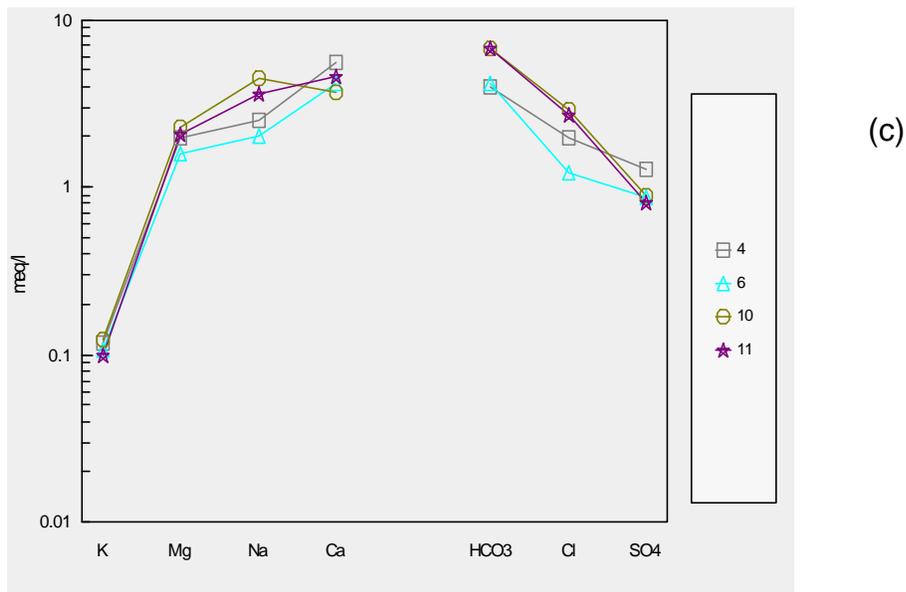
## Fingerprint Diagrams

Figure 8 (a) displays fingerprint diagrams of 12 ground water and surface water samples. Figures 8 (b) and (c) show sample subsets grouped for viewing ease by geographical location or other distinctive characteristics of interest. Each line on each diagram is a graphical representation of the concentration of the major ionic species of each sample. Water samples containing higher concentrations of ions plot higher on the diagram than those containing lower concentrations. Parallel lines indicate various dilutions of a similar water type. Lines with a fan shape indicate mixing of two distinct water types (Mazor, 1991). The fingerprint diagrams indicate the existence of several different water types. Interpretations based on these diagrams are as follows:

- < Domestic wells, 05N01W34ACD1 (#1, Figure 8 (b)) and 05N01W35CDD1 (#2, Figure 8 (b)), located in the upgradient portion of the project area, have water with similar ionic compositions. Water from these wells differs slightly in the relative cation percentages from water in well 05N01W35ABA1 (#3, Figure 8 (b)), which is located at the extreme upgradient boundary of the project area adjacent to the Farmers Union Canal. Water with similar distribution of ions, but increasing in ion concentrations with distance from the canal is related to the geochemical evolution of ground water as it flows away from the source of recharge.
- < ESD monitoring wells MW-2 (#10, Figure 8 (c)) and MW-4 (#11, Figure 8 (c)) have similar water, except that MW-4 contains more sodium than calcium and MW-2 water contains more calcium than sodium. Water from the most highly contaminated domestic wells (in terms of nitrate and pesticides), 05N01W34DCC1 (#4, Figure 8 (c)) and 04N01W03BAA1 (#6, Figure 8 (c)), has slightly different chemical characteristics than water from MW-2 or MW-4. Water from monitoring well MW-5 (upgradient from the rapid infiltration facility; #12, Figure 8 (a)) is different from any other sample. Elevated chloride, sulfate, and sodium indicate percolation of human or animal-impacted surface water, but do not identify the source as ESD. This characteristic found in water from wells upgradient from ESD (i.e., 05N01W34DCC1 and 04N01W03BAA1) may represent impacts from other sewage disposal systems or from the land application of animal wastes.
- < The ESD wastewater influent (#9, Figure 8 (a)) and the underdrain water (#8, Figure 8 (a)) are different from each other and neither compares to any other water sample. This indicates that the wastewater experiences significant geochemical changes as it percolates through the soil of the rapid infiltration system.



- |    |                     |
|----|---------------------|
| 1  | 05N01W34ACD1        |
| 2  | 05N01W35CDD1        |
| 3  | 05N01W35ABA1        |
| 4  | 05N01W34DCC1        |
| 5  | Farmers Union Canal |
| 6  | 04N01W03BAA1        |
| 7  | Foothill Ditch      |
| 8  | ESD Underdrain      |
| 9  | ESD Influent        |
| 10 | ESD MW-2            |
| 11 | ESD MW-4            |

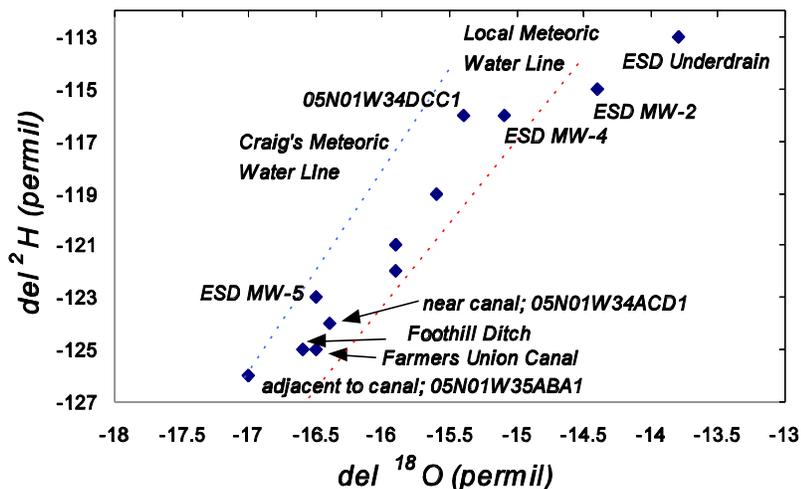


**Figure 8.** Fingerprint diagrams (displayed in various sample subsets for viewing ease).

< The ESD underdrain and wastewater influent samples contain high concentrations of potassium (17.5 and 11.5 mg/l, respectively) compared to all other samples. MW-2, located immediately downgradient from the rapid infiltration system, contains only 4.8 mg/l potassium. The relatively low concentration of potassium in MW-2 compared with the influent and underdrain samples suggests significant dilution by mixing of percolating wastewater with ground water flowing beneath the rapid infiltration system.

