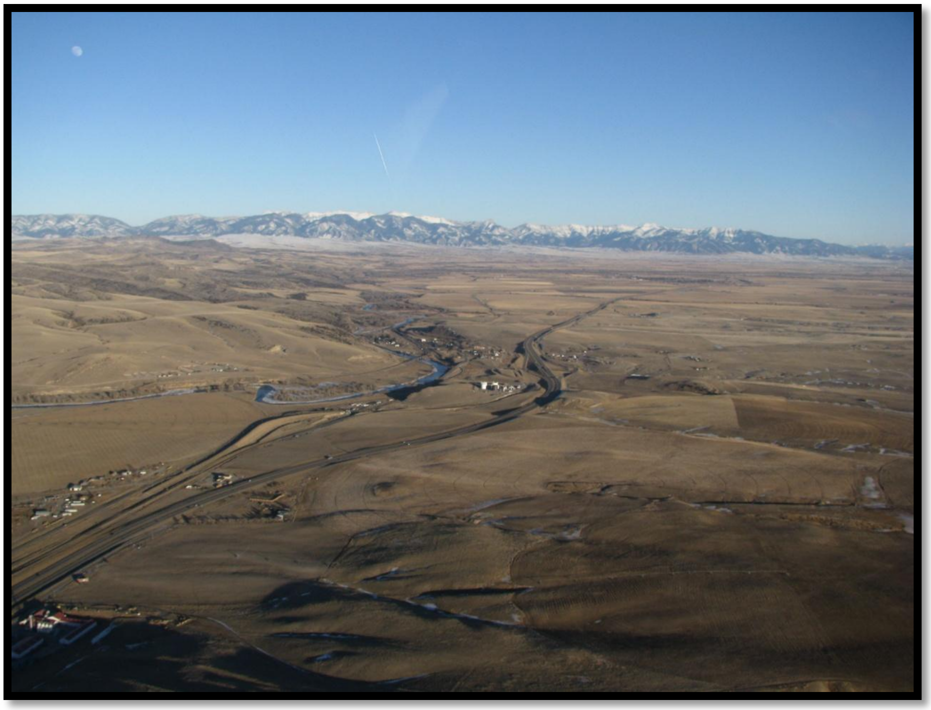
GROUNDWATER ASSESSMENT OF THE LOGAN AREA
GALLATIN COUNTY, MONTANA



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Acronyms and Abbreviations

bgs . . . . below ground surface
DO . . . . dissolved oxygen
EHS . . . . Environmental Health Services
USEPA . . . . .US Environmental Protection Agency
GIS . . . . Geographic Information Systems
GWIC . . . . Groundwater Information Center
GLWQD . . . . . . Gallatin Local Water Quality District
MBMG . . . . Montana Bureau of Mines and Geology
MCL . . . . maximum contaminant level
mg/L . . . . milligrams per liter
µS/cm . . . . microsiemens per centimeter
N . . . . nitrogen
ND . . . . not detected
Nitrate-N . . . . nitrate plus nitrite as nitrogen
NRCS . . . . Natural Resource Conservation Service
PCPP . . . . pharmaceuticals and personal care products
SC . . . . specific conductivity
SDWA . . . . Safe Drinking Water Act
SSURGO . . . . . Soil Survey Geographic database
SWL . . . . static water level
USDA . . . . United States Department of Agriculture
VOC . . . . volatile organic compound

1.0 EXECUTIVE SUMMARY

Groundwater in the Logan area was investigated in 2013 after elevated levels of nitrate-N (nitrate + nitrite as nitrogen) were documented in several private wells. Water quality data from the early to mid-2000's revealed nitrate-N values which exceeded the US Environmental Protection Agency maximum contaminant level of 10 mg/L. The area consists of numerous small lots clustered together and close proximity of drinking water wells and septic systems is one of the suspected causes of the elevated nitrate-N levels in certain wells. The area has a long history of land use by the railroad. Up-gradient from Logan is the Logan Landfill which receives solid waste from the Gallatin Valley. Some residents have expressed concerns that contaminated groundwater associated with these land use activities may extend into the Logan area. In 2013, fifteen domestic wells were sampled to further evaluate drinking water quality. Results from the targeted sampling indicate some wells are likely impacted from septic systems. Several wells were sampled for volatile organic compounds (VOCs) with no detectable levels found, suggesting little evidence of a direct impact to wells in Logan.

