Preliminary Assessment of Hydrogeology and Water Quality in Ground Water in Teton, County, Idaho

By
D. M. Cosgrove and J. Taylor
Idaho Water Resources Research Institute
University of Idaho

for the
Idaho Department of Environmental Quality

March, 2007

Idaho Water Resources Research Institute
Technical Report 07-002

Introduction

This report documents a preliminary investigation of the hydrology in Teton County, Idaho done by the Idaho Water Resources Research Institute (IWRRI) for the Idaho Department of Environmental Quality (IDEQ). IDEQ initiated this work in 2006 due to the high rate of housing development in Teton County, Idaho. IDEQ has mounting concerns over the potential introduction of water quality problems due to the installation of domestic onsite wastewater systems. An assessment of the area hydrogeology is necessary to evaluate Nutrient-Pathogen (N-P) Level 1 analyses submitted by developers (Howarth, et al, 2002). The N-P Level 1 evaluations include a spreadsheet analysis which requires hydrologic characteristics as input values. This project was intended to provide IDEQ with some guidelines regarding appropriate values for those inputs.

The project work documented in this report includes an assessment of the hydrogeology in the Teton Valley, based on published reports and the ground-water model in the valley and an assessment of the sensitivity of the N-P Level 1 evaluation tool to various aquifer parameters. After the project was underway, an opportunity arose for further funding to conduct a synoptic measurement of water quality parameters in the Teton Valley, so the work on this project was expanded to support that effort. The water quality results are included in this report. Additionally, as work on this project was underway, it became apparent that one of the greatest water quality concerns in the Teton Valley is the potential impact to water quality if the valley were to fully build out using onsite wastewater systems. To address this need, we added a task to create a crude spreadsheet-based tool to analyze nitrate loading for user-defined build-out scenarios. The nitrate loading tool is documented in a separate report (report in publication).

Objectives

Specific objectives of the project include: a) provide a general hydrologic characterization of the Teton Valley based on previously published reports and the ground-water model, b) provide maps of aquifer hydraulic conductivity, aquifer storage and hydraulic gradient, c) assess the N-P Level 1 evaluation tool for sensitivity to various inputs, d) analyze water quality in fifty wells in the valley and compare current water quality results with previously published results and e) create a spreadsheet-based tool to analyze potential nitrate loading in the ground water due to various build-out scenarios.

Acknowledgements

The authors would like to acknowledge IWRRI for providing USGS 104B grant money for the water quality sampling and analysis. We would also like to acknowledge Ms. Kathy Rinaldo and Mr. Sandy Mason at Valley Advocates for Responsible Development (VARD) and Ms. Lyn Benjamin and Mr. John Rice at Friends of the Teton River. They all provided feedback and guidance for the effort. In addition, Mr. Rice provided water quality sampling support as a match to the USGS 104B grant. We would also like to thank Mr. Kurt Hibbert, Teton County Planner, for consultation on the nitrate loading tool. We would also like to thank the well owners in Teton County for providing access to their wells and to Ms. Cami Johnson, a summer IWRRI intern, who assisted with

contacting well owners and collecting samples and Mr. Gary Billman, an undergraduate intern, for GIS support.

Study Area Description

The study area is primarily within Teton County, Idaho (Figure 1) located in eastern Idaho, on the border with Wyoming. The study area is located in an alluvial valley which has traditionally supported flood-irrigated agriculture. Extensive hydrologic alteration has occurred in the valley as a result of the conversion from flood irrigation to sprinkler irrigation (Van Kirk, 2005). Recently, the valley has been undergoing a rapid degree of resort and second home development. These changes in land use have raised concerns for both water supply and water quality throughout the valley.

Methods

The hydrologic characterization relied on previous hydrologic studies in the Teton Valley. Aquifer hydraulic characteristics were derived from a ground-water flow model created by Cascade Earth Sciences, Inc. (2003) and later modified by Nicklin Earth and Water, Inc. (Friends of the Teton River, 2005). Horizontal fluxes from the ground-water model were also used to provide fluxes for the nitrate loading tool.

The sensitivity of the N-P Level 1 evaluation tool was tested by assessing the equations used in the N-P Level 1 evaluation tool and analyzing response to variations in the input parameters. The water quality component of this study included sampling and analysis of water from fifty wells in the Teton Valley and comparing the results with a previous USGS evaluation of water quality in the valley.

Evaluation of Impacts of Onsite Waste Disposal

Onsite Wastewater Disposal Issues

Many of the subdivisions planned within the study area rely upon the installation of private onsite wastewater treatment systems. These onsite wastewater treatment systems may utilize the standard septic tank, or the more recently approved category of aerobic treatment systems, depending upon the site conditions and facility wastewater characteristics. Both the septic and aerobic systems consist of an underground tank and associated drain field. Household waste enters the tank on one side and processed liquid waste exits to the drain field on the other side. The processing includes solid and liquid waste separation and microbial waste reduction. Treated liquid waste is either gravity or pressure dosed to the drain field. When the onsite system is in constant use, the drain field is continually moist. This condition encourages the development of a microbial mat, referred to as a biomat, which acts as a tertiary filter reducing residual nutrients prior to encountering ground water.

Site characteristics impact not only the type of onsite wastewater system permitable, but also the size of the system required to adequately process the wastewater. The soil type where the drain field is located will impact the drain field size. Tight soils, such as silts and sandy clays, will require a larger area in order to effectively accept the wastewater volume at the lower infiltration rates associated with these soil types. Depth to and quality of the site's ground water will impact whether a standard septic system is permitable or whether an advanced onsite aerobic treatment system will be required. Typically, where ground water quality has not been degraded and the depth to ground water exceeds 10 feet, a standard septic system may be allowed. Otherwise, an advanced onsite aerobic treatment system may be required to reduce the nutrients and other constituents sufficiently to protect the ground water from significant degradation.

All domestic wastewater contains pathogenic microorganisms (bacterial, protozoan, viral, and helminth ova), nitrate, phosphate, pharmaceuticals and personal care products (PPCP), and synthetic organic molecules from household cleaners. These effluent constituents are either processed in the onsite system, sequestered in the precipitated solids in the tank, filtered out in the biomat, or adsorbed to soil and mineral particles beneath the drainfield. The wastewater may entrain some of these constituents, and given enough time, these constituents may migrate through the vadose zone and encounter the regional or sub-regional aquifer. An overloaded or poorly maintained onsite system, or too many onsite systems in an area, may cause these constituents to reach the aquifer more quickly, although local regulation should preclude permitting of onsite wastewater systems in densely populated areas.

DEQ and the Health Districts may require a developer, through their professional engineer or a professional geologist, to perform a Nutrient–Pathogen (N-P) Study. An N-P Study is a conservative evaluation of the proposed development's potential for impacting the quality of underlying ground water and/or adjacent surface water. This is accomplished through modeling the development's discharged wastewater, taking into account the volume, concentration of constituents, and location of these discharges, and evaluating how it interacts with the site's ground water. Site attributes identifying the ground water flow include hydraulic conductivity, the aquifer's gradient, and the ground water constituent concentrations. Additional site attributes that will influence the model's results may include, but are not necessarily limited to, the rate that rain or snow recharges the aquifer, and the volume and quality of infiltrating irrigation water. These variables are all combined in either simple arithmetic models, or may be analyzed in more complex numeric or fate and transport models commonly available to ground water hydrology professionals.

Based upon the N-P guidelines defining an 'area of concern' as "an area where the soil depth is shallow or there exists a predominance of gravel or other coarse-grained sediment, as shallow depth to ground water (10 ft or less)…," the health district or DEQ may require that an N-P Study be completed. In areas underlain by coarse gravels and shallow ground water, a common occurrence in the Teton Valley, concerns about onsite wastewater system siting are heightened. In this situation, the N-P Study must show that the ground water is not significantly degraded, and any adjacent surface water is suitably protected.

N-P Level 1 Spreadsheet Parameter Description

In order to understand the impact that variability in parameter values will have on the results of an N-P Level 1 evaluation, it is important to first understand how the variables are used in the spreadsheet. To conduct an N-P Level 1 evaluation, the user inputs 13 variables. Table 1 lists the variables which are used for the spreadsheet. For the purpose of explaining the equations used in the spreadsheet, a parameter name has been assigned to each parameter. Note that these parameter names were assigned by the authors of this report and are not used in the spreadsheet.

Of the 13 parameters which are input by the user, two (hydraulic conductivity and gradient) have to do with aquifer properties. The balance of the parameters describes the proposed project, ambient and introduced nitrate concentrations, rate of recharge, etc. For many of the parameters (e.g. mixing zone thickness, septic tank effluent), a default parameter value is suggested (see Table 1). Parameters varying from the default require justification in the analysis.

The goal of an N-P Level 1 evaluation is to demonstrate that the proposed project will not increase nitrate concentrations by greater than 1.0 mg/L at the compliance boundary (Howarth and others, 2002). Some of the input parameters have more flexibility in range of value than others, thus exerting more influence on the final result. Following is a description of the equations used in the spreadsheet and a discussion of how much influence key parameters exert on the final result.

N-P Level 1 Evaluation Spreadsheet Equations

The N-P Level 1 evaluation spreadsheet has two primary sets of equations: one which estimates the water budget components for the project and one which estimates the nitrogen budget for the project. The water budget components are expressed in met^3/yr and the nitrogen budget in mg/yr. The final result is either expressed as mg/L of nitrogen at the compliance boundary (obtained by dividing the nitrogen annual budget by the annual discharge rate and converting met^3 to liters) or as the number of housing units which are allowable to stay under the 1 mg/L limit of added nitrogen load.

These equations are discussed below.

Water Budget Equations

Three equations calculate the water budget for the proposed project. Each equation is presented below, along with an explanation of the variables used in the equation. Note that each equation includes a fair number of unit conversions in order to express the final value in consistent, desired units.

