ANALYSIS OF SEPTIC-TANK DENSITY FOR FOUR COMMUNITIES IN IRON COUNTY, UTAH: NEWCASTLE, KANARRAVILLE, SUMMIT, AND PARAGONAH

by Trevor H. Schlossnagle, Janae Wallace, and Nathan Payne

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Cover photo: *View to the north of the Kanarraville basin from Kanarra Creek.*

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CONTENTS

FIGURES

TABLES

ANALYSIS OF SEPTIC-TANK DENSITY FOR FOUR COMMUNITIES IN IRON COUNTY, UTAH: NEWCASTLE, KANARRAVILLE, SUMMIT, AND PARAGONAH

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ABSTRACT

Iron County is a semi-rural area in southwestern Utah that is experiencing an increase in residential development. Although much of the development is on community sewer systems, many subdivisions use septic tank soil-absorption systems for wastewater disposal. Many of these septic-tank systems overlie the basin-fill deposits that compose the principal aquifer for the area. The purpose of our study is to provide tools for water-resource management and land-use planning. In this study we (1) characterize the water quality of four areas in Iron County (Newcastle, Kanarraville, Summit, and Paragonah) with emphasis on nutrients, and (2) provide a mass-balance analysis based on numbers of septic-tank systems, groundwater flow available for mixing, and baseline nitrate concentrations, and thereby recommend appropriate septic-system density requirements to limit water-quality degradation.

We collected 57 groundwater samples and three surface water samples across the four study areas to establish baseline nitrate concentrations. The baseline nitrate concentrations for Newcastle, Kanarraville, Summit, and Paragonah are 1.51 mg/L, 1.42 mg/L, 2.2 mg/L, and 1.76 mg/L, respectively.

We employed a mass-balance approach to determine septic-tank densities using existing septic systems and baseline nitrate concentrations for each region. Nitrogen in the form of nitrate is one of the principal indicators of pollution from septic tank soil-absorption systems. To provide recommended septic-system densities, we used a mass-balance approach in which the nitrogen mass from projected additional septic tanks is added to the current nitrogen mass and then diluted with groundwater flow available for mixing plus the water added by the septic-tank systems themselves. We used an allowable degradation of 1 mg/L with respect to nitrate. Groundwater flow volume available for mixing was calculated from existing hydrogeologic data. We used data from aquifer tests compiled from drinking water source protection documents to derive hydraulic conductivity from reported transmissivities. Potentiometric surface maps from existing publications and datasets were used to determine groundwater flow directions and hydraulic gradients.

Our results using the mass balance approach indicate that the most appropriate recommended maximum septic-tank densities in Newcastle, Kanarraville, Summit, and Paragonah are 23 acres per system, 7 acres per system, 5 acres per system, and 11 acres per system, respectively. These recommendations are based on hydrogeologic parameters used to estimate groundwater flow volume. Public valley-wide sewer systems may be a better alternative to septic-tank systems where feasible.

INTRODUCTION

Purpose and Scope

Iron County is a semi-rural area in southwestern Utah that has experienced and continues to experience an increase in residential development. Although much of the development is on community sewer systems, many smaller towns and subdivisions use septic tank soil-absorption systems for wastewater disposal. Many of these septic-tank systems overlie basin-fill deposits that compose the principal aquifer for the area. Preservation of groundwater quality and the potential for groundwater quality degradation are critical issues that should be considered in determining the extent and nature of future developments in Iron County. Local government officials in Iron County have expressed concern about the potential impact that development may have on groundwater quality, particularly development that uses septic tank soil-absorption systems for wastewater disposal. Local government officials have asked the Utah Geological Survey to provide a basis for defensible land-use regulations to protect groundwater quality, and in particular for determining recommended densities for septic-tank systems as a land-use planning tool.

The purpose of our study is to provide land-use planners with science-based tools for approving new development in a manner that will protect groundwater quality in four distinct communities: Newcastle, Kanarraville, Summit, and Paragonah (figure 1). To accomplish this, we use a mass balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the basin-fill aquifers, and thereby recommend appropriate septic-system density requirements to limit water-quality degradation.

Previous Investigations

A comprehensive review of geologic studies conducted in our study areas within Iron County is beyond the scope of this report. We instead summarize a selection of relevant work completed in each study area.

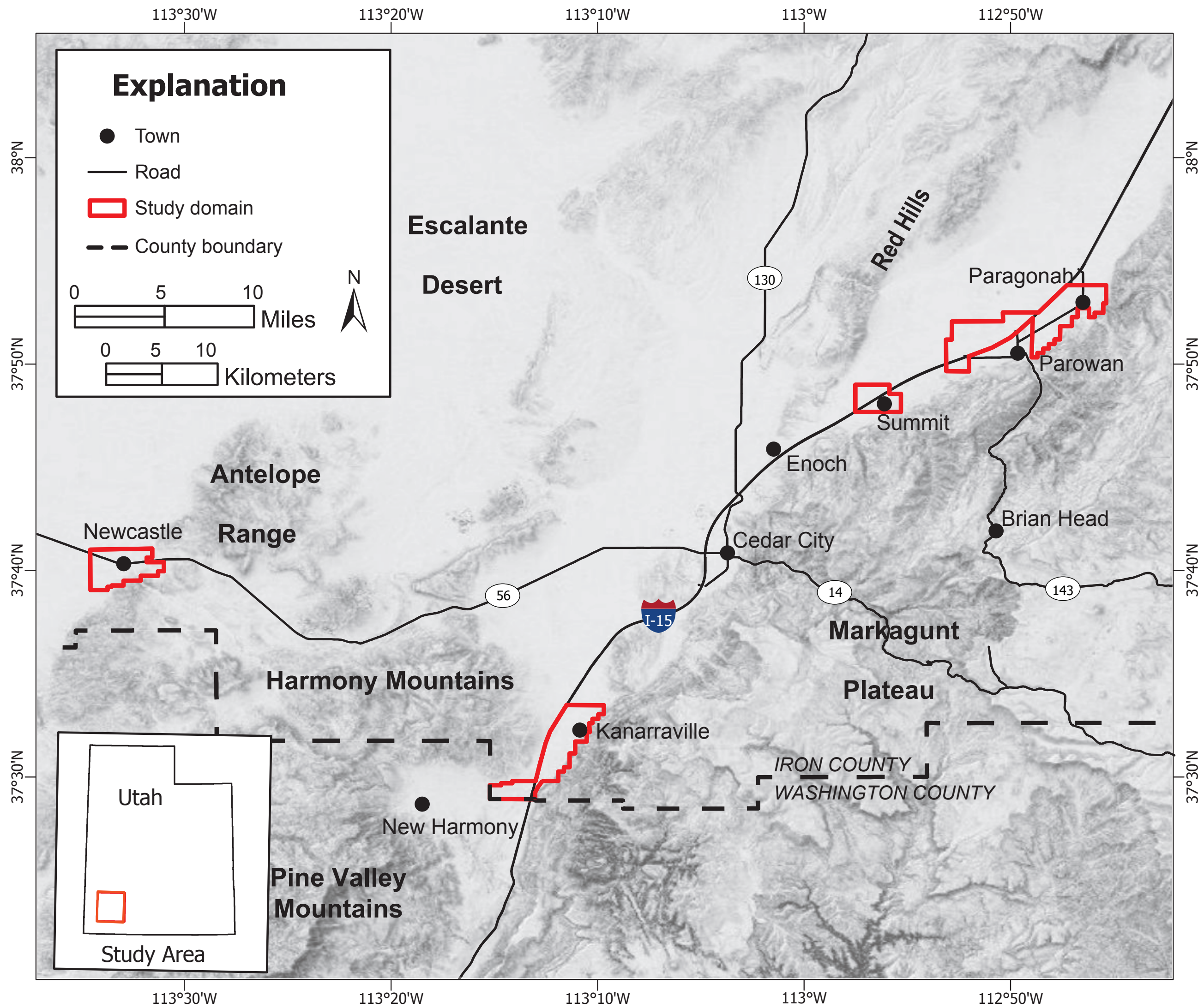

Figure 1. *Location of four study areas within Iron County, Utah.*

Newcastle

Sandberg (1963, 1966) compiled groundwater data and correlated previous groundwater studies in the Beryl-Enterprise area. Mower and Sandberg (1982) compiled groundwater data in the same area and produced a comprehensive study of groundwater conditions there. Blackett and Shubat (1992) produced a case study of the Newcastle geothermal system which led to further study by Blackett and others (1997) and Blackett (2004, 2007). Burden and others (2005) evaluated water-level change in the Beryl-Enterprise area, whereas Lowe and others (2009) evaluated groundwater sensitivity and vulnerability to pesticides in the area, partly based on mapping of recharge and discharge areas of the basin-fill aquifer done by Thomas and Lowe (2007). Lund and others (2005) evaluated the relationship between groundwater and land fissures in Escalante Valley.

Kanarraville

Cordova and others (1972) created a hydrologic budget for the basin-fill and consolidated rock aquifers in the central Virgin River basin. Cordova (1978) continued work in the area, focusing on the hydrology of the Navajo Sandstone. Hurlow (1998) produced a comprehensive study of the basin with respect to groundwater conditions. Heilweil and others (2000) built a groundwater flow model of consolidated rock aquifers in the region, and Inkenbrandt and others (2013) reported on the regional groundwater flow in the Virgin River basin.

Summit and Paragonah

Thomas and Taylor (1946) reported on the water resources and groundwater development of Parowan and Cedar Valleys. Sandberg (1963, 1966) compiled groundwater data and correlated previous groundwater studies in Parowan Valley, and later, Bjorklund and others (1977, 1978) described the water resources of Parowan Valley in detail. Hurlow (2002) produced a comprehensive study of Cedar Valley and parts of Parowan Valley with respect to groundwater conditions. DuRoss and Kirby (2004) investigated the relationship between ground cracks and groundwater within western Parowan Valley. Burden and others (2015) evaluated water-level changes in Parowan Valley, and Marston (2017) produced a comprehensive water resources study of the valley, including a groundwater budget. Also, several septic-tank density and groundwater quality studies have been conducted in nearby Cedar Valley (Wallace and Lowe, 1998a; Lowe and others, 2000, 2010).

SEPTIC-SYSTEM DENSITY ANALYSIS

Introduction

Land-use planners have long used soil maps and septic-tank suitability maps to determine where effluent from septic-tank systems is likely to percolate at a rate that will promote treatment in the soil zone. However, studies show that percolation alone does not remediate many constituents found in wastewater, such as nitrate. Under aerobic conditions, ammonium from septic-tank effluent can convert to nitrate, contaminating groundwater and posing potential health risks to humans (primarily very young infants; Comley, 1945; Fan and others, 1987; Bouchard and others, 1992). Studies involving lab rats ingesting a combination of nitrate and heptamethyleneimine in drinking water reported an increase in tumor occurrence (Taylor and Lijinsky, 1975). However, epidemiological investigations involving human beings have shown conflicting evidence. Stomach cancer in humans associated with nitrate from drinking water was reported in Colombia and Denmark (Cuello and others, 1976; Fraser and others, 1980). Conversely, investigations in the United Kingdom and other countries indicate no correlation between nitrate levels and cancer incidence (Forman, 1985; Al-Dabbagh and others, 1986; Croll and Hayes, 1988; Taneja and others, 2017). The U.S. Environmental Protection Agency (EPA) maximum contaminant level for drinking water (and Utah groundwater quality standard) for nitrate as nitrogen is 10 mg/L (U.S. EPA, 2022). With continued population growth and installation of septic tank soil-absorption systems in new developments, the potential for nitrate contamination will increase. One way to evaluate the potential impact of septic-tank systems on groundwater quality is to perform a nitrate mass-balance calculation (Hansen, Allen, and Luce, Inc., 1994; Zhan and McKay, 1998; Wallace and Lowe, 1998a, 1998b, 1998c, 1999; Lowe and Wallace, 1999; Lowe and others, 2000, 2002, 2003; Bishop and others, 2007a, 2007b; Jordan and others, 2019, Wallace and others, 2021). This type of analysis may be used as a gross model for evaluating the possible impact of proposed developments using septic-tank systems for wastewater disposal on groundwater quality, allowing planners to more effectively determine appropriate average septic-system densities.

The purpose of septic-tank density mapping conducted in this study is to provide recommended septic-tank densities for four different study areas in Iron County using the mass-balance approach to evaluate potential water-quality degradation. The 2020 population of Iron County was 57,289 (U.S. Census Bureau, 2021) with an average of 3.3 people per household (pph). The current minimum lot size in use for our study areas is 5 acres/system (Reed Erickson, Iron County Planner, written communication, 2021), based on a previous study for Cedar Valley in Iron County (Lowe and others, 2010). For each study area, we determined area acreage, groundwater flow volume, number of existing septic-tank systems, and present-day nitrate concentrations. We used nitrate as a proxy for dispersion and dilution of most common septic-tank effluent constituents because it is soluble, mobile, and less expensive to test than other constituents. We determined groundwater hydraulic conductivity from aquifer tests and determined hydraulic gradient from existing potentiometric surface maps to estimate groundwater flow volume. Then, using the estimated amount of wastewater and accompanying nitrogen load introduced per septic-tank system, we projected nitrogen loadings based on increasing numbers of septic-tank systems. By limiting allowable degradation of groundwater nitrate concentration to 1 mg/L (a common amount of water-quality degradation determined to be acceptable by local government officials), we were then able to derive septic-tank density recommendations for each study area. We used this analysis as a gross model for evaluating the possible impact on groundwater quality of proposed developments using septic-tank systems for wastewater disposal.

Groundwater Contamination from Septic-Tank Systems

As the effluent from a septic tank soil-absorption system leaves the drain field and percolates into the underlying soil, it can have high concentrations of pathogens, such as viruses and bacteria. Organisms such as bacteria can be mechanically filtered by fine-grained soils and are typically removed after traveling a relatively short distance in the unsaturated zone. However, in coarse-grained soils, or soils containing preferential flow paths such as fractures, worm burrows, or root holes, these pathogens can reach the water table. Pathogens can travel up to 40 feet in the unsaturated zone in some soils (Franks, 1972). Some viruses can survive more than 250 days (U.S. EPA, 1987), which is the minimum required groundwater travel time for public water-supply wells or springs to be separated from potential biological contamination sources.

Many household and industrial chemicals are commonly disposed of through septic systems and, unless they volatilize easily, are not remediated by percolation through soils in the unsaturated zone. Contamination from these chemicals can be minimized by reducing their disposal via septic-tank systems, maximizing the potential for dilution of those chemicals (Lowe and Wallace, 1999). Community awareness and education can also help reduce this waste.

Phosphate, typically derived from organic material or some detergents, is discharged from septic-tank systems. Although phosphate (and phosphorus) is a major factor in causing eutrophication of surface waters, it is generally not associated with water-quality degradation due to the use of septic-tank systems (Fetter, 2001). Phosphates are removed from septic-tank system effluent by adsorption onto fine-grained soil particles and by precipitation with calcium and iron. In most soils, complete removal of phosphate is common (Franks, 1972).

Ammonia and organic nitrogen, mostly from the human urinary system, are present in wastewater in septic tanks. Typically, almost all ammonia is converted into nitrate before leaving the septic-tank system drain field. Once nitrate passes below the zone of aerobic bacteria and the roots of plants, attenuation is negligible as it travels farther through the soil (Franks, 1972). Once in groundwater, nitrate becomes mobile and can persist in the environment for long periods of time. Areas having high densities of septic-tank systems risk elevated nitrate concentrations reaching unacceptable levels. In the early phases of groundwater quality degradation associated with septic-tank systems, nitrate is likely to be the only pollutant detected (Deese, 1986). Regional nitrate contamination from septic-tank discharge has been documented where many densely populated areas without sewer systems have existed (Fetter, 2001).

Groundwater having less than 0.2 mg/L nitrate is assumed to represent natural background concentrations; groundwater having nitrate concentrations between 0.21 and 3.0 mg/L is considered transitional and may or may not represent human influence (Madison and Brunett, 1985). Groundwater having concentrations exceeding 3 mg/L is typically associated with human- or animal-derived sources, but higher concentrations have also been identified with natural sources (Green and others, 2008), albeit less commonly. Changes in land-use practices in arid regions in the western U.S. have been attributed to changes in trends of water quality with emphasis on nitrate contamination (Xu and others, 2007).

Distances between septic tank soil-absorption system drain fields and sources of culinary water must be sufficient for dilution of nitrate in effluent to levels below the groundwater quality standard. We consider nitrate to be the key contaminant for use in determining the number or density of septic-tank systems allowed in our Iron County study areas. Projected nitrate concentrations in all or parts of aquifers can be estimated for increasing septic-tank system densities using a mass-balance approach.

The Mass-Balance Approach

General Methods

We used a mass-balance approach for water-quality degradation assessments because it is a practical method to apply under time, budget, and data availability/acquisition constraints, and it provides a quantitative basis for land-use planning decisions. To compute projected nitrate concentrations, we added the average nitrogen mass expected from projected new septic tanks to the existing mass of nitrogen in groundwater and then diluted with the estimated groundwater flow available for mixing, plus water that is added to the system by septic tanks. We used an average estimated discharge of 198 gallons (749 L) of effluent per day for a domestic home based on a per capita indoor usage of 60 gallons (227 L) per day (Utah Division of Water Resources, 2010) multiplied by an average 3.3-person household in Iron County (U.S. Census Bureau, 2021). We used an estimated nitrogen loading of 64 mg/L nitrate as nitrogen in effluent per domestic septic tank based on (1) average nitrogen loading of 17 grams nitrogen per capita per day (Kaplan, 1988), (2) 227 L per capita per day water use, and (3) an assumed retention of 15% of the nitrogen in the septic tank (to be later removed during pumping) (Andreoli and others, 1979). Our nitrogen loading estimate is similar to Bauman and Schafer's (1984) nitrogen concentration in septic-tank effluent of 62 ± 21 mg/L based on the averaged means from 20 previous studies. For our mass-balance calculations, we allowed a 1 mg/L degradation above current baseline levels of nitrate (a value adopted by other Utah counties as an acceptable level of degradation to be protective of water quality [Hansen, Allen, and Luce, Inc., 1994]) as a reference point to evaluate the potential impact of increased numbers of septic-tank systems. Local government officials may choose a different nitrate concentration as an acceptable level of degradation to be protective of water quality.