### Oxygen-Deuterium

Figure 9 is a graph of  $^2\text{H}$  versus  $^{18}\text{O}$  plotted with Craig's (1961) global meteoric water line and a local meteoric water line (Wood and Low, 1988). Most of the values follow the trend of the meteoric water lines with the exception of the samples collected from the ESD underdrain and monitoring well MW-2, located downgradient from the rapid infiltration facility. The underdrain sample shows significant enrichment of  $^2\text{H}$  and  $^{18}\text{O}$ , possibly as a result of evaporation of the lighter molecules of  $^1\text{H}$  and  $^{16}\text{O}$ . Significant evaporation would be expected



Sample Location	$^2\text{H}$ (‰)	$^{18}\text{O}$ (‰)
05N01W34ACD1	-124	-16.4
05N01W35CDD1	-122	-15.9
05N01W35ABA1	-126	-17.0
05N01W34DCC1	-116	-15.4
05N01W35ABA2S (Farmers Union Canal)	-125	-16.6
04N01W03BAA1	-119	-15.6
04N01W03BAA1 (Duplicate)	-119	-15.8
04N01W03CDD1S (Foothill Ditch)	-125	-16.5
04N01W03ADB2 (ESD Underdrain)	-113	-13.8
04N01W03ADB3S (ESD Influent)	-121	-15.9
04N01W03ACD1 (ESD MW-2)	-115	-14.4
04N01W03ADB1 (ESD MW-4)	-116	-15.1
04N01W03ADA1 (ESD MW-5)	-123	-16.5

**Figure 9.**  $^{18}\text{O}$  versus  $^2\text{H}$ .

given the relatively large surface area and shallow depth of the rapid infiltration system. Other biological and geochemical reactions occurring in the rapid infiltration system may account for the enrichment of  $^{18}\text{O}$  and  $^2\text{H}$ .

In summary, the  $^{18}\text{O}$  and  $^2\text{H}$  data suggest that the Foothills Ditch and the Farmers Union Canal are isotopically similar and have a source that is isotopically close to rainwater. The waters farther up the local meteoric water line are isotopically lighter, indicating greater evaporation prior to entering the ground water system.

### **Tritium**

The tritium results suggest that most of the water sampled during this project would be considered “modern” in age (Clark and Fritz, 1997). Certain samples, such as those collected from well 04N01W03BAA1 and the Foothill Ditch, contain the highest levels of tritium and may include slightly older water than the majority of the other samples (i.e., some component recharged in the 1960s or 1970s). The sample collected from the Farmers Union Canal contained the lowest levels of tritium and may represent the “youngest “ water in the project area.

### **Caffeine**

The caffeine analyses were not useful. The laboratory detection limit of  $0.8\ \mu\text{g}/\text{l}$  was probably too high to detect the low levels of caffeine that may be present in the municipal wastewater and the wells influenced by this wastewater. Literature describing the use of caffeine in environmental studies indicates that levels found in water samples can be an order of magnitude less than the detection limit achieved during this project (e.g., Seiler et al., 1999; Barber et al., 1995).

### **Volatile Organic Compounds (VOCs)**

All four domestic wells sampled for VOC analysis contained the pesticide-related compound 1,2,3-TCP ranging from  $2.21$  to  $11.9\ \mu\text{g}/\text{l}$ . The same four wells also contained the herbicide dacthal at concentrations ranging from  $9.6$  to  $53.0\ \mu\text{g}/\text{l}$ . One of the wells, 04N03WBAA1, also contained the herbicide atrazine at a concentration of  $1.8\ \mu\text{g}/\text{l}$ . These results correlate with the results from previous studies and confirm that shallow ground water in the area is impacted by agricultural chemicals. Drinking water MCLs have not been established for 1,2,3-TCP or dacthal. The MCL for atrazine is  $3\ \mu\text{g}/\text{l}$ .

### **Eagle Sewer District Rapid Infiltration System Monitoring**

Since its startup in 1984, the ESD rapid infiltration system has been a source of controversy and a concern to surrounding residents. Downgradient and cross-gradient monitoring wells around the facility have historically shown elevated levels of nitrate. The proximity of these wells to the feedlot, another potential source of nitrate, has made the interpretation of these water quality results difficult.