Equation 1 calculates the water budget for the ground water in the vicinity of the proposed project. Equation 1 is based on Darcys Law (Domenico and Schwartz, 1990).

$$GW\left(\frac{met^3}{yr}\right) = \left(\frac{k\left(\frac{ft}{d}\right)}{3.28\left(\frac{ft}{met}\right)} 365\left(\frac{d}{yr}\right)\right)\left(grad\left(unitless\right)\right)\left(\frac{\left(Mix\_thck\left(ft\right)\right)}{3.28\left(\frac{ft}{met}\right)}\right)\left(\frac{W\left(ft\right)}{3.28\left(\frac{ft}{met}\right)}\right) \quad \text{(eq. 1)}$$

where:

GW is calculated ground-water discharge rate (met^3/yr)

k is user-entered hydraulic conductivity (ft/d)
grad is user-entered hydraulic gradient (unitless)
Mix_thck is user-entered mixing thickness (ft)
W is user-entered aquifer width perpendicular to flow (ft)

Equation 2 calculates the discharge rate of the onsite waste disposal effluent. Equation 2 takes the user-entered septic effluent discharge rate per home, multiplies by the number of proposed homes, and converts units to the desired final units.

$$Eff\left(\frac{met^3}{yr}\right) = \left(Effl\_Sept\left(\frac{gal}{d * Homes}\right)\right)(Homes)\left(365\left(\frac{d}{yr}\right)\right)\left(.003785\left(\frac{met^3}{gal}\right)\right) \quad \text{(eq. 2)}$$

where:
Eff is calculated onsite disposal effluent discharge rate (met^3/yr)
Effl_Sept is user-entered onsite disposal effluent discharge rate (gal/d/home)
Homes is the user-entered number of homes (unitless)

Equation 3 takes the user-entered natural recharge rate and proposed project area (less percent impervious area) and calculates the total expected recharge rate for the whole project.

$$\mathrm{Re}ch\_Tot\left(\frac{met^3}{yr}\right) = \left(\mathrm{Re}ch\left(\frac{in}{yr}\right)\right)\left(.0254\left(\frac{met}{in}\right)\right)\left(Area(acre)\left(4049\frac{met^2}{acre}\right)\right)\left(1-\frac{\mathrm{Im}\,perv}{100}\right) \quad \text{(eq.3)}$$

where:
Rech_Tot is the calculated total natural recharge rate for the proposed project (met^3/yr)
Rech is the user-entered natural recharge rate (in/yr)
Area is the user-entered total proposed project area (acres)
Imperv is the user-entered percentage of the project which will be impervious

Nitrogen Budget Equations

Equations 4-6 calculate the nitrogen budget for the proposed project. Equation 4 calculates the annual nitrogen load contributed by the ground water (background nitrogen load).

$$Nitr\_Backgr\_Tot\left(\frac{mg}{yr}\right) = \left(Nitr\_In\left(\frac{mg}{L}\right)\right)\left(GW\left(\frac{met^3}{yr}\right)\right)\left(1000\left(\frac{L}{met^3}\right)\right) \quad \text{(eq.4)}$$

where:
Nitr_Backgr_Tot is the calculated total annual background nitrogen load (mg/yr)
Nitr_In is the user-entered nitrogen concentration of the ground water (mg/L)
GW is the ground-water discharge rate (met^3/yr) (calculated in eq. 1)

Equation 5 calculates the annual nitrogen load contributed by the onsite waste disposal effluent.

$$Nitr\_Sept\_Tot\left(\frac{mg}{yr}\right) = \left(Nitr\_Sept\left(\frac{mg}{L}\right)\right)\left(Eff\left(\frac{met^3}{yr}\right)\right)\left(1000\left(\frac{L}{met^3}\right)\right)(1-Rate\_Denitr) \quad \text{(eq.5)}$$

where:
Nitr_Sept_Tot is the calculated total annual nitrogen load from the septic effluent (mg/yr)

Nitr_Sept is the user-entered nitrogen concentration of the septic effluent (mg/L)
Eff is the septic system discharge rate (met^3/yr) (calculated in eq. 2)

Equation 6 calculates the annual nitrogen load contributed by the natural recharge.

$$Nitr\_Rech\_Tot\left(\frac{mg}{yr}\right) = \left(Nitr\_Rech\left(\frac{mg}{L}\right)\right)\left(Rech\_Tot\left(\frac{met^3}{yr}\right)\right)\left(1000\left(\frac{L}{met^3}\right)\right) \text{(eq.6)}$$

where:
Nitr_Rech_Tot is the calculated total annual nitrogen load from natural recharge (mg/yr)
Nitr_Rech is the user-entered nitrogen concentration of the natural recharge (mg/L)
Rech_Tot is the natural recharge discharge rate (met^3/yr) (calculated in eq. 3)

Sensitivity of N-P Level 1 Evaluation Spreadsheet Equations to User-entered Aquifer Parameters

It is anticipated that, for most proposed subdivisions, the ground-water discharge rate plus the rate of natural recharge to the aquifer would exceed the onsite waste disposal system discharge rate. It is also anticipated that the background nitrogen load contributed from ground water and natural recharge would be lower than the nitrogen load contributed from the onsite waste disposal systems. Therefore, the spreadsheet user is attempting to balance the mixing of the relatively clean background and recharge water with the relatively nitrogen-laden waste water. To that end, it benefits the proposed development to have a higher discharge rate for ground water and a lower discharge rate for the waste water effluent.

The two user-entered parameters which reflect aquifer properties are hydraulic conductivity (k) and gradient (grad), both of which are used in equation 1 above. Inspection of equation 1 shows that the total ground-water discharge is directly proportional to both k and grad. For example, if either k or grad is doubled, the ground-water discharge will also be doubled.

In physical hydrologic systems, hydraulic conductivity has a wide potential range of values and is very difficult to estimate. Domenico and Schwartz (1992) shows typical hydraulic conductivity values for gravel ranging over 2 orders of magnitude. Allowing for the reduction in hydraulic conductivity due to non-uniform gravels or mixed sand and gravel, hydraulic conductivity could easily range over 4 or 6 orders of magnitude. Although gradient can also vary over several orders of magnitude, gradient is far easier to measure and can be estimated to within one order of magnitude. In the N-P Level 1 evaluation spreadsheet, gradient is restricted to between 0 and .1.

Therefore, hydraulic conductivity is the aquifer parameter which is most difficult to estimate and which asserts the most influence over ground-water discharge rate, and, therefore, asserts the most control over the spreadsheet analysis of nitrogen loading. It should be noted that a spreadsheet user could use this natural range in hydraulic conductivity to either support a planned subdivision (by using a higher k value, thus increasing the ground-water discharge, thus allowing for more dilution effects) or to attempt to block a proposed subdivision (by using a lower k value, with the opposite effect).

Sensitivity of N-P Level 1 Evaluation Spreadsheet Equations to Other User-entered Parameters

Looking down the list in Table 1 of user-entered variables in the Level 1 N-P evaluation spreadsheet, the spreadsheet user has more discretion with some of the values than with others. Each of the parameters (other than hydraulic conductivity and gradient, which were previously discussed) is discussed below.

Mixing Zone Thickness

The mixing zone thickness is used in Equations 1 and 4 and is specified at 15 ft by regulation.

Width Across the Proposed Project

The width across the proposed project is a physical dimension of the proposed project which the developer can adjust to reduce the nitrogen loading at the compliance boundary. This parameter is used in Equations 1 and 4 and can easily be verified on a project plan.

Project Parcel Area

The area is the number of acres of the parcel being developed. This parameter can easily be verified on a project plan.

Percentage of Impervious Area

The percentage of impervious area represents the percentage of the parcel which will be impervious (rooftops, roads, driveways, parking lots, etc). This parameter is used in Equations 3 and 6. A decrease in impervious area increases the amount of estimated natural recharge, which increases dilution of the waste-water nitrogen. The percentage of impervious area can range from 0 to 100, but would normally be approximately 20%. Selection of this variable should be supportable through an analysis of the project plan.

Number of Planned Homes

This is the number of homes with onsite waste-water treatment systems in the proposed development. This parameter is used in Equations 2 and 5 and is adjusted until the additional nitrogen load is less than 1 mg/L at the compliance boundary.

Waste-Water Effluent Rate

This is the number of gallons per day per home which would be discharged from the onsite waste-water treatment system. This variable is used in Equations 2 and 5. The default value is 300 gal/d/home. However, a lower number might be justified based on seasonal use of resort property. A lower effluent rate translates to less of the nitrogen-laden effluent mixing with the ground-water, potentially justifying a higher housing density. Attempts should be made to reasonably predict the property usage in order to estimate this parameter properly.

Natural Recharge Rate

This is the rate of natural recharge to the ground-water due to rain or snow-melt. This is a difficult variable to estimate. In an arid region, it should be significantly less than average annual precipitation and may be as low as 0. This variable is used in Equations 3 and 6. A higher value for natural recharge rate provides more clean water for diluting the water-water effluent. It is possible that, in an aquifer with very low hydraulic conductivity, one could skew the results of the Level 1 N-P evaluation by overstating the rate of natural recharge, but western precipitation is low enough that the latitude on this variable is limited.

Upgradient Ground Water Nitrogen Concentration

This is the concentration of nitrogen in the ground-water flowing into the proposed development. This variable is used in Equation 4 and should be consistent with water quality analyses in the region. The Level 1 N-P evaluation spreadsheet is evaluating the nitrogen concentration in the water leaving the proposed development at the compliance boundary to ensure that the proposed development has not increased nitrogen concentrations in the vicinity of the proposed development by greater than 1 mg/L.

Waste Water System Nitrogen Concentration

The default value for the nitrogen concentration in the waste-water system is 45 mg/L. This variable is used in Equation 5. Clearly, a higher nitrogen concentration in the waste-water makes it more difficult to dilute the effluent to an acceptable level. A developer who uses a value lower than the default would have to justify that value based on specifications of the proposed waste water systems.

Denitrification Rate

This is a decimal fraction indicating the rate of denitrification due to microbial action. This variable is used in Equation 5 and reduces the overall nitrogen loading from the waste-water systems. An increase in this value represents a decrease in the nitrogen loading (indicating a more rapid rate of microbial denitrification). Any value other than 0 would need to be justified through sample analysis or site-specific literature.

Nitrogen Concentration in Natural Recharge

As the name implies, this is the concentration of nitrogen found in the natural recharge. This variable is used in Equation 6. A lower value implies cleaner recharge water available to mix with the waste-water effluent. Any value lower than the default value of .3 mg/L should be justified through sample analysis.

Analysis of Area Hydrology for Nutrient-Pathogen Analyses

Overview of Study Area Hydrology

The Upper Teton Valley is a mountain valley, extending from approximately Victor, Idaho at the southern boundary, to north of Felt, Idaho. Figure 1 shows the location of the Teton Valley. The Valley is bounded by the Teton Mountain Range to the east and by the Big Hole Mountain Range to the west. Both mountain ranges are steeply tilted by faulting. The valley floor has been formed by alluvial deposition at the mouth of streams draining both mountain ranges. The valley floor, therefore, is comprised of alluvial deposits from the two mountain ranges. Valley elevation ranges from approximately 6100 ft near Victor, Idaho to approximately 5900 ft near Tetonia, Idaho (Kilburn, 1964). The reader is referred to Kilburn (1964) for a more complete description of the area geology.

