Ground Water Quality Technical Report No. 14

Cumulative Impacts Assessment, Thousand Springs Area of the Eastern Snake River Plain, Idaho

State of Idaho
Department of Environmental Quality

July 2000

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation of the aquaculture industry, Idaho Power and Idaho State University and homeowners for sharing water quality data collected from springs and wells in the study area. Appreciation is also extended to Allan Wylie and Rodger Jensen , Idaho Water Resources Research Institute, who conducted a field tour and shared field information with the authors on flow characteristics of some of the major springs in the study area. The assistance of Gary Bahr and Mike Mitchell, Idaho State Department of Agriculture, and Ken Neely, Idaho Department of Water Resources who provided technical review of this document is greatly appreciated. Finally, thanks are extended to Steve Osborne, Derek Young and Alyssa Faaborg, DEQ for providing editorial review comments, graphics and final report preparation.

COVER PHOTO: Thousand Springs as it discharges from basalt of the Eastern Snake River Plain.

ABSTRACT

Nitrogen impacts to springs discharging from the Eastern Snake River Plain Aquifer along the reach from Thousand Springs to Clear Lakes were evaluated using two different ground water flow models (WhAEM and MODFLOW), statistical analysis of spring water quality data, and estimation of nitrogen loads from the sources within the study area. The purpose of this study was to evaluate nitrogen water quality data for springs which discharge along the north side of the Snake River canyon, from Clear Lakes to Thousand Springs. Objectives included estimation of ground water travel times, a delineation of the source area providing water to the springs, evaluation of sources of nitrogen to the aquifer supplying water to the springs and a statistical analysis of water quality data.

WhAEM model results identified areas of very rapid ground water flow in the aquifer, ranging from 100 to 180 feet per day. The highest velocities exist close to the Snake River where the hydraulic gradient steepens and the aquifer width is the smallest. The WhAEM model results indicated that the 10-year time of travel capture zone extended well to the east of the area of interest. The precision of the model simulation decreased with increasing time and distance. Therefore, the WhAEM simulation was limited to the 3-year time of travel capture zone. The simulation showed uniformly shaped time of travel zones, the result of uniform hydraulic conductivity, aquifer thickness and recharge rates which were used in the model.

To confirm the extremely high ground water flow velocities and also to more closely simulate actual hydrogeologic conditions, a simulation using MODFLOW was developed. Calibrated hydraulic conductivity, saturated aquifer thickness and recharge rates more closely matched actual aquifer conditions than for the WhAEM simulation, and the time of travel capture zones across the area of interest varied from less than six years in the northern part to more than 10 years in the southern part of the area. In general, the size of the capture zones were proportional to the spring discharge.

The MODFLOW results also fit well with the conceptual model of sources of recharge to the various springs as described by Clark and Ott (1996), who determined that water discharging from Crystal Springs and eastward is younger water derived primarily from recharge of surface water, either directly within the study area or as the primary source of ground water inflow from outside the model domain. Water in the central springs (Thousand, Box Canyon, Briggs) is older water derived mainly from recharge far upgradient of the study area. Water in the Malad Spring area is a mixture of younger surface water which leaks from the Big and Little Wood Rivers and older water similar to that described for the central springs.

An evaluation of potential nitrogen loads was conducted for sources within the WhAEM 3-year time of travel capture zone. The evaluation included five major sources. The sources and estimated percent contributions are as follows: commercial fertilizer (54 percent), cattle manure (combined dairy and beef - 42 percent), legume crops (2 percent), human waste (1 percent), and precipitation (1 percent). Data for number of beef cattle within the delineation area are believed to under represent actual numbers, so the estimated nitrogen contribution from cattle sources is probably low. The estimated total nitrogen load within the WhAEM

delineation area from the five sources is about 28 million pounds per year. The potential error of the estimates may be large due to uncertainty about the various sources.

An evaluation of trends for nitrogen sources was conducted using Idaho Agricultural Statistics and EPA data for nitrogen fertilizer, irrigated acreage and total number of animals for Gooding and Jerome Counties during the period 1985 to 2000. The evaluation indicates the following changes: nitrogen fertilizer use - 17 percent decrease for both counties during the period 1985 to 1991; irrigated acreage - 5 percent increase for Gooding County, 12 percent increase for Jerome County during the period 1987 to 1997; total number of cattle - 109 percent increase for Gooding County and 92 percent increase for Jerome County during the period 1986 to 2000.

A statistical analysis of nitrate+nitrite data from five springs (Box Canyon, Crystal Springs #1 and #2, Clear Spring and Niagara Springs) was conducted. The statistical results, using a linear regression analysis, indicate that nitrate+nitrite concentrations increased significantly for all five springs from 1991 or 1994 through 1999 at the 95 percent confidence level. linear regression analysis of data from the same season over several years was also conducted to minimize seasonality effects evident in the data. This analysis indicated that for Box Canyon, Niagara and Clear Springs, nitrate+nitrite concentrations increased significantly at the 95 percent confidence level for all four quarters. Crystal Spring #2 had a significant increase at the 95 percent confidence level in nitrate+nitrite concentration for three of four quarters through the period 1994 through 1999. At Crystal Spring #1 only one quarter out of four had a significant increase at the 95 percent confidence level in nitrate+nitrite concentration over time.

A liner regression analysis of long-term ground water nitrate+nitrate data was conducted for well 9S16E3ABC, located southwest of Jerome, where nitrate+nitrite data have been collected for 12 years. The regression results show that there is a statistically significant upward trend in nitrate+nitrite concentration at the 95 percent confidence level for this well. The mean nitrate+nitrite concentration in the well for 1990 was about 5.64 mg/l (n = 12), while the mean nitrate+nitrite concentration for 2000 is 9.22 mg/l (n = 9).

Most R^2 values for both spring and ground water quality data are less than 0.5, indicating that other factors such as seasonality effects, variation in nitrogen sources or variation of the concentration of an individual nitrogen source are occurring.

INTRODUCTION

Land use activities on the western part of the Eastern Snake River Plain (ESRP) have changed significantly over the past 10 years, and these changes may have the potential to degrade water quality to the point that treatment or alternate sources of drinking water may be needed. The primary land use activities in the area include irrigated agriculture, dairy and beef operations. The most important land use change in the western part of the ESRP is the increase in livestock over the past 10 years. The Department of Environmental Quality (DEQ) conducted a review of water quality data associated with springs which discharge from the Eastern Snake River Plain (ESRP) Aquifer along the reach of the Snake River from Clear Lakes to Thousand Springs to evaluate changes in water quality.

The primary contaminant of concern for the evaluation was nitrate plus nitrite as nitrogen. The Idaho Ground Water Quality Rule, adopted in 1997, established a Maximum Contaminant Level (MCL) of 10 milligrams per liter (mg/l) for nitrate plus nitrite (IDAPA 58.01.11). Nitrate is considered to be a conservative ion, in that it is transported though the unsaturated zone to the water table with little or no attenuation. Elevated levels of nitrate in ground water can serve as an indicator that other contaminants may be migrating to the water table.

One adverse health effect to humans exposed to nitrite or nitrate is a condition known as methemoglobinemia, which results in a reduced capacity of the blood to carry oxygen. Most methemoglobinemia health impacts have been observed in infants who have ingested nitrate-containing water used to prepare formula.

The Idaho Ground Water Quality Rule also states that appropriate actions should be taken when degradation of ground water quality occurs, even though numerical standards may not be exceeded (IDAPA 58.01.11, section 400).

PURPOSE AND OBJECTIVES

The purpose of this study was to evaluate nitrogen water quality data for springs which discharge along the north side of the Snake River canyon, from Clear Lakes to Thousand Springs. Objectives included estimation of ground water travel times, a delineation of the source area providing water to the springs, an evaluation of nitrogen sources within the delineation area and estimates of the total nitrogen load from the various sources. Two different ground water flow models were utilized to determine ground water travel times and areas of contribution to the springs. Sources of nitrogen were described and nitrogen loads from the various sources were estimated using methods similar to those used by Rupert (1996). A statistical analysis of water quality data from springs along the reach was conducted to analyze for trends in water quality

STUDY AREA

The study area includes the western half of Jerome County, the southeastern portion of

Gooding County and a portion of southwestern Lincoln county (Figure 1). The study area is bounded on the south and west by the Snake River, and on the north by the Little Wood River and Malad rivers. The eastern side of the study area is defined by a line which runs south from Shoshone to the Snake River.

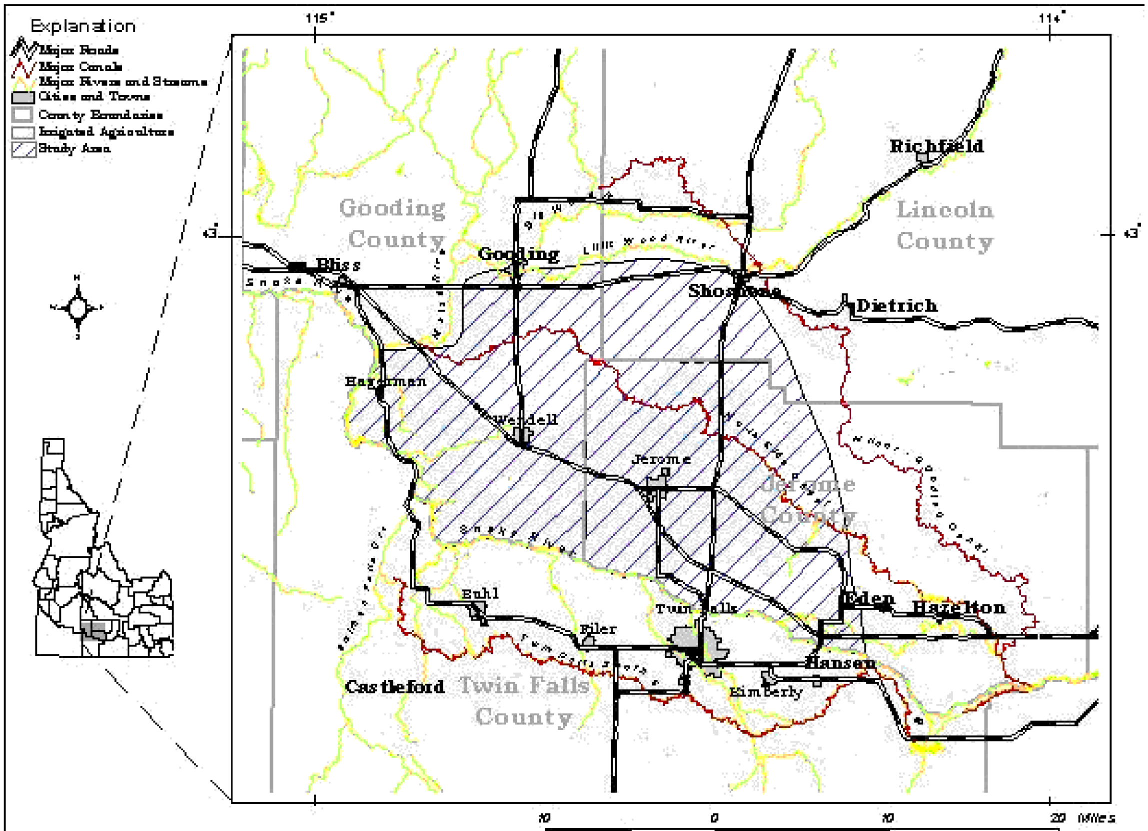


Figure 1. *Location of study area.*

Climate in the study area is semiarid; the average annual precipitation at Jerome for the period January 1961 through December 1990 was 10.76 inches (Western Regional Climate Center, 2000). Two major irrigation canals, the Milner-Gooding canal and the North Side canal, divert water from the Snake River at Milner Dam east of Twin Falls and traverse the study area. Both surface water and ground water are used for irrigation in the study area. Figure 2, a summer 1997 Landsat image, shows irrigated areas and the method of irrigation. From the image it is apparent that sprinkler irrigation predominates over flood irrigation. Figure 2 also shows the location of dairies in the study area and the location of major springs along the north canyon wall of the Snake River.

The study area lies within the western part of the Eastern Snake River Plain, a northeast-southwest trending structural feature. The uppermost rock unit within the study area is Quaternary age basalt flows of the Snake River Group. The total thickness of the basalt in the eastern part of the study area is estimated to be about 1,000 feet (Whitehead, 1992, plate 3). The basalt thins toward the west and is interbedded with and underlain by deposits of clay, silt, sand and gravel. The combined thickness of the sediments and basalt along the Snake River is probably 300 to 400 feet (Whitehead, 1992, plate 3). Data from a U.S. Geological Survey test well located about 12 miles northeast of Thousand Springs show that individual basalt flows average about 20 feet thick (Whitehead, 1992, Figure 12).

The sedimentary material was deposited in ancestral valleys of the Snake River within the study area. As individual basalt flows moved across the landscape, the valleys were dammed, causing the river to shift its course. Basalt formed pillow lava in water ponded behind basalt dams. In a survey of the north wall of the Snake River canyon from Milner to King Hill, Covington and Weaver (1990, 1991) determined that springs with the largest discharge issue from areas with pillow lava.

Springs along the north wall of the Snake River canyon are the regional discharge points for the Snake River Plain aquifer. Ground water in the aquifer generally moves from northeast to southwest, but within the study area the direction of movement is mostly east to west (Figure 3). The hydraulic gradient on the eastern side of the study area is about 0.005 and increases to about 0.016 near the discharge area along the Snake River.