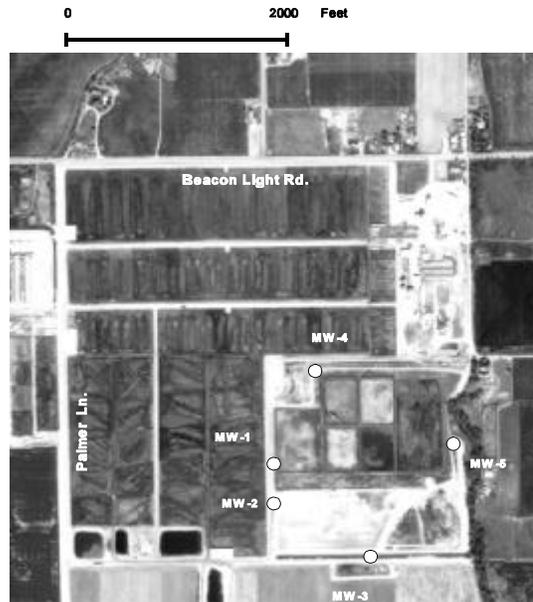
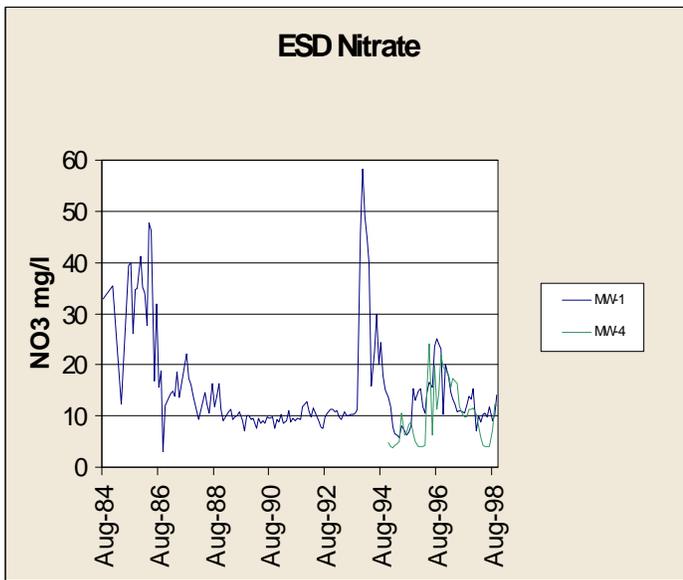
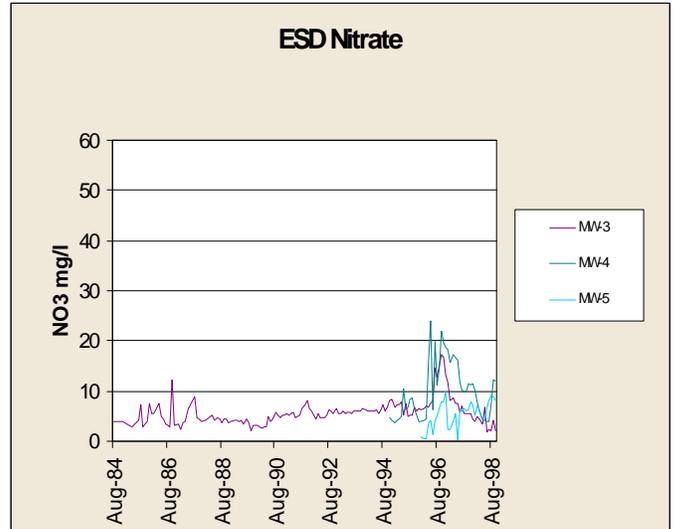
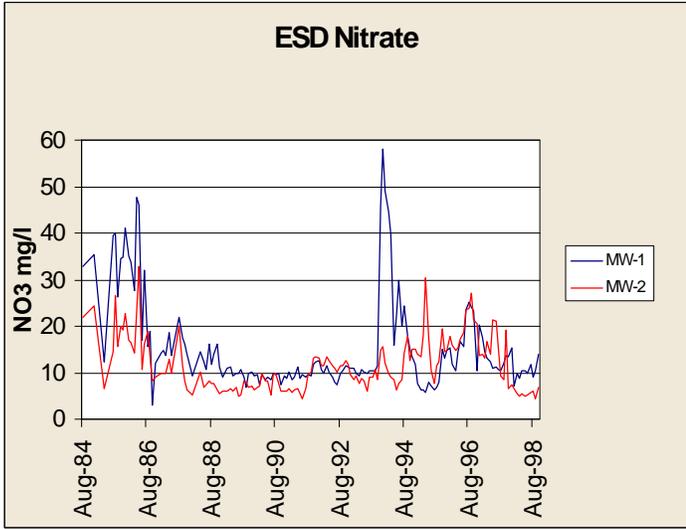
Figure 10 depicts long-term nitrate monitoring results for monitoring wells surrounding the ESD facility. Samples were collected monthly during most of the time represented in these figures. Wells MW-4 and MW-5 were installed more recently and therefore do not have the long monitoring history of the other wells. With respect to the location of the rapid infiltration basins and the direction of ground water flow: MW-1 and MW-2 are located downgradient; MW-3 and MW-4 are cross-gradient; and MW-5 is upgradient. No clear interpretations regarding long-term trends are apparent in the data. The most striking feature is the extreme variability in nitrate values, even in upgradient well MW-5.

In 1996, ESD began planning an expansion of the rapid infiltration system to accommodate increasing wastewater flows. The expansion proposal included conversion of agricultural land west of the existing facility, and feedlot, to additional rapid infiltration basins. IDEQ required that ground water monitoring wells be installed and water samples be collected prior to rapid infiltration facility expansion to assess existing ground water quality. Water samples were collected separately by IDEQ and ESD in November 1996 from three newly constructed monitoring wells on land currently used for growing alfalfa. The location of the wells is shown on Figure 11. The IDEQ samples were analyzed for common ions and nutrients. The ESD samples were also analyzed for certain pesticides. Monitoring well information and selected analytical results are presented in Table 11. The results were also plotted on a trilinear diagram in order to compare the chemical characteristics with the other results shown previously (Figure 12).

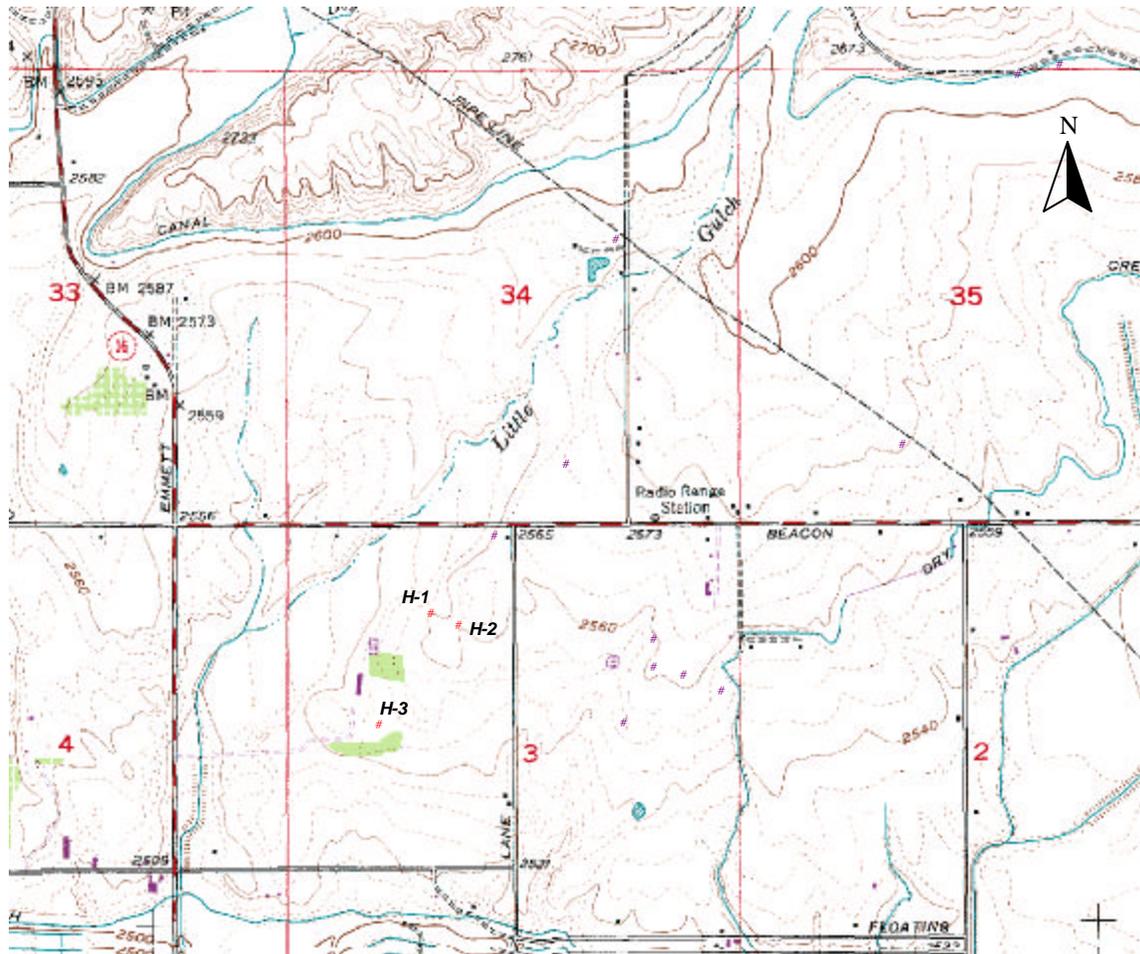
Because ESD implemented other expansion options, the planned rapid infiltration expansion did not take place. In 1997, the owner of the agricultural land then denied access to the three new monitoring wells; therefore, these three wells were not sampled for this project.