The southern end of the valley contains the headwaters of the Teton River, which runs from south to north through the valley (Figure 1). The Teton River is fed by tributaries draining both mountain ranges. The valley floor is more steeply tilted on the east side, between the Teton Range and the Teton River. North of Felt, Idaho, the Teton River takes a turn to the west and becomes tributary to the Snake River.

A predominantly unconfined alluvial aquifer underlies the valley. The aquifer is recharged by small amounts of tributary underflow, by seepage from the tributaries, by irrigation in the valley and by precipitation (Friends of the Teton River, 2005). The aquifer discharges to the Teton River and to an extensive wetland along the river (discussed later in this report). The wetland area is considered a fragile portion of the area ecosystem.

Hydrologic Study Results

Gradient

The gradient of the top of the saturated zone was initially estimated by evaluating the slope of the surface of the starting aquifer levels for the regional ground-water model developed for the Valley (Cascade Earth Sciences, Inc., 2003 and Friends of the Teton River, 2005). The starting aquifer levels for the model were derived by interpolating aquifer water levels in individual wells, however the model documentation does not specify which water levels were used for determining the starting aquifer water levels. This method failed, however, because the kriged surface showed gradients trending towards the north in approximately the upper half of the model area. This is counter to the potentiometric surface published in Kilburn (1964), which shows all gradients in the study area flowing towards the river. The lack of information regarding how the initial heads were derived for the model and the northward-trending gradients caused us to abandon the original method.

The final method selected for estimating gradient used the potentiometric surface published in Kilburn (1964). Gradient was estimated from this map for selected locations within the study area. Figure 2 shows the potentiometric surface map as published in Kilburn (1964) with the estimated gradient for selected locations. Note that Figure 2 also shows an arrow at each location which indicates the direction of ground-water flow.

Although the background map shown in Figure 2 is forty years old, there is no reason to believe that regional flow directions have changed in the study area. Changes to the hydrologic regime due to conversions from flood irrigation to sprinkler irrigation can result in less recharge to the aquifer and could change local gradients. However, the regional gradients should be relatively stable. The Kilburn (1964) map was selected as the best available information for the study area. If doubt exists regarding gradients in the vicinity of a specific proposed project, a local gradient should be estimated from surrounding wells.

Hydraulic Conductivity

Hydraulic conductivity was estimated using properties of the regional ground-water flow model for the Teton Valley (Cascade Earth Sciences, Inc., 2003 and Friends of the Teton River, 2005). The model hydraulic conductivities were interpolated using the kriging function in ESRI Arc-Map 9.0. Figure 3 shows the hydraulic conductivity map resulting from this kriging process. Hydraulic conductivities for the area range from 1 ft/d to around 50 ft/d. The relatively tight range of hydraulic conductivities is a direct result of the relatively tight range used for the ground-water model. Given the reasonably uniform nature of the stratigraphy, this relatively tight range of conductivity is credible. Note, however, that there is still a factor of 50 variation in hydraulic conductivity throughout the study area.

Although not a perfect representation of sub-surface parameters, Figure 3 is based upon a calibrated model, providing the best available knowledge of the hydraulic conductivity of the study area and should serve as a guide for selection of hydraulic conductivity values when using the N-P Level 1 evaluation spreadsheet.

Study Area Recharge

Natural recharge in the study area was estimated by the Teton ground-water model developers (Cascade Earth Sciences, Inc., 2003 and Friends of the Teton River, 2005). The model developers estimate 3 in/yr of recharge to the aquifer due to rain and snowmelt. There was little discussion about the 3 in/yr estimate. However, our experience on the eastern Snake River Plain, a similar high desert environment, is that 3 in/yr is a reasonable estimate for recharge.

Hydrologic Characteristic Summary

Figures 2 and 3 present a summary of the gradient and hydraulic conductivity for the study area. The reader is again cautioned that these figures are based on data from a forty year old report and data used in the ground-water flow model. Figures 2 and 3 should provide a guideline for parameters used in an N-P Level 1 assessment. As more hydrologic data become available in the study area, these figures should be updated and refined.

Water Quality Investigation

Our objectives in the water quality component of this study were to determine baseline nitrate concentrations within Teton County and to determine whether nitrate concentrations have changed significantly since the 2002 USGS water quality sampling. This round of analysis of nitrate concentrations in Teton County is important for establishing whether existing changes in land use have already impacted water quality in the valley and to provide a baseline for future water quality analysis, especially given the projected development in the valley.

Sampling and Analysis

Selection of Water Quality Sampling Wells

Forty-nine wells were selected for ground-water sampling. Sampling well selection started with an evaluation of the wells which were sampled for the 2002 USGS study. We attempted to sample as many of the 2002 wells as possible. For many of the 2002 wells, the exact well location or owner could not be identified. Of the 49 wells sampled for this effort, 17 were sampled in the 2002 study. The rest of the wells were selected to a) provide good spatial coverage of the valley and b) provide a higher sample density in sensitive areas such as wetlands or areas close to the Teton River. Sample well locations are shown in yellow on Figure 4. Figure 4 also delineates the wetlands in the study area.

In addition to sampling ground-water in the valley, 11 surface water sites were sampled and analyzed. Figure 4 shows the location of sampled surface water sites in blue.

Ground Water Sample Collection and Water Quality Analysis

Ground water samples were collected following the guidelines of the Ground Water and Soils Quality Assurance Project Plan (IDEQ, 2001). A Hydrolab Minisonde 4a water quality multiprobe with flow cell was used to measure DO, pH, specific conductance, temperature, and ORP in the field. The wells were purged until temperature, conductance, and pH stabilized. Alkalinity was determined in the field for 76% of the samples by acid titration to a pH endpoint of 4.6 using a Hach Kit. Alkalinity for the remaining 24% of the samples was determined mathematically by setting the charge balance to zero and solving for alkalinity as mg/L $CaCO_3$. All wells were sampled once. A blank was collected in the field for most sampling days. DI water was used for the blanks in the field. During analysis, all blanks showed non-detect levels of all constituents, indicating that no contamination was introduced during sampling.

Groundwater samples for major and trace inorganic ions were filtered using an inline Millipore disposable groundwater filter capsule (GWSCO4501, 0.45µm). Groundwater samples for major cations were acidified to a pH < 2 with concentrated nitric acid. Groundwater samples to be analyzed for ammonium were acidified to a pH < 2 with concentrated sulfuric acid. All samples were stored in 60 ml Nalgene bottles, packed on blue ice in the field and stored at 4ºC in the lab until analysis.

The surface water samples were collected by employees of Friends of Teton River. The authors have no insight regarding the collection procedures used. Field parameters (DO, pH, specific conductance, temperature, and ORP) are not available for the surface water samples due to the different sample collection methods.

Results

Water Sample Analysis

Major cations and anions (Na, Ca, Mg, K, NH_4, F, Cl, SO_4, NO_3, and PO4) were measured using Ion Chromatography (IC, Dionex, Sunnyvale, CA). The charge balance error, expressed as a percentage, was calculated for wells with field-measured alkalinity data. Ninety-five percent of the samples measured were within the acceptable range of <5%.

$$CBE = 100*(meq_{cations}-meq_{anins}) / (meq_{cations} + meq_{anions}) \quad \text{(eq. 7)}$$

The water quality parameters for the ground-water samples are listed in Table 2. Figure 5 shows a piper diagram of the ground-water chemistry. Inspection of Figure 5 shows that the ground-water samples cluster together on the Piper diagram indicating the quality of the ground water throughout Teton County is very uniform and predominantly Ca-Mg-HCO3 water with the exception of sample S14, which had high levels of NaCl (Table 2). Well S14 is located near a highway maintenance facility, so the high levels of NaCl may reflect road salt leeching into the ground in the vicinity of the facility.

Specific conductance of ground-water samples in the valley ranged from 95-537 µS/cm, with the exception of sample S14 which was at 1129 µS/cm, consistent with the high NaCl concentrations in that sample. There were five wells (S30, S27, S28, S40 west of the river, and S26 east of the river) with negative ORP, low oxygen, low sulfate, and low nitrate, indicating reducing conditions.

Because the focus of this investigation was the quality of the ground water, no Piper diagram was generated for the surface water samples. Table 3 lists the water quality parameters for the surface water samples.

Nitrate Results

The nitrate concentrations in all 49 ground-water samples and 11 surface-water samples were below the EPA regulatory limit of 10 mg/L NO_3 as N. Only 10% of the ground-water samples were between 4.96 and 8.17 mg/L NO_3 as N. All other ground-water samples were below 4.96 mg/L NO_3 as N (Table 2). One surface-water sample had a slightly elevated nitrate level (7.64 mg/L NO_3 as N); however, all other surface water samples were below 4.96 mg/L NO_3 as N (Table 3).

The six highest nitrate samples are spatially distributed throughout the study area. Figure 6 shows the location of the six highest nitrate samples. One of the relatively high nitrate results in ground-water samples is located west of the river. The other four ground-water samples and the single surface-water sample with relatively high nitrate levels are located east of the river and evenly distributed north to south. The reader is again reminded that the EPA guideline for nitrate is 10 mg/L and that none of the samples was above the EPA guideline.

Groundwater samples that had nitrate concentrations above 1mg/L NO_3 as N were grouped into clusters regionally to determine whether any spatial pattern exited. This clustering is shown in Figure 7. As can be seen in Figure 7, no spatial pattern exists for wells with > 1mg/L NO_3 as N.

Comparison with USGS Results

As mentioned earlier, the USGS conducted previous sampling of ground water in the Teton Valley in 2002 for 17 of the 49 wells sampled for this study. We compared previous and current nitrate concentrations for those 17 wells. Table 4 shows a comparison of concentrations measured in 2002 and the current study for those 17 wells and notes whether the nitrate concentrations have increased or decreased in the ensuing four years. Figure 8 shows bar graphs for each of the analysis dates. Only two wells were analyzed in August, 2002 and are not shown on Figure 8, but the data is listed in Table 4.