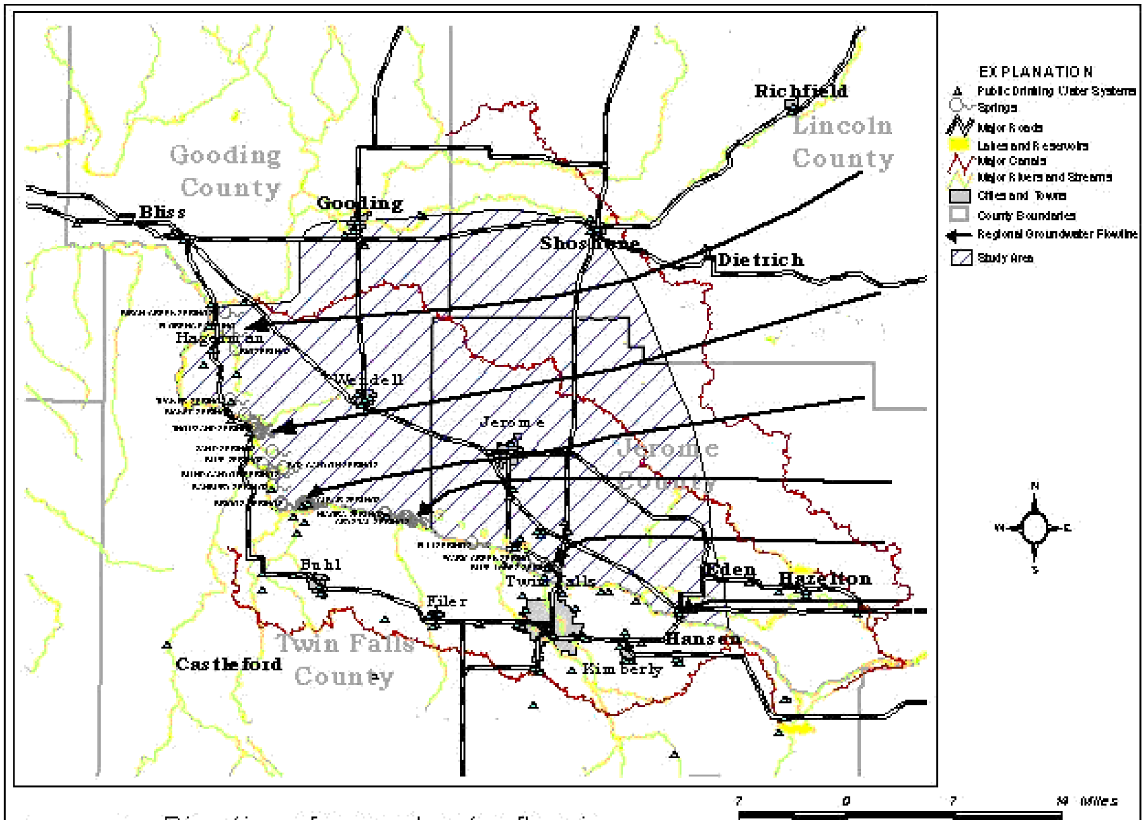


Figure 3. *Direction of ground water flow in the study area (from Clark and Ott, 1996).*

ANALYTICAL ELEMENT MODEL

The Wellhead Analytic Element Model (WhAEM 2000 for Windows) was used to estimate the source area providing ground water to the springs discharging from Clear Lakes through Thousand Springs. WhAEM is a public domain ground water flow model for capture zone delineation that was developed under contract with the EPA for Wellhead Protection and Source Water Assessment programs. There are typically two types of ground water models used in capture zone delineations: analytical and numerical. An analytical model uses simplified equations that have exact solutions. A numerical model approximates the partial differential equations describing groundwater flow and solute transport. Numerical models, though still simplifications of the actual hydrogeology, are typically much more complex than analytical models. Discussions held with personnel from the Idaho Department of Water Resources, U.S. Bureau of Reclamation, and the University of Idaho/Idaho Water Resources Research Institute determined it was appropriate to use an analytical model as an initial assessment. If the analytical model results compared well with observed data, then further modeling would not be necessary.

The conceptual hydrogeologic model of the aquifer was developed using data contained in USGS and IDWR publications. WhAEM requires that aquifer parameters (thickness, hydraulic conductivity, porosity, recharge, and base elevation) are constant throughout the model domain and do not change with time (steady-state conditions).

Model and Aquifer Parameters

A flux inspection line was used to calibrate the model to observed spring discharge. The flux inspection line extends from just north of Thousand Springs to just south of Clear Lakes Springs. A spring discharge of 3000 cfs (259,000,000 ft^3/day) was used in the simulation. This spring discharge value includes the discharge from Clear Lakes Springs through Thousand Springs (Covington and Weaver, 1991).

The aquifer parameters were varied within published ranges to match observed heads and to match flux. Different combinations of hydraulic conductivity, porosity, and aquifer thickness were used until the flux was matched. The combinations that decreased the time of travel distances were preferred. Less emphasis was placed on matching head values due to potential changes in water level elevations within the study area.

Hydraulic conductivity - The actual hydraulic conductivity varies significantly within the study area (see references below). A value of 6,300 feet/day was selected because it yielded reasonable results.

Garabedian, 1992	Ranges from 1,780 to 6,300 ft/day using 165 foot thick aquifer.
Moreland, 1976	Ranges from 810 to 24,000 ft/day using 165 foot thick aquifer.
Lindholm, 1993, Table 1	Ranges from 3,500 to 36,000 feet/day. Based on aquifer test data from wells in Gooding and Jerome Counties.
Whitehead & Lindholm, 1985	Approximately 4,000 feet/day

Effective Porosity - A porosity of 0.20 was used based on Ackerman, 1995. He used a porosity of 0.21 to calibrate his advective transport model of the Eastern Snake River Plain Aquifer. Ackerman cited a number of studies to support his porosity value. Additionally visual observation of basalt outcrops in the study (March 8, 2000), and review of more than 100 well logs indicate an abundance of high porosity zones.

Areal Recharge - An areal recharge value of approximately 1 foot per year (0.003 feet/day) was used. Garabedian (1992, Plate 8) indicates recharge within the study area ranged from 2 to 20 inches per year during 1976 to 1980.

Saturated Aquifer Thickness - An aquifer thickness of 165 feet was used in the final model. Garabedian (1992, Plate 5) estimates the aquifer ranges in thickness from 100 to 200 feet in the study area and is 100 feet thick at the western end. This thickness provides reasonable results.

Boundary Conditions

Western and Southern Boundaries - A constant head linesink with an elevation of 3,051 to 3,050 feet above mean sea level (amsl) was used to simulate the elevation of spring discharge along the east and north sides of the Snake River. The linesink extends from 1 mile east of Clear Lakes to approximately Hagerman. The elevations of the springs were determined from Covington and Weaver, 1991. The base of the aquifer is set at 3,050 feet amsl. A no-flow boundary was placed west and south of the linesink. The no-flow boundary extends from Hagerman to 2 miles east of Twin Falls.

Eastern Boundary - A constant head line source with an elevation of 3,850 to 3,851 feet amsl is placed approximately 20 miles east of the city of Jerome. The location of the constant head boundary is based on water level elevations reported by Garabedian, 1992 and the desire to keep the model within the Twin Falls 1:100,000 quad map.

Northern Boundary - Infinite areal extent was used at the northern boundary.

Additional Spring Discharges

Ground water wells were placed at the locations of Niagara Springs, Crystal Springs, and Blue Lakes Springs to simulate spring discharges at these locations. The withdrawal rates are:

- Blue Lakes Springs = 18,000,000 ft^3/day,
- Crystal Springs = 39,000,000 f^3/day, and
- Niagara Springs = 27,000,000 ft^3/day.

Model Calibration

The model was calibrated primarily to the spring discharge from Clear Lakes through Thousand Springs. Head values at eight locations monitored by the USGS also were used to help calibrate the model, but to a lesser degree. No combination of aquifer parameters yields a solution with differences of less than 75 feet between the observed and modeled water level elevations at all eight locations. The differences between the observed heads and the modeled heads are smallest within 5 or 6 miles of the springs, indicating that the model parameters provide a reasonable representation of aquifer conditions in this area.

Numerous simulations were performed to evaluate the impact of aquifer parameters (aquifer thickness, hydraulic conductivity, and recharge) on head distribution and spring discharge (Figures 4-9). The best fit to observed head conditions occurred with a no-recharge scenario (Figure 4). In the no-recharge scenario, all modeled head values were within 100 feet or less of the observed heads. However, this scenario underestimated the spring discharge by approximately 10 percent. Increasing the areal recharge to 1 foot per year caused the spring discharge to increase to the observed value, but it also resulted in a greater difference in the modeled head versus the observed heads. No difference in ground water velocity was observed between the no-recharge and recharge scenarios. Because much of the study area is irrigated, and to maintain consistency with the USGS model by Garabedian (1992), the simulation with areal recharge was selected as the preferred scenario (Figure 9).

<u>Model Results</u>

Initially, the intent of the simulation was to identify the 10-year time of travel capture zone for the springs. However, preliminary model runs showed the 10-year time of travel extending well beyond the area of interest. Additionally, the precision of the WhAEM model decreases with increasing time and distance from the springs due to increasing hydrogeologic variability. To decrease the inaccuracy of the model, the simulation was limited to a 3-year time of travel with 1-, 2- and 3-year time of travel boundaries.

The results of the simulations indicate ground water near the Snake River Canyon is moving toward the springs at an extremely fast rate of approximately 180 feet per day within the 1-year time of travel zone. The ground water velocity decreases with increasing distance from the springs, due to a lower ground water gradient. The average ground water velocity in the 2-year to 3-year time of travel zone is 100 feet per day. The average ground water velocity during the entire 3-year time of travel is estimated to be 135 feet per day. To confirm this incredibly high ground water velocity, a more robust numerical model simulation was conducted.

The final 3-year time of travel capture zones (wellhead protection areas) estimated by the WhAEM simulations were aligned to reflect the results of the Groundwater Modeling System (GMS) simulations (discussed below). The spring-specific capture zones, shown on Figure 10, should only be considered approximations due to uncertainties in the model input parameters.

NUMERICAL SIMULATION

The goal of this numerical modeling exercise was to refine and improve the results produced by the WhAEM model. The GMS software package was used to verify the WhAEM simulations. GMS consists of a graphical user interface and a number of numerical ground water models, including MODFLOW and MODPATH. Numerical models use approximations (e.g. finite differences, or finite elements) to solve the differential equations describing groundwater flow or solute transport. The approximations require that the model domain and time be discretized. In this discretization process, the model domain is represented by a network or grid cells or elements, and the time of the simulation is represented by time steps. The accuracy of numerical models depends upon the accuracy of the model input data, the size of the space and time discretization (the greater the discretization steps the greater the possible error), and the numerical method used to solve the model equations.

Numerical Model Overview

Two numerical models were selected to refine the source water delineations and time of travel capture zones developed using the Analytic Element method: the United States Geological Survey flow model MODFLOW (McDonald and Harbaugh, 1988) and the particle-tracking model MODPATH (Pollack, 1994), as implemented in the GMS software distributed by BOSS International, Inc.

The conceptual hydrogeologic model of the aquifer is identical to that described previously: an unconfined multilayer aquifer system in fractured basaltic media with springs providing the primary discharge points for the uppermost layers. Because of the difficulty of clearly delineating the various aquifer layers on geological evidence, most previous models of the Eastern Snake Plain aquifer have arbitrarily defined certain zones of saturated thickness for their model layers. The present model retains this convention and focuses on the upper 200-300 feet of saturated thickness as that which provides the bulk of water to the springs.

Given the modeling and calibration process used and the assumptions made, the solution presented represents a non-unique solution. A different combination for various aquifer properties could likely produce an equally well-calibrated simulation with different calibrated values of these properties and with varying results for capture zones and travel times. The level of uncertainty in this regard is not quantified. While it is not possible to describe the aquifer properties with complete certainty, this model provides our best scientific estimate given the available data.

Model and Aquifer Parameters

Several changes were made to the model domain used in the WhAEM model. The model domain was extended to the north to include several significant springs north of Thousand Springs that had the potential to alter ground water flow patterns. These include the Big/Billingsley/Bickel spring complex and Malad springs. In order to accommodate the flow of these additional springs, model boundary conditions to the north were simulated as specified head. Zones of hydraulic conductivity, recharge, and aquifer bottom elevation were developed to attempt to account for the variability of these parameters across the mode domain. In addition, all springs were modeled as discrete discharge areas.

The flow model was calibrated, primarily through the adjustment of the hydraulic conductivity distribution, aquifer bottom elevation and, to a lesser extent, surface water-supplied recharge areas, to contoured potentiometric head values. These contours were derived from observed water level measurements from 1980 (Garabedian, 1992). The calibration process also attempted to match estimates of surface recharge and ground water pumpage occurring within the model domain (Maupin, 1997).

The results of the calibrated flow model were then used in MODPATH to generate pathlines and times of travel zones from each of the spring groups modeled. Particles were placed in the fixed discharge cells representing the lateral extent of each of the spring groups and tracked backward for up to 10 years.

The discharge of the springs included in the model are presented in Table 1. Some springs in close proximity to one another were grouped together. Discharge data for the various springs are from USGS sources (Covington and Weaver, 1990, 1991).

Table 1. Modeled discharge of selected spring groups.