2.0 INTRODUCTION

2.1 Background

The unincorporated community of Logan is located in the northwestern corner of Gallatin County, Montana. The Logan area is on a small alluvial terrace adjacent to the Gallatin River and is surrounded by exposed bedrock. The Gallatin River is located to the north of Logan and Interstate-90 to the south. A railroad line and Frontage Road pass through the community. Homes in the area are on small lots and use individual wells for water supply and individual septic systems for wastewater treatment. There have been complaints of surfacing sewage in the community in the past (Gallatin County EHS). In May 2008, the Gallatin Local Water Quality District (GLWQD) participated in a public education meeting with residents and provided drinking water test kits to those who were interested. The Logan area was added to the GLWQD in 2010. Logan is considered the outlet for both surface water and groundwater for the Gallatin Valley. However, information on groundwater quality, groundwater flow patterns and the connection between the Gallatin River and groundwater is limited to USGS studies from 1960 (Hackett and others) and 1995 (Slagle). In 2013, the Montana Bureau of Mines and Geology (MBMG) Groundwater Investigation Program drilled and installed a shallow and deep pair of monitoring wells near the river to examine the geology of the area and gain a better understanding of the hydrogeologic properties of the underlying Madison Limestone as part of the Groundwater Investigation Program study in the area (Tom Michalek, pers. comm., Aug 2014).

2.2 Purpose and Scope

Elevated levels of nitrate-N (>2 mg/L) have been documented in several private wells in Logan. Because the area consists of numerous small lots clustered together with drinking water wells and septic systems within close proximity to one another, septic systems are one of the suspected causes of the elevated nitrate-N levels in certain wells.

There is also a long history of land use by the railroad, including operation of a rail yard and engine maintenance facility. While there are currently no indications of groundwater contamination from railroad activities in Logan, contamination of groundwater with fuels, solvents and metals is common in many rail yards in Montana. The Logan Landfill which is operated by the Gallatin Solid Waste Management District is located just over a mile to the southeast of Logan. Some residents have expressed concerns that contaminated groundwater associated with the landfill may extend into the Logan area.

The purpose of this project was to gather groundwater quality data from Logan area wells to investigate contamination of groundwater from septic systems, the railroad and the landfill. The scope of the project was focused on the unincorporated area of Logan (**Figure 1**).