We determined groundwater flow available for mixing—the major control on nitrate concentration in aquifers when using the mass-balance approach (Wallace and Lowe, 1999)—using aquifer test data compiled from drinking water source protection documents in the study areas. We obtained the number of septic-tank systems based on data provided by the Southwest Utah Public Health Department and aerial imagery to identify structures served by a septic-tank system.

We used the following equation to determine the projected nitrate concentration resulting from additional septic systems, and thus to determine how many septic-tank systems can be added before exceeding a designated target nitrate concentration:

$$N_P = \frac{[(ST_T - ST_C)Q_{ST}] * N_{ST} + [N_A(Q_{GW} + [ST_T * Q_{ST}])]}{[ST_T * Q_{ST}] + Q_{GW}} \quad (1)$$

where:

N_P is the projected nitrate concentration (mg/L),

N_A is the ambient (baseline) nitrate concentration for the domain (mg/L),

N_{ST} is the estimated average nitrate concentration from septic tanks (mg/L),

ST_T is the total number of septic tanks in the domain (variable, unitless),

ST_C is the current number of septic tanks (constant, unitless),

Q_{ST} is the flow from each septic tank in liters per second (L/s),

Q_{GW} is the groundwater flow available for mixing (L/s).

To determine a recommended septic-system density, we divided the domain area acreage by the total number of septic tanks (STT) that would exist at the projected nitrate concentration (NP).

Groundwater Flow Calculations

We calculated groundwater flow available for mixing as:

$$Q=KbLI \tag{2}$$

where:

Q is the volume of discharge (ft^3/s),

K is the hydraulic conductivity (ft/s),

b is the vertical mixing zone thickness (ft),

L is the width of cross section (ft) where flow occurs,

I is the hydraulic gradient (ft/ft).

We used data from aquifer tests compiled from drinking water source protection documents (Diedre Beck, Utah Division of Drinking Water, written communication, August 2021) to derive hydraulic conductivity from reported transmissivities. We used potentiometric surface maps from existing publications and datasets to determine groundwater flow directions and hydraulic gradients. We used a mixing zone thickness of 50 feet based on aquifer thickness; we assume uniform and complete mixing/dilution of septic-tank effluent occurs within this layer. The upper part of the aquifer is where nitrate associated with septic-tank systems is most likely to degrade water quality. Bauman and Schafer (1984) found that mixing zone thickness has minimal impact on nitrate concentrations in aquifers having low groundwater velocities like those commonly found in Utah.

Limitations

There are many limitations to any mass-balance approach (see, for example, Zhan and McKay, 1998; Lowe and others, 2000). We identified the following limitations to our application of the mass-balance approach:

- Calculations of groundwater available for mixing are based on data compiled from isolated aquifer tests and regional potentiometric surface maps.
- Baseline nitrate concentration is attributed to natural sources, agricultural practices, and use of septic-tank systems, but projected nitrate concentrations are based on septic-tank systems only and do not include nitrate from other potential sources (such as fertilizer or livestock).
- The approach assumes uniform geologic conditions within a given area, and thus does not account for local variation that may cause flow variability that can reduce or enhance mixing.
- Calculations do not account for localized, high-concentration nitrate plumes associated with individual or clustered septic-tank systems.
- Calculations assume that the septic-tank effluent from existing homes is in a steady-state condition with the aquifer.
- Calculations assume negligible denitrification and instantaneous groundwater mixing for the entire mixing zone below the study area.

Additionally, calculations do not account for changes in groundwater conditions due to groundwater withdrawal from wells, are based on aquifer parameters that must be extrapolated to larger areas where they may not be entirely representative, and may be based on existing data that do not represent the entire study area.

Although many caveats exist in applying this mass-balance approach, we believe it is the best available method in land-use planning because it provides a general basis for making recommendations for septic-tank system densities. In addition, the approach is cost-effective and can be applied in areas with limited information.

SITE-SPECIFIC SEPTIC-SYSTEM DENSITY EVALUATIONS

Newcastle

Location, Geography, and Climate

Newcastle is in western Iron County, between 38°41'4" and 37°39'3" north latitude and 113°34'32" and 113°31' west longitude (figure 1). Newcastle is located at the eastern edge of Escalante Valley, at the southwestern extent of the Escalante Desert, a northeast-trending basin in the Basin and Range physiographic province. Escalante Valley is bordered by the Antelope Range to the east, near Newcastle, and by the Pine Valley Mountains to the southeast. The valley is approximately 3 to 11 miles wide by 16 miles long, opening to the northeast into the Escalante Desert. Elevations in the Newcastle area range from about 6400 feet in the nearby Antelope Range foothills to about 5200 feet in the valley bottom toward Beryl Junction to the west. Pinto Creek is the sole perennial stream entering Escalante Valley from the east in the Newcastle region.

The climate of Newcastle is semi-arid and characterized by large daily temperature variations; warm, dry summers; and moderately cold winters. Average annual precipitation for the Newcastle area from PRISM 30-year normals (1991–2020) is 13 to 14 inches (PRISM Climate Group, 2021).

Population and Land Use

Newcastle and its surrounding area within the study domain has a population of approximately 370 people (U.S. Census Bureau, 2021). Land use in the Newcastle study domain consists of residential areas and agriculture, including croplands, livestock grazing, dairy farming, and geothermally heated greenhouses.

Geologic Setting

Escalante Valley is separated from the Antelope Range to the east by the Antelope Range fault, a north-northeast striking normal fault (figure 2). The Antelope Range near Newcastle consists primarily of Cretaceous sedimentary rocks and Tertiary sedimentary and volcanic rocks. The Quaternary basin-fill deposits of Escalante Valley consist of unconsolidated to semi-consolidated alluvium, colluvium, and alluvial-fan deposits. A moderate-temperature geothermal anomaly (130°C) is located near the surface trace of the Antelope Range fault near Newcastle and extends into a shallow aquifer to the north and west (Blackett and Shubat, 1992).

Groundwater Conditions

Groundwater in the Newcastle region of Escalante Valley occurs in unconsolidated and semi-consolidated basin-fill aquifers. Blackett and Shubat (1992) conducted gravity surveys that indicate the basin-fill deposits are as much as 5250 feet thick in the Newcastle region. All wells within the Newcastle study area are completed in these basin-fill deposits. Unconfined conditions in the basin-fill aquifer occur throughout the study area along the eastern margins of the valley in coarse-grained sediments of alluvial fans (figure 3; table 1). Mower and Sandberg (1982) reviewed well logs and found that less than 25% of the upper 200 feet of basin fill is sand or gravel. Despite this, confined conditions are lacking in most regions of the aquifer.

Aquifer properties in Escalante Valley vary depending on the thickness and type of sediments found in the basin-fill aquifer. Mower and Sandberg (1982) compiled aquifer test data for six wells in and around Newcastle and calculated a range for average transmissivity values of 13,000 to 120,000 ft^2/day, and

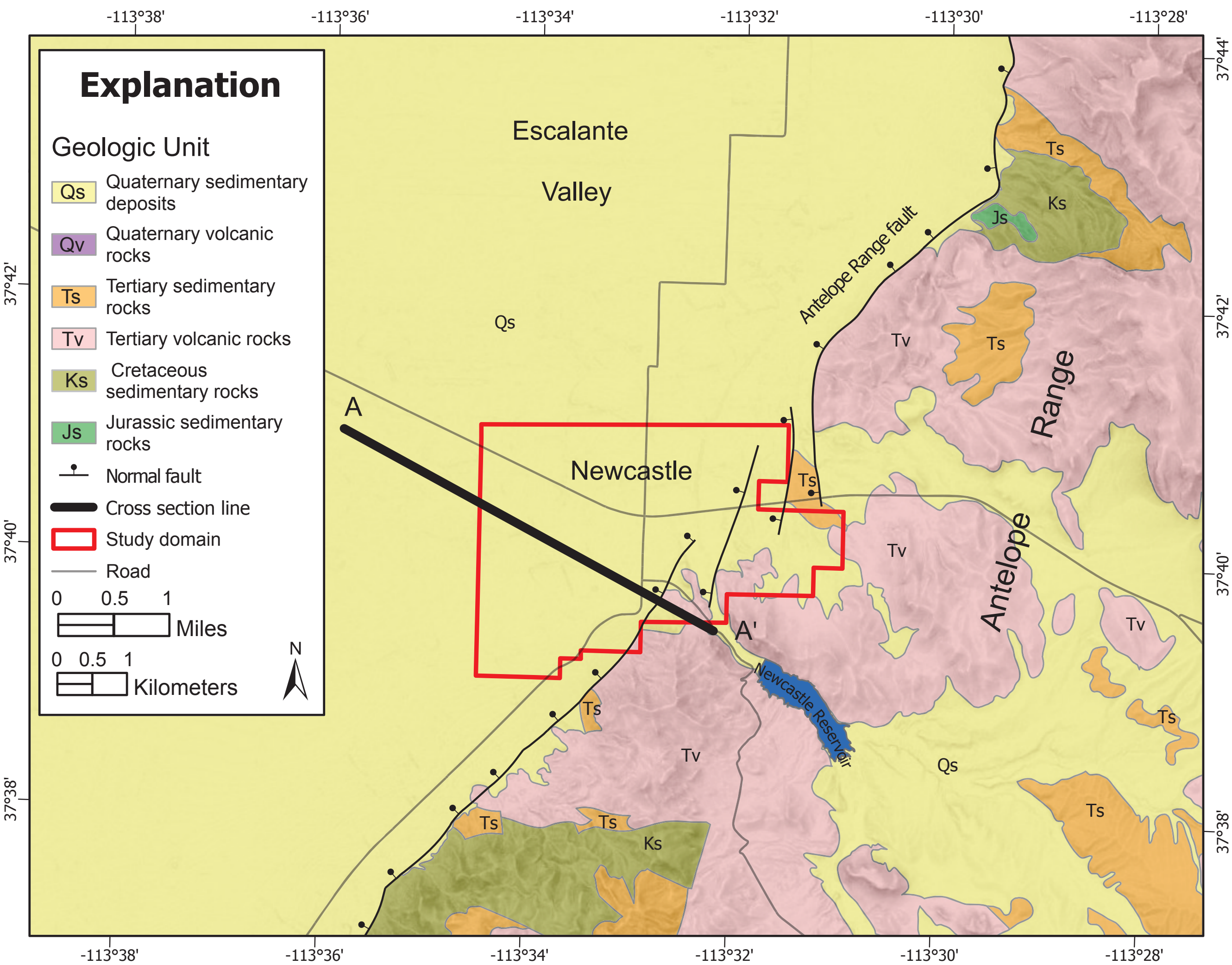

Figure 2. Simplified geologic map of the Newcastle area, Iron County, Utah, modified from Rowley and others (2006). Cross section A-A' shown on figure 3.

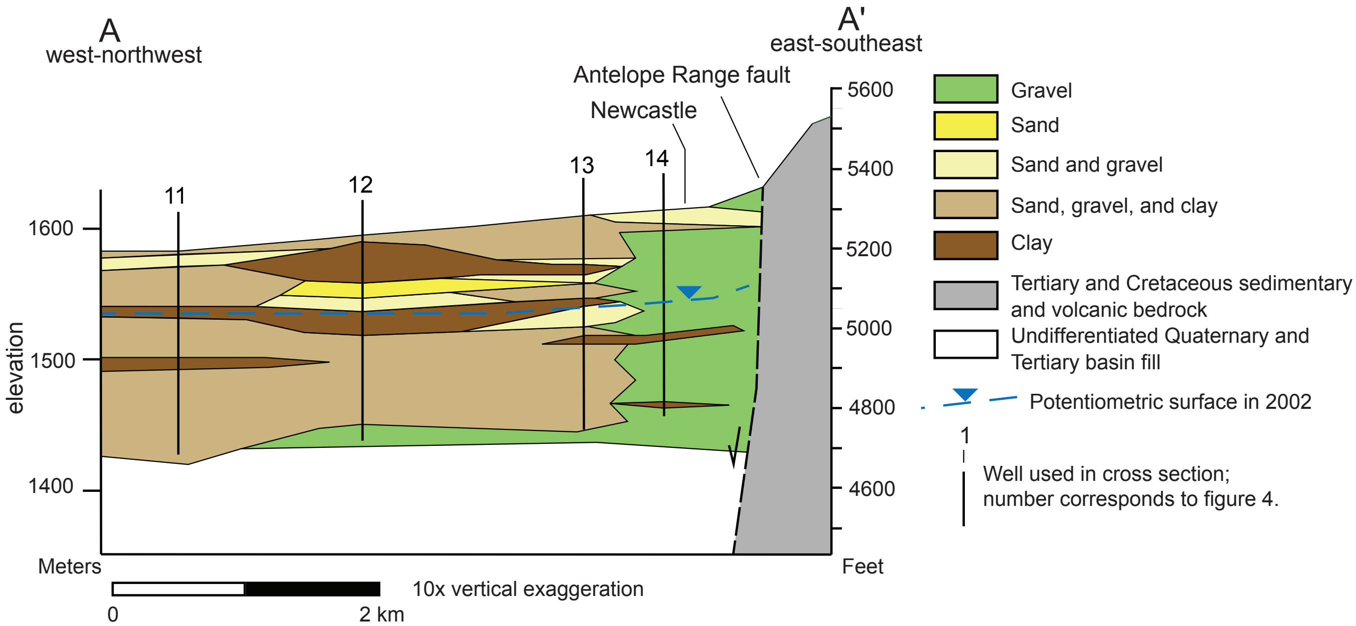

Figure 3. *Schematic geologic cross section of the Newcastle area modified from Lund and others (2005). Location of cross section shown on figures 2 and 4. Cross-section well HydroIDs keyed to table 2.*

Table 1. *Cross-section wells for Newcastle, Iron County, Utah.*

HydroID[1]	WIN[2]	Latitude	Longitude
11	22518	37.669500	-113.597043
12	-	37.676305	-113.575196
13	439224	37.658340	-113.564736
14	431740	37.660512	-113.556446

[1] Hydro ID is the unique site identifier used in generating cross-sections
[2] WIN is the unique well identifier used by the Utah Division of Water Rights

a storage coefficient range of 0.0014 to 0.025. We compiled aquifer test data from drinking water source protection documents (Diedre Beck, Utah Division of Drinking Water, written communication, August 2021) for three public supply wells in the Newcastle area and calculated a range for average hydraulic conductivity values of 116 to 207 ft/day, and a transmissivity range of 18,520 to 41,400 ft^2/day.

Groundwater in the Newcastle area generally flows perpendicular to lines of equal potentiometric level shown on figure 4. Groundwater movement in the Newcastle area is generally from southeast to northwest, from the recharge area in the Antelope Range and basin margin toward the basin center and Escalante Desert. However, large-scale groundwater pumping in the Beryl-Enterprise area has created a groundwater sink in the southern part of Escalante Valley, which may have a seasonal or long-term effect on flow direction. Burden and others (2005) showed that water levels have declined 50 to 71 feet in the Newcastle area between 1975 and 2005 due to increasing irrigation withdrawals since 1950.

Septic-Tank Density Evaluation

Groundwater flow variables: We calculated groundwater flow scenarios using hydraulic conductivities derived from three aquifer tests in the greater Newcastle area (figure 4). The highest conductivity, 545 ft/day, is from a well located west-southwest of the study domain. The middle conductivity, 165 ft/day, is from a well within the study domain. The lowest conductivity, 116 ft/day, is from a well to the west in Beryl Junction. We used an average hydraulic gradient of 0.00052, mixing depth of 50 feet, and 3.58-mile transect for each scenario, resulting in groundwater flux rates across the transect of 3.1 ft^3/s, 0.94 ft^3/s, and 0.66 ft^3/s, respectively (table 2).

Existing nitrate concentrations: We collected groundwater samples from 11 wells and one surface water sample in the Newcastle area for analysis of nitrate plus nitrite, ammonia, and phosphate (figure 5). Nitrate plus nitrite concentrations ranged from <0.1 mg/L (non-detect) to 4.48 mg/L nitrogen as nitrate, with an average of 1.51 mg/L (table 3). Higher nitrate concentrations are generally downgradient from the town of Newcastle, but are also in close proximity to agricultural fields and/or large animal feed operations. The highest nitrate concentration was from a well adjacent to a large dairy farm. Ammonia was detected in one sample at 0.079 mg/L, whereas the remainder were reported as non-detected at <0.05 mg/L. Phosphate ranged from <0.02 mg/L (non-detect) to 0.082 mg/L.