Spring Group	Discharge (ft^3/day)
Malad	106,253,000
Billingsley, Big, Tucker, and Bickel	28,345,900
Thousand	130,257,000
Box Canyon, Blueheart, and Sand	79,778,000
Briggs and Banbury	20,544,600
Clear	42,713,000
Crystal and Niagara	66,011,000
Blue Lakes	18,285,400
Devil's Corral/Washbow	6,212,800
Total Discharge All Springs	498,436,000 (5769 cfs)

Hydraulic conductivity – Hydraulic conductivity zones were developed based on the calibrated steady-state transmissivity distribution of Moreland (1976). Initial hydraulic conductivity values for these zones were also derived from Moreland (1976), assuming a saturated thickness of 200 feet, similar to that assumed by Garabedian (1992). Hydraulic conductivity values in the delineated zones were then adjusted manually during the calibration process. The range of final calibrated hydraulic conductivity values was 328 to 9840 ft/day. Specific values for each zone are presented in Figure 11. These values generally agree with those used or measured in other studies referenced earlier.

Effective Porosity - 0.20 –This estimate is based on the work of Ackerman (1995) as described in the earlier WhAEM modeling section.

Areal Recharge – Zones of recharge were developed based on the map of land use and source of irrigation water in Rupert (1997, Figure 6). Three zones were developed representing native rangeland, irrigated agriculture supplied by ground water pumpage, and irrigated agriculture supplied by surface water diversions. These zones and associated final calibrated model values are presented in Figure 12.

Total recharge estimates for the study area and starting values for irrigated agricultural zones were based on estimates of water withdrawal, consumptive use, and conveyance losses for surface water and ground water irrigated areas taken from Maupin (1997). Native rangeland recharge rates were taken from Garabedian (1992) and were 1 inch per year (0.084 feet per year). Recharge rate values were adjusted as part of the calibration process. It was assumed that irrigated areas supplied by ground water experienced a net loss of water from the aquifer due to consumptive use by crops using sprinkler irrigation. Recharge rate estimates for irrigated areas supplied by surface water include canal conveyance losses.

The estimated total recharge or removal from the aquifer for surface water or ground water supplied irrigated agriculture in the study area was calculated by adjusting the total volume of surface water withdrawals in Gooding, Jerome, and Lincoln counties for 1992 from Maupin (1997, Table 7) by the fraction of surface water or ground water irrigated land present in each county in the model domain compared to total county acreages presented by Maupin (1997, Table 3).

Simulated recharge to the aquifer from surface water supplied areas in the final flow budget (Table 2) represented 122 percent of the estimated total recharge for surface-supplied irrigated acreage in the study area. Simulated removals from the aquifer from ground water pumping and sprinkler irrigation were 93 percent of estimated withdrawals. Contributions from rangeland were considered insignificant and were included with surface water supplied agricultural land recharge.

Saturated Aquifer Thickness - Using a stepped series of zones of aquifer bottom elevation (Figure 13) along with the final simulated head values (Figure 14) resulted in aquifer thickness varying from about 150 to 300 feet. Garabedian (1992, Plate 5) estimates the aquifer ranges in thickness from 100 to 200 feet in the study area and is 100 feet thick at the western end.

Boundary conditions

The general location of boundary conditions for the modeled domain is shown in Figure 15.

Western and Southern Boundary - Individual springs were modeled using wells in groups of cells with a cumulative specified discharge equal to the measured discharge. A cumulative spring discharge of 498,436,000 ft3/day (5769 cfs) was used in the simulation. This spring discharge value includes the discharge of major springs from Devil's Corral Springs through Malad Springs (Covington and Weaver, 1990a, 1990b, 1991 and Moreland, 1976) and is similar to measured discharge from the springs from the late 1980's (Clark and Ott, 1998). Areas between these specified discharge areas were modeled with no-flow boundary conditions.

Eastern Boundary - A constant head boundary with an elevation of 3,800 feet amsl was placed in the location where potentiometric contours with this water level elevation have been reported in several earlier studies (Garabedian, 1992 and Moreland, 1976), about 14 miles east of the City of Jerome.

Northern Boundary - The majority of the northern boundary was modeled using a specified head. The head specified along this boundary varied from 3800 to 3200 feet based on measured water level elevations. The objective of using a specified head condition along this border was to provide additional inflow to the model domain that represents leakage from the Big Wood and Little Wood River and inflow from the Snake Plain Aquifer outside the model domain. The remaining western portion of this boundary, not accounted for by the fixed discharge cells representing Malad Springs, was modeled as no flow.

Model Results

Flow Simulation - Table 2 presents a summary of the water budget for the final calibrated flow simulation. Excellent balance was achieved between inflows and outflows. It can be seen that, over the entire study domain, ground water inflows from outside the study area are the dominant source of water input and approximately balance the amount of water discharged at the springs. If more localized regions of the study area, such as the capture zones of individual springs, are examined the flow budget components will have different proportions. For example, surface recharge will be more dominant in the budgets of the southern springs.

Table 2. Water budget for the Box Canyon MODFLOW flow simulation.
(All values expressed as cubic feet per day.)

	In	Out
Storage	0.0	0.0
Constant Head	5.789E+8	1.470E+8
Wells	0.0	4.988E+8
Recharge	7.932E+7	1.249E+7
Total	6.582E+8	6.582E+8
In - Out	0.0	
Percent Discrepancy	0.0	

Figure 14 illustrates the final simulated calibrated isocontour values of the potentiometric surface compared to contoured values based on water level observations from 1980 obtained from the Idaho Department of Water Resources GIS web site. The overall shape and configuration of the water table is reproduced with simulated water levels tending t be somewhat higher than observed water levels.

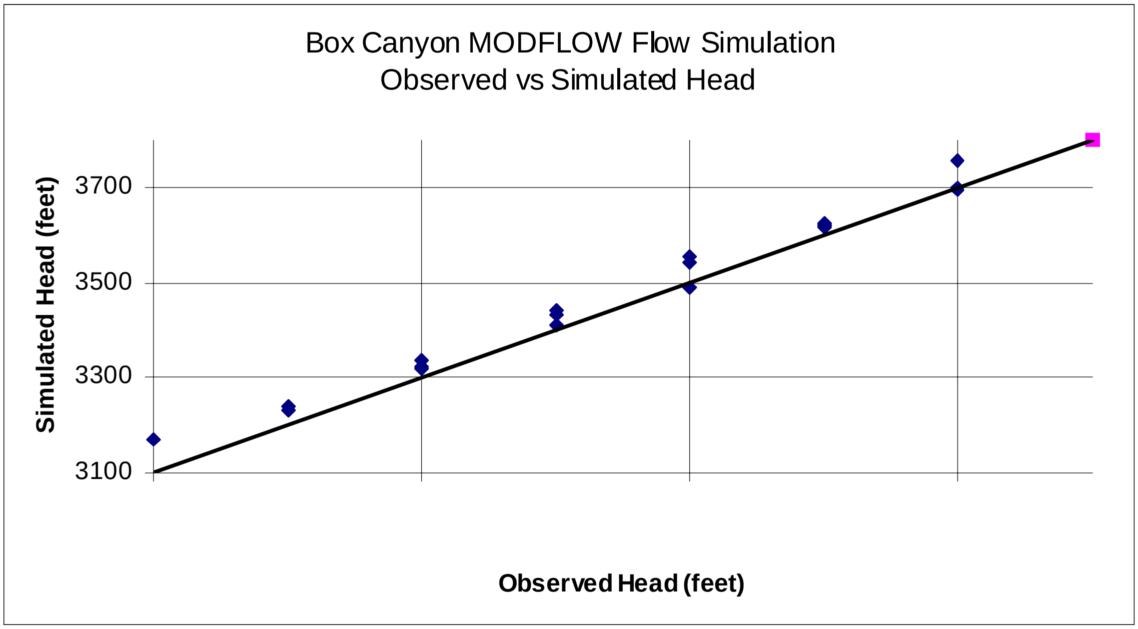


Figure 16. Box Canyon MODFLOW flow simulation, simulated versus observed heads for selected observation points in the study area.

This trend is also illustrated by a plot of simulated versus observed water levels for selected observation points from the 1980 contours (Figure 16). The mean error in heads was 25 feet. Two areas with large discrepancies occur near Thousand Springs and in the far southeastern portion of the study area (Figure 14).

<u>Time of Travel Capture Zones</u>

The results of the MODPATH particle tracking of ground water backward from the points o spring discharge were simplified and are presented as 0 to 3, 3 to 6, and 6 to 10 year time o travel capture zones in Figure 15. It can be seen that time of travel zones for springs discharging in the upper three-quarters of the study area do not exceed six years, while times of travel for portions of Crystal springs, Blue Lakes and Devil's Corral springs to the eastern edge of the model domain exceed ten years. A more realistic result, different from that of the WhAEM model, is that the sizes of capture zones are generally proportional to the magnitude of discharge at the various springs.

Ground water velocities for the various springs ranged over an order of magnitude from about 10 to 130 feet per day

Table 3. Ground water velocity estimates (feet per day) for various springs, based on MODFLOW results.

Spring/Spring Group	Ground water velocity (ft/day)
Malad, Thousand, Briggs/Banbury and Box/Blueheart/Sand	120-130
Big/Billingsley/Bickel	75
Clear	110
Crystal/Niagara	25-100
Blue Lakes	15
Devil's Corra	10

While the results of this numerical modeling effort illustrate the variability in ground water velocities which likely occur across the study area, they support the very high velocities (up to 180 feet per day) estimated by the WhAEM modeling, especially in the northern three-quarters of the study area.

The segregation of springs by velocity as well as the shape and orientation of their capture zones fits well with the conceptual model of the sources of recharge to the various springs as described by Clark and Ott (1996), based on isotope and other chemical sampling results along with evaluation of stream flow and discharge data. Water discharging from Crystal Springs and eastward is postulated to be younger water derived primarily from recharge of surface water, either directly within the study area or as the primary source of ground water inflow from outside the model domain. Water at the central springs (Thousand, Box Canyon, Briggs) is older water derived primarily from mountain recharge far upgradient of the study area. Water in the Malad Spring area is a mixture of younger water recharged from leakage from the Big and Little Wood rivers and older water similar to that described for the central springs.

The GMS simulation provides a more accurate depiction of ground water flow because the aquifer parameters vary within the model domain to reflect spatially variable hydrogeologic conditions. Thus, the data input requirements are more intensive. The aquifer parameters used in GMS were consistent with the simulation used by Moreland (1976) to describe ground water flow in the Snake River Plain Aquifer. The ground water flow velocity and flow direction calculated by GMS were very similar to the WhAEM results. Differences in flow direction were evident beyond the one-year time of travel boundary. The GMS ground water flow paths were aligned in a more east to west direction as compared to a northeast to southwest flow direction estimated by WhAEM.

NITROGEN LOADING EVALUATION

One of the objectives of this report was to evaluate the various sources of nitrogen within the WhAEM model delineation area (Figure 10) and to prepare estimates of the total load of nitrogen from these sources for 1999. The WhAEM delineation results show the one-, two- and three-year time of travel zones for ground water moving from the eastern side of the delineation area to a spring discharge area along the north wall of the Snake River canyon. The area included within all three time of travel zones was used for the nitrogen source estimates.

Rupert (1996) developed a nutrient budget for the upper Snake River Basin, an area which extends from Yellowstone Park in Wyoming to King Hill and includes 35,800 square miles. In that study, the following sources and percent of total nitrogen load were estimated: domestic septic systems (1 percent), precipitation (6 percent), cattle manure (29 percent), fertilizer (45 percent), and legume crops (19 percent). The same nitrogen sources and conversion factors used in the upper Snake River Basin study were used to evaluate loads for the WhAEM delineation area. The following sections describe the various nitrogen sources, methods used to estimate nitrogen loads from each source for 1999 and the estimated nitrogen loads. Tables 4-10 list the various sources of nitrogen in the delineation area and the estimated load from each source.

Crop Nitrogen Requirements - Actual commercial fertilizer application rates are not available for cropland in Idaho, and so nitrogen application rates were estimated by calculating the amount of nitrogen fertilizer that should be applied to the eight major crops (alfalfa, barley, corn, wheat, dry beans, beets, potatoes and oats) by following the University of Idaho fertilizer guides (Tindall, 1991). A GIS coverage developed by DEQ indicates that there are about 163,400 irrigated acres in the delineation area. Irrigated acreage for the eight major crops grown in Gooding and Jerome Counties and the total irrigated acreage in the two counties were determined from Idaho Agricultural Statistics Services (IASS) data. Irrigated acres of the eight major crops within the delineation area were then determined by proportion.

The amount of nitrogen fertilizer applied to each crop was estimated by using University of Idaho fertilizer guides and the reported crop yields (IASS data) for the major crops. A soil test nitrogen value of 20 milligram/kilogram (mg/kg) was assumed to determine the nitrogen application rate for each crop. The estimated acreage for each crop within the delineation area and the estimated nitrogen requirement by crop is shown in Table 4. The estimated crop nitrogen requirement in the delineation area is 15,220,000 pounds (7,610 tons) of nitrogen per year. The estimated crop nitrogen requirement divided by the irrigated acreage within the delineation area (163,400 acres) gives an average nitrogen application rate of about 93 pounds per acre.

Table 4. Estimated crop nitrogen requirements, WhAEM delineation area.