**Table 11.** Location Information and Analytical Data for Monitoring Wells on the Proposed Eagle Sewer District Expansion Site.

<i>Sample Location</i>	<i>Latitude (decimal degrees)</i>	<i>Longitude (decimal degrees)</i>	<i>Well Depth (feet)</i>	<i>Sample Date</i>	<i>Dacthal (µg/l)</i>	<i>Chloride (mg/l)</i>	<i>Total Kjeldahl Nitrogen as N (mg/l)</i>	<i>Nitrate as N (mg/l)</i>	<i>Total Dissolved Solids (mg/l)</i>
04N01W03BAC1 (H-1)	43.718	-116.446	77	11/14/96	2.22	23.1	<0.05	16.2	444
04N01W03BAD1 (H-2)	43.717	-116.445	78	11/14/96	0.26	21.3	<0.05	12.2	448
04N01W03BCD1 (H-3)	43.714	-116.448	64	11/14/96	0.83	89.8	0.59	34.9	832



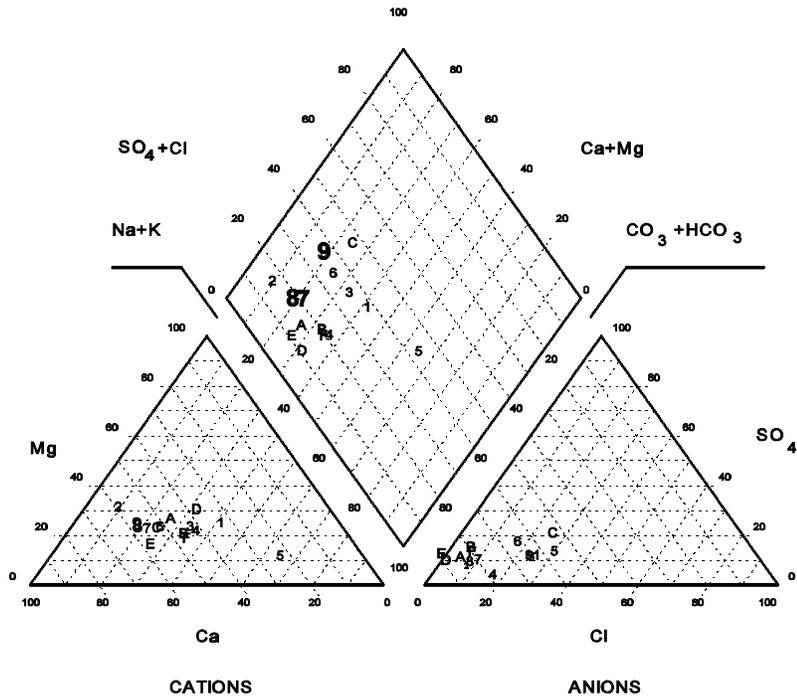
**Figure 10.** Eagle Sewer District nitrate monitoring results and well location map.



0.5                      0                      0.5                      1 Miles

- # Sampling Locations
- # ESD Expansion Site Wells

**Figure 11.** Monitoring wells on the proposed Eagle Sewer District expansion site.



- |   |                               |   |                                     |
|---|-------------------------------|---|-------------------------------------|
| 1 | 04N01W03ACD1 (ESD MW-2)       | 9 | <b>04N01W03BCD1 (ESD H-3)</b>       |
| 2 | 04N01W03ADA1 (ESD MW-5)       | A | 04N01W03CDD1S (Foothill Ditch)      |
| 3 | 04N01W03ADB1 (ESD-MW-4)       | B | 05N01W34ACD1                        |
| 4 | 04N01W03ADB2 (ESD underdrain) | C | 05N01W34DCC1                        |
| 5 | 04N01W03ADB3S (ESD influent)  | D | 05N01W35ABA1                        |
| 6 | 04N01W03BAA1                  | E | 05N01W35ABA2S (Farmers Union Canal) |
| 7 | <b>04N01W03BAC1 (ESD H-1)</b> | F | 05N01W35CDD1                        |
| 8 | <b>04N01W03BAD1 (ESD H-2)</b> |   |                                     |

**Figure 12.** Trilinear diagram that includes data from three monitoring wells installed on the proposed Eagle Sewer District expansion site (H-1, H-2, and H-3).

## Nitrate Results and Potential Point Sources of Nitrogen

Four of the five domestic wells sampled contain nitrate above the public drinking water MCL of 10 mg/l. The levels of nitrate in these five wells ranged from 0.751 to 53.0 mg/l (Table 7). Total nitrogen levels, represented by total Kjeldahl nitrogen plus nitrate, were low in the Farmers Union Canal, the ESD underdrain, and the most upgradient well, 05N01W35ABA1. The total nitrogen level, occurring primarily as nitrate, was higher in the Foothill Ditch (5.29 mg/l nitrate), suggesting that the Foothill Ditch intercepts some of the shallow ground water near the downgradient boundary of the project area. The total nitrogen level in wastewater entering the rapid infiltration system was about 23.5 mg/l, existing primarily in the form of ammonia.

Ground water quality degrades as it progresses from the northeast to the southwest. Wells 05N01W34DCC1 and 04N01W03BAA1 exhibit the highest levels of nitrate, total dissolved solids, chloride, sulfate, dacthal, and atrazine (found only in well 04N01W03BAA1) when compared with all other drinking water wells sampled for this project.

Table 12 lists simplified estimates of nitrogen production from the three main point sources of nitrogen that exist in the project area: the ESD rapid infiltration system, the feedlot, and residential subsurface sewage disposal systems. Prior to July 1997, the ESD underdrain system could not reliably collect enough water for sampling. Later, the underdrain system was replaced and the collection of adequate water for sampling now occurs regularly. Thirty underdrain analyses were submitted by ESD for the period July 1997, through October 1998 (JUB, 1999). Total Kjeldahl nitrogen levels ranged from 1.16 to 2.24 mg/l and nitrate ranged from below the detection limit of 0.1 mg/l to a high of 1.74 mg/l. Nitrate was only detected in eight of the 30 samples. These historic results agree with the results from samples collected during this project.