Several of the wells showed a decrease in nitrate concentration between 2002 and 2006, while others showed an increase. Two wells, S1 and S4, had a decrease of 1.65 and 2.63 mg/L NO_3 as N, while wells S14, S16, and S19 showed increases of 1.69, 1.09, and 1.09 mg/L NO_3 as N, respectively, between 2002 and 2006. Four wells exhibited an increase of less than 1 mg/L NO_3 as N. Eight wells exhibited a decrease of less than 1 mg/L NO_3 as N. Wells in the Fox Creek and Victor, Idaho area exhibited a decrease in nitrate concentrations between 2002 and 2006 while the wells north of Driggs exhibited both increases and decreases. Figure 9 shows the location of all wells for this study. The wells which were previously sampled in 2002 are marked in Figure 9 with either a black, downward pointing arrow, indicating a decrease in nitrate concentration, or a red, upward point arrow, indicating an increase in nitrate concentration. For wells with an increase or decrease in nitrate concentration greater in magnitude than 1 mg/L, the change in concentration is noted in Figure 9. Overall, there has been little change in nitrate concentrations between 2002 and 2006, with no apparent spatial trends.

The 2002 sampling occurred in May, August and October, whereas the 2006 sampling occurred in July. Some of the exhibited changes in nitrate concentrations could be indicative of seasonal changes in nitrate levels, rather than any long-term trend. The seasonal use of many of the residences in the Teton Valley may cause a seasonal variation in nitrate discharges from onsite wastewater systems. Additionally, nitrate concentrations in the ground water as a result of agricultural activity may also have a seasonal variation.

Discussion and Conclusions

The water quality investigation does not show any alarming results. Even wells with the highest concentrations of nitrate levels are well below the EPA regulatory limit of 10 mg/L NO_3 as N, indicating no immediate problem. Wells with higher nitrate concentrations were not located within a specific region in Teton County, but were distributed throughout the county.

Because most of the sampled wells were relatively deep, the water quality may reflect water quality deep in the aquifer and not near the surface of the aquifer. It is possible that water near the surface of the aquifer could exhibit higher concentrations of nitrate since both probable sources of nitrate are surface sources; however, few shallow wells were available for the study.

The comparison of nitrate concentrations between 2002 and 2006 was encouraging. Little degradation in water quality due to nitrate concentrations was observed. As the valley continues to build out, area planners have an opportunity to protect the water quality within the valley.

Seasonal effects could play an important role in the nitrate concentrations in Teton Valley. Seasonal variation could occur due to increased population in the summer and winter seasons, fertilization due to farming and residential lawns, and increased filtration in the spring and summer due to precipitation and irrigation runoff. Nitrate accumulation could occur in groundwater as the number of onsite wastewater systems in the area increases (Pang et al. 2006). Care should be taken to limit the permitted density of onsite wastewater systems. Care should also be taken to not permit onsite waste water systems in or near ecologically fragile wetlands. Future work should be done to monitor the seasonal fluctuations of nitrate in groundwater, to look for seasonal variations in nitrate concentrations. With the rapid growth in the region and the corresponding increase in the number of onsite wastewater and drain fields, nitrate concentrations should be regularly monitored to ensure safe drinking water for private well owners and to avoid contamination of the aquifer or river.

References

Domenico P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology, John Wiley & Sons, U.S.A.

Friends of the Teton River, 2005. Groundwater-aquifer recharge demonstration project Fox Creek Area, Teton Valley, Idaho, Driggs, Idaho.

Howarth, R., B. Burnell and B. Wicherski, 2002. Nutrient-pathogen evaluation program for on-site wastewater treatment systems, Idaho Department of Environmental Quality in coordination with Central District Health Department, Boise, ID, 26 p.

Idaho Department of Environmental Quality, 2001. Ground Water and Soils Quality Assurance Project Plan, Boise, Idaho.

Kilburn, *****

Nicklin, M., 2003. Final Report: Ground-water model for the upper Teton watershed, project report prepared for Cascade Earth Sciences, Inc, Pocatello, Idaho.

Pang, L., C. Nokes, J. Šimůnek, H. Kikkert, R. Hector, 2006. Modeling the Impact of Clustered Septic Tank Systems on Groundwater Quality. Vadose Zone Journal. 5:599-609.

U.S. Environmental Protection Agency, 2006. http://www.epa.gov/safewater/mcl.html

U.S. Environmental Protection Agency, 2006. Monitoring and Assessing Water Quality: Nitrates. http://www.epa.gov/owow/monitoring/volunteer/stream/vms57.html

Van Kirk, R. and A. Jenkins, Hydrologic Alteration in the upper Teton watershed and its implications for cutthroat trout restoration, project completion report for Friends of the Teton River, Driggs, ID, 2005.

Parameter Name	Description	Units	Range
k	Hydraulic conductivity	ft/d	Site-specific
grad	Hydraulic gradient	unitless	≤0.1
Mix-thck	Mixing zone thickness	ft	Default to 15 ft
W	Aquifer width perpendicular to flow (width across the proposed project, perpendicular to the local aquifer flow direction)	ft	Site-specific
Area	Parcel area	acres	Site-specific
Imperv	Percentage of parcel which is impervious	percentage	≤ 100
Homes	Number of homes in parcel	unitless	Site-specific
Effl_Sept	Septic tank effluent discharge rate (per home)	gal/d/home	Default to 300 gal/d/home
Rech	Natural recharge rate	In/yr	Site-specific
Nitr_In	Upgradient ground water nitrate concentration	Mg/L	Site-specific
Nitr_Sept	Septic tank effluent nitrate concentration	Mg/L	Default to 45 mg/L
Rate_Denitr	Denitrification rate	decimal fraction	Default to 0
Nitr_Rech	Nitrate concentration in natural recharge	mg/L	Default to 0.3 mg/L

Table 1. Parameters used in N-P Level 1 analysis spreadsheet.

Sample	Temp °C	pH	ORP (mv)	Sp. Cond (µS/cm)	%D.O.	Charge balance error	Alkalinity mg/L CaCO3	Fluoride mg/L	Chloride mg/L	Nitrate as N mg/L	Sulfate mg/L	Phosphate as P mg/L	Ammonium as N mg/L	Sodium mg/L	Magnesium mg/L	Potassium mg/L	Calcium mg/L
S1	7.81	7.2	256	385	NM	0%	228	0.10	1.69	2.41	6.16	N.D	N.D.	2.01	15.71	0.00	67.28
S2	8.39	6.88	128	338	NM	4.66%	157	0.14	1.40	0.56	24.04	N.D.	N.D.	6.06	18.54	0.00	45.69
S3	9.21	7.3	112	475	104.3	0.22%	174	0.23	1.72	4.96	13.06	N.D	N.D.	4.25	21.78	0.27	71.54
S4	8.07	6.43	133	444	NM	2.27%	241	0.20	1.61	1.40	3.98	N.D.	N.D.	2.65	19.27	0.82	71.08
S5	8.32	7.26	134	462	96.4	3.20%	204	0.11	1.38	2.47	44.84	N.D.	N.D.	3.42	21.31	0.00	69.42
S6	7.04	7.66	124	261	NM	0%	156	0.10	0.45	0.12	1.04	N.D.	N.D.	1.43	12.63	0.00	41.28
S7	8.17	7.45	168	418	NM	0%	222	0.13	1.15	5.05	6.15	N.D.	N.D.	1.92	20.05	0.00	64.29
S8	6.94	7.33	180	266	66.4	5.44%	157	0.07	0.67	0.05	1.68	N.D.	N.D.	1.40	13.33	0.00	47.90
S9	9.78	7.32	134	457	NM	0%	231	0.22	3.82	5.99	9.22	N.D.	N.D.	7.44	12.98	1.08	79.24
S10	7.41	7.37	110	351	60.7	4.76%	168	0.12	5.08	1.29	7.97	N.D.	N.D.	6.37	13.21	1.16	52.75
S11	8.07	7.28	143	313	NM	4.83%	180	0.04	0.95	0.45	1.13	N.D.	N.D.	2.12	13.07	0.00	57.58
S12	8.91	7.33	125	329	NM	4.17%	171	0.65	1.18	1.59	6.04	N.D.	N.D.	2.58	14.21	0.00	56.07
S13	8.06	7.81	155	342	NM	0%	121	0.06	1.01	2.71	7.00	N.D.	N.D.	1.48	14.29	0.59	53.54
S14	9.26	7.22	101	1129	NM	4.06%	173	0.07	237.08	3.75	3.39	N.D.	N.D.	137.52	16.20	1.22	77.72
S15	9.18	7.57	100	362	53.9	4.17%	187	0.36	1.42	1.66	3.53	N.D.	N.D.	4.28	18.88	0.00	51.60
S16	7.80	8.19	111	284	NM	3.73%	142	0.07	1.13	1.83	2.23	N.D.	N.D.	0.84	11.33	0.64	46.21
S17	8.88	7.44	103	242	70.2	0%	120	0.06	8.41	0.95	6.17	N.D.	N.D.	4.46	6.52	0.00	41.83
S18	8.67	6.59	168	95	54.5	0%	56	0.18	1.24	0.18	0.60	N.D.	N.D.	3.76	2.86	1.05	15.73
S19	8.01	7.47	106	537	110.5	0.57%	268	0.26	6.07	8.17	9.69	N.D.	N.D.	12.01	30.78	0.66	63.11
S20	8.90	7.32	156	307	NM	3.94%	161	0.05	1.70	1.74	1.73	N.D.	N.D.	2.87	9.97	0.18	54.89
S21	7.58	7.1	120	317	NM	2.73%	164	0.29	3.98	1.06	5.36	0.02	N.D.	9.63	17.63	0.23	44.86
S22	8.00	7.33	133	462	105	0%	212	0.42	12.30	7.73	12.56	N.D.	N.D.	11.71	22.69	0.44	60.69
S23	7.68	6.17	175	106	NM	3.93%	40	0.28	2.01	0.48	1.46	N.D.	N.D.	5.70	3.72	0.92	12.85
S24	7.54	7.07	133	285	NM	0%	150	0.23	2.28	0.17	2.55	N.D.	N.D.	7.31	8.12	0.35	42.96
S25	7.74	7.38	225	365	NM	0%	211	0.07	1.85	1.78	1.81	N.D.	N.D.	1.91	16.68	0.12	59.26
S26	14.80	7.63	-118	463	48.6	3.37%	140	N.A.	12.92	0.01	0.11	N.D.	N.D.	7.52	19.38	2.39	71.54
S27	7.64	7.43	-184	375	NM	1.54%	213	0.11	1.46	N.D.	0.36	N.D.	0.41	9.55	17.74	0.25	59.34
S28	9.19	8.84	-184	265	0.8	3.86%	145	0.34	0.92	N.D.	N.D.	0.02	0.84	8.30	12.26	1.39	35.26
S29	7.91	7.52	115	357	45.2	4.12%	180	0.31	1.13	0.35	9.72	N.D.	N.D.	4.46	18.33	0.78	51.98
S30	7.21	7.75	-198	417	19.9	3.63%	225	0.17	1.60	N.D.	3.75	0.18	N.D.	9.92	16.37	0.00	63.75
S31	7.94	7.24	193	298	94.9	2.48%	173	0.07	0.48	0.10	1.75	N.D.	N.D.	1.55	14.26	0.00	48.77
S32	8.31	7.79	129	338	NM	4.30%	192	0.06	1.04	3.90	1.13	N.D.	N.D.	2.48	14.48	0.00	56.94

ND non detect
NM not measured

Table 2. 2006 water chemistry results for wells in Teton County, Idaho. Red print indicates calculated alkalinity (not field-measured). Note that MCL for nitrate is 10 mg/L.