Results: We created a plot of projected nitrate concentrations in the Newcastle area of concern versus number of septic-tank systems (figure 6), using an average baseline nitrate concentration of 1.64 mg/L based on data collected for this

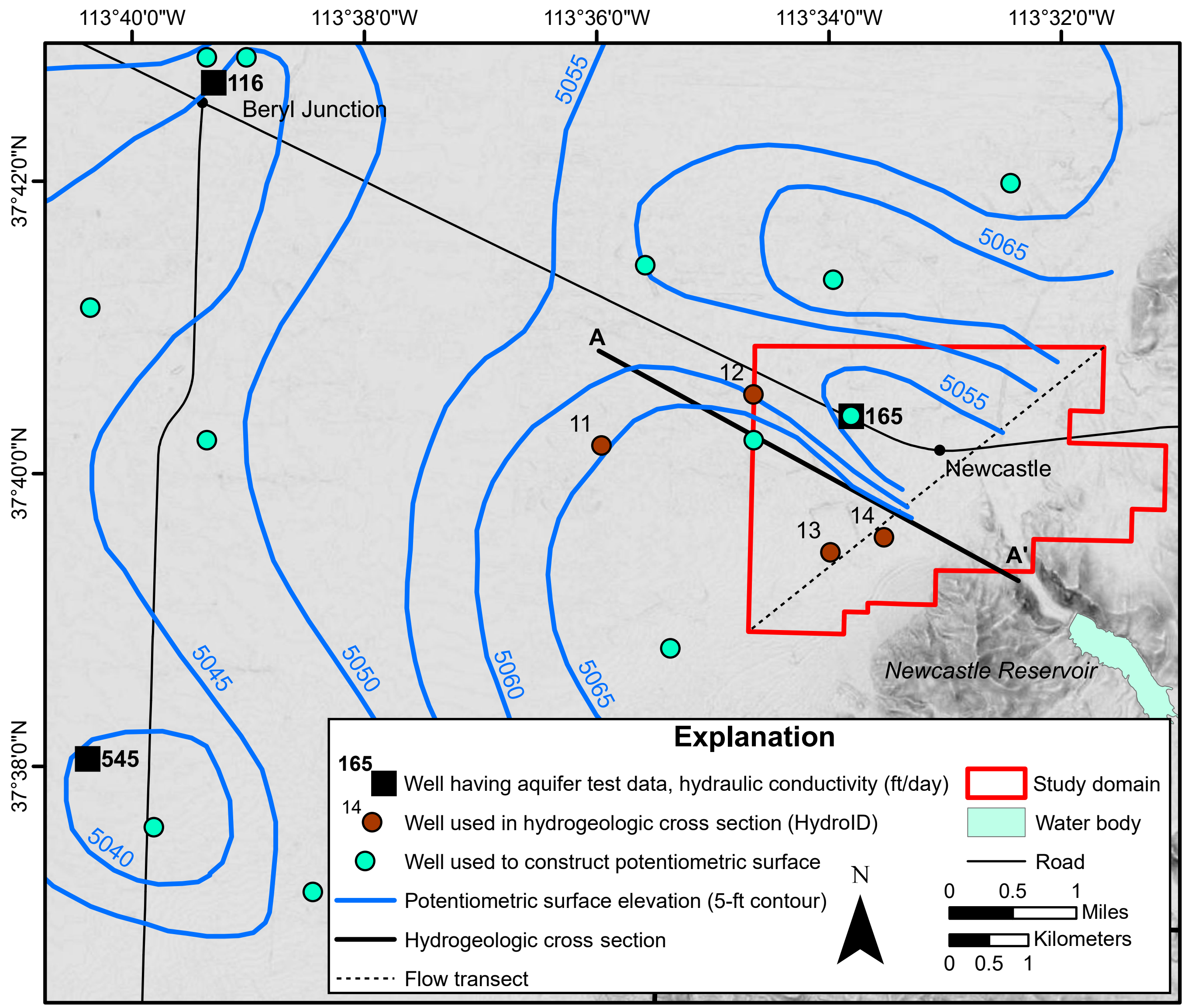

Figure 4. Potentiometric surface contours based on 2002 water-level elevations, modified from Lund and others (2005), and wells having aquifer test data in the Newcastle study domain. Cross section A-A' shown on figure 3. Cross-section well HydroIDs keyed to table 2.

Table 2. Aquifer parameters used to compute groundwater flow available for mixing for study areas in Iron County.

Parameter	Newcastle	Kanarraville	Summit	Paragonah
hydraulic conductivity (K)	116 ft/day	1.2 ft/day	27 ft/day	6.7 ft/day
	165 ft/day	84 ft/day	68 ft/day	19.5 ft/day
	545 ft/day	-	-	30 ft/day
thickness of mixing zone (b)	50 ft	50 ft	50 ft	50 ft
width of cross-section (L)	3.58 mi	1.74 mi	2.16 mi	8.5 mi
hydraulic gradient (I)	0.00052	0.012	0.0073	0.0093
groundwater flow available for mixing (Q)	0.66 cfs	0.08 cfs	1.30 cfs	1.61 cfs
	0.94 cfs	5.37 cfs	3.27 cfs	4.71 cfs
	3.1 cfs	-	-	7.25 cfs

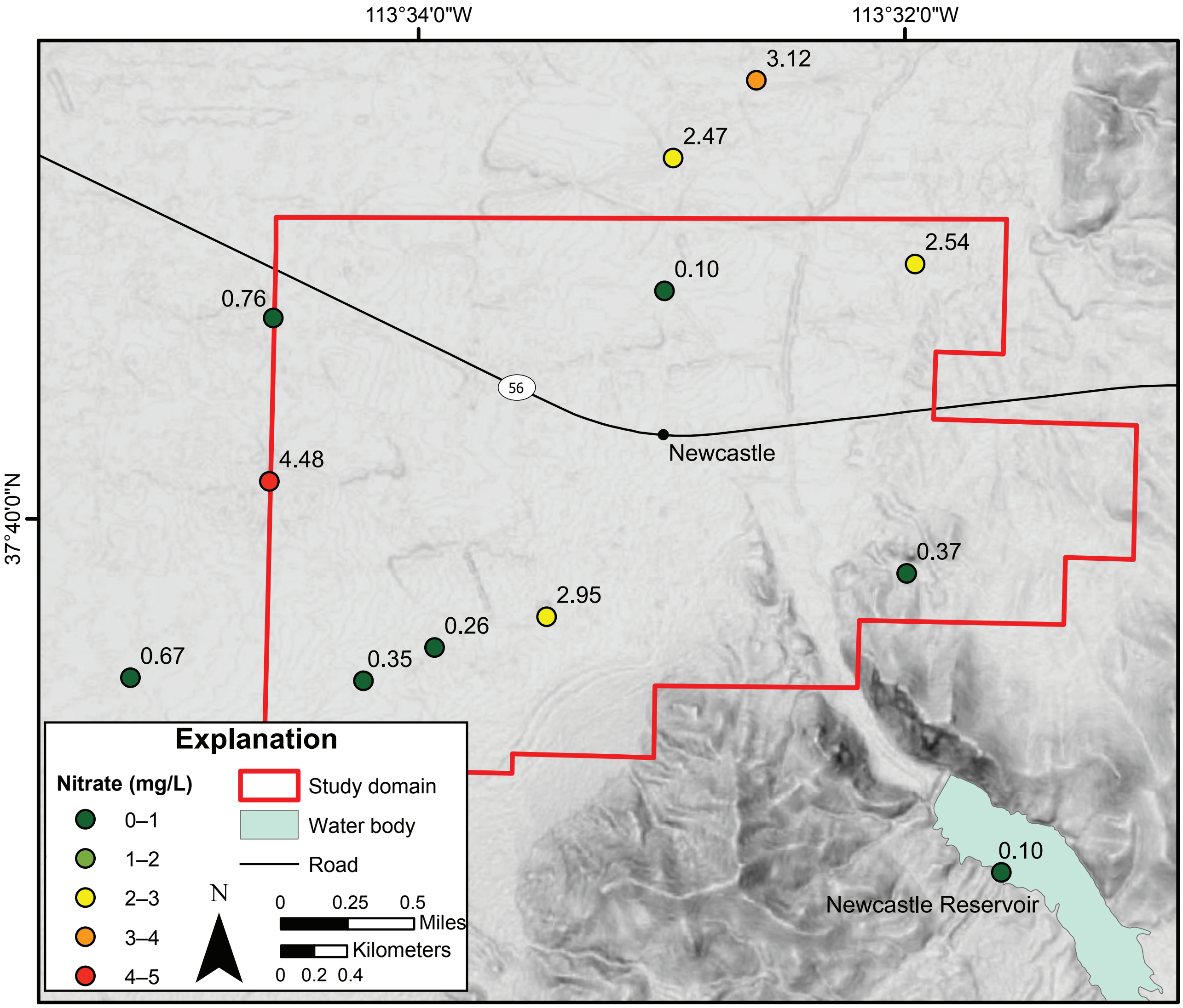

Figure 5. *Nitrate concentrations for wells and surface water in the Newcastle study domain.*

Table 3. *Nitrate data and field parameters for Newcastle, Iron County, Utah.*

Site ID	WIN[1]	Latitude	Longitude	pH	Temperature (°C)	Specific Conductance (µS/cm)	Nitrate (mg/L)[2]
WL-NCTUL	-	37.68728	-113.548906	7.67	26.8	1525	2.47
WL-NCHOL1	81	37.680027	-113.549251	8.13	21.3	625	*0.1*
WL-NCGAR	11731	37.664974	-113.532129	7.29	13.4	773	0.372
WL-NCMIL1	-	37.658128	-113.585126	7.58	21.4	675	0.667
WL-NCHOL2	1500	37.669052	-113.575976	7.56	27.5	1575	4.48
WL-NCHOL3	32460	37.69164	-113.54335	7.4	24.8	744	3.12
WL-NCMIL2	444144	37.658311	-113.569151	-	65	3250	0.348
WL-NCMIL3	29676	37.660229	-113.564342	7.69	57	2100	0.263
WL-NCMIL4	431740	37.662079	-113.556718	7.45	60	2200	2.95
WL-NCHOL4	-	37.677965	-113.576015	7.36	17.6	1320	0.76
WL-NCTAY	438102	37.681865	-113.532122	7.28	20.4	731	2.54
LK-NCRES	-	37.648802	-113.525088	8.68	18.5	610	*0.1*

[1]WIN is the unique well identifier used by the Utah Division of Water Rights

[2] Results in italics denote sample reporting limit

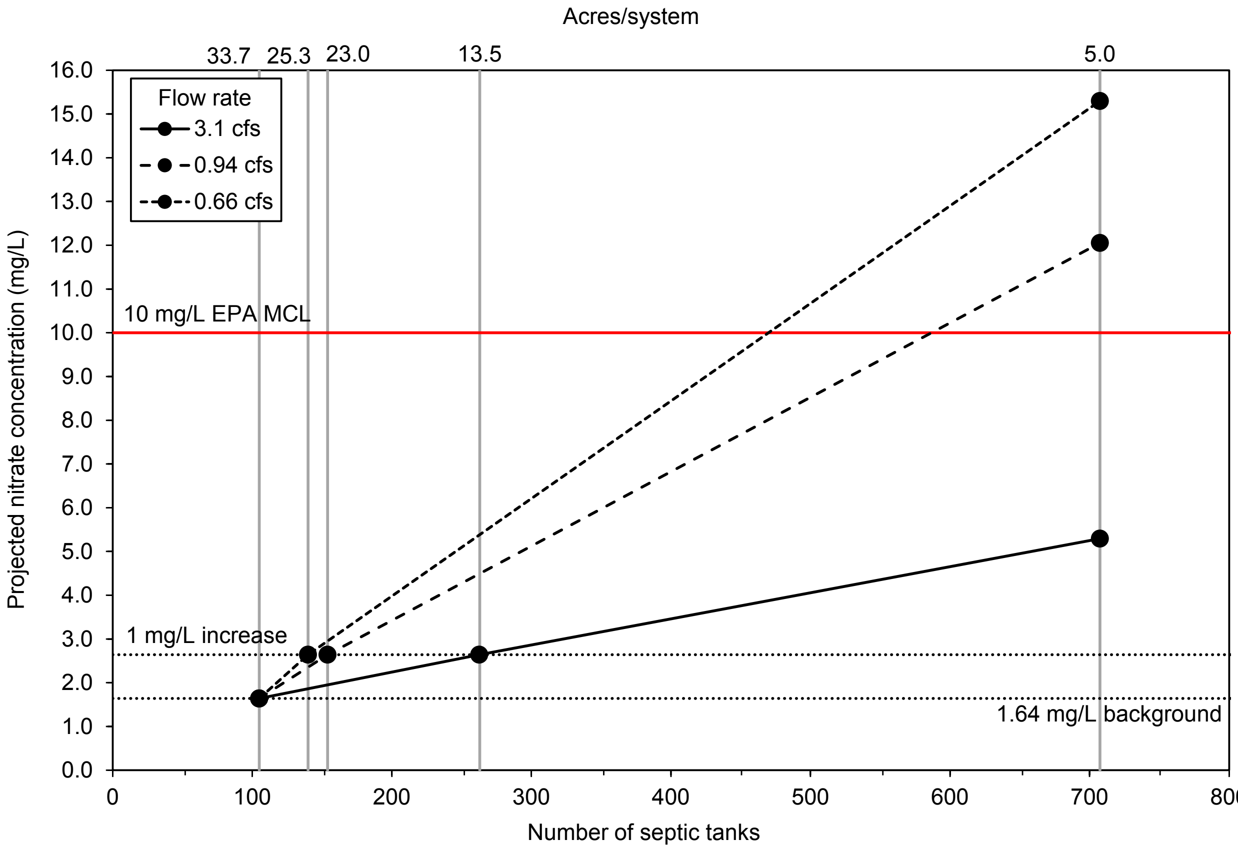

***Figure 6.** Projected septic-system density versus nitrate concentration for the Newcastle study domain based on 105 existing septic systems.*

study, excluding the surface water sample. The Newcastle area of concern is approximately 3540 acres and has approximately 105 septic-tank systems within and up-gradient, making the current septic-tank system density 33.7 acres/system. Using the groundwater parameters described above, estimated groundwater flow available for mixing in the Newcastle area ranges from 679 acre-feet/year to 2244 acre-feet/year. For the Newcastle area to maintain an overall nitrate concentration of 2.64 mg/L, the total number of septic-tank systems should not exceed 154, 140 using the most conservative groundwater flow estimate, or 263 using the least conservative groundwater flow estimate. This result corresponds to an increase of 35 to 158 new septic-tank systems and a septic-tank system density of 13.5 acres/system to 25.3 acres/system.

Discussion: Based on the scenarios presented above, the Newcastle area should not exceed a septic-system density of 14 acres/system. However, this result is based on a high hydraulic conductivity located west-southwest of the study domain. A more conservative density of 23 acres/system based on the hydraulic conductivity located within the study domain may be more appropriate for long-term land-use planning. Under the conservative scenarios, the current 5-acre minimum lot size will result in exceedances of the EPA 10 mg/L maximum contaminant level (MCL). Some consideration should also be given to the location of existing water supply sources. Currently, there are few drinking water supply wells within the study area; most are irrigation or geothermal wells. However, the primary drinking water supply for Newcastle residents is a well approximately 3.25 miles northwest of the townsite, downgradient from existing and future septic systems. Although the basin-fill aquifer in the Newcastle area is generally unconfined, fine-grained layers in the basin-fill can potentially slow vertical groundwater mixing. However, given the presence of elevated nitrate concentrations in deep wells, it is likely that water from the 50-foot mixing zone is reaching the aquifer. A valley-wide public sanitary sewer system is also an option for the Newcastle region.

Kanarraville

Location, Geography, and Climate

Kanarraville is in southern Iron County, between 37°32'36" and 37°31'57" north latitude and 113°11'13" and 113°10'23" west longitude (figure 1). The Kanarraville study domain is in the Kanarraville basin, a narrow alluvial basin at the northern end of the central Virgin River basin. This northeast-trending basin lies just south of Cedar Valley, in the transition zone between the Basin and Range and Colorado Plateau physiographic provinces. The Kanarraville basin is bordered by the Hurricane Cliffs to the east, the Harmony Mountains to the northwest, and opens to the New Harmony basin to the southwest. The basin is approximately 11 miles long and 1.6 miles wide. Elevations in the study domain range from about 6200 feet in the Hurricane Cliffs at the eastern edge of town to 5200 feet at the southern end of the study domain toward New Harmony. Three perennial streams enter the Kanarraville basin from the east: Kanarra Creek, Spring Creek, and Camp Creek.

The climate of Kanarraville is semi-arid and characterized by warm, dry summers and moderately cold winters. Average annual precipitation for the Kanarraville area from PRISM 30-year normals (1991–2020) is 13 to 14 inches (PRISM Climate Group, 2021).

Population and Land Use

Kanarraville and its surrounding area within the study domain has a population of approximately 680 people (U.S. Census Bureau, 2021). Land use in the Kanarraville study domain consists of residential areas and agriculture, including croplands and livestock grazing.

Geologic Setting

The Kanarraville basin is a wedge-shaped basin formed by normal slip on the Hurricane fault, a major north-south striking Quaternary fault structure in southern Utah (Hurlow, 1998). The footwall of the fault is the Hurricane Cliffs to the east, composed of Permian to Cretaceous sedimentary rocks (figure 7). To the west, the Harmony Mountains consist of Tertiary volcanic rocks and volcaniclastic alluvial-fan deposits. The basin fill consists of unconsolidated Tertiary and Quaternary fluvial and alluvial-fan deposits. Quaternary sediments are up to 1100 feet thick near the Hurricane fault (Hurlow, 1998).