**Table 12 . Nitrogen Loading from Major Point Sources.**

<i>Source of Nitrogen</i>	<i>Pounds of Nitrogen Produced per day</i>	<i>Pounds of Nitrogen Produced per year</i>	<i>Information Sources</i>
Eagle Sewer District Rapid Infiltration System (30 mg/l nitrogen concentration, 1 MGD <sup>†</sup> discharge)	250	91,250	Eagle Sewer District monitoring results and operation records
Large Cattle Feedlot (8000 <sup>‡</sup> head each producing 0.4 lb/day nitrogen)	3,200	1,168,000	<i>Idaho Waste Management Guidelines for Confined Animal Feeding Operations</i> (1993)
Residential Subsurface Sewage Disposal Systems (45 homes with discharge of 300 gal/day and nitrogen concentration of 40 mg/l)	4.5	1,642	Nitrogen loading rates from various Nutrient-Pathogen studies submitted to Central District Health Dept.; number of dwellings estimated from 1995 aerial photograph

<sup>†</sup> MGD = million gallons per day

<sup>‡</sup> Represents half of the reported capacity and acknowledges that the feedlot operates at less than full capacity

Comparison of the total nitrogen levels entering the rapid infiltration system (influent sample) and the total nitrogen in the underdrain suggests an efficient treatment of nitrogen through the system. Based on these data, approximately 90% of the nitrogen may be removed within the first 10 feet of soil in the rapid infiltration system. This is beyond the range of 30 to 80% nitrogen removal reported for typical rapid infiltration facilities by the EPA (1977).

Nitrate contamination may be caused by the ESD rapid infiltration system. However, the 30 underdrain analyses suggest that the system has been efficiently removing nitrogen since at least July 1997. The rapid infiltration system relies on the conversion (oxidation) of ammonium in the influent wastewater to nitrate in the shallow subsurface below the basins. This is followed by denitrification (under anaerobic conditions) and release of nitrogen gas (an acceptable constituent) to the atmosphere. An efficient denitrification process requires a population of facultative or anaerobic microorganisms along with an adequate supply of organic carbon as an energy source for the microbes. Organic carbon can be a limiting constituent for achieving denitrification (Canter, 1997).

Soils tend to adsorb ammonium near the surface where wastewater begins to infiltrate. This may result in the temporary buildup of ammonium in a shallow layer (EPA, 1977). A "wave" of nitrate-rich infiltrating water can then be produced when the number of nitrifying bacteria reach a level that permits rapid oxidation of the adsorbed ammonium. This recurring nitrate wave phenomenon is readily observed in systems that alternate flooding and drying (EPA, 1977). Alternate flooding and drying is an inherent operating characteristic of rapid infiltration systems. Whether or not this ammonium buildup phenomenon occurs at the ESD facility is not known. However, many of the recent ESD underdrain samples were collected at two-week intervals, and this phenomenon was not detected.

Nitrate contamination may also be caused by the cattle feedlot that exists in the area. Feedlot cattle produce an estimated 62 pounds of manure per day per 1,000 pounds of live weight (Palmer, 1993). The amount of nitrogen in the manure equates to about 0.4 pounds per day or 156 pounds per year for each animal.

Access to lands and facilities associated with the feedlot was not granted, so an analytical assessment of the feedlot waste products and potential ground water impacts could not be made. Deep nitrogen leaching from feedlot soils is considered negligible under typical operating conditions (e.g., Stewart et al., 1967; Stewart, 1970; Mielke et al., 1974; Saint-Fort et al., 1995). Animal waste management practices may represent the highest contamination potential related to feedlot operations. In particular, liquid wastes resulting from storm water contacting manure include a potential hydraulic driving force which increases the risk of nitrogen leaching. Animal waste loading, in excess of plant uptake requirements, on offsite agricultural land is also a significant potential source of nitrate contamination.

Recent and historical aerial photographs were obtained to evaluate the configuration of the feedlot and surrounding area (Appendix B). Plate 1 is a photograph taken in May 1972, and Plate 2 is a photograph taken in April 1995. Plate 2 shows the current configuration of the

feedlot and the ESD rapid infiltration facility. The photograph represented in Plate 1 was taken before the existence of the rapid infiltration facility. A tilled agricultural field is visible in the area now occupied by ESD. The most noteworthy feature on Plate 1 is the apparently random accumulation of wastewater on the feedlot property, including some rather significant areas of ponding in the northeastern portion of the feedlot footprint. These ponded areas represent potential sources of deep nitrogen leaching that could not otherwise be identified based on current land use configurations.

Wastewater from the feedlot now drains to the south and is collected in four lagoons constructed of native soil material. A soil evaluation was performed by the Natural Resources Conservation Service (NRCS) in 1998 in preparation for modification of the large elongate lagoon shown on Plate 2. Soil beneath the bottom of the lagoon was determined to have adequate characteristics for a natural soil liner. In contrast, soil analyses from adjacent fields indicated too much sand content for liner material. The NRCS evaluation also states that none of the lagoons appear to be leaking. The basis for this statement is not provided in their report. Potential ground water impacts from the feedlot lagoons were not assessed during this project due to the access limitations.

### **Nitrogen Isotope Analyses**

The sources of elevated nitrate in ground water were assessed through the use of nitrogen isotope analyses. Figure 13 provides a graphical representation of the  $^{15}\text{N}$  results as they appear by location. Significant  $^{15}\text{N}$  fractionation is observed in the analytical results (Table 9). Nitrogen found in samples collected from 05N01W34ACD1 and 05N01W35ABA1 is depleted with respect to  $^{15}\text{N}$  compared with all other samples. The sample collected from 05N01W35ABA1 contains very little nitrogen, while the sample collected from 05N01W34ACD1 contains a relatively high level (12.3 mg/l) of nitrate. The  $^{15}\text{N}$  results coupled with the location of this well (i.e., downgradient from agricultural fields and upgradient from the feedlot and rapid infiltration facility) and the relatively high concentration of nitrate strongly suggests that the elevated nitrate found in 05N01W34ACD1 is likely a result of leaching of inorganic commercial nitrogen fertilizer.

The results for samples collected from three other domestic wells with elevated nitrate reflect intermediate  $^{15}\text{N}$  values, from 5.0 to 6.4‰, suggesting a mixture of two or more nitrogen sources. Given the land use characteristics, these values likely represent a combination of inorganic commercial nitrogen fertilizer, animal manure, and septic tank effluent. However, the density of septic systems in the area is relatively low, so the significance of this source may be less than the other two potential sources (see Table 12).