Sample	Temp °C	pH	ORP (mv)	Sp. Cond (us/cm)	%D.O.	Charge balance error	Alkalinity mg/L CaCO3	Fluoride mg/L	Chloride mg/L	Nitrate as N mg/L	Sulfate mg/L	Phosphate as P mg/L	Ammonium as N mg/L	Sodium mg/L	Magnesium mg/L	Potassium mg/L	Calcium mg/L
S33	8.12	7.50	129	400	NM	4.82%	224	0.05	1.24	0.82	3.81	N.D.	N.D.	2.72	16.63	0.16	73.50
S34	7.39	7.89	100	266	106.9	7.96%	131	0.09	0.84	0.85	1.83	N.D.	N.D.	1.66	13.29	0.66	40.54
S35	7.21	7.12	91	415	59.9	0%	233	0.42	3.84	0.85	3.39	N.D.	N.D.	7.20	27.24	0.00	46.62
S36	4.01	7.75	33	289	NM	3.89%	153	0.09	0.84	0.14	6.34	N.D	N.D.	2.56	13.56	0.58	44.66
S37	8.97	7.65	140	338	88.6	3.17%	182	0.13	2.03	0.79	1.96	N.D.	N.D.	2.89	13.59	1.39	55.15
S38	7.66	7.62	116	285	85.7	4.09%	148	0.15	3.78	0.19	2.65	N.D.	N.D.	3.29	14.96	1.00	39.94
S39	14.46	7.82	41	283	25.2	2.45%	130	0.94	1.72	0.07	10.55	N.D	N.D.	16.63	8.24	2.35	31.90
S40	7.80	7.54	-257	302	1.4	2.97%	160	0.23	0.82	0.00	3.22	0.06	0.92	7.34	12.55	0.07	42.77
S41	7.82	7.50	134	312	NM	0%	196	0.10	1.08	1.05	1.69	N.D.	N.D.	1.93	14.18	0.00	55.85
S42	9.85	7.37	184	310	117.1	0.57%	186	0.16	1.95	1.21	1.72	N.D.	N.D.	1.63	14.88	0.00	49.33
S43	8.54	7.23	145	371	112.6	0.62%	215	0.10	0.87	2.82	3.65	N.D.	N.D.	1.74	17.42	0.00	56.32
S44	10.79	7.09	160	424	67.1	1.95%	219	0.29	5.81	0.24	2.85	N.D.	N.D.	18.21	11.62	4.83	51.19
S45	8.62	7.52	13	232	78.8	0.00%	167	0.10	0.76	0.52	1.19	N.D.	N.D.	2.29	13.83	0.00	32.30
S46	8.21	7.14	169	314	NM	1%	167	0.12	1.03	1.48	2.27	N.D.	N.D.	2.69	15.58	0.00	41.65
S47	7.70	6.97	93	433	NM	1.96%	210	0.14	1.73	2.80	24.46	N.D.	N.D.	2.51	23.80	0.68	61.48
S48	7.43	7.31	168	378	NM	0%	215	0.12	1.42	3.44	6.81	N.D.	N.D.	2.72	18.97	0.13	61.06
S49	8.90	6.76	141	322	NM	0%	197	0.05	0.91	0.19	1.28	N.D.	N.D.	1.86	10.25	0.00	61.34

ND non detect

NM not measured

Table 2 (concluded). 2002 water chemistry results for wells in Teton County, Idaho. Red print indicates calculated alkalinity (not field-measured). Note that MCL for nitrate is 10 mg/L.

Surface Water Samples	Fluoride mg/L	Chloride mg/L	Nitrate as N mg/L	Sulfate mg/L	Phosphate as P mg/L	Ammonium as N mg/L	Sodium mg/L	Magnesium mg/L	Potassium mg/L	Calcium mg/L
TR-1	0.15	1.21	1.86	13.78	N.D.	0.02	2.65	15.65	0.54	62.92
TC-2	0.04	0.33	0.11	2.11	N.D.	0.04	1.06	5.27	0.00	23.88
TR-3	0.06	0.59	0.46	4.19	N.D.	0.01	1.53	10.92	0.15	47.96
TR-4	0.06	0.63	0.16	3.22	N.D.	0.11	1.89	9.91	0.63	50.27
Fish	0.09	0.49	0.16	1.88	N.D.	0.01	1.47	15.86	2.01	61.26
Six	0.31	1.91	7.64	8.70	N.D.	0.03	1.66	10.75	0.03	37.20
Fox-1	0.14	1.42	3.04	5.99	N.D.	0.01	2.59	18.35	0.81	67.77
Fox-2	0.03	0.31	0.12	1.73	N.D.	0.05	1.01	9.02	0.00	39.13
Woods	0.05	3.78	1.24	3.90	0.19	1.05	4.43	10.93	1.13	54.05
Warm	0.15	0.55	0.01	19.33	N.D.	0.01	1.76	14.99	0.14	51.74
Darby	0.06	0.30	0.11	1.91	N.D.	0.03	0.99	10.00	0.00	35.47

ND non detect

Table 3. 2006 water chemistry results for surface water samples in Teton County, Idaho. Note that MCL for nitrate is 10 mg/L.

Sample	May_2002	Aug_2002	Oct_2002	Jul_2006	Increase or Decrease in Nitrate Concentrations
S1	*NM*	*NM*	4.06	2.41	Decrease
S2	*1.28*	*NM*	1.34	0.56	Decrease
S4	4.86	*NM*	3.19	1.40	Decrease
S5	2.01	*NM*	2.25	2.47	Increase
S7	*5.74*	*NM*	*NM*	5.05	Decrease
S8	0.43	*NM*	*NM*	0.05	Decrease
S25	1.88	*NM*	1.90	1.78	Decrease
S12	1.49	2.91	2.25	1.59	Decrease
S13	2.95	*NM*	3.44	2.71	Decrease
S14	*2.43*	*NM*	1.7	3.75	Increase
S16	0.63	*NM*	0.85	1.83	Increase
S17	0.88	1.26	0.88	0.95	Decrease
S18	0.03	*NM*	*NM*	0.18	Increase
S19	6.79	*NM*	7.37	8.17	Increase
S20	3.28	*NM*	1.60	1.74	Decrease
S22	7.53	*NM*	7.65	7.73	Increase
S23	0.38	*NM*	0.48	0.48	Increase

Table 4. A comparison of nitrate concentrations for samples analyzed in 2002 and 2006 for Teton County, Idaho. The nitrate concentration is mg/L NO_3 as N.

NM indicates not measured. Note that MCL for nitrate is 10 mg/L.

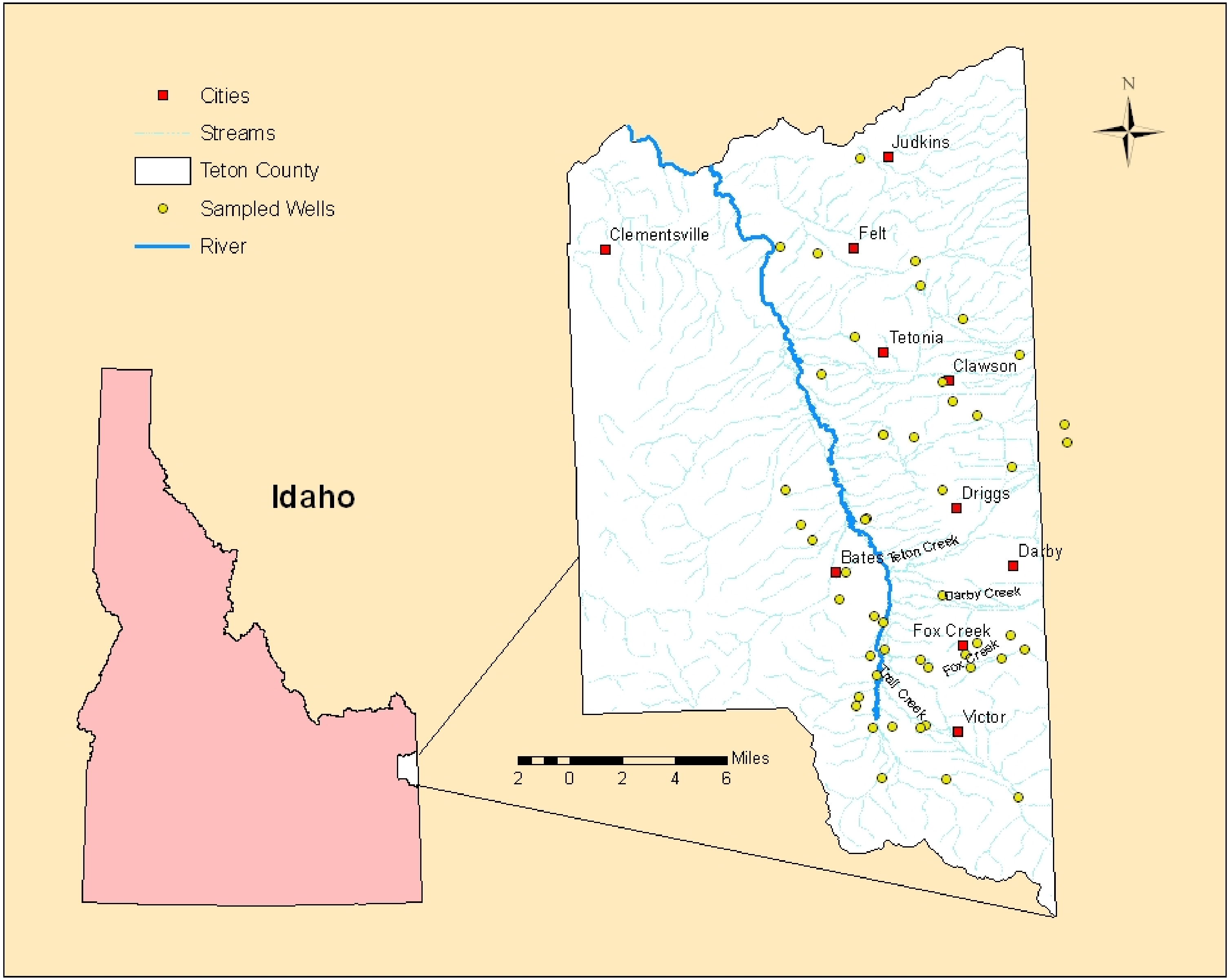

Figure 1. Study area and location within Idaho.