Estimated Crop Nitrogen Requirement, Delineation Area

Crop acreage: Crop	Crop Year	Gooding (acres)	Jerome (acres)	Total Acres	UoI Fertilizer Guide (lbs/acre)	Nitrogen	Yield Goal
Alfalfa	1998	37300	41900	79200	Alfalfa	0	6 tons/ac
Barley	1999	2300	12400	14700	Barley	150	100 bu/ac
Corn	1998	23000	19200	42200	Corn	200	25 t/acre
Wheat (all)	1999	7700	20900	28600	Wheat	200	100 b/ac
Dry Beans	1998	1700	13300	15000	Beans	50	2200 lbs/a
Beets	1998	5200	15100	20300	Beets	75	25 t/acre
Potatoes	1998	14000	16000	30000	Potatoes	160	400 cwt/ac
Oats	1999	1500	3000	4500	Oats (1)	150	100 bu/ac
					Pasture	75	
Crop Totals		92700	141800				
Total Irr Acreage		154400	204700	**359100**			

Fertilizer application rates for all crops were estimated based on the following soil test values: N=20 mg/kg, P=10 mg/kg, K=100 mg/kg.

(1) - Used same fertilizer guide as barley

Total irrigated acres in delineation area = **163360**

Crop	Delineation Acreage	Nitrogen Reqmt (lbs)
Alfalfa	36029	0
Barley	6687	1003089
Corn	19197	3839488
Wheat (all)	13011	2602118
Dry Beans	6824	341187
Beets	9235	692609
Potatoes	13647	2183595
Oats	2047	307068
Pasture	56684	4251300
Total Ac	163362	15220455
Total N Requirement		**15,220,000** lbs

Table 4 shows that there is a difference of about 56,700 acres between the total irrigated acreage in the WhAEM delineation area (163,400 acres) and the 8 major irrigated crops in the delineation area (106,700 acres). This difference amounts to about 35 percent of the total irrigated acreage; the 56,700 acres may be used as pasture land, or the acreage may be used for other crops. For the purposes of this study it was assumed that this acreage was planted to pasture. The University of Idaho Fertilizer Guide states that irrigated pasture responds well to a nitrogen application of up to 150 pounds per acre nitrogen (Tindal, 1991); for this evaluation a value of 75 pounds nitrogen per acre was chosen to calculate nitrogen applications to the 56,700 acres. The application rate of 75 pounds per acre represents a midrange value of the recommended nitrogen application rate, and also accounts for nitrogen deposition from grazing animals.

No credit was taken for nitrogen in manure applied to irrigated crop land in the delineation area. If producers are considering the nitrogen content in manure as they should, then the commercial fertilizer requirement for crops grown in the WhAEM delineation area would be reduced. The estimated nitrogen fertilizer application to irrigated farmland in the WhAEM delineation area is about 93 pounds per acre.

An independent estimate of nitrogen fertilizer use in the area can be derived from county fertilizer estimates (EPA, 1990) and irrigated acreage for the same period (IASS, 2000). summary of fertilizer data from 1985 through 1989 for the upper Snake River Basin is available in Rupert (1994, Table 1); data for Gooding and Jerome Counties are summarized in the following table.

Table 5. Estimated annual nitrogen fertilizer use in Gooding and Jerome Counties, 1985-89 (from Rupert, 1994).

County	Nitrogen Use by Year (tons)				
	1985	1986	1987	1988	1989
Gooding	4364	3786	3779	3810	4220
Jerome	6530	5665	5655	5701	6315

Total irrigated acreage for Gooding and Jerome Counties (IASS, 2000) was 107,793 acres and 135,272 acres respectively for 1987. These data show an average annual nitrogen application of about 70 and 84 pounds per irrigated acre for Gooding and Jerome Counties, respectively, compared with the above estimate of about 93 pounds per acre for the WhAEM delineation area.

Domestic and Urban Nitrogen Sources - The 1990 Census data (Idaho Department of Commerce, 1992) show the population within the delineation was 22,245 persons. This population includes a rural component as well as urban dwellers living in the cities of Jerome and Wendell. The city of Jerome has a NPDES permit which allows the city to treat and discharge treated municipal wastewater to a manmade waterway which flows to the

Snake River. This nitrogen source is therefore transported out of the area.

The city of Wendell treats municipal wastewater in five lagoons and land applies the treated wastewater to 43 acres of pasture under a DEQ Wastewater Land Application Permit. The most recent report states that the annual nitrogen load to the land application site is 117 pounds per acre for a nitrogen load of approximately 5,000 pounds per year (DEQ Wastewater Land Application permit files).

DEQ data indicate that wastewater treated in facultative lagoons has a total nitrogen load of about 0.02 pounds of nitrogen per person per day. The nitrogen load in domestic wastewater is estimated to range from 0.01 to 0.04 pounds per person per day (U.S. Environmental Agency, 1980). The nitrogen factor of 0.04 pounds of nitrogen per person per day and the total population within the delineation area was used to estimate the total nitrogen load of 324,800 pounds per year from human sources in the delineation area (Table 6). This calculation probably overestimates nitrogen input from human sources by choosing the higher domestic nitrogen loading factor and also by including the city of Jerome load that is actually removed from the area. The calculations do not include nitrogen fertilizer applications to lawns in the urban areas of Wendell and Jerome.

Table 6. Domestic and urban nitrogen contribution in the WhAEM delineation area

	Delineation Area Population	Human Nitrogen Contribution (lbs/person/day)	Total Human N Contribution (lbs/day/yr)	Total Human N Contribution (lbs/year)
Rural Jerome and Gooding Counties	15,012	0.04	600.48	219,175
Urban Jerome and Gooding Counties	7233	0.04	289.32	105,601
Total	22,245	0.04	889.8	**324,776**

Livestock Sources of Nitrogen - Nitrogen contribution in the delineation area was estimated for both dairy and beef cattle. The number of milking dairy cows in the delineation area for 1999 was obtained from a DEQ GIS coverage; the number of milking dairy cows was multiplied by a factor of 0.25 to estimate the number of dry dairy cows and heifers and calves in the delineation area. The total number of dairy cows was then multiplied by a factor of 90 lbs nitrogen per cow per year to give an estimated nitrogen load of 11,129,900 pounds per year. The nitrogen generation factor per dairy cow was selected as the midrange from several sources including ISDA nutrient management plans, The American Society of Agricultural Engineers (ASAE, 1998), Natural Resources Conservation Service Agricultural Waste Management Field Handbook and Overcash, Humenik and Miner (1983, vol. I and II). This estimate represents total nitrogen remaining after storage, handling and spreading losses. The estimate assumes that manure application rates and mineralization from organic to inorganic forms of nitrogen in the delineation area are at steady state.

Estimates were made for nitrogen contribution from classes of cattle other than dairy animals. Idaho Agricultural Statistics Service data (2000) list two additional classes of cattle: beef cows that have calved and "other cattle" which includes calves, bulls, steers and heifers. The total of these two classes of cattle was 164,500 head in Gooding and Jerome Counties for 1999. The only non-dairy cattle information available for the delineation area was a DEQ GIS coverage which shows about 15,800 head of beef cattle. Although this number probably seriously underestimates the number of cattle other than dairy cows in the delineation area, it was the best number available at the time of the study. Therefore, nitrogen contribution from cattle other than dairy animals was estimated by multiplying 15,800 head of beef cattle by a factor of 40 pounds of nitrogen per head per year. The estimated nitrogen load from this source is 632,000 pounds per year.

Table 7. Nitrogen contribution from cattle in the WhAEM delineation area

Cattle Type	Number of Cattle	Estimated N Contributi (lbs/cow/year)	Total N (lbs)
Dairy Cattle (Milkers)	98,932	90	8,903,900
Dairy Cattle (Dry)[1]	24,733	90	2,226,000
Beef Cattle	15,800	40	632,000
Total All Cattle	139,465	--	**11,761,900**

[1] Also includes dairy heifers and calves

Precipitation - Total nitrogen deposited by precipitation in the delineation area was estimated using the same methods employed by Rupert (1996, p. 6). The following equation includes the factors used to estimate total nitrogen input from precipitation (modified from Rupert, 1996):

$$B = (E \times Q \times I) \times D,$$

where

B = total nitrogen input from precipitation, in kilograms;
E = total nitrogen concentration in precipitation, in milligrams per liter;
Q = annual rainfall, in meters;
I = land area within WhAEM delineation area, in square meters; and
D = dry deposition constant (unitless).

Maupin (1995) estimated total nitrogen concentration in precipitation for the upper Snake River Basin to range from 0.18 to 0.27 mg/l. The midrange concentration of 0.225 mg/l total nitrogen in precipitation was used to calculate nitrogen loading from precipitation in the delineation area. The 29-year precipitation average of 10.76 inches at Jerome was multiplied by 0.225 mg/l total nitrogen to estimate the nitrogen contribution from precipitation. The estimated nitrogen contribution from precipitation is 201,700 pounds per year.

Legume Crops - Nitrogen contribution from plow down of legume crops (alfalfa and beans) was estimated by multiplying the acreage for each crop by a factor of 60 pounds per acre for alfalfa and 40 pound per acre for beans (Tindall, 1991). The alfalfa and bean acreage within the delineation area was assumed to be in proportion to the total alfalfa and bean acreage in Gooding and Jerome Counties. It was assumed that one quarter of the legume acreage would be rotated out each year, so one quarter of the total nitrogen load from legume crops (2,434,800 pounds) would be contributed each year. The estimated nitrogen contribution from these two sources is 608,700 pounds per year (Table 8).

Table 8. Legume crop nitrogen contribution in the WhAEM delineation area

Crop	Acres	N contribution (lbs/acre)	Total Nitrogen (lbs)
Alfalfa	36,029	60	2,161,800
Beans	6824	40	273,000
Total Legumes	42,853	100	**2,434,800**

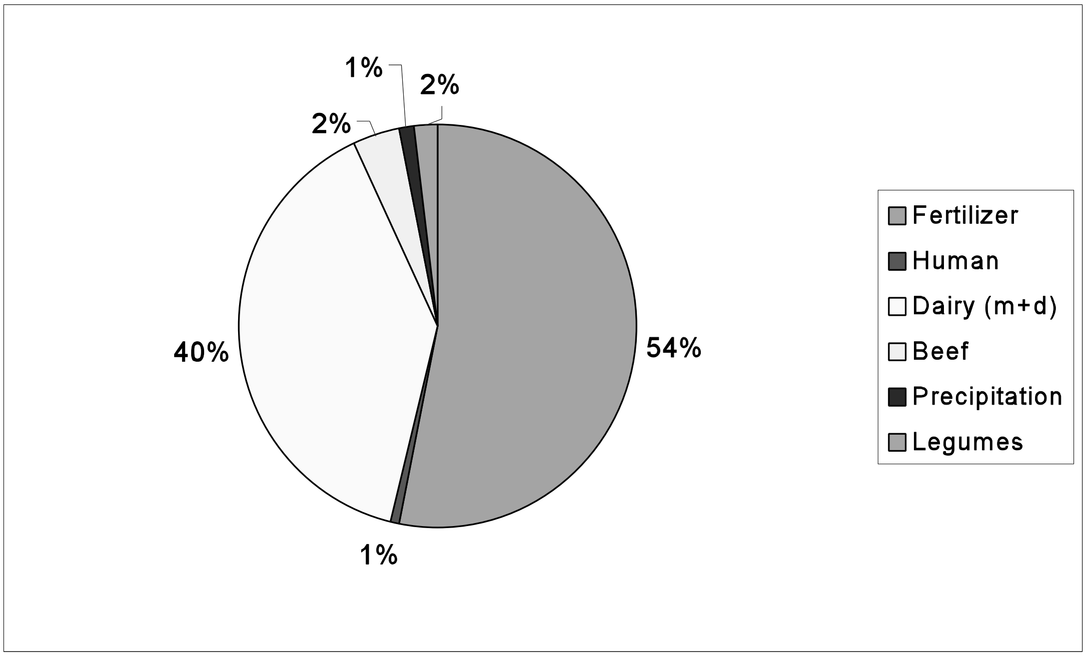
Wastewater Land Application - There is one wastewater land application site in the delineation area. The City of Wendell land applies wastewater to 43 acres of pasture under a Wastewater Land Application Permit issued by DEQ. For purposes of simplification, the nitrogen load from this segment of the population was included in the human sources of nitrogen section. Domestic wastewater contains a larger concentration of nitrogen than treated municipal wastewater, so including the Wendell nitrogen source with the domestic nitrogen load probably overestimates nitrogen loading from human sources.

Table 9. Total estimated nitrogen contribution in the WhAEM delineated area

Source	Nitrogen (lbs)	Percent Contribution
Fertilizer	15,220,000	54.0
Human	324,800	1.0
Dairy (milkers, drys, heifers and calves)	11,129,900	40.0
Beef	632,000	2.0
Precipitation	201,700	1.0
Legumes	608,700	2.0
Total	**28,117,100**	100.0

A graphical summary of the above nitrogen estimates (Figure 17) shows that commercial fertilizer, cattle (dairy - milking and dry cows, and beef animals) and legume sources account for about 98 percent of the nitrogen load in the WhAEM delineation area. As more accurate estimates of nitrogen contribution from the various sources become available, the relative percentage contributed from each source would be expected to change.

Figure 17. Percentage estimates of nitrogen load from various sources in Box Canyon delineation area



Nitrogen Load Trends

Impacts to ground water quality, either increasing or decreasing trends, may not be evident due to the transit time of pollutants through the vadose zone to the water table. In addition, once pollutants reach the water table, the travel time in ground water to the point of use can vary depending on ground water flow velocities and the location of the point of use relative to pollutant sources. Therefore, it is worthwhile to review trends for areas overlying the aquifer which have the potential to impact groundwater quality. The preceding nitrogen load analysis shows that the major sources of nitrogen in the study area are from fertilizer and livestock sources. In order to address potential trends, these two nitrogen sources should be compared to the irrigated acreage over the same period. If the irrigated acreage and nitrogen sources remain the same, then the nitrogen load per acre should be constant; changes in irrigated acreage and/or nitrogen load will result in an increase or decrease in nitrogen on a per acre basis.