The ESD influent and underdrain samples have  $^{15}\text{N}$  values of 8.9 and 8.6‰, respectively. These are enriched in  $^{15}\text{N}$  compared with the majority of the surrounding ground water samples. These values represent the  $^{15}\text{N}$  signature of the ESD wastewater at the time this study was conducted. The nitrogen in these two samples existed primarily in the form of ammonia or organic nitrogen and not nitrate. The dominant nitrogen form in all other measurable samples was nitrate. The rapid infiltration system relies on the nitrification of ammonia-rich wastewater followed by denitrification: all occurring within the upper few feet of soil. Presumably, the water reaching the underdrain collection system has been subjected to the nitrification-denitrification cycle. This is supported by the apparent significant reduction in total nitrogen when comparing influent and underdrain samples. It is unclear how the nitrification-denitrification cycle might affect the comparison of the  $^{15}\text{N}$  results in the ESD influent and underdrain samples with  $^{15}\text{N}$  results from other samples where the primary nitrogen form was nitrate. Investigators reported that when the conversion of ammonia to nitrate is rapid and complete, no isotopic fractionation occurs (Exner and Spalding, 1994). Others reported that denitrification (the conversion of nitrate to nitrogen gas) caused the remaining nitrate to become progressively enriched in  $^{15}\text{N}$  (e.g., Aravena and Robertson, 1998; Bottcher et al., 1990).

Downgradient well MW-2 and cross-gradient well MW-4 contain water exhibiting further  $^{15}\text{N}$  enrichment with values of 14.8 and 16.6‰, respectively. These values are clearly in the range associated with human or animal waste and are different (i.e., more enriched) than the ESD influent wastewater and underdrain water. These highly  $^{15}\text{N}$ -enriched samples may reflect impact by the rapid infiltration system with the  $^{15}\text{N}$  enrichment resulting from the denitrification of the wastewater. However, it appears unlikely that additional  $^{15}\text{N}$  enrichment through denitrification would occur in the wastewater below the depth of the underdrain collection system (about 10 feet below ground). The recent underdrain monitoring results show very little nitrogen in the underdrain water, indicating that most of the denitrification has occurred prior to the water reaching the depth of the underdrain.

Alternatively, the enriched  $^{15}\text{N}$  results may reflect an impact from the feedlot. Deep nitrogen leaching through feedlot soils is not expected under typical operating conditions (e.g., Stewart et al., 1967; Stewart, 1970; Mielke et al., 1974; Saint-Fort et al., 1995). However, past waste handling practices and storm water management may have provided a mechanism for deep nitrogen leaching and ground water impacts detected in wells MW-2 and MW-4.

The sample collected from upgradient well MW-5 is not particularly distinctive with a  $^{15}\text{N}$  value of 7.8‰. This sample is more enriched in  $^{15}\text{N}$  than water from other wells located farther upgradient in the project area. All other water quality parameters indicate that this well is not influenced by ESD wastewater or other flowpaths that have resulted in elevated nitrate farther to the west.

## CONCLUSIONS AND RECOMMENDATIONS

An integration of several data evaluation and laboratory techniques was used in an attempt to identify sources of elevated nitrate in ground water. Considered together, the methods employed in this project support the following conclusions regarding nitrate contamination sources:

- < The geologic conditions in the project area make the shallow unconfined aquifer vulnerable to contamination from land uses. Sandy, permeable soils allow the downward movement of nitrate and agricultural chemicals such as 1,2,3-TCP, 1,2-DCP, dacthal, and atrazine. The occurrence of these contaminants is pervasive in the project area, suggesting impacts from non-point sources.
- < The  $^{15}\text{N}$  results included a wide range of values, which suggested different nitrogen sources in different parts of the project area. The use of  $^{15}\text{N}$  analyses for identifying sources of nitrogen contamination appears promising.
- < Domestic wells north of Beacon Light Road do not appear to be impacted by the ESD facility or the feedlot. This is supported by the measurement of the local ground water flow direction, the  $^{15}\text{N}$  results, and the common inorganic chemistry results. The  $^{15}\text{N}$  results from samples collected north of Beacon Light Road may reflect a combination of sources including leaching of inorganic chemical nitrogen fertilizer, land applied animal manure, and septic tank effluent. However, the density of septic systems in the area is relatively low, so the significance of this source is probably less than the other two potential sources.
- < The occurrence of enriched  $^{15}\text{N}$  in samples collected in monitoring wells immediately north and west of the ESD facility indicates a different source of nitrogen in this area compared to the area north of Beacon Light Road. The two potential nitrogen sources in this area are the ESD rapid infiltration facility and the feedlot. The lack of nitrogen in the rapid infiltration facility underdrain system and the difference in  $^{15}\text{N}$  results between the underdrain sample and the  $^{15}\text{N}$  results in either MW-2 or MW-4 suggests a source of nitrogen other than ESD. Although direct evidence indicating the feedlot source of this nitrogen is lacking, it is the most probable source. Historic areas of water accumulation on the feedlot property may represent potential nitrogen sources not visible today. Access to wells more directly downgradient from the feedlot would be helpful in making this determination.

This report represents the culmination of several years of problem assessment by various resource agencies. The information contained in this report will be presented, in coordination with ISDA, to groups or technical forums with responsibility for directing agricultural practices in Idaho. The Agricultural Ground Water Quality Coordination Committee (Coordination Committee), established through the Agricultural Ground Water Quality Protection Program, represents the best forum for presentation of the findings of this report. The objectives of the

Coordination Committee are to “facilitate, coordinate, and ensure consistency of all components of the state’s Agricultural Ground Water Quality Protection Program” (Ground Water Quality Council, 1996). It is anticipated that improvements to ground water quality, directed by the Coordination Committee, will be sought through one or more of the following mechanisms: (1) information and education; (2) implementation, monitoring, and revision of agricultural best management practices, or; (3) regulatory strategies.

The following activities are also recommended:

- < Temporal variation, particularly with regard to the isotope values, was not evaluated as a part of this project. As IDEQ and other resource agencies gain experience with isotopic studies, the significance of this issue should be addressed.
- < IDEQ and ISDA should discuss the results of this project with the feedlot owners and solicit their cooperation in evaluating current and historic waste management practices. Modification of these practices should be sought when appropriate.
- < Long-term ground water monitoring and additional sampling in previously inaccessible areas would be useful. Cooperative interagency efforts will probably be needed to accomplish additional sampling. This activity is contingent upon the ability of IDEQ and ISDA to allocate staff resources and funding for analytical costs.
- < IDEQ should discuss the results of this project with IDWR in order to establish well construction practices that will prevent the contamination of drinking water supplies.
- < IDEQ, ISDA, and CDHD should identify a means by which potential home buyers can be notified of the ground water contamination.
- < ISDA should work with agricultural producers and pesticide applicators to develop protective pesticide application practices which take into account soil and hydrogeologic conditions specific to this area.
- < ISDA should work with agricultural producers and homeowners to develop protective fertilizer and irrigation water management practices.
- < All agencies holding water quality data for the area (i.e., ISDA, IDEQ, and IDWR) should compile and organize the data into a single database.