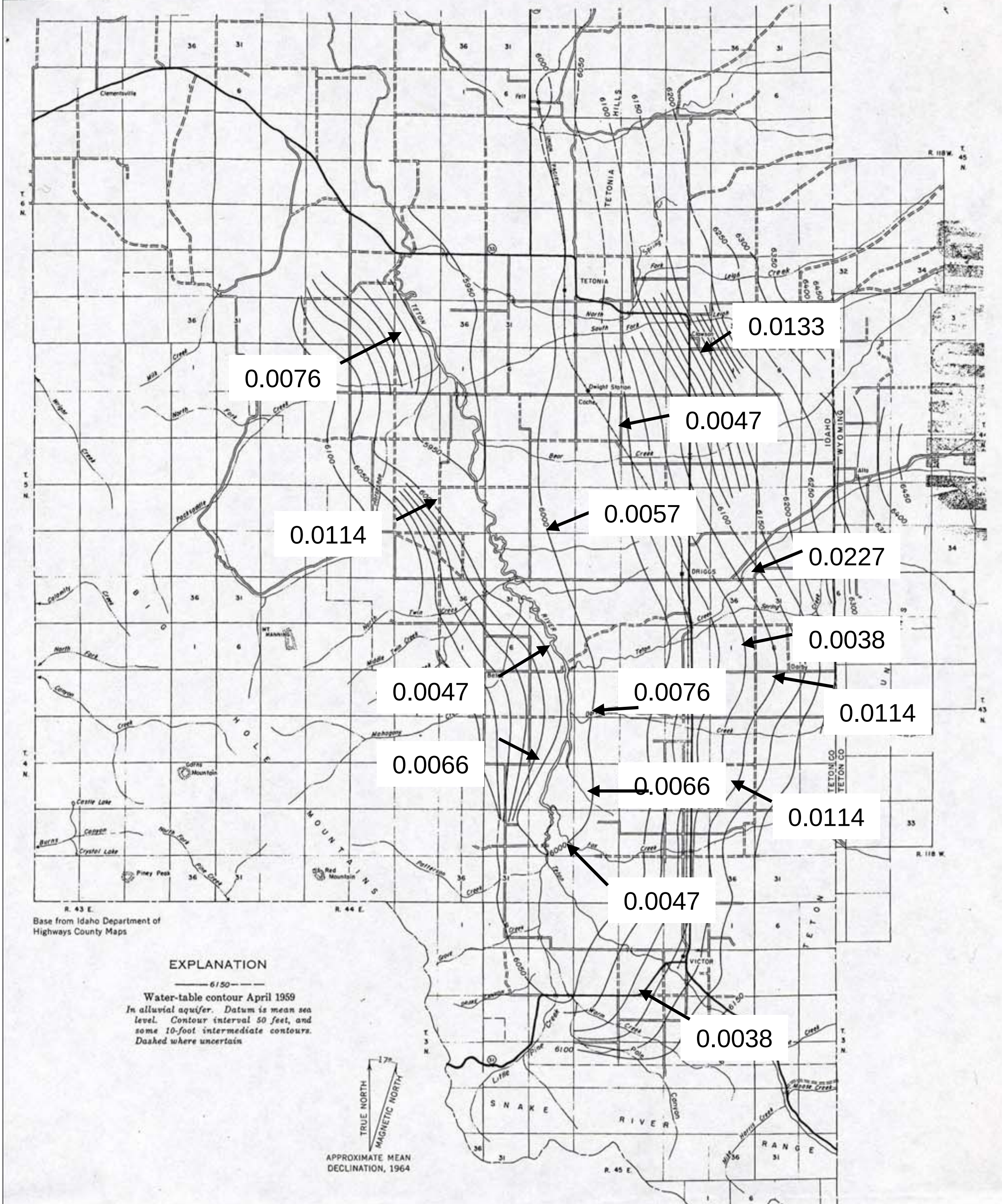

Figure 2. Gradient (ft/ft) in selected locations. Map reprinted from Kilburn, 1964.

MAP SHOWING APPROXIMATE CONFIGURATION OF THE WATER TABLE IN THE UPPER TETON VALLEY, IDAHO AND WYOMING

SCALE 1:125 000

2 0 2 4 6 MILES

2 0 2 4 6 KILOMETERS

735-911 O - 64 (In pocket)

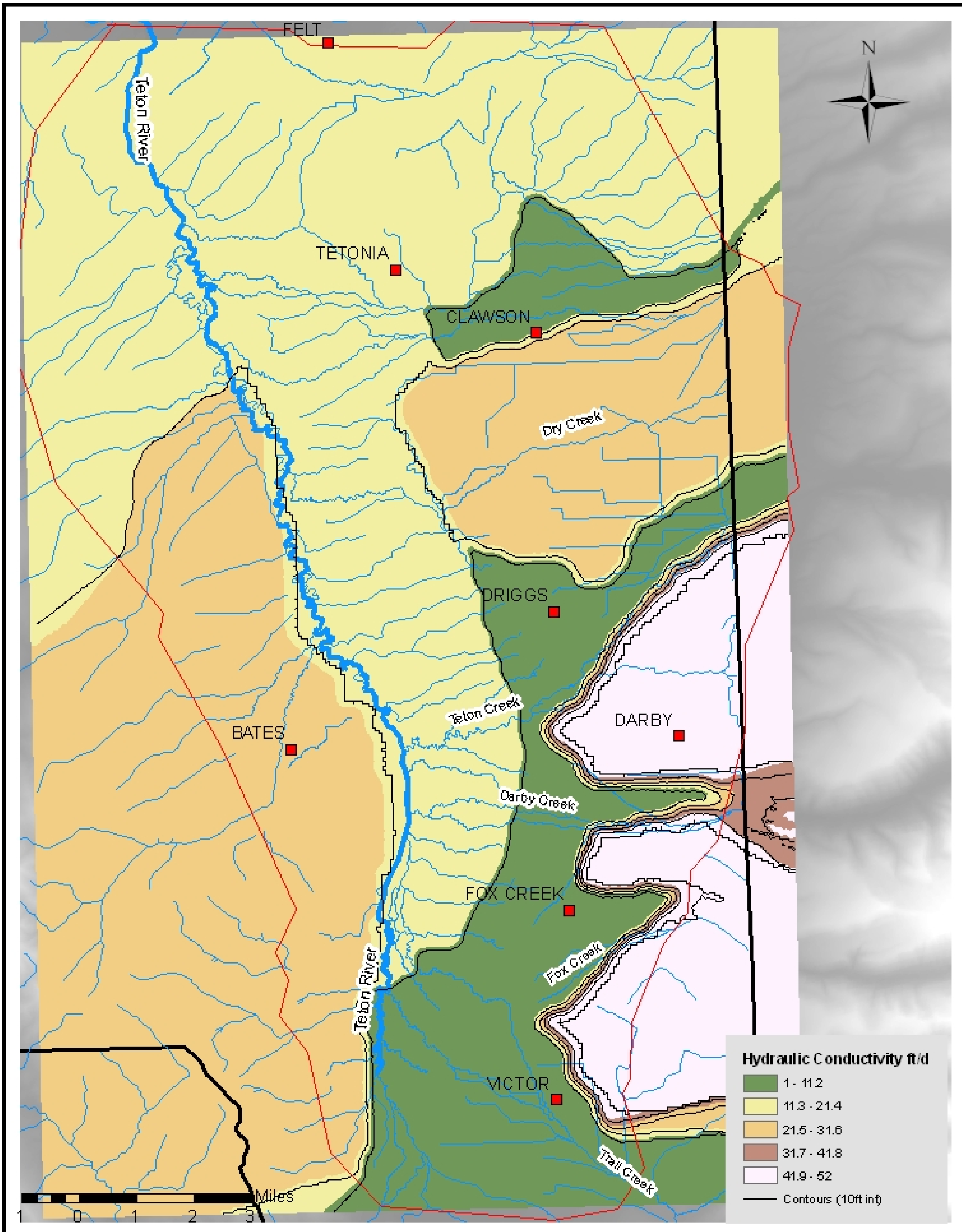

Figure 3. Hydraulic conductivity (ft/d).