Although data are not available for these three factors for the delineation area, county level data for irrigated acreage and total number of animals are available (Idaho Agricultural Statistics Service, 2000). As discussed above, estimates of nitrogen fertilizer use on a county level basis also are available during the period from 1985 through 1991 (EPA, 1990). Table 10 shows nitrogen fertilizer use, irrigated acreage and animal data which are available during the period 1985 to 2000, while Figure 18 shows a graphical presentation of the same factors over the period.

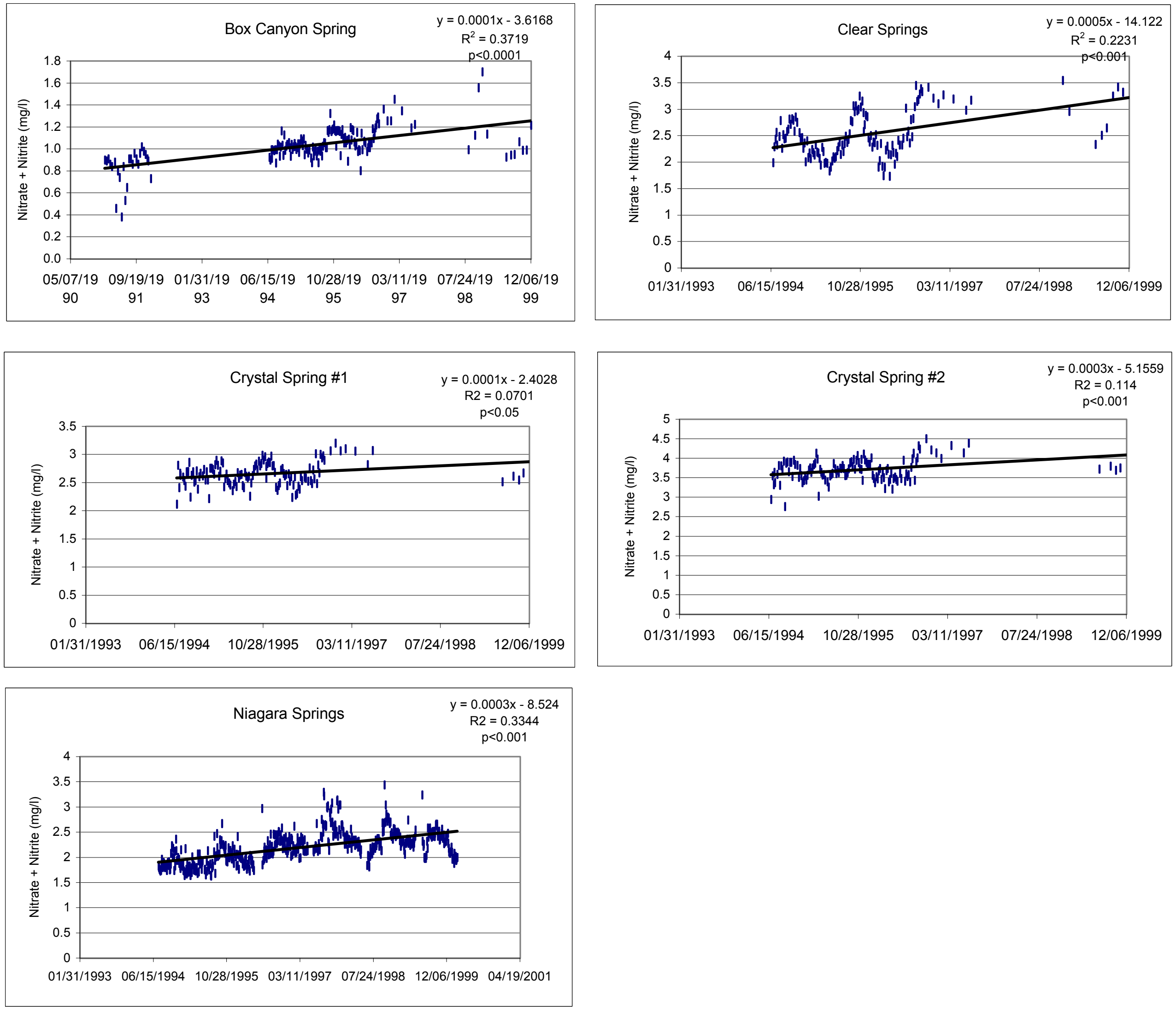
Table 10. Estimated nitrogen fertilizer use, irrigated acreage and total cattle, Jerome and Gooding Counties, 1985-2000

	Jerome County			Gooding County		
Year	Nitrogen Fertilizer Use (tons)	Irrigated Acreage	Total # of Cattle (IASS)	Nitrogen Fertilizer Use (tons)	Irrigated Acreage	Total # of Cattle (IASS)
1985	6530			4364		
1986	5665		82000	3786		76000
1987	5655	135272	70000	3779	107793	65000
1988	5701			3810		
1989	6315		70000	4220		78000
1990			74000			82000
1991	5437		81000	3633		90000
1992		150444	89000		115398	97000
1993			90000			102000
1994			93500			112500
1995			109000			130000
1996			116000			133500
1997		151726	122000		112665	138000
1998			133500			140000
1999			137500			141500
2000			157500			158000

Estimated nitrogen fertilizer use decreased by 17 percent for both Gooding and Jerome counties from 1985 to 1991, while irrigated acreage increased by five percent for Gooding County and 12 percent for Jerome County over the period 1987 to 1997. Taken together, these data indicate that nitrogen fertilizer application decreased on a per acre basis during the late 1980s in Gooding and Jerome Counties. Data are not available to analyze fertilizer application rates during the 1990s.

The total number of animals in Gooding County has increased by 92 percent for the period 1986 to 2000, while the total number of animals has increased by 108 percent in Jerome County during the same period (Table 11 and Figure 18). The change in nitrogen load associated with the increased number of animals in the two counties is difficult to estimate since the number of animals in a given weight class is unknown. On a pounds per acre basis, an overall increase in nitrogen load from cattle sources probably has occurred in the two counties over the past ten to 15 years. The slight increase in irrigated acreage from

Figure 18. Regressions for the complete data sets for Box Canyon, Clear Springs, Crystal Spring #1 and #2, and Niagara Springs.



1987 to 1997 (up to 12 percent) is probably more than offset by nitrogen generated by the increased cattle numbers from 1985 to 2000 (up to 108 percent).

STATISTICAL ANALYSIS OF NITROGEN DATA

Potential ground water contamination has been a major concern to the citizens in south-central Idaho for several years. The level of concern by the citizens has increased as the land use above the aquifer for dairy and animal feeding operations has intensified. Several ground water studies have been conducted on the Snake River aquifer. Most of the studies have concluded that nitrate+nitrite is elevated in the groundwater of Gooding and Jerome Counties. These previous studies, however, were conducted over a limited time frame, typically one to two years.

The purpose of this part of the study was to analyze water quality data that had been collected over a sufficiently long time frame at regular intervals to determine if changes in nitrate+nitrite concentration are occurring and, if a trend was evident, at what rate it was increasing or decreasing. DEQ was able to locate sufficient data for regression analysis on five springs in Gooding and Jerome Counties: Box Canyon Spring, Crystal Spring #1 and #2, Clear Spring, and Niagara Springs. Long-term ground water nitrate+nitrate data are available for one well located in the delineation area, southwest of Jerome. Data have been collected from this well starting in 1989 and continuing to the present.

Data Analysis

The spring data used in this analysis was collected by the aquaculture industry, Idaho Power, and Idaho State University (ISU). The aquaculture industry began sampling nitrate+nitrite levels in these springs in the summer of 1994 due to concerns that nitrate levels would become a permit condition in upcoming NPDES permit renewals. These entities are also dependent on the discharge of good quality water from springs in the study area. The Box Canyon, Crystal Springs #1 and #2, and Clear Spring samples were collected and analyzed using accepted procedures by a local lab. The lab follows EPA protocols and conducts periodic Quality Assurance/Quality Control (QA/QC) on all of their samples. Sampling frequency was reduced in 1997 due to a redirection of resources by the aquaculture industry. The number of data points ranged from about 50 samples at Box Canyon Springs during 1995 to 5 to 10 samples per year at other springs. These spring water quality data allow for a more robust analysis of ground water trends than data from monitoring wells where samples may be collected once every one to three years.

Niagara Springs data has been collected from 1994 to the present by Idaho Power at the Niagara Springs fish hatchery. The Niagara Springs samples were sent to Alchem Laboratories, Inc., Boise, Idaho, and Rangen's Laboratory for analysis. Idaho Power collects the samples following accepted procedures and conducts periodic QA/QC.

The ISU data were collected by Dr. Chuck Brockway in 1991 and 1992 as part of a water quality study funded by DEQ. The samples were sent to the Idaho Bureau of Labs. The samples were collected following accepted procedures and 10% of the samples had

QA/QC run on them. The data used in this analysis are available upon request from the DEQ Twin Falls Regional Office.

Because the spring sampling intervals were not consistent within the study period, a formal trend analysis could not be performed. The data were, however, sufficient for DEQ to conduct several regression analyses. The first analysis conducted was a linear regression analysis on each of the five springs. In all cases, there was a statistically significant upward trend in nitrate+nitrite concentrations from 1991 or 1994 through 1999, at the 95 percent confidence level.

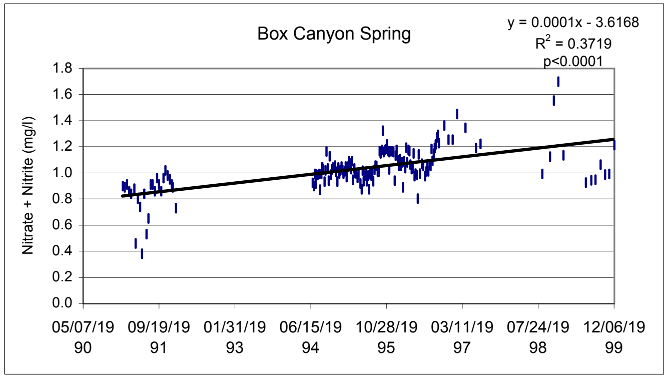
For the springs, visual inspection of the data reveals that the nitrate+nitrite concentrations exhibited some periodicity or seasonality (Figure 19). This seasonality could result in the erroneous conclusion that a trend exists when in fact the trend is only an artifact of sampling frequency. To determine if the increase in nitrate+nitrite was an artifact of sampling frequency a regression analysis was conducted by calendar quarter, so only data collected in the same calendar quarters were regressed against data for the six-year period. The calendar quarters were January - March, April - June, July - September and October - December. Analyzing the data by calendar quarter should minimize or eliminate any effect of sampling frequency on the analysis. Although analyzing data from similar calendar quarters may eliminate the effect of seasonality on the data analysis, it also decreases the power of the statistical test due to the smaller sample size.

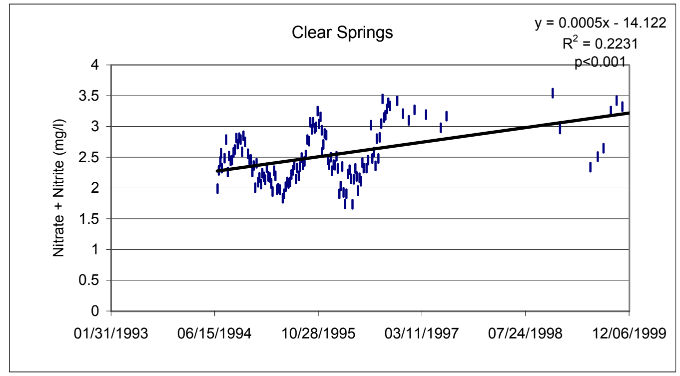
The quarter-by-quarter analysis of the Box Canyon, Niagara, and Clear Springs data indicated that there were significant increases in nitrate+nitrite through time for all four quarters (Figures 20, 21, and 22). Crystal Spring #2 had a significant increase in nitrate+nitrite through time for three out of the four quarters (Figure 23). At Crystal Spring #1 only one quarter out of the four had a significant increase over time (Figure 24).

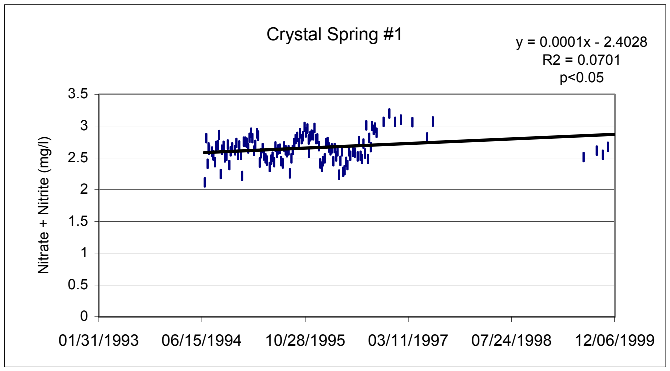
A total of 146 nitrate+nitrite data points from the well located at Township 9 South, Range 16 East, Section 3ABC (9S16E3ABC) were available for statistical evaluation. The drillers log indicates the well is 170 feet deep and has casing set to 143 feet below land surface. There is a casing seal to a depth of 18 feet below land surface. The subsurface material at the well consists of top soil from 0 to 9 feet, basalt from 9 to 163 feet, and sand and gravel from 163 to 170 feet. The well was drilled in 1977 and the depth to water reported on the drillers log was 138 feet below land surface. On June 17, 1991 the depth to water was measured by DEQ at 143.09 feet below land surface. Water samples for nitrate-nitrogen analysis were collected from the well by the owner after the well had been pumping for some time. The samples were collected in sample bottles supplied by DEQ and analyzed at the Idaho Bureau Of Laboratories in Boise, Idaho. From 1 to 25 samples per year were collected from the well over a 12 year period.