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<b>Summary driller's report for 05N01W34DCC1</b>				<b>Water Level</b>						
				Static water level		50'				
				Flowing?		No				
<b>Nature of Work</b>				<b>Well Test Data</b>						
New well				Bail						
				Air		yes				
				Discharge GPM:		45				
<b>Proposed Use</b>				Hours Pumped:						
Domestic										
				<b>Lithologic Log</b>						
				Bore Diam	Depth (ft)		Material	Water		
					From	To		yes	no	
<b>Method Drilled</b>				6"       4"	0	5	overburden		X	
Cable					5	9	sandy clay		X	
					9	27	clay & sand		X	
<b>Well Construction</b>					27	35	gravel	X		
Casing schedule	Diam	From (ft)	To (ft)		35	40	clay			
0.250 steel	6"	2	90		40	120	blue clay w/ sand streaks	X		
	4.5"	90	150		120	150	blue clay			
					150		sand red	X		
Was casing drive shoe used?					yes					
Was a packer or seal used?					no					
Perforated?				no						
Well screen installed?				no						
Gravel packed?										
Surface seal depth?				40'						
Materia used in seal?				puddling clay						
Sealing procedure used?				slurry pit						
Method of joining casing				welded						
<b>Location of Well</b>										
SW 1/4 SE 1/4 Sec. 34 T5N R1W				<b>Work Started:</b> 9/20/87		<b>Work Ended:</b> 9/28/87				

<b>Summary driller's report for 05N01W34ACD1</b>				<b>Water Level</b>					
				Static water level		50'			
				Flowing?		No			
<b>Nature of Work</b>				<b>Well Test Data</b>					
New well				Bail		yes			
				Air		25			
				Discharge GPM:		1			
				Hours Pumped:					
<b>Proposed Use</b>				<b>Lithologic Log</b>					
Domestic				Bore Diam	Depth (ft)		Material	Water	
					From	To		yes	no
<b>Method Drilled</b>				6"	0	2	top soil		X
Cable					2	60	sand		X
					60	73	sandy clay		X
<b>Well Construction</b>					73	85	(?) sand	X	
Casing schedule	Diam	From (ft)	To (ft)						
0.250 steel	6"	+1	78						
Was casing drive shoe used?				yes					
Was a packer or seal used?				yes					
Perforated?				no					
Well screen installed?				yes Johnson 305					
Gravel packed?				no					
Surface seal depth?				18'					
Materia used in seal?				bentonite					
Sealing procedure used?				overbore to seal depth					
Method of joining casing									
<b>Location of Well</b>									
SW 1/4 NE 1/4 Sec. 34 T5N R1W				<b>Work Started: 7/21/88</b>		<b>Work Ended: 7/23/88</b>			

<b>Summary drillers' report for 04N01W03BAA1</b>				<b>Water Level</b>								
				Static water level		50'						
				Flowing?		No						
<b>Nature of Work</b>				<b>Well Test Data</b>								
New well				Bail								
				Air		yes						
				Discharge GPM:		45						
				Hours Pumped:								
<b>Proposed Use</b>				<b>Lithologic Log</b>								
Domestic				Bore Diam	Depth (ft)		Material	Water				
					From	To		yes	no			
<b>Method Drilled</b>				8"	0	5	sand & clay		X			
Cable					4	40				dry sand		X
					40	65				sandy clay		X
					65	70				sand & gravel	X	
<b>Well Construction</b>												
Casing schedule	Diam	From (ft)	To (ft)									
0.250 steel	8"	+18"	70									
Was casing drive shoe used?												
Was a packer or seal used?				no								
Perforated?				no								
Well screen installed?				no								
Gravel packed?				no								
Surface seal depth?				18'								
Materia used in seal?				well cuttings								
Sealing procedure used?				overbore to seal depth								
Method of joining casing												
<b>Location of Well</b>												
NW 1/4 NE 1/4 Sec. 3 T4N R1W				<b>Work Started:</b> 11/1		<b>Work Ended:</b> 11/4 year?						

<b>Summary driller's report for 04N01W03ACD1 (ESD MW-2)</b>				<b>Water Level</b>					
				Static water level		35'			
				Flowing?		No			
<b>Nature of Work</b>				<b>Well Test Data</b>					
New well				Bail					
				Air					
				Discharge GPM:					
				Hours Pumped:					
<b>Proposed Use</b>				<b>Lithologic Log</b>					
Monitoring				Bore Diam	Depth (ft)		Material	Water	
					From	To		yes	no
<b>Method Drilled</b>				6"	0	35	sand & some clay		
					35	47			
<b>Well Construction</b>									
Casing schedule	Diam	From (ft)	To (ft)						
PVC	6"		45						
Was casing drive shoe used?									
Was a packer or seal used?									
Perforated?		yes 35-45'							
Well screen installed?									
Gravel packed?									
Surface seal depth?									
Materia used in seal?									
Sealing procedure used?									
Method of joining casing									
<b>Location of Well</b>									
SW 1/4 NE 1/4 Sec. 3 T4N R1W				<b>Work Started:</b> 1981 or 1982		<b>Work Ended:</b>			

<b>Summary driller's report for 04N01W03ADB1 (ESD MW-4)</b>				<b>Water Level</b>					
				Static water level		40'			
				Flowing?		No			
<b>Nature of Work</b>				<b>Well Test Data</b>					
New well				Bail					
				Air					
				Discharge GPM:		25			
<b>Proposed Use</b>				Hours Pumped:					
Monitoring				1					
				<b>Lithologic Log</b>					
		Bore Diam	Depth (ft)		Material	Water			
			From	To		yes	no		
<b>Method Drilled</b>		8"	0	18	sandy clay				
Air rotary			18	21	sand				
			21	23	sandy clay				
<b>Well Construction</b>			23	26	sand				
Casing schedule	Diam		From (ft)	To (ft)	26			29	sandy clay
0.250 steel	8"		+2	5	29			30	sand
PVC	6"		3	47	30			37	clay
PVC screen	6"		47	63	37			38	sand
Was casing drive shoe used?	yes				38			41	clay
Was a packer or seal used?	yes				41			43	coarse sand
Perforated?				43	47	sandy clay			
Well screen installed?	yes			47	63	gravel			
Gravel packed?				63		sandy clay			
Surface seal depth?	45'								
Materia used in seal?	bentonite								
Sealing procedure used?									
Method of joining casing									
<b>Location of Well</b>				<b>Work Started: 11/2/94    Work Ended: 11/4/94</b>					
SE 1/4 NE 1/4 Sec. 3 T4N R1W									