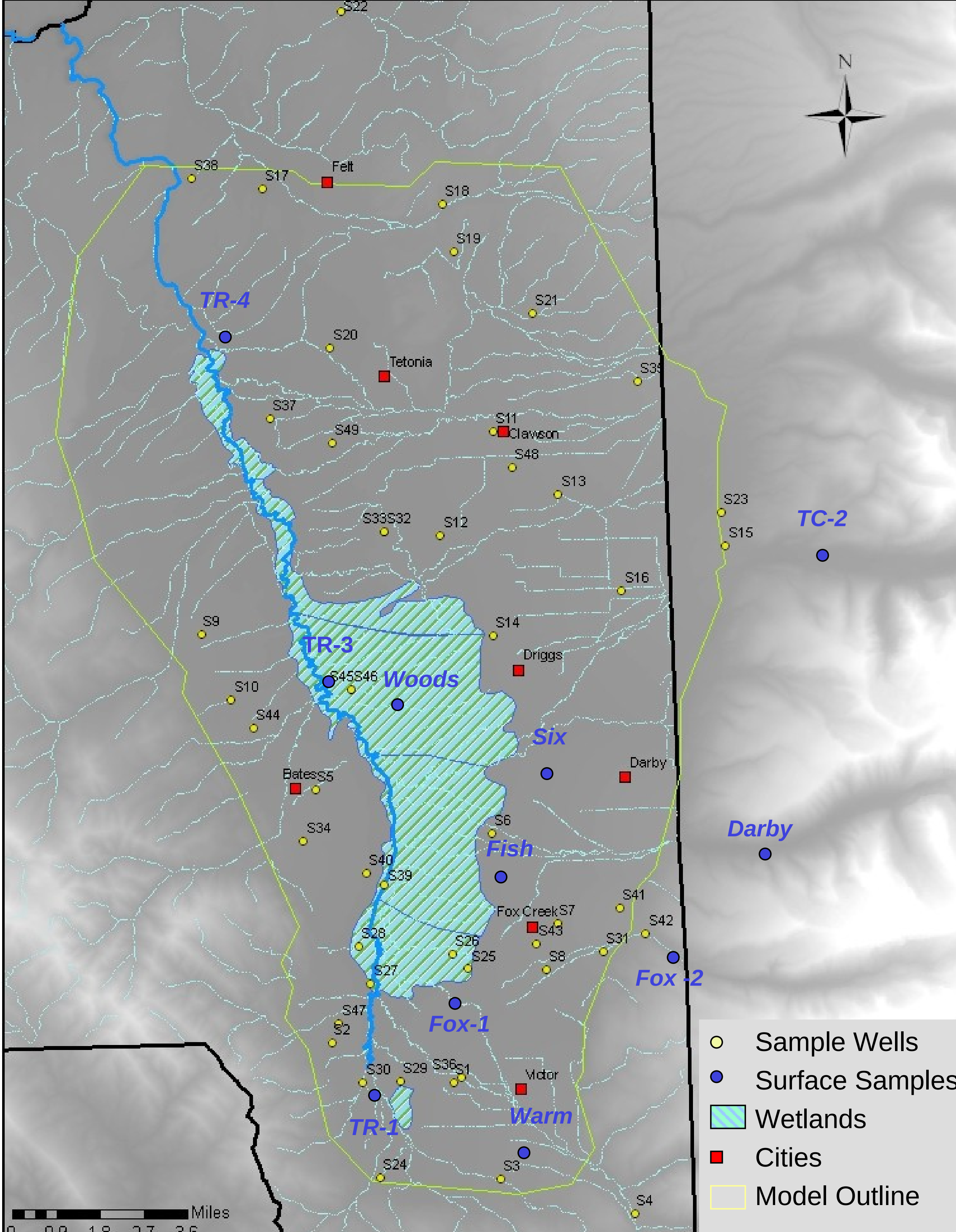

Figure 4. Location of sample wells and surface sample sites.

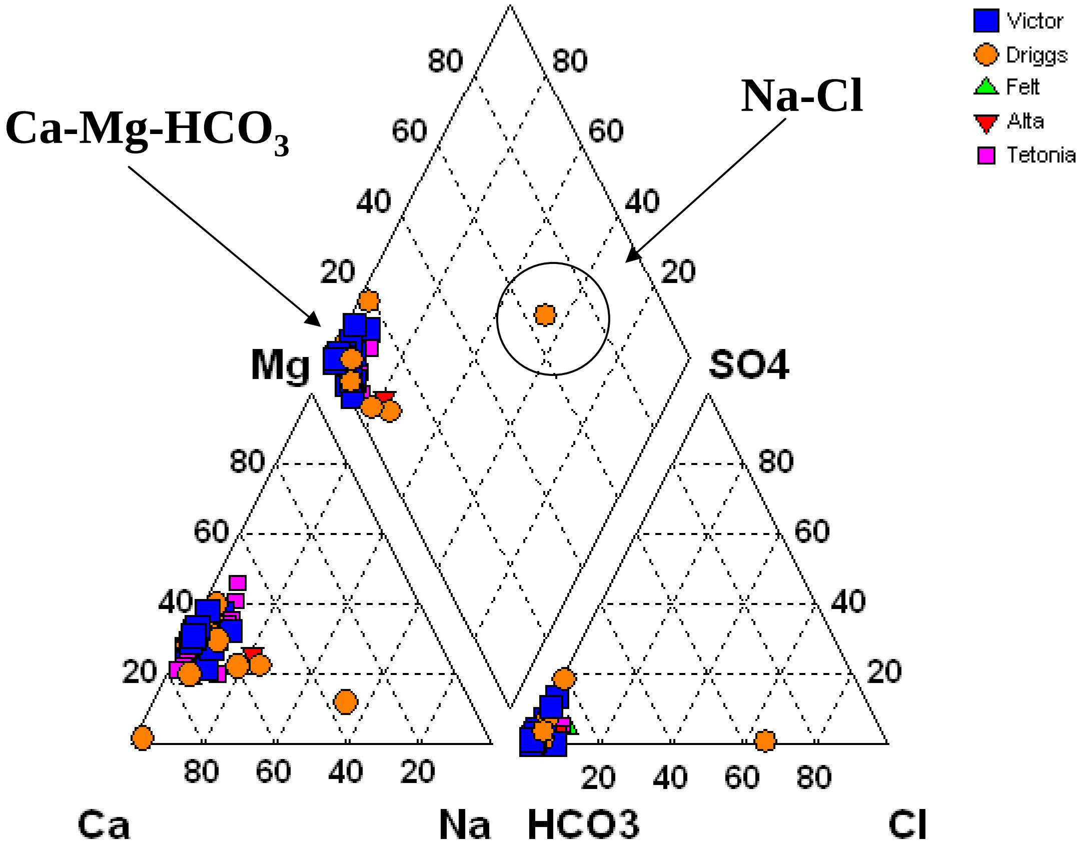

Figure 5. Piper Diagram of the water chemistry from sampled wells in Teton County.

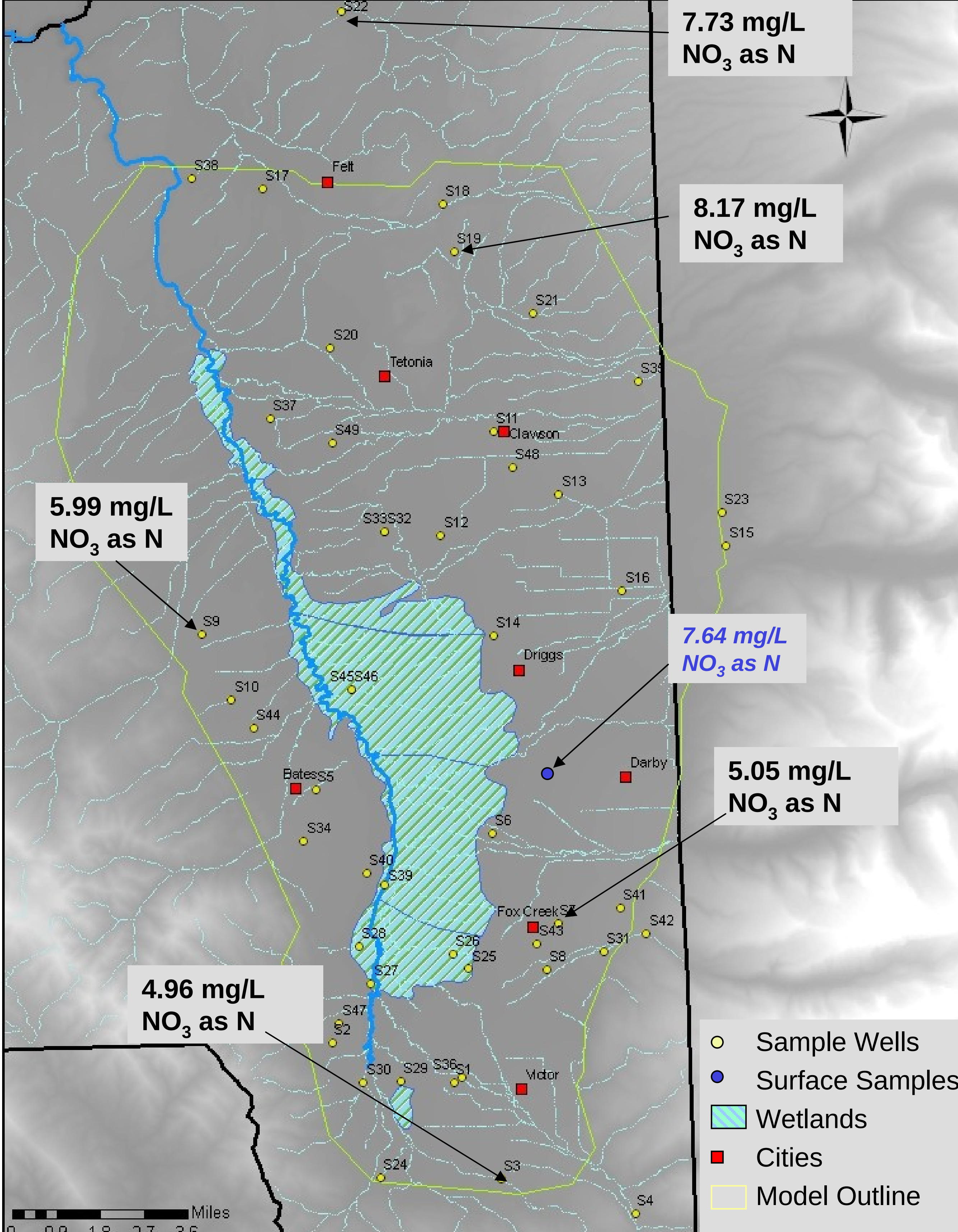

Figure 6. Sampling sites with elevated nitrate concentrations in the ground water (black print) and surface water (blue print) samples. All samples are well below the regulatory limit of 10 mg/L NO3 as N.