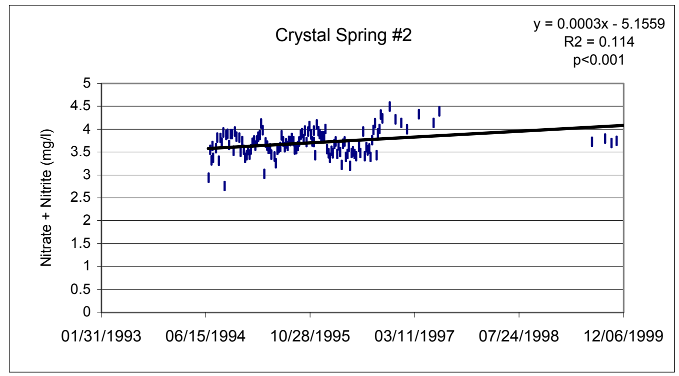
In addition to nitrate+nitrite sample analysis, ISDA collected a sample from the well on February 2000 for analysis of the stable isotope of nitrogen, ^{15}N. (For a summary of nitrogen isotope analysis and its use in evaluation of nitrogen sources in ground water, the reader is referred to Howarth, 1999 and Seiler, 1996.) The sample was analyzed at the Water Sciences Laboratory at the University of Nebraska-Lincoln, using Method N15IRMS.0002 -

Figure 19. Regressions for the complete data sets for Box Canyon, Clear Springs, Crystal Spring #1 and #2, and Niagara Springs.









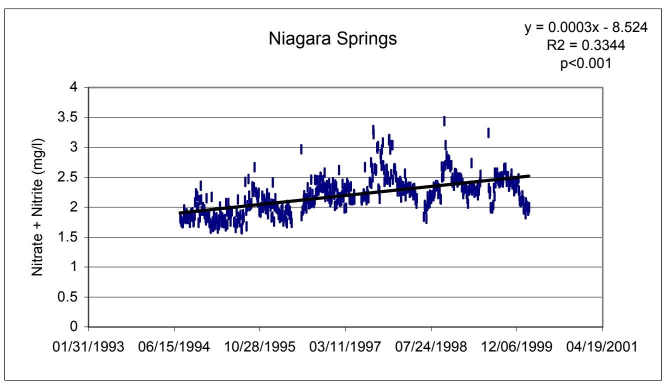


Figure 20. Box Canyon regressions by quarter.

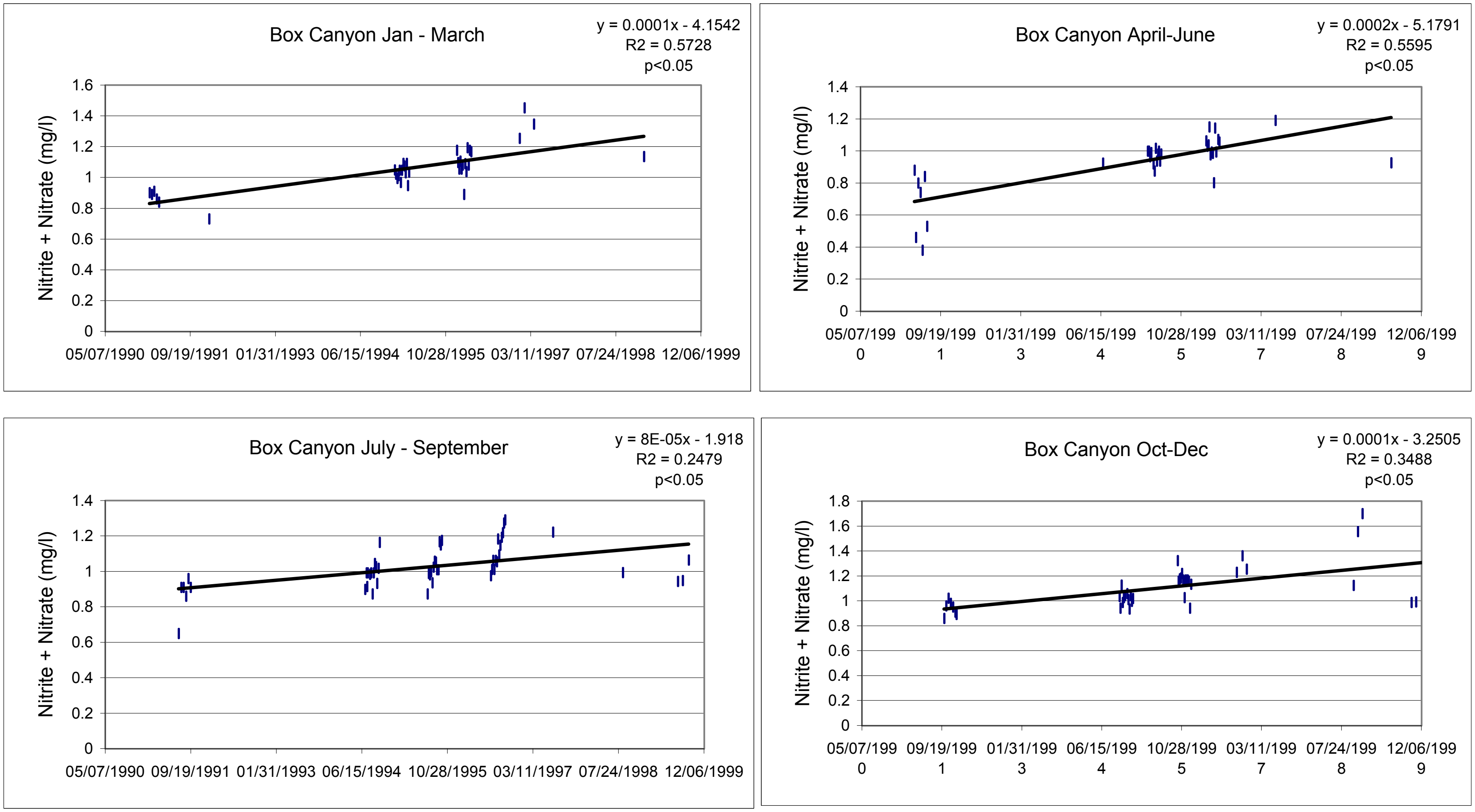


Figure 21. Niagara Springs regressions by quarter.

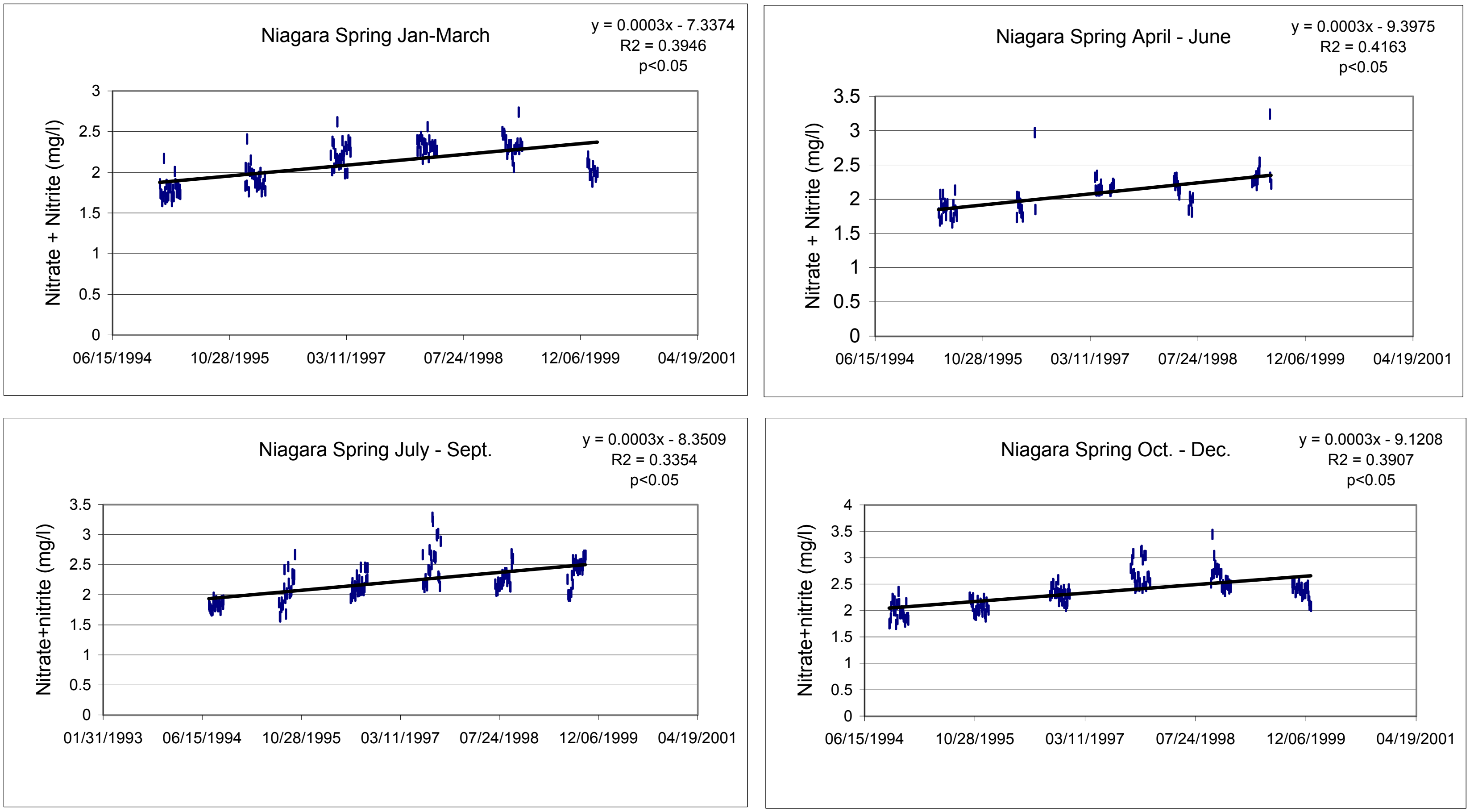
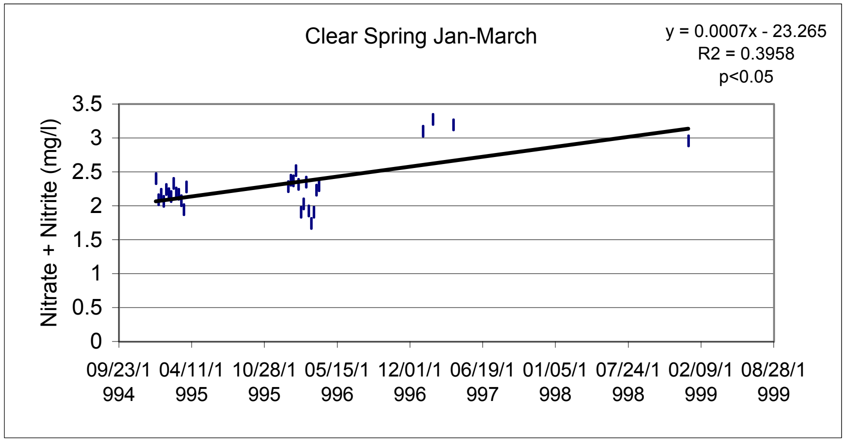
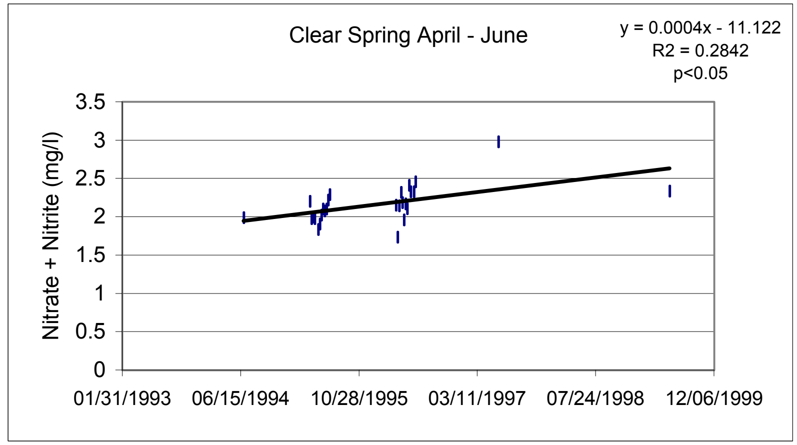
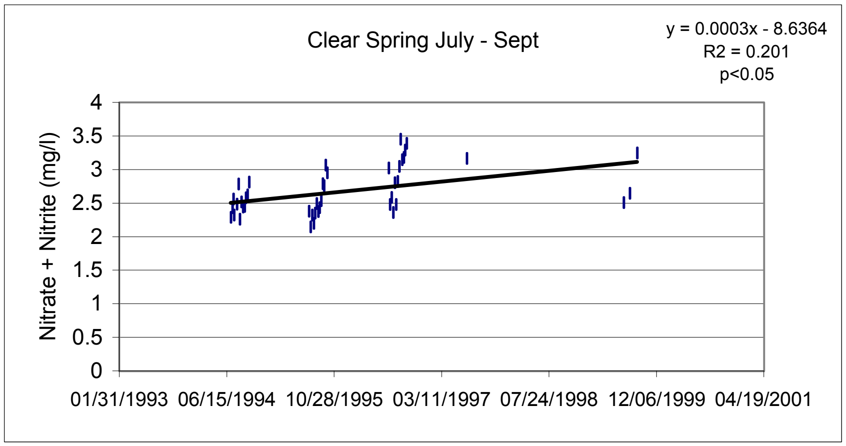


Figure 22. Clear Springs regressions by quarter.