<b>Summary driller's report for 04N01W03ADA1 (ESD MW-5)</b>				<b>Water Level</b>					
				Static water level		20'			
				Flowing?		No			
<b>Nature of Work</b>				<b>Well Test Data</b>					
New well				Bail					
				Air					
				Discharge GPM:		60			
<b>Proposed Use</b>				Hours Pumped:					
Monitoring				4					
				<b>Lithologic Log</b>					
				Bore Diam	Depth (ft)		Material	Water	
					From	To		yes	no
<b>Method Drilled</b>				10"	0	3	coarse sand		X
Air rotary					3	4	hard dry brown silty clay		X
					4	20	coarse brown sand		X
<b>Well Construction</b>					20	30	sand		X
Casing schedule	Diam	From (ft)	To (ft)	8"	30	32	coarse sand & silty clay mix	X	
0.250 steel	8"	+2	3		32	34	coarse sand	X	
PVC	6"	+2	36		34	36	clay & gravel	X	
PVC screen	6"	36	51		36	40	sand & large gravel	X	
Was casing drive shoe used?      yes					40	47	sand	X	
Was a packer or seal used?					47	50	gravel	X	
Perforated?					50	51	sand	X	
Well screen installed?              yes				51	53	sand & gravel	X		
Gravel packed?				53		clay		X	
Surface seal depth?                  30'									
Materia used in seal?              bentonite									
Sealing procedure used?									
Method of joining casing									
<b>Location of Well</b>									
SE 1/4 NE 1/4 Sec. 3 T4N R1W				<b>Work Started:</b> 12/21/95		<b>Work Ended:</b> 1/6/96			

<b>Summary driller's report for 04N01W03BAC1 (ESD H-1)</b>				<b>Water Level</b>				
				Static water level		45'		
				Flowing?		No		
<b>Nature of Work</b>				<b>Well Test Data</b>				
New well				Bail				
				Air				
				Discharge GPM:		24		
<b>Proposed Use</b>				Hours Pumped:				
Monitoring				2				
				<b>Lithologic Log</b>				
		Bore Diam	Depth (ft)		Material	Water		
			From	To		yes	no	
<b>Method Drilled</b>		10"	0	4	top soil		X	
Air rotary			4	12	brown sand		X	
			12	18	sandy clay		X	
<b>Well Construction</b>		6"	18	24	sandy clay		X	
Casing schedule	Diam		From (ft)	To (ft)	24	28	brown sand & some stone hard	X
0.250 steel	6"		+2.5	6	28	42	brown sand	X
PVC	4"		+2	40	42	58	sandy brown clay	X
s.s. screen	6"		40	60	58	78	sand & gravel	X
Was casing drive shoe used?			yes		78		brown clay	
Was a packer or seal used?								
Perforated?								
Well screen installed?		yes						
Gravel packed?								
Surface seal depth?		18'						
Materia used in seal?		bentonite						
Sealing procedure used?		overbore						
Method of joining casing								
<b>Location of Well</b>								
NE 1/4 NW 1/4 Sec. 3 T4N R1W				<b>Work Started:</b> 10/21/96		<b>Work Ended:</b> 11/5/96		

<b>Summary driller's report for 04N01W03BAD1 (ESD H-2)</b>				<b>Water Level</b>						
				Static water level		45'				
				Flowing?		No				
<b>Nature of Work</b>				<b>Well Test Data</b>						
New well				Bail						
				Air						
				Discharge GPM:		24				
<b>Proposed Use</b>				Hours Pumped:		2				
Monitoring				<b>Lithologic Log</b>						
				Bore Diam	Depth (ft)		Material	Water		
					From	To		yes	no	
<b>Method Drilled</b>				10"	0	4	top soil		X	
Air rotary					4	12	brown sand		X	
					12	14	sandy clay		X	
					14	18	brown sand		X	
<b>Well Construction</b>					6"	18	26	brown sand		X
Casing schedule	Diam	From (ft)	To (ft)			26	28	sandstone hard		X
0.250 steel	6"	+2.5	6			28	42	brown sand		X
PVC	4"	+2	45			42	56	sandy brown clay		X
s.s. screen	4"	45	65			56	76	sand & gravel	X	
Was casing drive shoe used?      yes					76		brown clay		X	
Was a packer or seal used?										
Perforated?										
Well screen installed?                      yes										
Gravel packed?										
Surface seal depth?                              18'										
Materia used in seal?                              bentonite										
Sealing procedure used?                              overbore										
Method of joining casing										
<b>Location of Well</b>										
NE 1/4 NW 1/4 Sec. 3 T4N R1W				<b>Work Started:</b> 11/6/96 <b>Work Ended:</b> 11/8/96						

<b>Summary driller's report for 04N01W03BCD1 (ESD H-3)</b>				<b>Water Level</b>						
				Static water level		44'				
				Flowing?		No				
<b>Nature of Work</b>				<b>Well Test Data</b>						
New well				Bail						
				Air						
				Discharge GPM:		24				
<b>Proposed Use</b>				Hours Pumped:		2				
Monitoring				<b>Lithologic Log</b>						
				Bore Diam	Depth (ft)		Material	Water		
					From	To		yes	no	
<b>Method Drilled</b>				10"	0	4	top soil		X	
Air rotary					4	10	brown sand		X	
					10	14	brown sandy clay		X	
<b>Well Construction</b>					14	18	brown sand		X	
Casing schedule	Diam	From (ft)	To (ft)		6"	18	24	brown sand		X
0.250 steel	6"	+2.5	6			24	32	brown clay		X
PVC	4"	+2	38			32	41	brown sand		X
s.s. screen	4"	38	58			41	56	brown sandy clay		
Was casing drive shoe used?      yes						56	62	sand & gravel	X	
Was a packer or seal used?						62		brown clay		
Perforated?										
Well screen installed?              yes										
Gravel packed?										
Surface seal depth?                  18'										
Materia used in seal?                bentonite										
Sealing procedure used?            overbore										
Method of joining casing										
<b>Location of Well</b>										
SW 1/4 NW 1/4 Sec. 3 T4N R1W				<b>Work Started:</b> 11/10/96		<b>Work Ended:</b> 11/11/96				

Plate 1  
Photo Date:  
5/1/72



Ponding

Feedlot

0.5 Miles

**Plate 2**  
**Photo Date:**  
**4/23/95**



0.5 Miles