Groundwater Conditions

Groundwater in the Kanarraville basin occurs in unconfined conditions in primarily unconsolidated basin-fill aquifers. Quaternary basin-fill deposits range from a maximum thickness of about 1100 feet near the Hurricane fault and thin toward the mountains to the west (Hurlow, 1998). All wells in the Kanarraville study area are completed in basin-fill deposits, except for one well completed in consolidated rock adjacent to the Hurricane fault that is not in use due to poor yield. Well logs along the valley axis show mostly coarse- to mixed-grained sediments, with only discrete lenses of fine-grained material rather than continuous layers that could provide for confined conditions (figure 8; table 4).

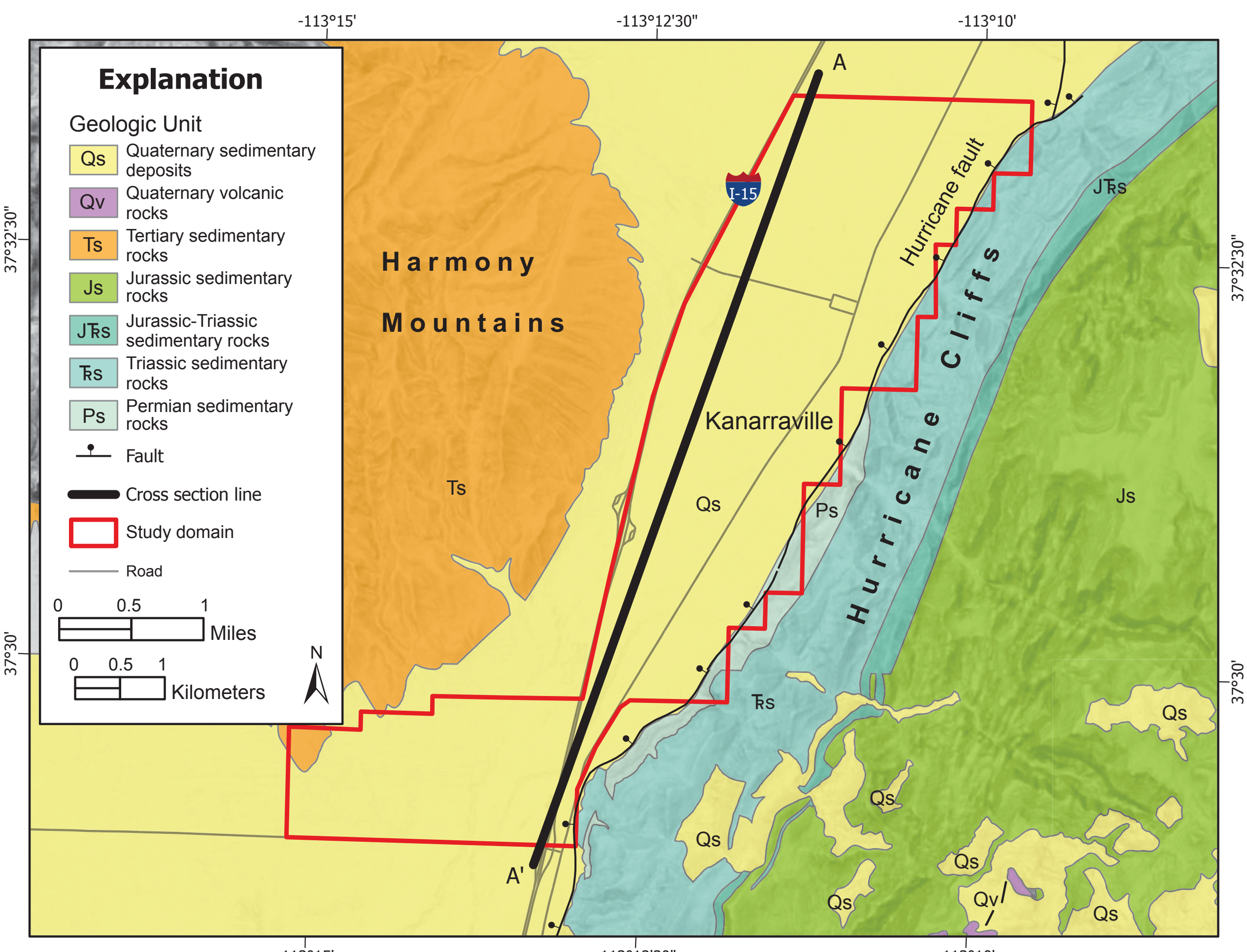

Figure 7. *Simplified geologic map of the Kanarraville area, Iron County, Utah, modified from Rowley and others (2006) and Biek and others (2010). Cross section A-A' shown on figure 8.*

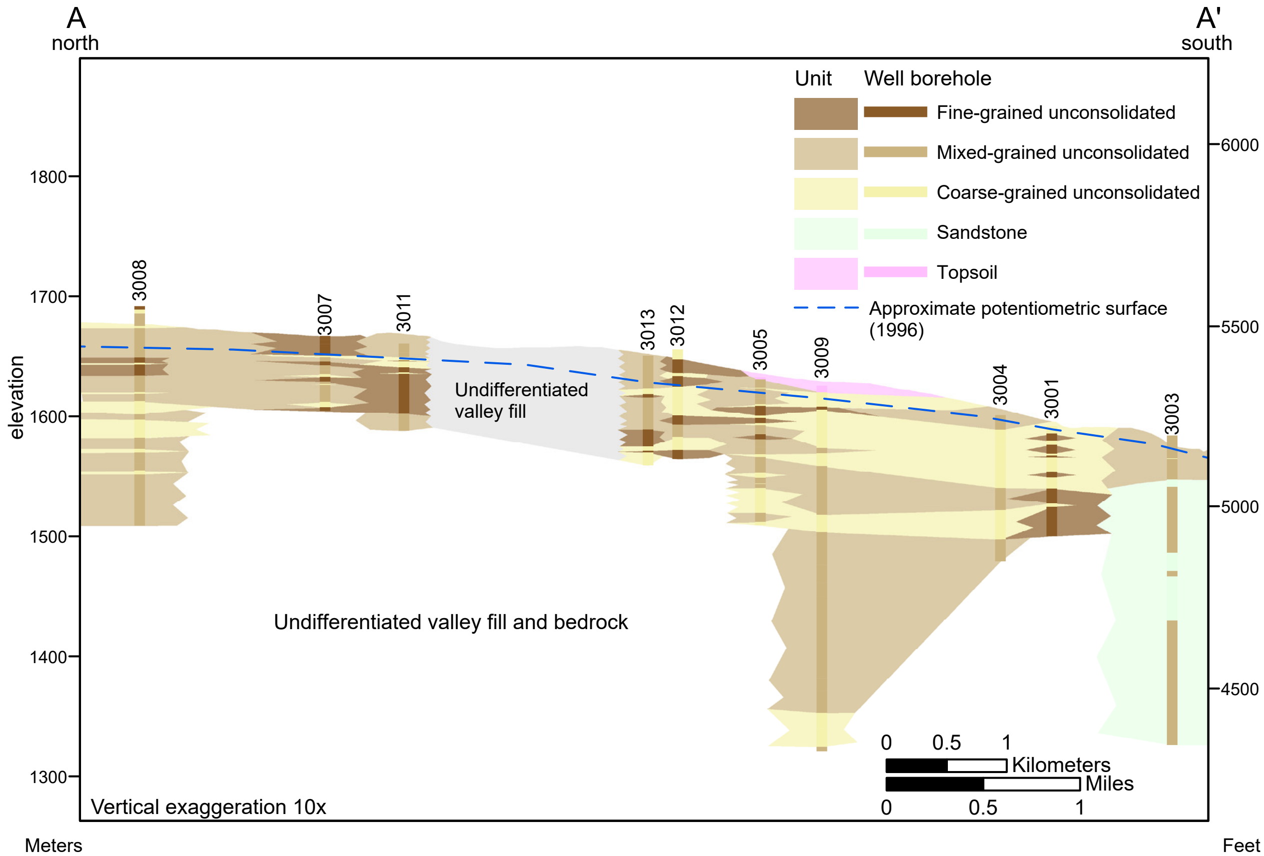

Figure 8. *Schematic geologic cross section of the Kanarraville area. Location of cross section shown on figures 7 and 9. Cross-section well HydroIDs keyed to table 4.*

Table 4. *Cross-section wells for Kanarraville, Iron County, Utah.*

HydroID[1]	WIN[2]	Latitude	Longitude
3001	26983	37.492757	-113.222846
3003	33587	37.48224	-113.219118
3004	432669	37.496259	-113.22078
3005	434934	37.512657	-113.211082
3007	440788	37.544015	-113.199575
3008	441408	37.558296	-113.198192
3009	441863	37.508334	-113.21312
3011	442675	37.538572	-113.202585
3012	11560	37.517086	-113.203146
3013	445196	37.5203	-113.206382

[1] Hydro ID is the unique site identifier used in generating cross-sections
[2] WIN is the unique well identifier used by the Utah Division of Water Rights

Aquifer properties in the Kanarraville basin vary depending on the thickness and type of sediments found in the aquifer. Cordova and others (1972) compiled specific capacity and aquifer test data from four wells in the Kanarraville and New Harmony basins and calculated a range for average hydraulic conductivity of 35 to 200 ft/day, and a transmissivity range of 2540 to 16,000 ft^2/day. We compiled aquifer test data from drinking water source protection documents (Diedre Beck, Utah Division of Drinking Water, written communication, August 2021) for four public supply wells in the Kanarraville and New Harmony region and calculated a range for average hydraulic conductivity values of 1.2 to 84 ft/day, and a transmissivity range of 330 to 5880 ft^2/day.

Cordova and others (1972) produced a water-level map for the central Virgin River basin constructed from water-level measurements made in 1970, including the New Harmony and Kanarraville basins. They showed that groundwater movement in the Kanarraville basin is generally from north to south, with recharge occurring in the Harmony Mountains to the west and Hurricane Cliffs to the east.

Septic-Tank Density Evaluation

Groundwater flow variables: We calculated groundwater flow scenarios using hydraulic conductivities derived from two aquifer tests in the greater Kanarraville area (figure 9). The higher conductivity, 84 ft/day, is from a well central to the study domain, while the lower conductivity, 1.2 ft/day, is from the farthest south extent of the study domain toward New Harmony. We used a hydraulic gradient of 0.012, mixing depth of 50 feet, and 1.74-mile transect for both scenarios, resulting in groundwater flux through the transect location of 5.37 ft^3/s and 0.08 ft^3/s, respectively (table 2).

Existing nitrate concentrations: We collected groundwater samples from 14 wells and one surface water sample in the Kanarraville area for analysis of nitrate plus nitrite, ammonia, and phosphate (figure 10). Nitrate plus nitrite concentrations ranged from <0.1 mg/L (non-detect) to 4.75 mg/L, with an average of 1.42 mg/L (table 5). The highest nitrate concentrations are downgradient from agricultural fields and the town of Kanarraville, suggesting a possible connection to fertilizer or septic-tank leachate. Ammonia was detected in one sample at 0.389 mg/L, whereas the remainder were reported as non-detected at <0.05 mg/L. Phosphate ranged from <0.02 mg/L (non-detect) to 0.106 mg/L.

Results: We plotted the projected nitrate concentrations in the Kanarraville area of concern versus number of septic-tank systems (figure 11). We used an average baseline nitrate concentration of 1.51 mg/L based on data collected for this study, excluding the surface water sample. The Kanarraville area of concern is approximately 5140 acres and has approximately 308 septic-tank systems within and up-gradient, making the current septic-tank system density 16.7 acres/system. Using the groundwater parameters described above, estimated groundwater flow available for mixing in the Kanarraville area ranges from 57 acre-feet/year to 3885 acre-feet/year. For the Kanarraville area

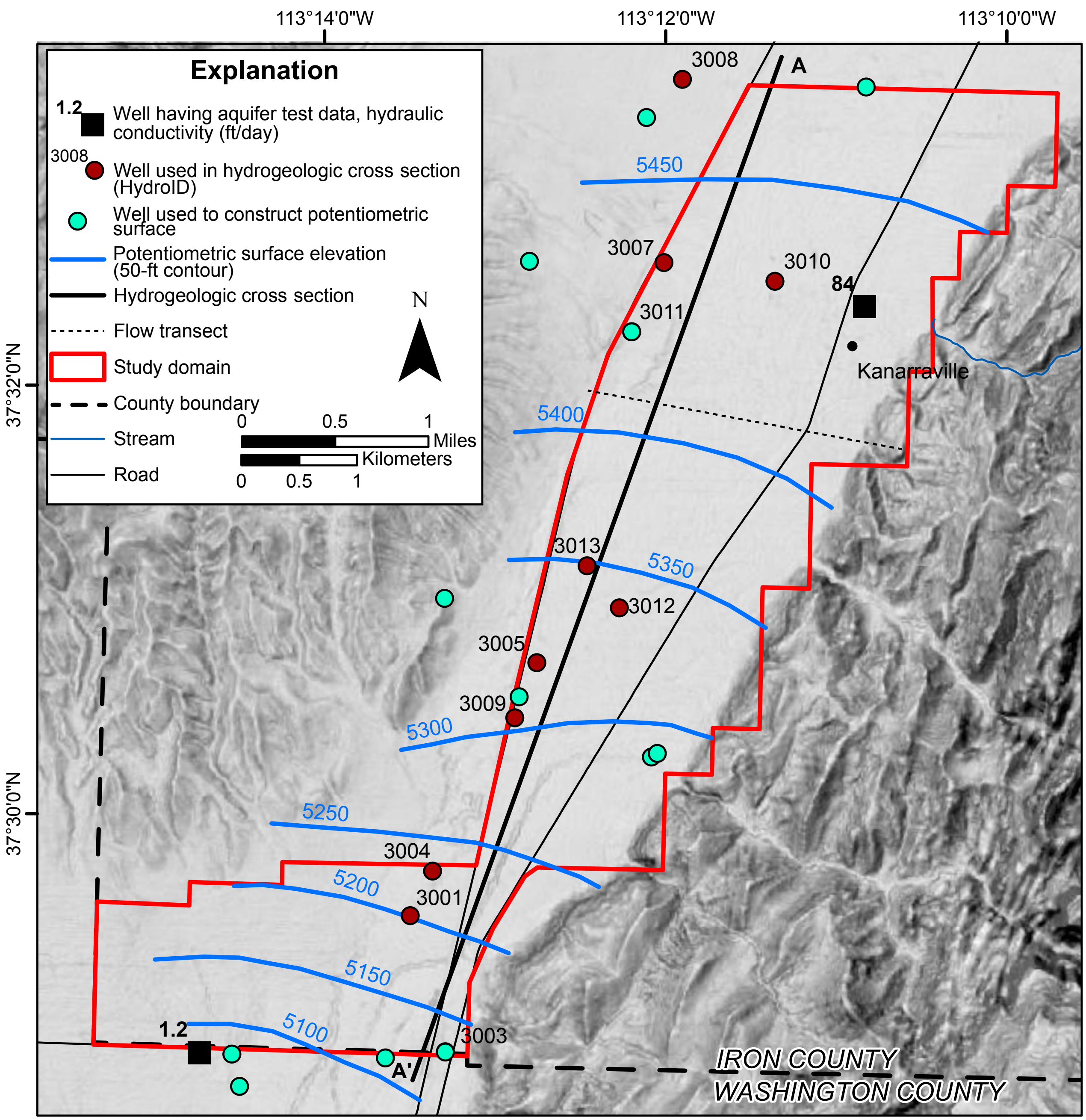

Figure 9. Potentiometric surface contours based on 1996 water-level elevations and wells having aquifer test data in the Kanarraville study domain. Cross section A-A' shown on figure 8. Cross-section well HydroIDs keyed to table 4.