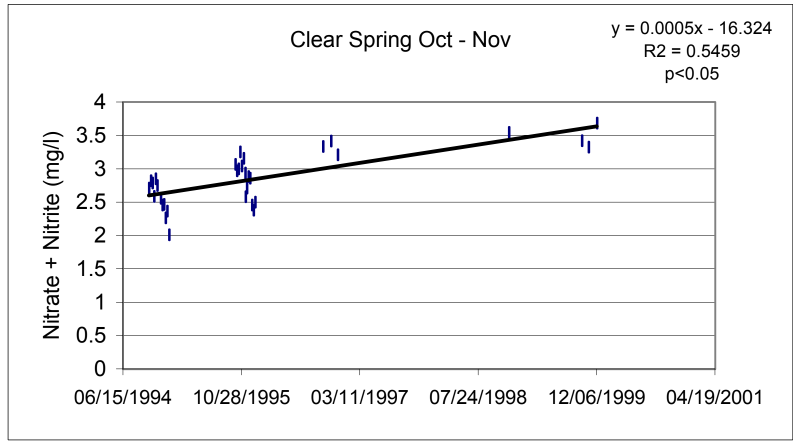


Figure 23. Crystal Spring #2 regresssions by quarter.

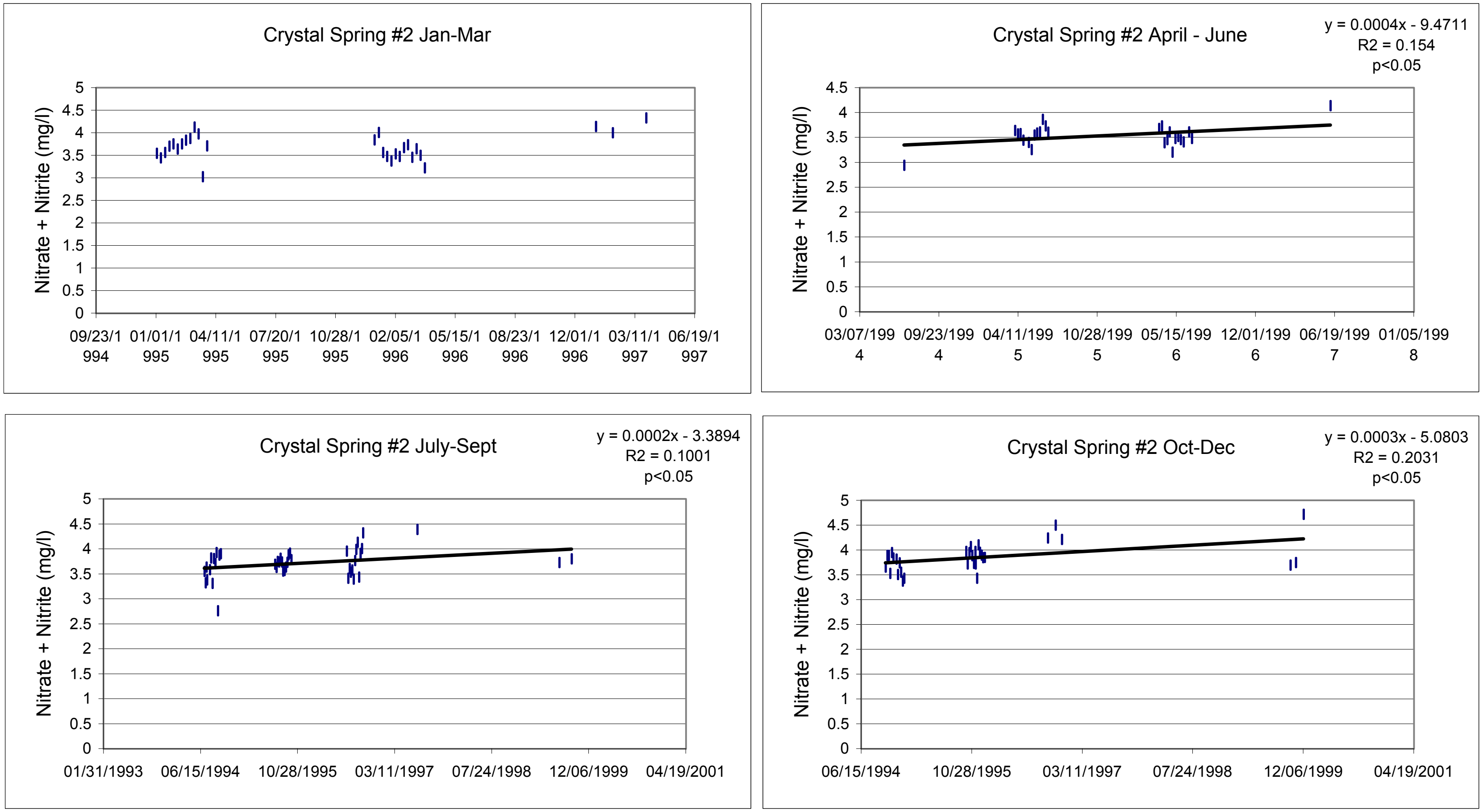
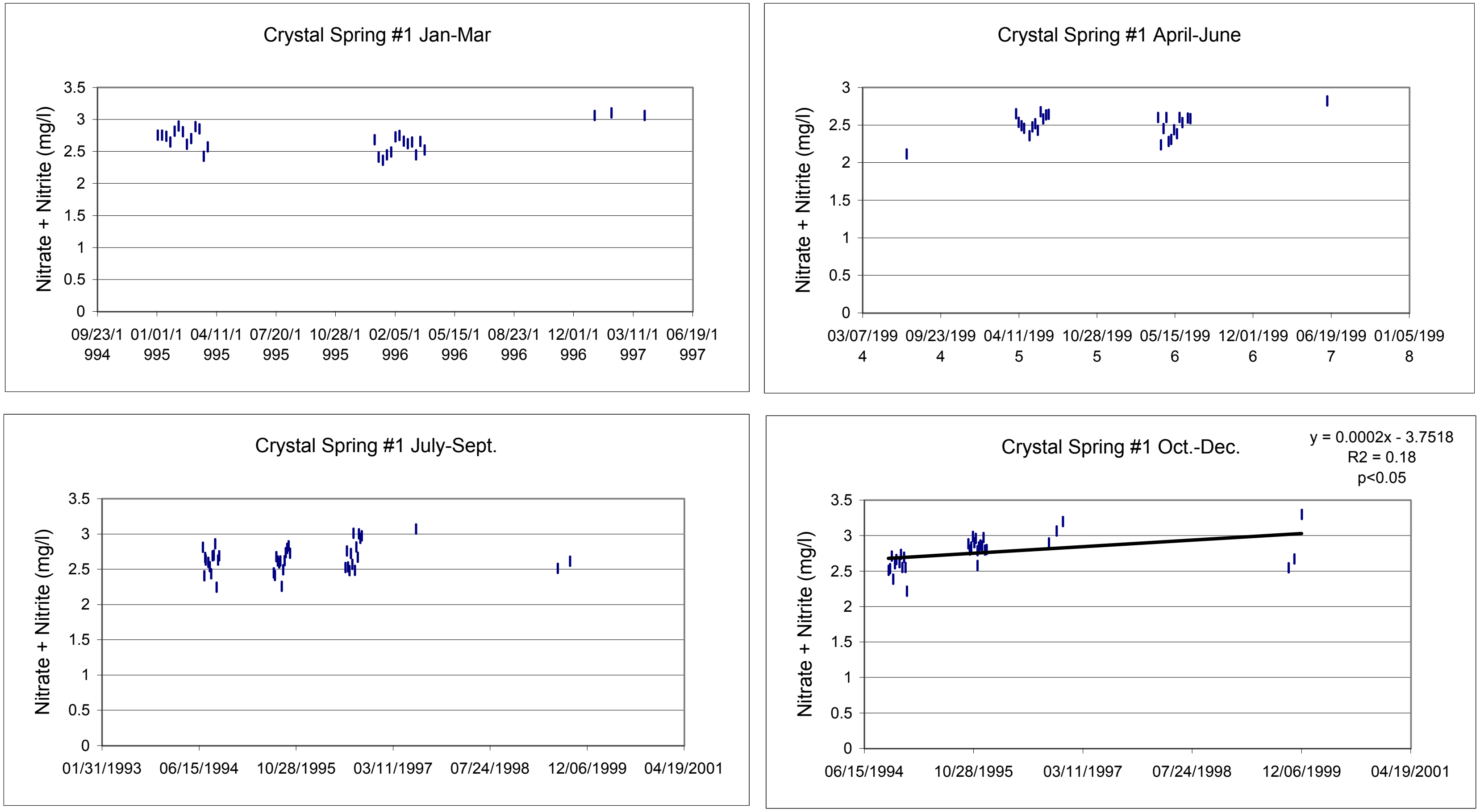


Figure 24. Crystal Spring #1 regressions by quarter.



Isotope Ratio Mass Spectrometric analysis. The lab returned an $\delta^{15}N$ value of 8.90 ‰, which indicates an organic nitrogen source, either from plant residue, animal or human waste. Typical δ^{15} N values are listed in Table 12. The δ^{15} N value from the domestic well indicates that neither commercial nitrogen fertilizer nor precipitation is the source of the nitrogen in the well water.

Table 11. Typical δ^{15} N values.

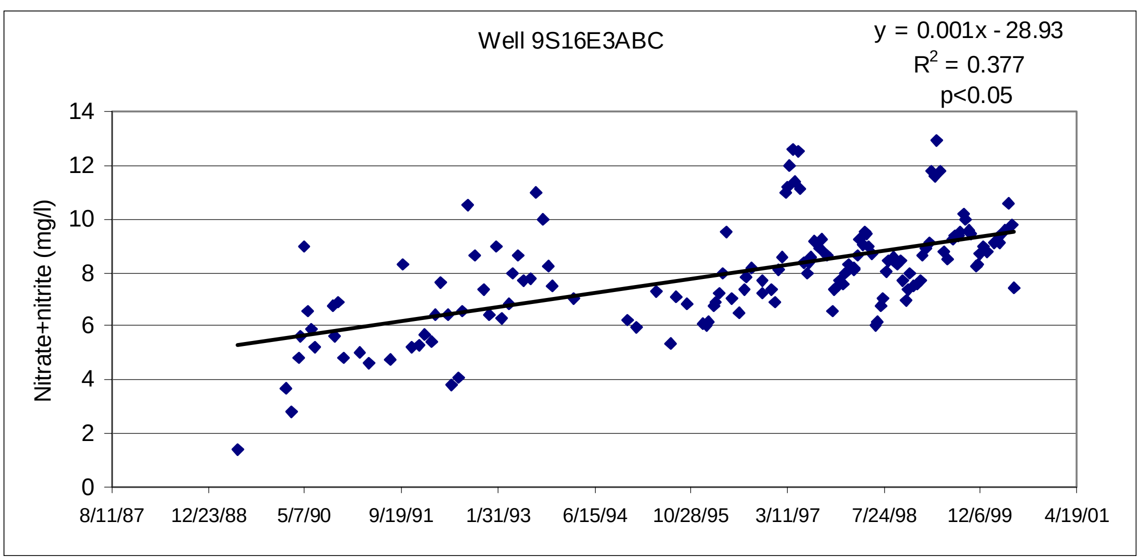
Potential Contaminant Source	$\delta^{15}N$ (‰)
Commercial fertilizer	-4 to +4
Animal or human waste	Greater than +10
Precipitation	-3
Organic nitrogen in soil	+4 to +9

(after Seiler, 1996)

A dye tracer test of the septic tank at the residence where the well is located, conducted from March 1997 through November 1998, indicated that effluent from the septic tank at the residence is not the source of the elevated nitrogen in the well.

A linear regression analysis was conducted on the nitrate data from well 9S16E3ABC. The regression results show that there is a statistically significant upward trend in nitrate+nitrite concentration at the 95 percent confidence level (Figure 25). The mean nitrate+nitrite concentration in the well for 1990 was about 5.64 mg/l (n = 12), while the mean nitrate+nitrite concentration for 2000 is 9.22 mg/l (n = 9).

Figure 25. Regression for the complete data set for well 9S16E3ABC.



The data indicate that there may be

seasonal variations in the data, so a linear regression analysis was conducted on the data set on a calender quarter basis in the same manner as the spring water quality regression analysis. This analysis showed that for all four calender quarters there has been a significant increase in nitrate+nitrite concentrations at the 95 percent confidence level.

The R^2 value (coefficient of determination) associated with each data plot is the fraction of the total variation in nitrate+nitrite concentration that can be accounted for by the association between nitrate+nitrite and sample. The value can vary between zero and one. Most R^2 values for both spring and ground water quality data are less than 0.5, indicating that other factors such as seasonality effects or variation in nitrogen sources or the concentration of an individual nitrogen source are occurring.