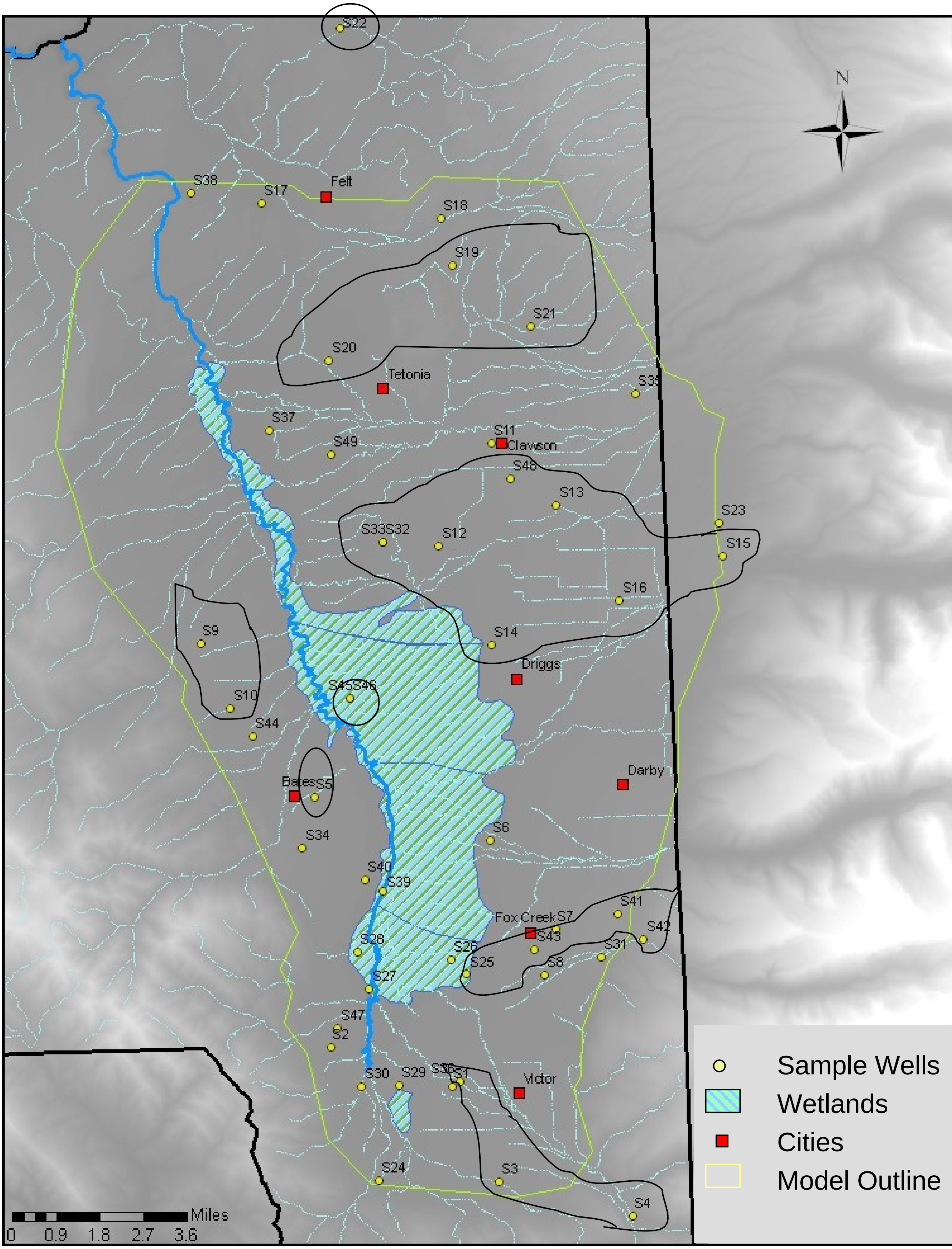

Figure 7. Location of ground-water samples with nitrate concentrations greater than 1 mg/L NO_3 as N.

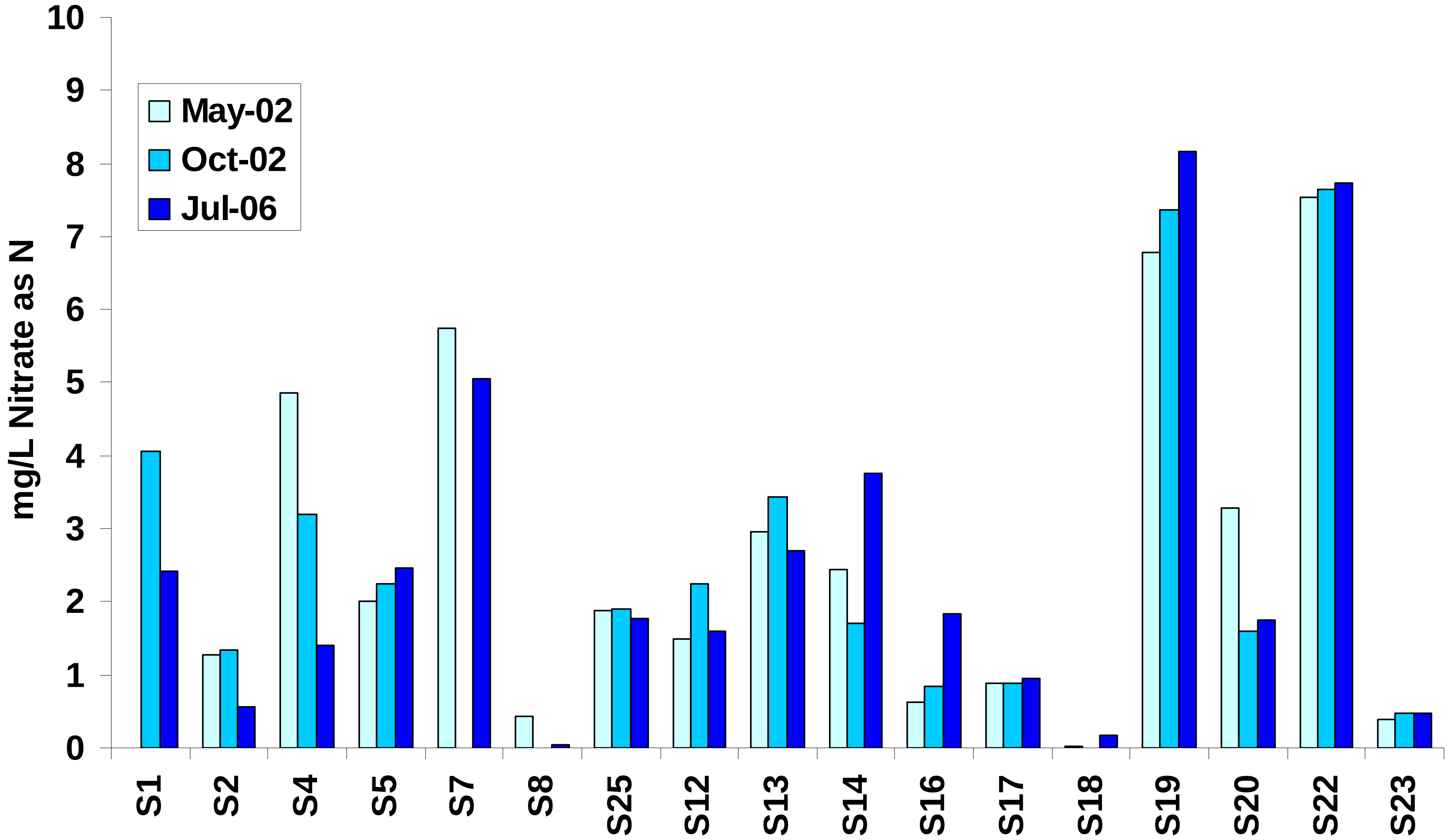

Figure 8. Comparison of 2002 and 2006 nitrate concentrations in ground-water wells.

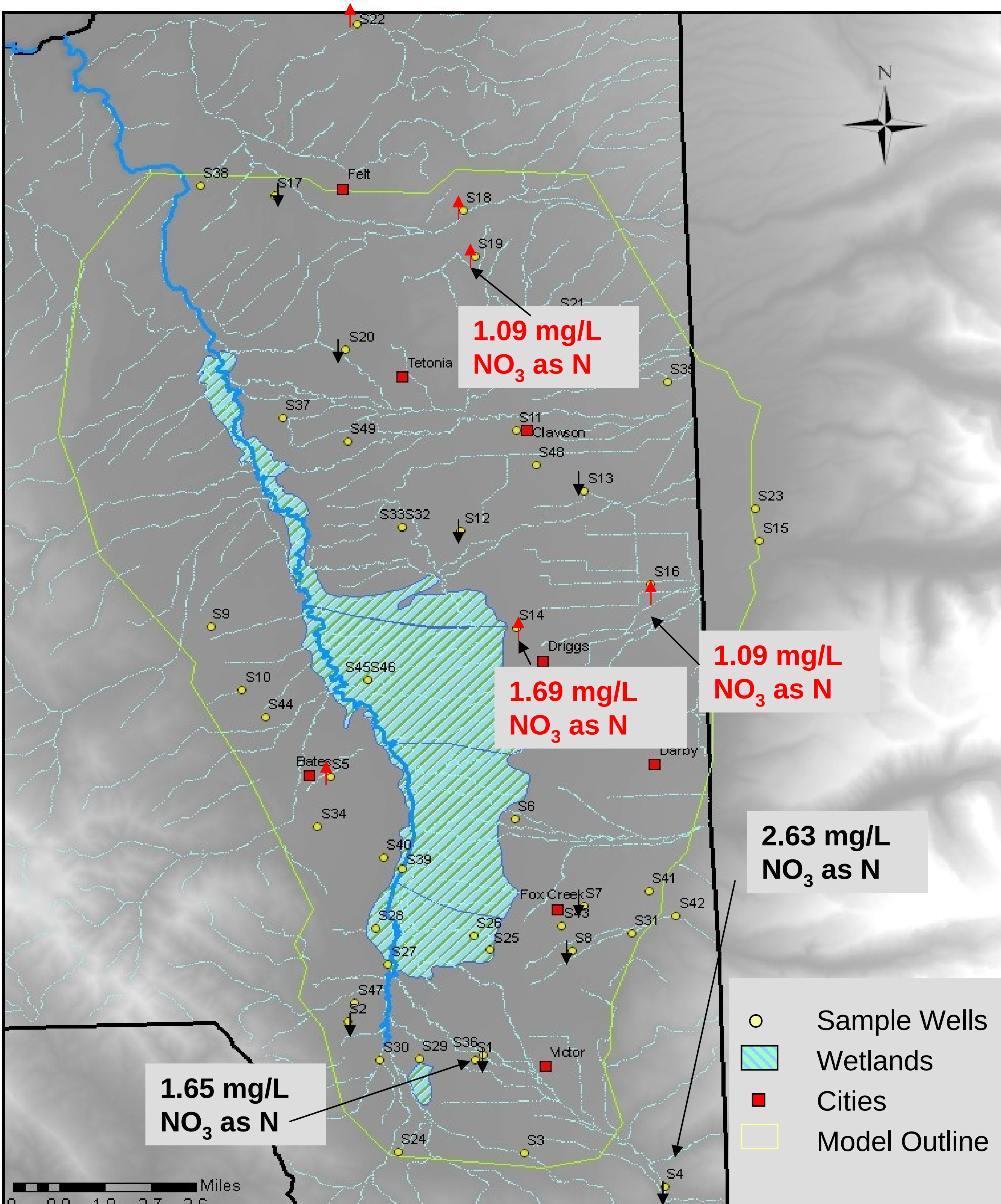

Figure 9. Labeled wells indicate locations of samples with a greater than 1 mg/L NO3 as N decrease (black) and increase (red), unless otherwise stated for nitrate concentrations between 2002 and 2006. Small black and red arrows indicate wells which changed less than 1 mg/L between 2002 and 2006.