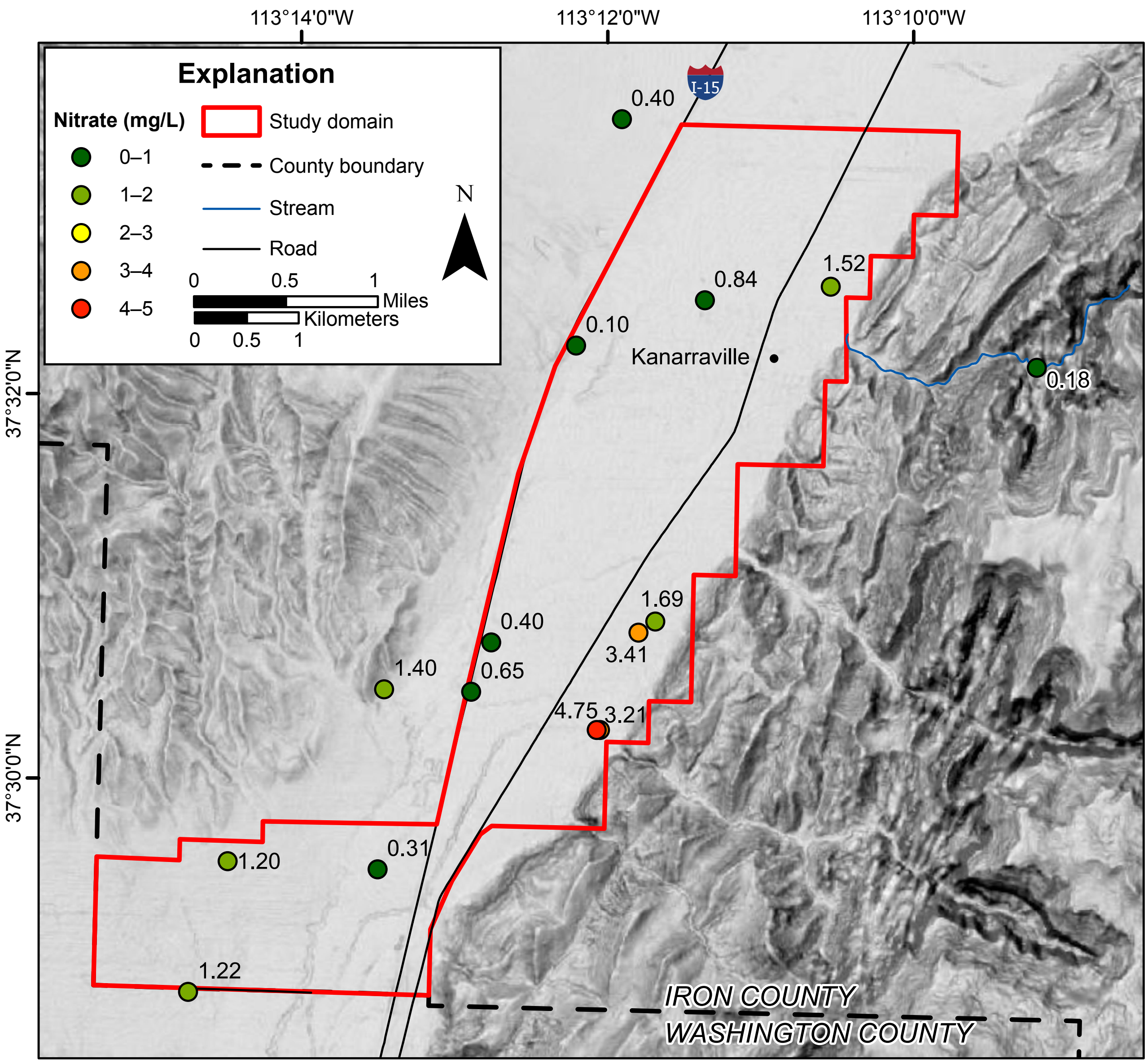

Figure 10. Nitrate concentrations for wells and surface water in the Kanarraville study domain.

to maintain an overall nitrate concentration of 2.51 mg/L, the total number of septic-tank systems should not exceed 743, or 319 using the more conservative groundwater flow estimate. This result corresponds to an increase of 11 to 435 new septic-tank systems and a septic-tank system density of 6.9 acres/system to 16.1 acres/system.

Discussion: Based on the scenarios presented above, the Kanarraville area should not exceed a septic-system density of 7 acres/system. However, care should be used in land-use planning in the southern part of the study area, as the lower hydraulic conductivity suggests the more conservative 16-acres/system density may be more appropriate there. Under this conservative scenario, the current 5-acre minimum lot size will quickly result in exceedances of the EPA 10 mg/L MCL in this area. A valley-wide public sanitary sewer system is also a viable option for the Kanarraville region.

Parowan Valley

Location, Geography, and Climate

Parowan Valley is in eastern Iron County, between 38°4'32" and 37°46'52" north latitude and 112°59'10" and 112°41'11" west longitude (figure 1). Parowan Valley is a northeast-southwest-trending, elongate valley in the Basin and Range physiographic province, bordered by the Markagunt Plateau to the east, the Red Hills to the west, and Cedar Valley to the southwest. Parowan Valley is approximately 30 miles long and approximately 7 miles wide at the valley center. The floor of Parowan Valley covers about 160 square miles. Elevations range from about 6200 feet along the eastern valley margins to about 5700 feet at Little Salt Lake in the west. Little Salt Lake is a playa that acts as a terminus for most surface water in Parowan Valley, except for a small area draining southwest

Table 5. *Nitrate data and field parameters for Kanarraville, Iron County, Utah.*

Site ID	WIN[1]	Latitude	Longitude	pH	Temperature (°C)	Specific Conductance (µS/cm)	Nitrate (mg/L)[2]
WL-KVKFR	442499	37.542761	-113.188696	6.79	13	800	0.844
WL-KVBZI	438940	37.513808	-113.195066	7.13	19	1075	3.41
WL-KVBZID	-	37.514808	-113.19328	7.3	23.6	875	1.69
WL-KVTOW	30835	37.544193	-113.175021	7.05	13.6	955	1.52
WL-KVERM	442675	37.538572	-113.202585	7.68	13.9	445	*0.1*
WL-KVDDI	-	37.505303	-113.19902	7.24	16.8	1593	3.21
WL-KVCSC	435638	37.505278	-113.199356	7.01	16.8	1580	4.75
WL-KVSOS	444002	37.508385	-113.222614	7.77	20.8	475	1.4
ST-KVCRK	-	37.537577	-113.152364	8.46	12.5	335	0.177
WL-KVDHR	26983	37.492757	-113.222846	7.2	17.7	1030	0.307
WL-KVDAV	26145	37.493143	-113.239203	7.52	18.4	446	1.2
WL-KVHAR	434499	37.48173	-113.243154	7.55	18	609	1.22
WL-KVDKM	441408	37.558296	-113.198192	7.63	15	465	0.397
WL-KVDOT	434934	37.512657	-113.211082	7.5	16.3	615	0.396
WL-KVHOL	441863	37.508334	-113.21312	7.39	16.3	649	0.645

[1]WIN is the unique well identifier used by the Utah Division of Water Rights

[2] Results in italics denote sample reporting limit

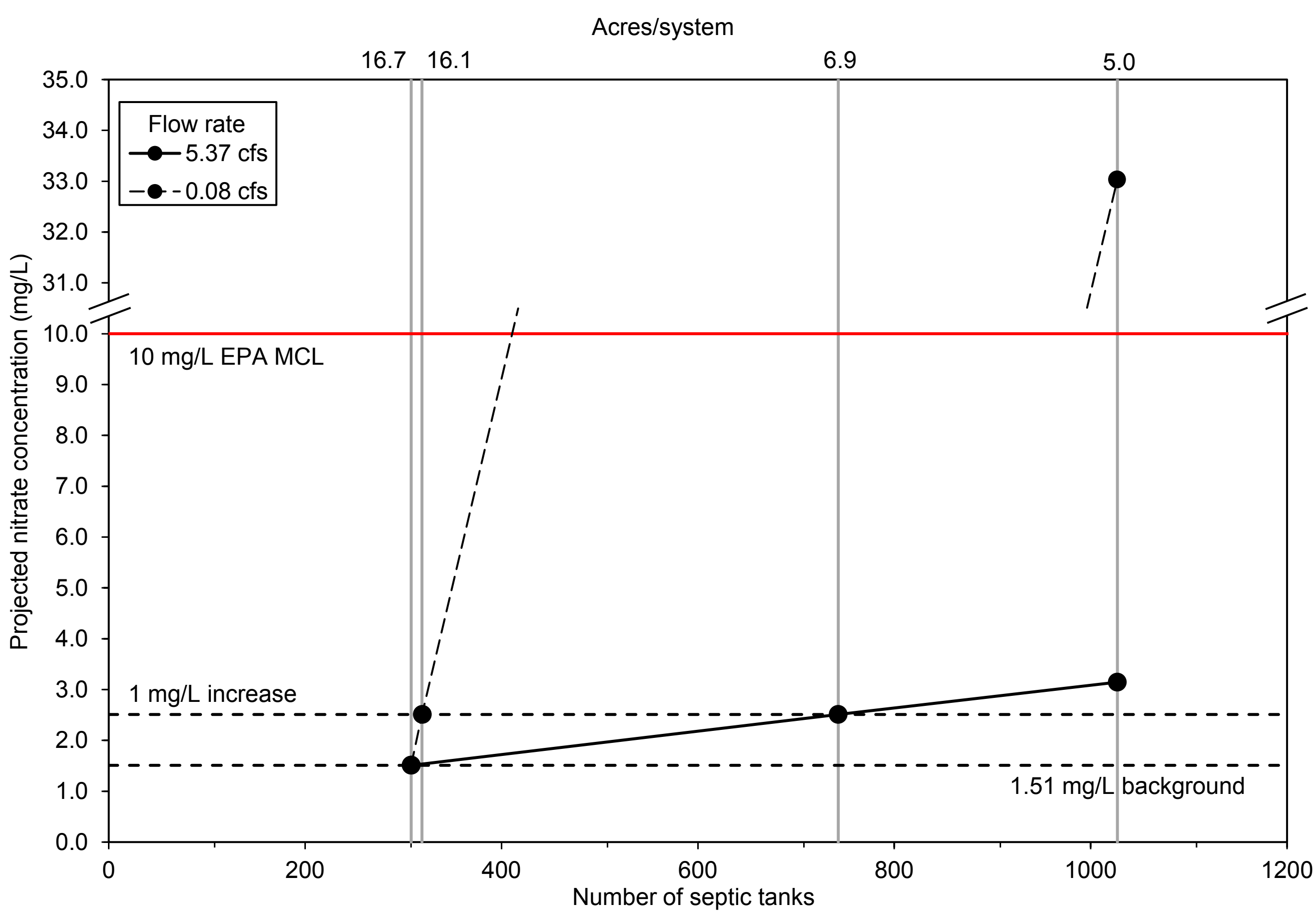

Figure 11. *Projected septic-system density versus nitrate concentration for the Kanarraville study domain based on 308 existing septic systems. Shift in 0.08 cfs projection is due to break in the y-axis scale.*

into Cedar Valley. Five perennial streams enter the east side of the valley from the Markagunt Plateau: Cottonwood Creek, Little Creek, Red Creek, Parowan Creek, and Summit Creek.

The climate of Parowan Valley is semi-arid and characterized by large daily temperature variations; warm, dry summers; and moderately cold winters. Average annual precipitation for Parowan Valley from PRISM 30-year normals (1991–2020) is 12 to 13 inches (PRISM Climate Group, 2021).

Population and Land Use

Parowan Valley has approximately 4200 people, an increase from about 3300 people in 2010, mostly centered around the towns of Parowan and Paragonah (U.S. Census Bureau, 2021). The Summit and Paragonah study domains have populations of 187 people and 704 people, respectively, based on 2020 census data blocks. Land use in the Summit and Paragonah study domains consists mainly of agriculture, including croplands and livestock grazing, a large salvage/junkyard, and residential areas.

Geologic Setting

The valley is separated from the Markagunt Plateau to the east by the Paragonah fault, a normal fault with Parowan Valley occupying the hanging wall (figure 12). The geologic units within Parowan Valley range from Cretaceous to Quaternary in age. Cretaceous units include the sandstones and conglomerates of the Straight Cliffs, Wahweap, and Grand Castle Formations in the east, as well as the Iron Springs Formation to the west. The Tertiary Claron Formation overlies Cretaceous units on the east and west sides of the valley. Tertiary and Quaternary volcanics including basalt,

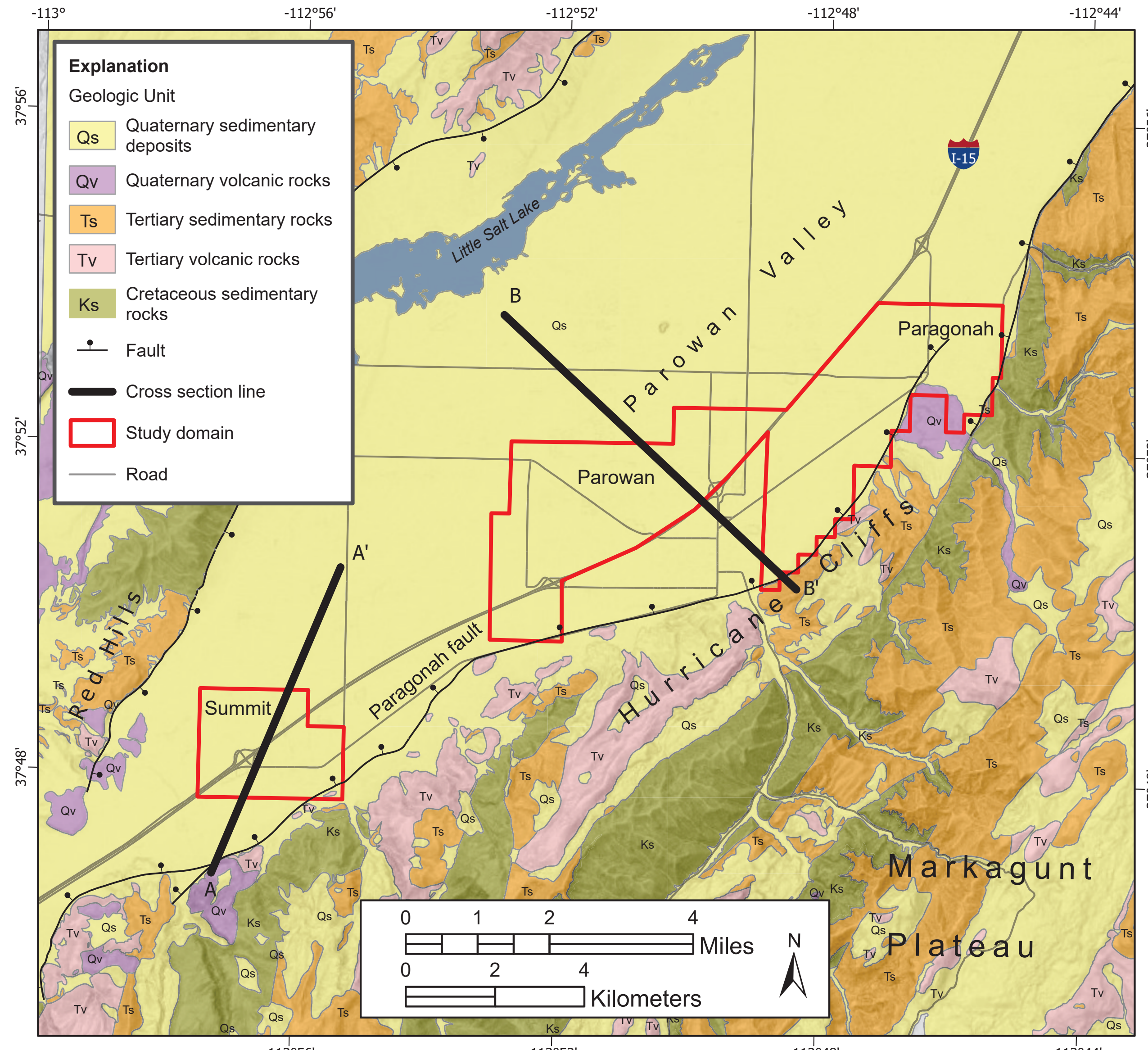

Figure 12. Simplified geologic map of Parowan Valley, Iron County, Utah, modified from Biek and others (2015). Cross section A-A' shown on figure 13, B-B' shown on figure 14.

pyroclastics, and ash flows are located northwest of Parowan Valley as well as south and west of Summit. Quaternary basin-fill sediments include alluvium, colluvium, and alluvial-fan deposits across most of the valley, and fine-grained playa deposits associated with the Little Salt Lake.

Groundwater Conditions

Groundwater in Parowan Valley occurs in unconfined and confined conditions in both unconsolidated basin-fill aquifers and consolidated rock aquifers. Quaternary unconsolidated basin-fill deposits in Parowan Valley are at least 2000 feet thick, based on well logs and seismic reflection profiles (Hurlow, 2002). Most wells in the study areas within Parowan Valley (table 6) are completed in basin-fill deposits, with the exception of several wells completed in lava flows and consolidated bedrock in the Summit area (figure 13). Unconfined conditions in the basin-fill aquifer occur along the eastern margins of the valley in proximal coarse sediments of alluvial fans. Confined conditions exist in the central and eastern parts of the valley where fine-grained distal alluvium and lacustrine sediments are more common. Well logs from the eastern part of the valley show a continuous, thick clay layer contributing to the confined conditions in this region of the basin-fill aquifer (figure 14).

Table 6. *Cross-section wells for Parowan Valley, Iron County, Utah.*

HydroID[1]	WIN[2]	Latitude	Longitude
1001	1326	37.796291	-112.952846
1002	9152	37.805456	-112.937572
1004	13945	37.816748	-112.936747
1005	13947	37.830436	-112.934388
1006	13949	37.827548	-112.942561
1007	14107	37.805919	-112.946725
1008	15916	37.787577	-112.954033
1009	430313	37.806166	-112.937197
1010	441716	37.787903	-112.948019
1011	444449	37.813767	-112.938425
1012	437658	37.83525	-112.93092
1013	436029	37.8382	-112.92298
2002	12152	37.85556	-112.80974
2003	13963	37.86817	-112.84122
2004	13987	37.855001	-112.830729
2005	13990	37.855355	-112.840143
2006	14006	37.838083	-112.820345
2007	18717	37.85101	-112.81206
2008	20763	37.88414	-112.87754
2009	26908	37.875779	-112.857819
2010	28529	37.864247	-112.835037
2011	31564	37.845008	-112.821146
2012	426887	37.88653	-112.86245
2013	433995	37.891281	-112.881789
2014	437138	37.882556	-112.862208
2015	437824	37.882659	-112.862215

[1] Hydro ID is the unique site identifier used in generating cross-sections
[2] WIN is the unique well identifier used by the Utah Division of Water Rights

Aquifer properties in Parowan Valley vary depending on the thickness and type of sediments found in the basin-fill aquifer. Bjorklund and others (1978) compiled aquifer test data for four wells in Parowan Valley and calculated a range for average hydraulic conductivity values of 21 to 37 ft/day, a transmissivity range of 1400 to 17,900 ft^2/day, and a storage coefficient range of 0.00007 to 0.02. We compiled aquifer test data from drinking water source protection documents (Diedre Beck, Utah Division of Drinking Water, written communication, August 2021) for seven public supply wells in Parowan Valley and calculated a range for average hydraulic conductivity values of 6.7 to 116 ft/day, and a transmissivity range of 1725 to 14,600 ft^2/day.