Discussion

The analysis performed in this paper indicates that a statistically significant upward trend in nitrate+nitrite concentrations exists in 4 of the 5 springs (Box Canyon, Niagara, Clear Springs and Crystal Springs #2). The fifth spring (Crystal Spring #1) may also have an upward trend but due to the variability in the data and the low number of sample points only one of the four calendar quarters had a statistically significant upward trend. This analysis also indicates that the rate of nitrate+nitrite increase is not consistent between quarters. The second quarter had the greatest increase in both Box Canyon and Crystal Spring #2, whereas the first and fourth quarters had a greater positive slope for Clear Springs.

DEQ has established an action level for areas where concentrations of nitrate + nitrite reach 5 mg/l and also exhibit an upward trend. In an attempt to determine when a spring may reach the action level of 5 mg/l the regressions were extended until the action level was intercepted. Table 13 gives the year that the limit would be reached for the quarter with the greatest slope and the quarter with the shallowest slope. The predicted dates for reaching the action level assume that the amount of nitrate+nitrite being introduced into the ground water will continue to increase at the same rate. It is possible that the slopes of the lines may increase or decrease, thereby making these predictions inaccurate.

Table 13. Estimated date when nitrate+nitrite concentrations will reach 5 mg/l. The estimate assumes that the rate of increase does not change from current levels.

Spring Name	Earliest Date[1]	Latest Date[2]
Clear Springs	2005	2015
Crystal Springs #2	2006	2013
Niagara Springs	2019	2027
Box Cany Springs	2058	2124
Crystal Springs #1	2028	NA

[1]Based on quarters with the steepest slopes.

[2]Based on quarters with the shallowest slopes.

Two of the springs (Clear Springs and Crystal Springs #2) could reach a concentration of 5 mg/l nitrate+nitrite within 5 to 6 years, whereas the remaining springs may not reach a concentration of 5 mg/l for 20 to 120 years. Even though some of the springs may not reach the action level for several decades this should not mean that there is not a significant concern. These springs' increases in nitrate+nitrite may accelerate, making these long term predictions an underestimate of the severity of the problem.

Well 9S16E3ABC is located within the 0 to 3 year time of travel zone, as predicted by the MODFLOW flow simulation. The well lies on a ground water flow path that contributes water to the Crystal Springs/Niagara Springs complex. Recharge to ground water feeding these springs is postulated to be from primarily from surface water, and isotopic evidence indicates that the water is young relative to the central springs (Thousand, Box Canyon, Briggs). The nitrate+nitrite concentrations in water discharging from Crystal Springs/Niagara Springs was about 2.4 mg/l in 1994 (Clark and Ott, 1996), while the nitrate+nitrite concentration from two samples from well 9S16E3ABC averaged 6.7 mg/l for 1994. This difference probably reflects the fact that water samples from the springs reflect a composite of the entire saturated thickness of the aquifer while the well withdraws water from the upper part of the aquifer.

This analysis points out the need to develop a plan that will decrease nitrates in the springs. This plan should include long-term monitoring to track the nitrate+nitrite levels in the springs in this region. An extended monitoring record will help to confirm the trends found in this analysis. The analysis also points out the need to install properly constructed ground water monitoring wells which sample the uppermost part of the aquifer. Mixing in ground water flow systems is more dominant in the horizontal rather than in the vertical direction, and therefore contaminants entering an aquifer tend to remain in the uppermost part of an aquifer. Wells withdrawing water from deeper in the aquifer will record lower contaminant concentrations than ones completed in the uppermost part of the aquifer, and therefore impacts to an aquifer will be underestimated.

This analysis also suggests that there may be an overabundance of nitrogen being applied to areas upgradient of the springs. A more detailed analysis of nitrogen inputs, nitrogen cycling and ground water transport should be done to determine the level of nitrogen that can be safely applied to lands above and upgradient of these springs.

CONCLUSIONS AND RECOMMENDATIONS

Concerns about nitrogen impacts to ground water in the western portion of the Eastern Snake Plain aquifer prompted an analysis of water quality data for springs discharging from the north canyon wall of the Snake River from Clear Lakes Springs to Thousand Springs. Land use activities, including agricultural activity and animal industry operations, have the potential to generate significant nitrogen loads, which if not managed properly can impair ground water quality.

The study included ground water flow simulation using two different modeling methods, analysis of sources of nitrogen within the study area, and a statistical evaluation of water quality data from spring samples. The ground water flow models WhAEM and MODFLOW were used to simulate ground water movement in the study area. Based on data published in USGS and IDWR reports, a conceptual model of the aquifer was developed: that is, an unconfined multilayer aquifer system in fractured basalt with most discharge occurring from springs in the uppermost layers. Aquifer parameters used in both model simulations were taken from previously published modeling reports.

The most reasonable scenario selected for the WhAEM model evaluation included a simulation with areal recharge of about 1 foot per year, a hydraulic conductivity of 6,300 feet per day, an aquifer thickness of 165 feet and an effective porosity of 0.20. Model predicted heads were in fair agreement with measured heads; no combination of aquifer parameters yielded solution differences of less than 75 feet between predicted and measured heads.

Preliminary model results indicated that ground water flow velocities are extremely rapid, especially in the western part of the study area, so the simulation was limited to the area included within the 3-year time of travel. This convention helped reduce the inaccuracy of the model results since the model precision decreased with increasing time and distance from the springs. The WhAEM model results indicate ground water flow velocities range from 100 feet per day in the 3-year time of travel area to as much as 180 feet per day in the 1-year time of travel area. These ground water travel velocities are a factor of 10 to 20 higher than any previously reported for ground water flow systems in Idaho, so a more robust numerical model simulation using MODFLOW was conducted to confirm the WhAEM results.

The same conceptual hydrogeologic model used for the WhAEM simulation was used for the MODFLOW simulation. Changes made to the WhAEM model domain included extension of the model boundary to the north to account for several significant springs, simulation of the northern boundary as a specified head boundary and treating all springs as discrete discharge areas. Also, zones of hydraulic conductivity, recharge and aquifer bottom elevation were developed to account for the variable aquifer properties observed in the study area.

Calibrated hydraulic conductivity values ranged from 328 to 9,840 ft/day and a porosity value of 0.2 was used throughout the model domain. Saturated aquifer thickness varied from about 300 feet on the east to about 150 feet in the western part of the model domain. MODFLOW model results were imported into MODPATH to generate flow lines and time of travel zones for each of the major spring groups modeled. Time of travel results were simplified into three general time of travel capture zones: 0 to 3, 3 to 6, and 6 to 10 years. A general observation is that the size of each capture zone is generally proportional to the magnitude of discharge at the various springs. Estimated ground water velocities for springs included in the mode domain are shown in Table 14.

Table 14. Ground water flow velocities (in feet per day) estimated from MODFLOW model results.

Spring/Spring Group	Ground water velocity (ft/day)
Malad, Thousand, Briggs/Banbury and Box/Blueheart/Sand	120-130
Big/Billingsley/Bickel	75
Clear	110
Crystal/Niagara	25-100
Blue Lakes	15
Devil's Corral	10

The variable ground water flow velocities reflect the variable hydraulic conductivity values which are known to exist across the study area. The higher ground water flow velocities support the large flow velocities estimated by the WhAEM modeling efforts. The MODFLOW/MODPATH model results also fit well with the conceptual model of sources of recharge to the various springs as described by Clark and Ott (1996). Water discharging from Crystal Springs and eastward is believed to be younger water derived primarily from recharge of surface water, either directly within the study area or as the primary source of ground water inflow from outside the model domain. Water in the central springs (Thousand, Box Canyon, Briggs) is older water derived mainly from recharge far upgradient of the study area. Water in the Malad Spring area is a mixture of younger surface water which leaks from the Big and Little Wood Rivers and older water similar to that described for the central springs.

An evaluation of potential nitrogen loads within the WhAEM delineation area included the following sources: domestic septic systems, precipitation, cattle manure, commercial fertilizer, and nitrogen released from plow down of legume crops. Nitrogen from the various sources is estimated to total about 15,000 tons per year (Table 15).

Table 15. Summary of nitrogen sources within WhAEM delineation area and estimated nitrogen loads per year.

Nitrogen source	Nitrogen load, lbs	Percent of total
Fertilizer	15,220,000	54
Human waste	324,800	1
Dairy manure	11,129,900	40
Beef manure[1]	632,000	2
Precipitation	201,700	1
Legumes	608,700	2
Total	28,117,100	100

[1] Accurate count of beef animals not available.

The total nitrogen fertilizer use divided by the irrigated acreage in the delineation area gives an application rate of about 93 pounds per acre. This number compares well with previous estimates of nitrogen fertilizer use (EPA, 1990) where estimates of about 70 and 84 pounds per acre were derived for Gooding and Jerome Counties, respectively. The estimated nitrogen contribution from human waste is probably high for three reasons: 1) the amount of nitrogen generated per person was selected from the high end of the range of values; 2) nitrogen from urban dwellers (Wendell) was included with rural dwellers, while the city has a wastewater treatment system which removes more nitrogen than a septic tank and drain field system; and 3) the population of Jerome was included in the calculations, while in actuality treated wastewater from the Jerome wastewater treatment plant is discharged to surface water and effectively removed from the study area. The human nitrogen source calculations did not include nitrogen fertilizer applied to lawns in the urban areas of Wendell and Jerome.

The estimated nitrogen load contributed from dairy cows is probably reasonable since the number of dairy cows in the delineation area was derived from current ISDA dairy herd numbers. This number includes nitrogen contributed by dairy heifers and calves. The estimate for nitrogen contributed from beef cattle is believed to be low due to an incomplete count of beef animal numbers in the delineation area. Estimates of nitrogen from precipitation were based on USGS precipitation sample data collected at a station in the Snake River Basin and precipitation data from the City of Jerome. Estimates of nitrogen from plow down of legume crops were based on values presented in Tindall (1991).

IASS data were used to evaluate trends in the major nitrogen sources (cattle and fertilizer) within Gooding and Jerome Counties during the period 1985 to 2000. Estimates for the period 1985 to 1991 indicate that nitrogen fertilizer use decreased by about 17 percent for both Gooding and Jerome Counties. For the period 1987 to 1997 irrigated acreage increased slightly in the two counties (5 and 12 percent for Gooding and Jerome Counties, respectively). The total number of cattle increased by 108 and 92 percent for the two counties, respectively, during the period 1986 to 2000. These data indicate that on a pounds per acre basis, the increase in nitrogen load from animal sources has more than offset the slight increase in irrigated acreage available for application of nitrogen generated by the increased cattle numbers.

A statistical analysis was conducted on water quality data from five springs which discharge along the north canyon wall of the Snake River: Box Canyon Springs, Crystal Springs #1 and#2, Clear Spring and Niagara Springs. Water quality data are available for the springs from 1991 or 1994 through 1999. Results of a linear regression analysis indicate that nitrate+nitrite concentrations increased significantly at the 95 percent confidence level for each of the five springs. A quarter-by-quarter linear regression analysis of the data, conducted to minimize seasonal water quality variations, indicated that for Box Canyon, Niagara and Clear Springs nitrate+nitrite concentrations increased significantly at the 95 percent confidence level for all four quarters. Crystal Spring #2 had a significant nitrate+nitrite concentration increase at the 95 percent confidence level for three of the four quarters. At Crystal Spring #1 there was a significant nitrate+nitrite concentration increase at the 95 percent confidence level in one of four quarters through time. To estimate when the DEQ action level of 5 mg/l nitrate+nitrate will be exceeded, the regressions were extended until the action level was intercepted. This evaluation assumes that the amount of nitrate+nitrite transported to the ground water continues to increase at the same rate. The estimates suggest that for springs with the steepest regression slopes (Clear Springs and Crystal Springs #2) the 5 mg/l action level could be reached in 5 to 6 years.

A statistical analysis was also conducted on water quality data from a well located at 9S16E3ABC, where water samples have been analyzed for nitrate+nitrite concentrations. Results of a linear regression analysis indicate that nitrate+nitrite concentrations increased significantly at the 95 percent confidence level over a 12 year period. A linear regression analysis done on a calender quarter basis also confirmed that nitrate+nitrite concentrations increased significantly at the 95 percent confidence level for each calender quarter (January-March, April-June, July-September, and October-December). A nitrogen isotope analysis of water from the well gave a $\delta^{15}N$ value of 8.9 ‰, indicative of nitrogen from animal or human waste, or from organic nitrogen in soil. A dye tracer test conducted over a 20 month period on the septic tank associated with the well indicated that the septic tank is not the source of nitrogen in the well.

Most R^2 values for both spring and ground water quality data are less than 0.5. These values indicate that other factors such as seasonality effects due to variation in nitrogen sources or variation of the concentration of an individual nitrogen source are creating large variations in ground water nitrate concentrations.

In order to assist in evaluating land use and water quality issues, the following activities are suggested:

- A better estimate of cattle numbers is needed for the western part of the ESRP so that updated estimates of nitrogen input from manure sources can be prepared.

- Commercial fertilizer use in the same area should be tabulated to improve estimates of nitrogen input from this source.

- The installation of properly constructed ground water monitoring wells should be considered for selected locations in the western part of the ESRP. The locations should take into consideration the time of travel variations across the area and existing land use activities.

- Analysis of the stable isotopes of oxygen ($^{18}O/^{16}O$) and hydrogen ($^{2}H/^{1}H$) should be considered for future water sampling programs in the area to augment nitrogen isotopes data being collected. These parameters can provide additional information about the sources of contamination and the timing and location of recharge events. Temporal variations in nitrogen sources in the area could be more accurately described through the use of the stable isotopes of oxygen, hydrogen and nitrogen. Isotope data currently being collected in the area by all organizations should be shared so that solutions to water quality issues can be developed.

- The Agricultural Ground Water Coordination Committee should be considered as a forum for presentation of the study results.

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