Groundwater movement in Parowan Valley is generally from east to west, from the recharge area of the Markagunt Plateau toward Little Salt Lake. Confined conditions are common in the central valley aquifer, as flowing wells and springs were historically common here (Thomas and Taylor, 1946). Groundwater in southern Parowan Valley moves to the northwest, except for the very southern end, where groundwater flows toward Enoch in Cedar Valley, due to a groundwater divide near Summit (Marston, 2017).

Marston (2017) produced a water-level map for the Parowan Valley basin-fill aquifer constructed from water-level measurements made in 2012 and 2013, showing the highest groundwater elevations near the valley margin at Summit Creek and the lowest groundwater elevations near Little Salt Lake in the valley center (figure 15). As of 2013, water levels in the central and southern areas of Parowan Valley had decreased an average of 50 feet since 1974, with areas experiencing intense irrigation pumping decreasing as much as 90 feet (Marston, 2017).

Summit Septic-Tank Density Evaluation

Groundwater flow variables: We calculated groundwater flow scenarios using hydraulic conductivities derived from two aquifer tests in the greater Summit area (figure 15). The higher conductivity, 68 ft/day, is from a well central to the study domain, and the lower conductivity, 27 ft/day, is from a well to the west of the study domain toward Enoch. We used a hydraulic gradient of 0.0073 based on a water-level map for the basin-fill aquifer constructed from water-level measurements made in 2012 and 2013 (Marston, 2017). We used a mixing depth of 50 feet and 2.16 mile transect for both scenarios, resulting in groundwater flux rates of 3.27 ft^3/s and 1.30 ft^3/s, respectively (table 2).

Existing nitrate concentrations: We collected groundwater samples from seven wells and one surface water sample in the Summit area for analysis of nitrate plus nitrite, ammonia, and phosphate (figure 16). Nitrate plus nitrite concentrations

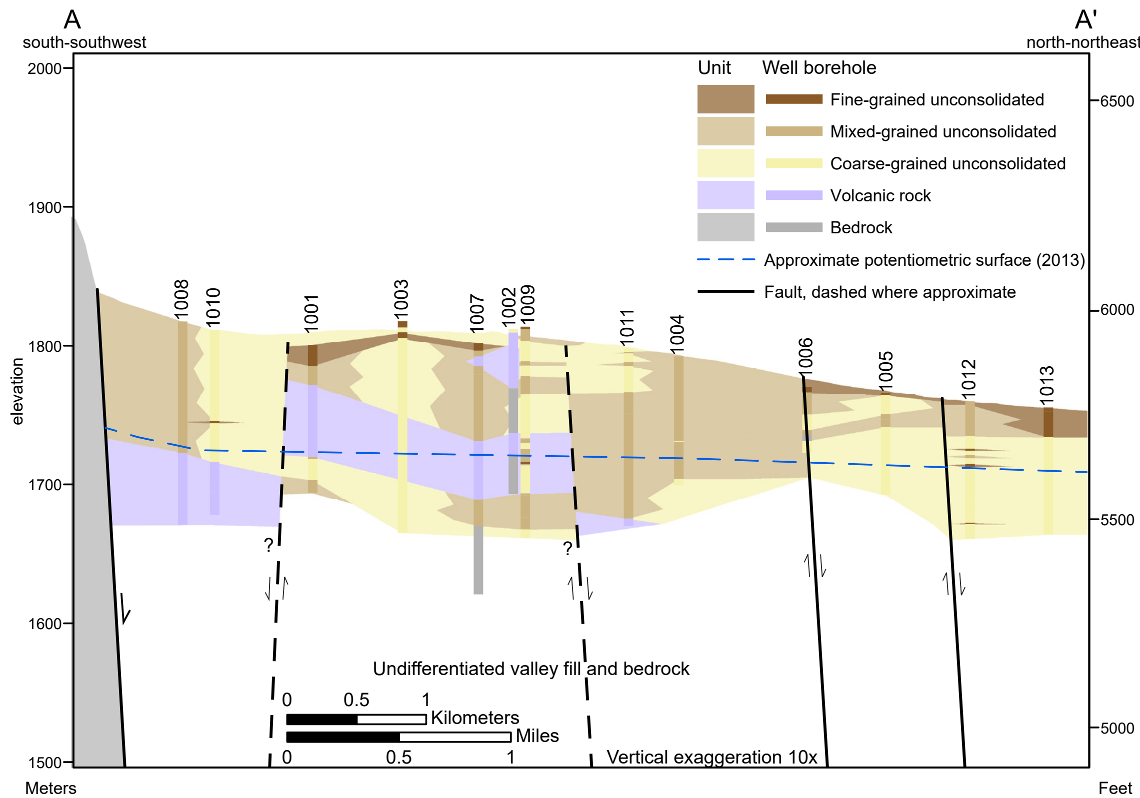

Figure 13. Schematic geologic cross section of the Summit area. Location of cross section shown on figures 12 and 15. Potentiometric surface elevation based on 2013 water-level elevations, modified from Marston (2017). Cross-section well HydroIDs keyed to table 6.

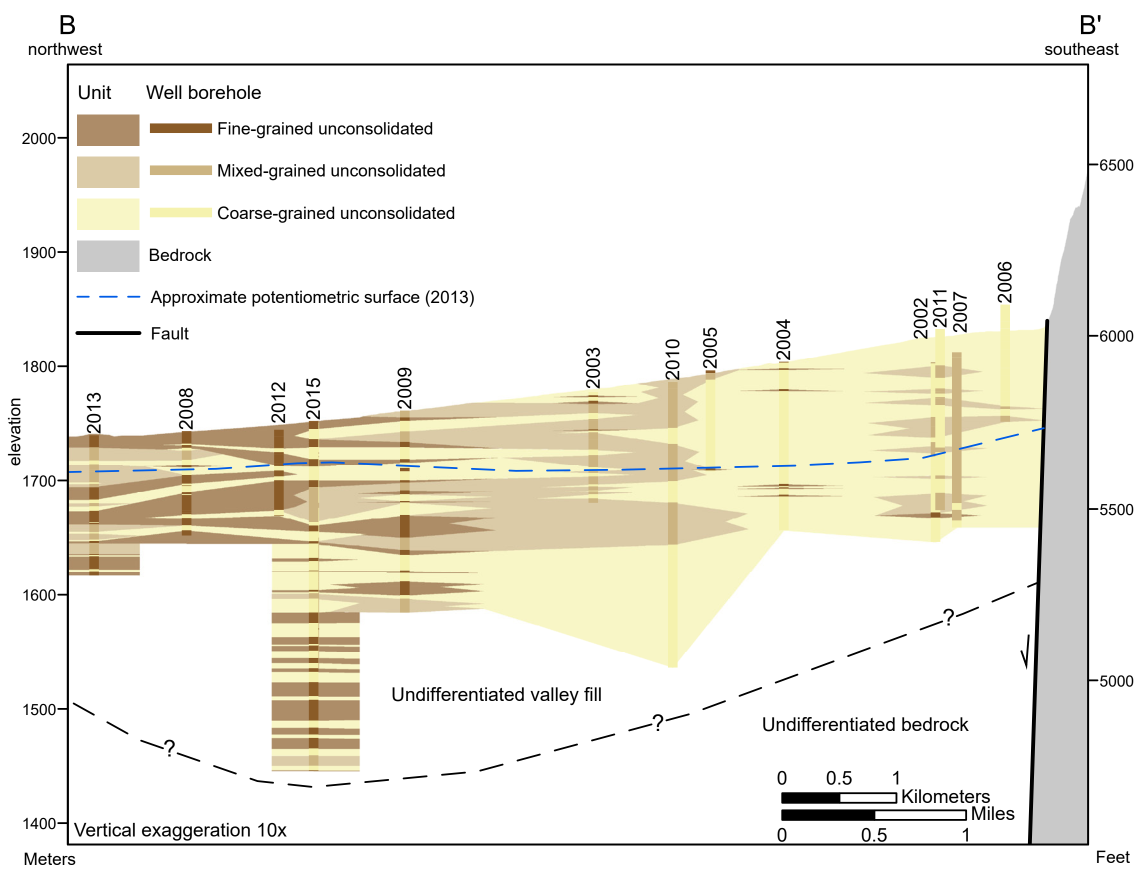

Figure 14. Schematic geologic cross section of the Paragonah area. Location of cross section shown on figures 12 and 15. Potentiometric surface elevation based on 2013 water-level elevations, modified from Marston (2017). Cross-section well HydroIDs keyed to table 6.

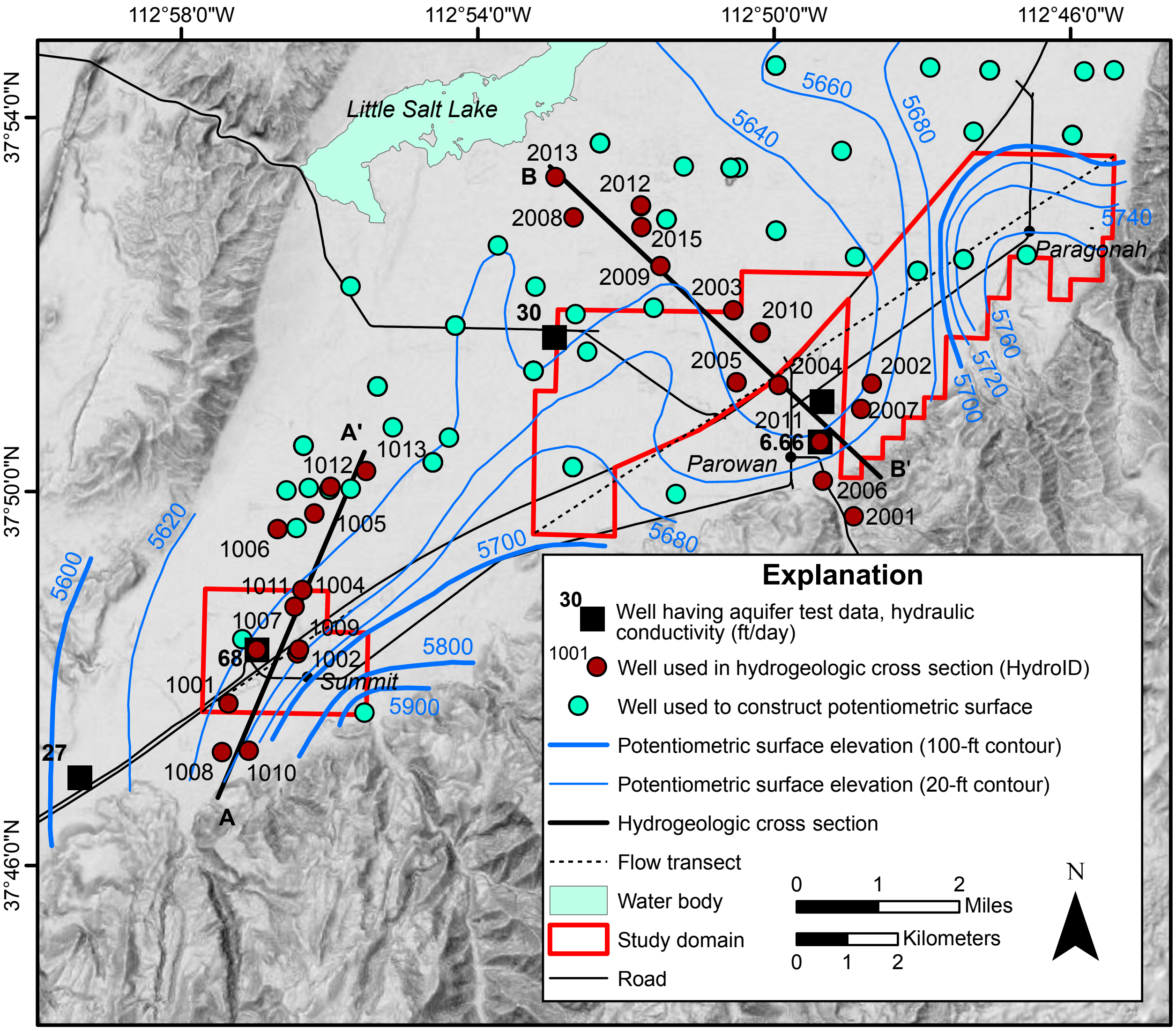

Figure 15. *Potentiometric surface contours based on 2013 water-level elevations, modified from Marston (2017), and wells with aquifer test data in the Summit and Paragonah study domains. Cross section A-A' shown on figure 13, B-B' shown on figure 14. Cross-section well HydroIDs keyed to table 6.*

ranged from <0.1 mg/L (non-detect) to 4.11 mg/L, with an average of 2.20 mg/L (table 7). The highest nitrate concentration is downgradient from the town of Summit and near agricultural fields. Ammonia was reported as non-detected at <0.05 mg/L in all samples. Phosphate ranged from <0.02 mg/L (non-detect) to 0.036 mg/L.

Results: We plotted projected nitrate concentrations in the Summit area of concern versus the number of septic-tank systems (figure 17). We used an average baseline nitrate concentration of 2.5 mg/L based on data collected for this study, excluding the surface water sample. The Summit area of concern is approximately 1780 acres and has approximately 84 septic-tank systems within and up-gradient, making the current septic-tank system density 21.2 acres/system. Using the groundwater parameters described above, estimated groundwater flow available for mixing in the Summit area ranges from 941 acre-feet/year to 2370 acre-feet/year. For the Summit area to maintain an overall nitrate concentration of 3.5 mg/L, the total number of septic-tank systems should not exceed 348, or 190 using the more conservative groundwater flow estimate. This result corresponds to an increase of 106 to 264 new septic-tank systems and a septic-tank system density of 5.1 acres/system to 9.4 acres/system.

Discussion: Based on the scenarios presented above, the Summit area should not exceed a septic-system density of 5 acres/system. However, a density of 9 acres/system based on the most conservative scenario may be more appropriate for long-term land-use planning. Unlike the other domains in this study, under the most conservative scenario, the current 5-acre minimum lot size will likely not result in exceedances of the EPA 10 mg/L MCL. Although the basin-fill aquifer in the Summit area is generally unconfined, fine-grained layers in the basin fill can potentially slow vertical groundwater movement. However, the presence of elevated nitrate concentrations in wells means it is likely that water from the mixing zone is reaching deeper regions of the aquifer.

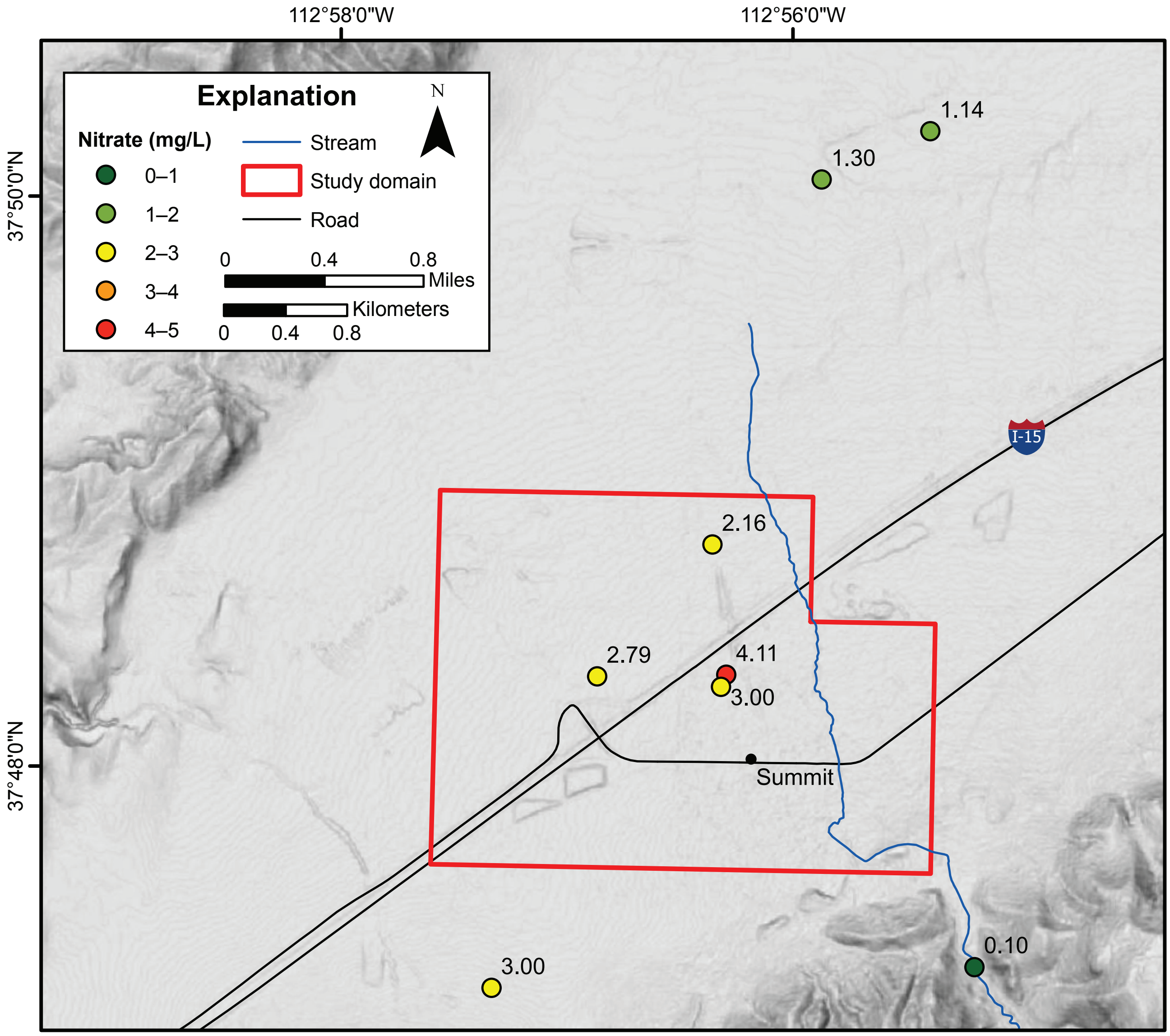

Figure 16. Nitrate concentrations for wells and surface water in the Summit study domain.

Table 7. Nitrate data and field parameters for Summit, Iron County, Utah.

Site ID	WIN[1]	Latitude	Longitude	pH	Temperature (°C)	Specific Conductance (µS/cm)	Nitrate (mg/L)[2]
WL-PGGARD	436029	37.8382	-112.92298	8.06	20	356	1.14
WL-PGDALL	437658	37.83525	-112.93092	7.34	14.2	444	1.3
WL-SMRER	444449	37.813767	-112.938425	7.35	20.2	599	2.16
WL-SMCAL	14107	37.805919	-112.946725	7.41	16.8	610	2.79
WL-SMAGM	15916	37.787577	-112.954033	7.88	19.8	556	3
WL-SMBLA	430313	37.806166	-112.937197	7.56	19.5	626	4.11
WL-SMBLA2	9152	37.805456	-112.937572	7.24	20.7	642	3
ST-SMCRK	-	37.789377	-112.918462	8.47	16.2	430	0.1

[1]WIN is the unique well identifier used by the Utah Division of Water Rights

[2] Results in italics denote sample reporting limit

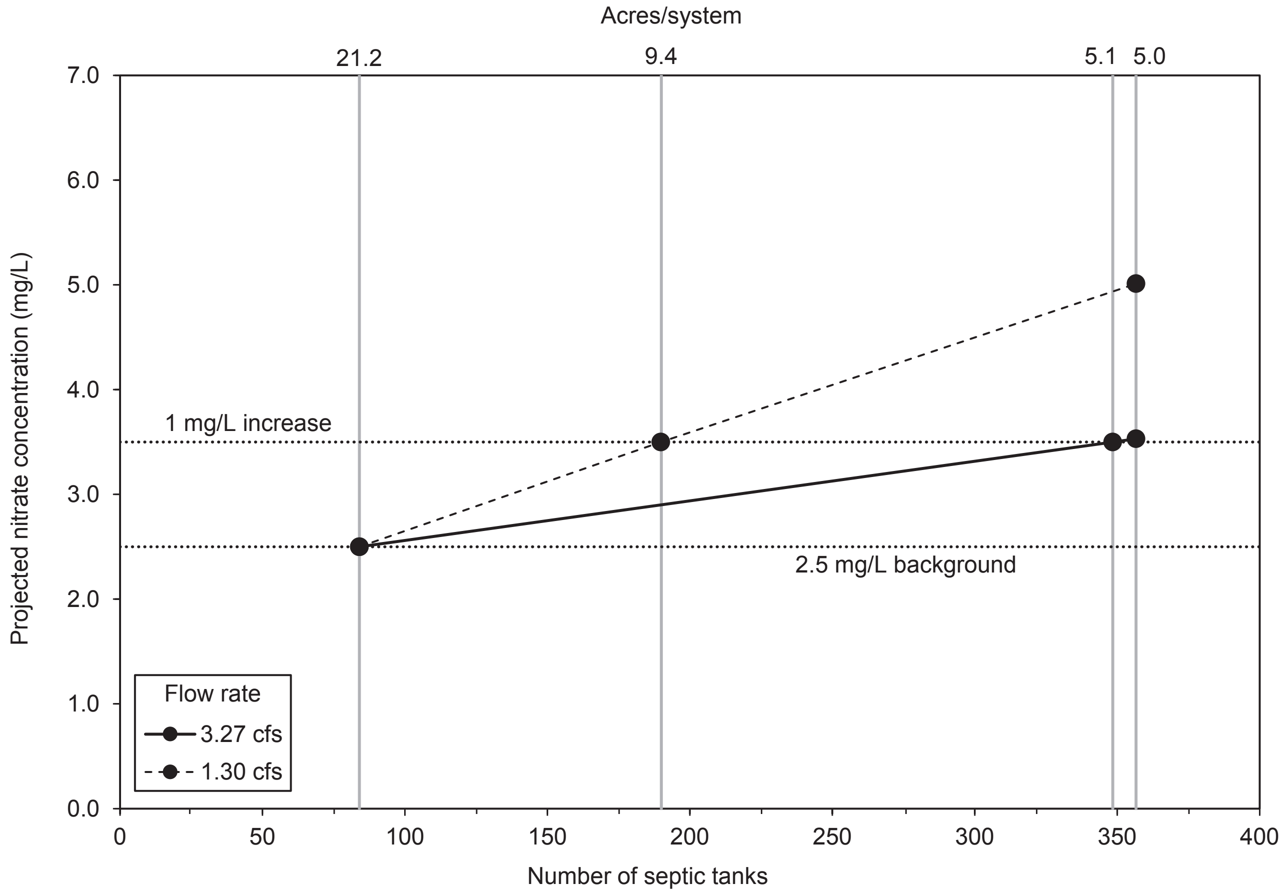

Figure 17. *Projected septic-system density versus nitrate concentration for the Summit study domain based on 84 existing septic systems.*

Paragonah Septic-Tank Density Evaluation

Groundwater flow variables: We calculated groundwater flow scenarios using hydraulic conductivities derived from three aquifer tests in the greater Paragonah area (figure 15). The highest conductivity, 30 ft/day, is within the western part of the study domain. The middle and lower conductivities, 19.5 ft/day and 6.7 ft/day, are from wells central to the study domain in Parowan. We used an average hydraulic gradient of 0.0093 based on a water-level map for the basin-fill aquifer constructed from water-level measurements made in 2012 and 2013 (Marston, 2017). We used a mixing depth of 50 feet and 8.5 mile transect for each scenario, resulting in groundwater flow available for mixing of 7.25 ft^3/s, 4.71 ft^3/s, and 1.61 ft^3/s, respectively (table 2).

Existing nitrate concentrations: We collected groundwater samples from 25 wells in the Paragonah area for analysis of nitrate plus nitrite, ammonia, and phosphate (figure 18). Nitrate plus nitrite concentrations ranged from 0.2 mg/L to 4.95 mg/L, with an average of 1.76 mg/L (table 8). The highest nitrate concentrations are near agricultural fields or septic-tank systems. Ammonia was reported as non-detected at <0.05 mg/L in all samples. Phosphate ranged from <0.02 mg/L (non-detect) to 0.043 mg/L.

Results: We plotted projected nitrate concentrations in the Paragonah area of concern versus the number of septic-tank systems (figure 19). We used an average baseline nitrate concentration of 1.76 mg/L based on data collected for this study. The Paragonah area of concern is approximately 8060 acres and has approximately 329 septic-tank systems within and up-gradient, making the current septic-tank system density 24.5 acres/system. Using the groundwater parameters described above, estimated groundwater flow available for mixing in the Paragonah area ranges from 1165 acre-feet/year to 5248 acre-feet/year. For the Paragonah area to maintain an overall nitrate concentration of 2.76 mg/L, the total number of septic-tank systems should not exceed 724, 934 using the least conservative groundwater flow estimate, or 468 using the most conservative groundwater flow estimate. This recommendation corresponds to an increase of 139 to 605 new septic-tank systems and a septic-tank system density of 8.6 acres/system to 17.2 acres/system.

Discussion: Based on the scenarios presented above, the Paragonah area should not exceed a septic-system density of 9 acres/system. However, a slightly more conservative density of 11 acres/system based on a hydraulic conductivity centrally located within the study domain may be more

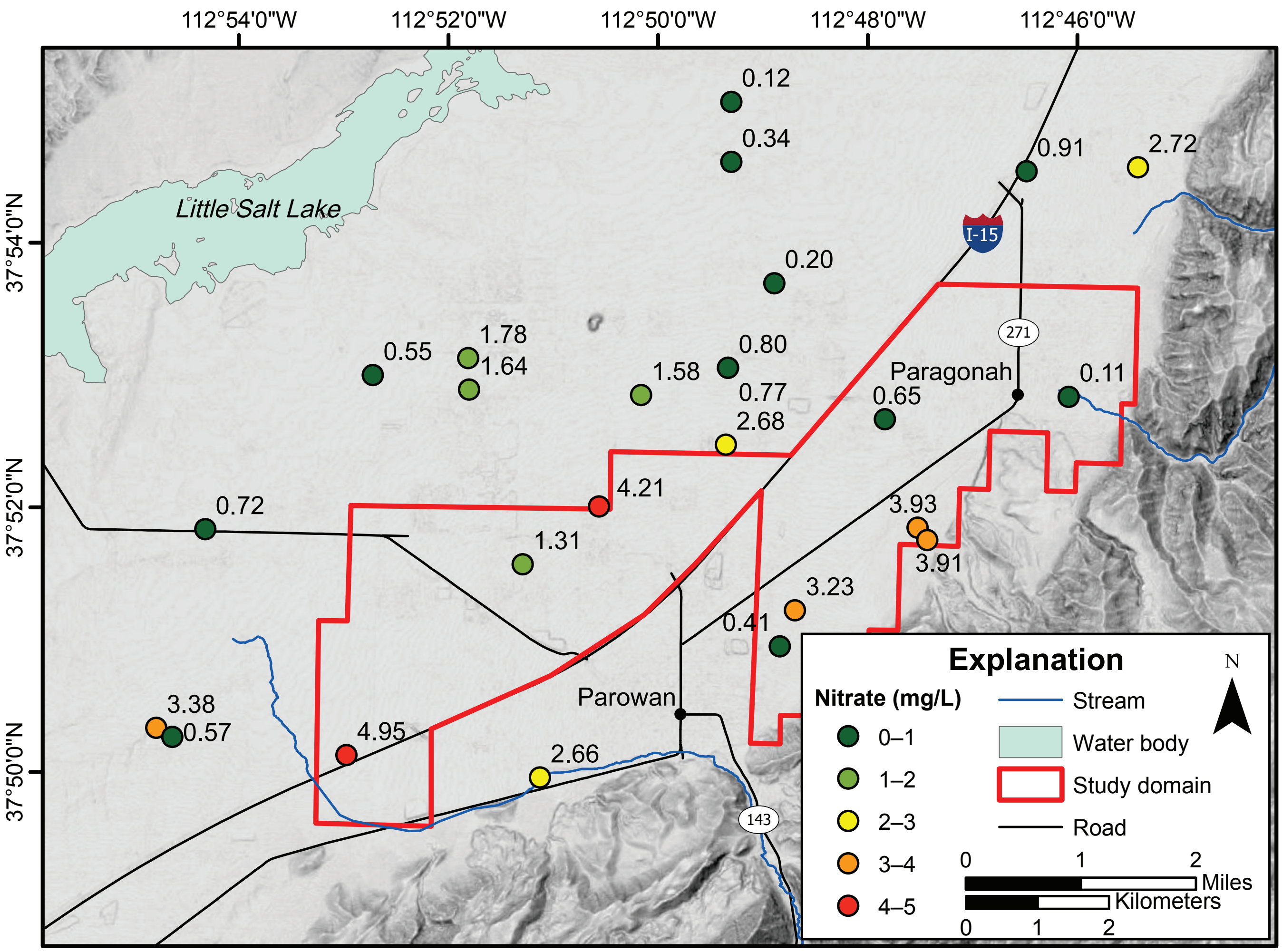

Figure 18. *Nitrate concentrations for wells in the Paragonah study domain.*

appropriate for long-term land-use planning. Under the most conservative scenario based on the lowest hydraulic conductivity, the current 5-acre minimum lot size may result in exceedances of the EPA 10 mg/L MCL. Although some regions of the basin-fill aquifer in Parowan Valley are confined, much of the Paragonah study area overlies unconfined conditions. Relatively few fine-grained layers in this area exist to slow vertical groundwater movement. Elevated nitrate concentrations in wells are also more common in this area than the areas with confined conditions. A valley-wide public sanitary sewer system may also be an option for the Paragonah region, or expansion of the existing sewer system serving the city of Parowan.

SUMMARY AND CONCLUSIONS

Iron County is a semi-rural area in southwestern Utah that has experienced and continues to experience an increase in residential development. Much of the development is occurring in small towns, subdivisions, and rural areas that lack community sewer systems, instead relying on individual septic-tank soil-absorption systems. Groundwater from basin-fill aquifers is the primary source of drinking water in much of Iron County. Septic-tank effluent carries constituents which undergo little to no natural remediation during percolation toward the aquifer. Attenuation of these constituents is typically achieved via dilution upon reaching the aquifer. We used nitrate, a common and mobile septic-tank effluent constituent, to evaluate dilution of wastewater in the upper zones of valley-fill aquifers. Our evaluation used a mass-balance method based on volume of groundwater flow available for mixing with septic-tank effluent in each study area aquifer. Discharge, projected number of septic-tank systems, and septic-tank density for each study area are summarized in table 9. The mass-balance approach indicates that the most appropriate recommended maximum septic-tank densities in Newcastle, Kanarraville, Summit, and Paragonah are 23 acres per system, 7 acres per system, 5 acres per system, and 11 acres per system, respectively. These recommendations are based on hydrogeologic parameters used to estimate groundwater flow volume. Public valley-wide sewer systems may be a better alternative to septic-tank systems where feasible.

Table 8. *Nitrate data and field parameters for Paragonah, Iron County, Utah.*

Site ID	WIN[1]	Latitude	Longitude	pH	Temperature (°C)	Specific Conductance (µS/cm)	Nitrate (mg/L)
WL-PGEIN	443077	37.88314	-112.76688	7.11	16.5	598	0.11
WL-PGEVANS	443389	37.87985	-112.79605	7.8	17	326	0.646
WL-PGADAM1	-	37.88596	-112.82113	7.81	15.9	474	0.772
WL-PGADAM2	426887	37.88653	-112.86245	-	13.9	411	1.78
WL-PGSTOW	13963	37.86817	-112.84122	7.46	15.2	530	4.21
WL-PGWOOD1	437824	37.88256	-112.86221	7.8	14.5	405	1.64
WL-PGMAT	431659	37.83916	-112.91083	7.7	13.9	436	3.38
WL-PGRAY	-	37.83805	-112.90822	8.14	18.6	318	0.566
WL-PGADAM3	-	37.86430	-112.90369	8.26	14	307	0.724
WL-PG EVAN2	13992	37.86068	-112.85315	7.77	9.1	440	1.31
WL-WOOD2	123499	37.88231	-112.83488	7.88	19	404	1.58
WL-PGBESS	440334	37.87625	-112.82124	7.88	20	470	2.68
WL-PGLION	23342	37.83388	-112.84972	7.15	15.5	743	2.66
WL-PGTANN	18717	37.85101	-112.81206	7.25	23	717	0.407
WL-PGSTEW	12152	37.85556	-112.80974	7.57	16	600	3.23
WL-PGLLOYD	16533	37.86627	-112.79052	7.43	14.2	624	3.93
WL-PGJOHN	428813	37.86476	-112.78895	7.35	15.8	680	3.91
WL-PGCLUFF1	6996	37.91144	-112.77429	8.1	14.5	331	0.906
WL-PGCLUFF2	431118	37.91220	-112.75657	7.94	13.6	541	2.72
WL-PGSCHMI	19178	37.91947	-112.82144	8.15	13.2	350	0.12
WL-PGHANA	23427	37.91190	-112.82123	7.97	16.2	409	0.343
WL-PGALL	445116	37.89673	-112.81402	8.13	15.5	351	0.2
WL-PGADAM4	-	37.88596	-112.82111	7.73	15.2	566	0.799
WL-PGRENZ	20763	37.88414	-112.87754	8.03	14	400?	0.548
WL-PGPGF	436238	37.83622	-112.88052	7.15	14.6	960	4.95

[1]WIN is the unique well identifier used by the Utah Division of Water Rights

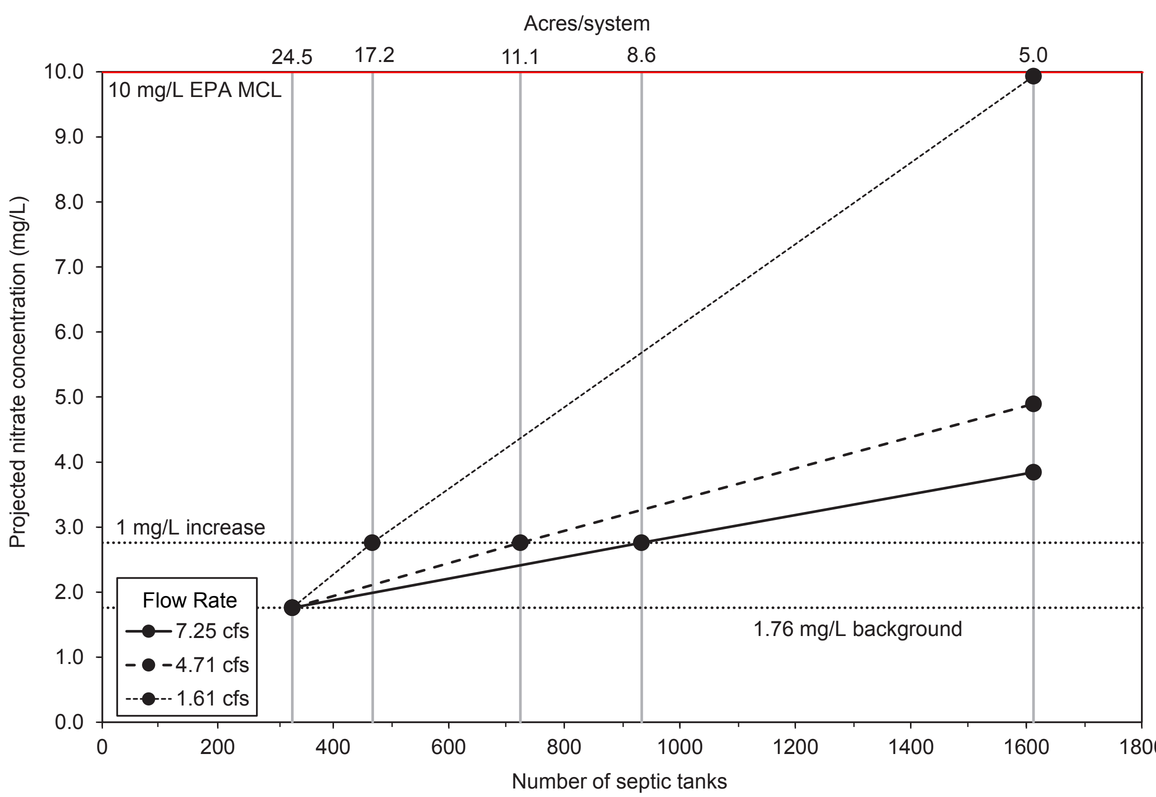

Figure 19. *Projected septic-system density versus nitrate concentration for the Paragonah study domain based on 329 existing septic systems.*

Table 9. *Results of mass balance analysis for different groundwater flow scenarios in all study areas in Iron County.*

Study Domain	Area (acres)	Discharge (cfs)	Current density (acres/system)	Current septic tanks	Projected total septic tanks	Calculated density (acres/system)
Newcastle	3540	0.66	33.7	105	140	25.3
		0.94			154	23
		3.1			263	13.5
Kanarraville	5140	0.08	16.7	308	319	16.1
		5.37			743	6.9
Summit	1780	1.3	21.2	84	190	9.4
		3.27			348	5.1
Paragonah	8060	1.61	24.5	329	468	17.2
		4.71			724	11.1
		7.25			934	8.6

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REFERENCES

Al-Dabbagh, S., Forman, D., Bryson, D., Stratton, I., and Doll, R., 1986, Mortality of nitrate fertilizer workers: British Journal of Industrial Medicine, v. 43, 507 p.

Andreoli, A., Bartilucci, N., Forgione, R., and Reynolds, R., 1979, Nitrogen removal in a subsurface disposal system: Journal Water Pollution Control Federation, p. 841–854.

Bauman, B.J., and Schafer, W.M., 1984, Estimating ground-water quality impacts from on-site sewage treatment systems, *in* Proceedings of the Fourth National Symposium on Individual and Small Community Sewage Systems: American Society of Agricultural Engineers Publication 07-85, p. 285–294.

Biek, R.F., Rowley, P.D., Hayden, J.M., Hacker, D.B., Willis, G.C., Hintze, L.F., Anderson, R.E., and Brown, K.D., 2010, Geologic map of the St. George and east part of the Clover Mountains 30' x 60' quadrangles, Washington and Iron Counties, Utah: Utah Geological Survey Map 242, scale, 1:100,000, https://doi.org/10.34191/m-242.

Biek, B., Rowley, P.D., Anderson, J.J., Maldanado, F., Moore, D.W., Hacker, D.B., Eaton, J.G., Hereford, R., Sable, E.G., Filkhorn, H.F., and Matyjasik, B., 2015, Geologic map of the Panguitch 30 x 60 quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Map M-270dm, 1:62,500 scale, https://doi.org/10.34191/m-270dm.

Bishop, C.E., Wallace, J., and Lowe, M., 2007a, Recommended septic tank soil-absorption-system densities for the principal valley-fill aquifer, Sanpete Valley, Sanpete County, Utah: Utah Geological Survey Report of Investigation 259, 36 p., https://doi.org/10.34191/ri-259.

Bishop, C.E., Wallace, J., and Lowe, M., 2007b, Recommended septic tank soil-absorption-system densities for the shallow unconfined aquifer in Cache Valley, Cache County, Utah: Utah Geological Survey Report of Investigation 257, 35 p., https://doi.org/10.34191/ri-257.

Bjorklund, L.J., Sumsion, C.T., and Sandberg, G.W., 1977, Selected hydrologic data, Parowan Valley and Cedar City Valley drainage basins, Iron County, Utah: Utah State Engineer Utah Basic-Data Release No. 28, 55 p.

Bjorklund, L.J., Sumsion, C.T., and Sandberg, G.W., 1978, Ground-water resources of the Parowan-Cedar City drainage basin, Iron County, Utah: Utah Department of Natural Resources Technical Publication No. 60, 93 p., scale 1:250,000.

Blackett, R.E., 2004, Newcastle, Utah small-scale geothermal power development project—exploratory drilling: Utah Geological Survey Report of Investigation 252, 8 p., 7 appendices, https://doi.org/10.34191/ri-252.

Blackett, R.E., 2007, Temperature-depth monitoring in the Newcastle geothermal system: Utah Geological Survey Report of Investigation 258, 23 p., https://doi.org/10.34191/ri-258.

Blackett, R.E., Ross, H.P., and Forster, C.B., 1997, Effect of geothermal drawdown on sustainable development, Newcastle area, Iron County, Utah: Utah Geological Survey Circular 97, 30 p., https://doi.org/10.34191/c-97.

Blackett, R.E., and Shubat, M.A., 1992, A case study of the Newcastle geothermal system, Iron County, Utah: Utah Geological Survey Special Study 81, 30 p., https://doi.org/10.34191/ss-81.

Bouchard, D.C., Williams, M.K, and Surampalli, R.Y., 1992, Nitrate contamination of groundwater—sources and potential health effects: American Water Works Association Journal, v. 84, no. 9, p. 85–90.

Burden, C.B., and others, 2005, Ground-water conditions in Utah, spring of 2005: Utah Department of Natural Resources Cooperative Investigations Report No. 46, 138 p.

Burden, C.B., and others, 2015, Groundwater conditions in Utah, spring of 2015: Utah Department of Natural Resources Cooperative Investigations Report No. 56, 136 p.

Comley, H.H., 1945, Cyanosis in infants caused by nitrates in well water: Journal of the American Medical Association, v. 129, p. 112.

Cordova, R. M., Sandberg, G. W., and McConkie, W., 1972, Ground-water conditions in the central Virgin River Basin, Utah: Utah Department of Natural Resources Technical Publication No. 40, 64 p.

Cordova, R. M., 1978, Ground-water conditions in the Navajo Sandstone in the central Virgin River basin, Utah: Utah Department of Natural Resources Technical Publication No. 61, 66 p.

Croll, B.T., and Hayes, C.R., 1988, Nitrate and water supplies in the UK: Environmental Pollution, v. 50, no. 1-2, p. 163–187.

Cuello, C., Correa, P., Haenszel, W., Cordillo, G., Brown, C., Archer, M., and Tannenbaum, S., 1976, Gastric cancer in Colombia—cancer risk and suspected environmental agents: Journal National Canadian Institute, v. 57, p. 1015–1020.

Deese, P.L., 1986, An evaluation of septic leachate detection: U.S. Environmental Protection Agency Project Summary EPA/600/52-86/052, 2 p.

DuRoss, C.B., and Kirby, S.M., 2004, Reconnaissance investigation of ground cracks along the western margin of Parowan Valley, Iron County, Utah: Utah Geological Survey Report of Investigation 253, 17 p., https://doi.org/10.34191/ri-253.

Fan, A.M., Willhite, C.C., and Book, S.A., 1987, Evaluation of the nitrate drinking water standard with reference to infant methemoglobinemia and potential reproductive toxicology: Regulatory Toxicologic Pharmacology, v. 7, no. 2, p. 135–148.

Fetter, C.W., Jr., 2001, Applied hydrogeology: Upper Saddle River, New Jersey, Prentice Hall, 598 p.

Forman, D., 1985, Nitrates, nitrites and gastric cancer in Great Britain: Nature, v. 313, p. 620–625.

Fraser, P., Chilvers, C., Beral, V., and Hill, M.J., 1980, Nitrate and human cancer, a review: International Journal of Epidemiology, v. 9, p. 3–11.

Franks, A.L., 1972, Geology for individual sewage disposal systems: California Geology, v. 25, no. 9, p. 195–203.

Green, T.G., Fisher, L.H., and Bekins, B.A., 2008, Nitrogen fluxes through unsaturated zones in five agricultural settings across the United States: Journal of Environmental Quality, v. 37, p. 1073–1085.

Hansen, Allen, and Luce, Inc., 1994, Hydrogeologic/water quality study, Wasatch County, Utah: Salt Lake City, unpublished consultant's report, p. III-1–III-18.

Heilweil, V.M., Freethey, G.W., Wilkowske, C.D., Stolp, B.J., and Wilberg, D.E., 2000, Geohydrology and numerical simulation of groundwater flow in the central Virgin River Basin of Iron and Washington Counties, Utah: Utah Department of Natural Resources, Division of Water Rights Technical Publication No. 116, 206 p.

Hurlow, H.A., 1998, The geology of the central Virgin River basin, southwestern Utah, and its relation to groundwater conditions: Utah Geological Survey Water-Resources Bulletin 26, 53 p., 7 pl., scale 1:48,000 and 1:100,000, https://doi.org/10.34191/WRB-26.

Hurlow, H.A., 2002, The geology of Cedar Valley, Iron County, Utah and its relation to ground-water conditions, Utah Geological Survey Special Study 105, 74 p., 2 plates, https://doi.org/10.34191/ss-105.

Inkenbrandt, P., Thomas, K.J., and Jordan, J.L., 2013, Regional groundwater flow and water quality in the Virgin River basin and surrounding areas, Utah and Arizona: Utah Geological Survey Report of Investigation 272, 52 p., https://doi.org/10.34191/ri-272.

Jordan, J.L., Smith, S.D., Inkenbrandt, P.C., Lowe, M., Hardwick, C., Wallace, J., Kirby, S.M., King, J.K., and Payne, E.E., 2019, Characterization of the groundwater system in Ogden Valley, Weber County, Utah, with emphasis on groundwater–surface-water interaction and the groundwater budget: Utah Geological Survey Special Study 165, 222 p., 3 plates, https://doi.org/10.34191/ss-165.

Kaplan, O.B., 1988, Septic systems handbook: Chelsea, Michigan, Lewis Publishers, Inc., 290 p.

Lowe, M., and Wallace, J., 1999, The hydrogeology of Ogden Valley, Weber County, Utah, and recommended wastewater management practices to protect groundwater quality, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 313–336.

Lowe, M., Wallace, J., and Bishop, C.E., 2000, Analysis of septic-tank density for three areas in Cedar Valley, Iron County, Utah—a case study for evaluations of proposed subdivisions in Cedar Valley: Utah Geological Survey Water Resource Bulletin 27, 66 p., https://doi.org/10.34191/wrb-27.

Lowe, M., Wallace, J., and Bishop, C.E., 2002, Water-quality assessment and mapping for the principal valley-fill aquifer in Sanpete Valley, Sanpete County, Utah: Utah Geological Survey Special Study 102, 91 p., 13 plates, https://doi.org/10.34191/ss-102.

Lowe, M., Wallace, J., and Bishop, C.E., 2003, Ground-water quality classification and recommended septic tank soil-absorption-system density maps, Cache Valley, Cache County, Utah: Utah Geological Survey Special Study 101, 31 p., 10 plates, https://doi.org/10.34191/ss-101.

Lowe, M., Wallace, J., Emerson, R., Johnson, A., and Riding, R., 2009, Ground-water sensitivity and vulnerability to pesticides, Beryl-Enterprise area, Iron, Washington, and Beaver Counties, Utah: Utah Geological Survey Report of Investigation 266, 28 p., 2 plates, https://doi.org/10.34191/ri-266.

Lowe, M., Wallace, J., Sabbah, W., and Kneedy, J., 2010, Science-based land-use tools to help protect Groundwater Quality, Cedar Valley, Iron County, Utah: Utah Geological Survey Special Study 134, 125 p., 6 plates., https://doi.org/10.34191/ss-134.

Lund, W.R., DuRoss, C.B., Kirby, S.M., McDonald, G.N., Hunt, G., and Vice, G.S., 2005, The origin and extent of earth fissures in Escalante Valley, Southern Escalante Desert, Iron County, Utah: Utah Geological Survey Special Study 115, 33 p., https://doi.org/10.34191/ss-115.

Madison, R.J., and Brunett, J.O., 1985, Overview of the occurrence of nitrate in ground water of the United States, *in* National water summary 1984—hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 93–105.

Marston, T.M., 2017, Water resources of Parowan Valley, Iron County, Utah: U.S. Geological Survey Scientific Investigations Report 2017–5033, 58 p.

Mower, R.W., and Sandberg, G.W., 1982, Hydrology of the Beryl-Enterprise area, Escalante Desert, Utah, with emphasis on ground water: Utah Department of Natural Resources Technical Publication No. 73, 66 p.

PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, data created November 2021, accessed March 2022.

Rowley, P.D., Williams, V.S., Vice, G.S., Maxwell, D.J., Hacker, D.B., Snee, L.W., and Mackin, J.H., 2006, Interim geologic map of the Cedar City 30' x 60' quadrangle, Iron and Washington Counties, Utah: Utah Geological Survey Open-File Report 476DM, scale 1:100,000, https://doi.org/10.34191/ofr-476dm.

Sandberg, G.W., 1963, Ground-water data, Beaver, Escalante, Cedar City, and Parowan Valleys, parts of Washington, Iron, Beaver, and Millard Counties, Utah: Utah State Engineer Basic-Data Report No. 6, 26 p.

Sandberg, G.W., 1966, Ground-water resources of selected basins in southwestern Utah: Utah State Engineer Technical Publication 13, 43 p.

Taneja, P., Labhasetwar, P., Nagarnaik. P., and Ensink, J.H.H., 2017, The risk of cancer as a result of elevated levels of nitrate in drinking water and vegetables in Central India: Journal of Water & Health, v. 15, p. 602–614.

Taylor, H.W., and Lijinsky, W., 1975, Tumor induction in rats by feeding heptamethyleneimine and nitrite in water: Cancer Research, v. 35, p. 505–812.

Thomas, H.E., and Taylor, G.H., 1946, Geology and ground-water resources of Cedar City and Parowan Valleys, Iron County, Utah: U.S. Geological Survey Water-Supply Paper 993, 210 p.

Thomas, K.J., and Lowe, M., 2007, Recharge and discharge areas for the principal basin-fill aquifer, Beryl-Enterprise Area, Iron, Washington, and Beaver Counties, Utah: Utah Geological Survey Map 225, 24 p., 1 plate, https://doi.org/10.34191/m-225.

U.S. Census Bureau, 2021, 2020 Census data, Online, https://data.census.gov/cedsci/, accessed May 2022.

U.S. Environmental Protection Agency, 1987, Guidelines for delineation of wellhead protection areas: U.S. Environmental Protection Agency document no. EPA 440/6-87- 010, 114 p.

U.S. Environmental Protection Agency, 2022, Current drinking water standards: Online, https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations, accessed March 3, 2022.

Utah Division of Water Resources, 2010, 2009 residential water use—survey results and analysis of residential water use for seventeen communities in Utah: Salt Lake City, 37 p.

Wallace, J., and Lowe, M., 1998a, The potential impact of septic tank soil-absorption systems on water quality in the principal valley-fill aquifer, Cedar Valley, Iron County, Utah—assessment and guidelines: Utah Geological Survey Report of Investigation 239, 11 p., https://doi.org/10.34191/ri-239.

Wallace, J., and Lowe, M., 1998b, The potential impact of septic tank soil-absorption systems on water quality in the principal valley-fill aquifer, Tooele Valley, Tooele County, Utah—assessment and guidelines: Utah Geological Survey Report of Investigation 235, 10 p., https://doi.org/10.34191/ri-235.

Wallace, J., and Lowe, M., 1998c, The potential impact of septic tank soil-absorption systems on water quality in the principal valley-fill aquifer, Ogden Valley, Weber County, Utah—assessment and guidelines: Utah Geological Survey Report of Investigation 237, 11 p., https://doi.org/10.34191/ri-237.

Wallace, J., and Lowe, M. 1999, A mass-balance approach for recommending septic tank–soil-absorption system density/lot-size requirements based on potential water-quality degradation due to nitrate examples from three Utah valleys, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 267–274.

Wallace, J., Schlossnagle, T.H., and Payne, N., 2021, Analysis of septic-tank densities in a pristine aquifer: Johns and Emery Valleys near Bryce Canyon City, Garfield County, Utah: Utah Division of Water Quality unpublished contract deliverable, 58 p.

Xu, Y., Baker, L.A., and Johnson, P.C., 2007, Trends in ground water nitrate contamination in the Phoenix, Arizona Region: Ground Water Monitoring & Remediation, v. 27, no. 2, p. 49–56.

Zhan, Honbin, and McKay, W.A., 1998, An assessment of nitrate occurrence and transport in Washoe Valley, Nevada: Environmental and Engineering Geoscience, v. 4, no. 4, p. 479–489.