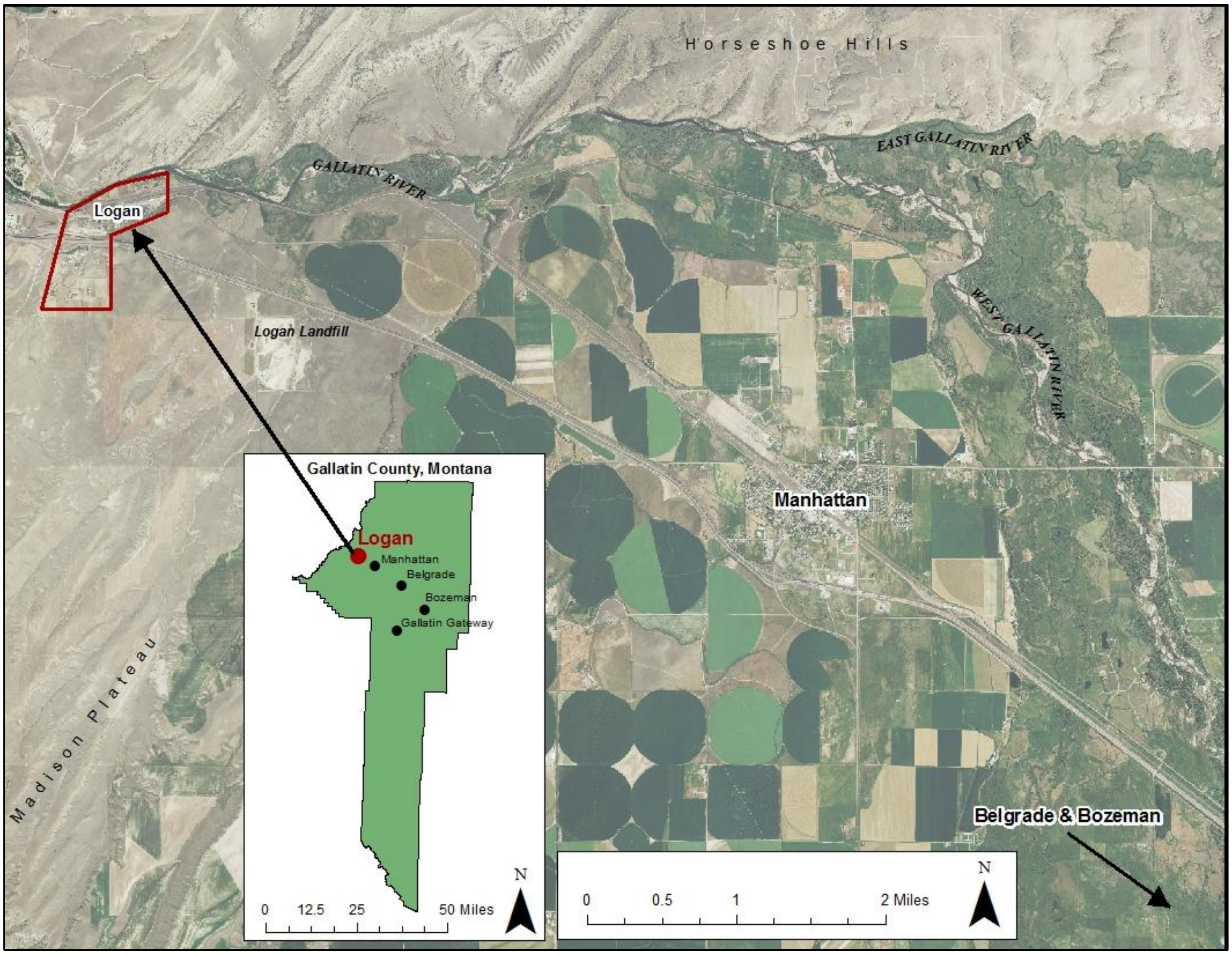


Figure 1. Logan project area in the northern Gallatin Valley.

2.3 Groundwater Assessment Objectives

To the extent possible, the objectives of this project were to:

- Investigate the cause of elevated nitrate-N levels in water wells in the Logan area.
- Evaluate whether groundwater in the Logan area is contaminated from land use activities at the Logan Landfill and/or the railroad.

3.0 LOGAN PROJECT AREA

3.1 Topography, Climate, Soils

Logan is on an alluvial terrace to the south of the Gallatin River. The climate for the Logan area is semi-arid and averages about 12 inches of rain per year. Soils in the Logan area consist mainly of Ryell silt loam with 0 to 2 percent slopes (4A), Kalsted sandy loam with 4 to 8 percent slopes (35C) and Chinook-Kalsted sandy loams with 8 to 15 percent slopes (438D). The limitation of Kalsted soils is lime content. Both Kalsted and Chinook soils are susceptible to soil and water erosion. Ryell silt loam soils have alluvium as the dominant parent material and are excessively permeable, with an increased potential for groundwater pollution because of this factor (Brooks and others, 2002). **Figure 2** illustrates the soils for the Logan area from the Soil Survey for Gallatin County, Montana.

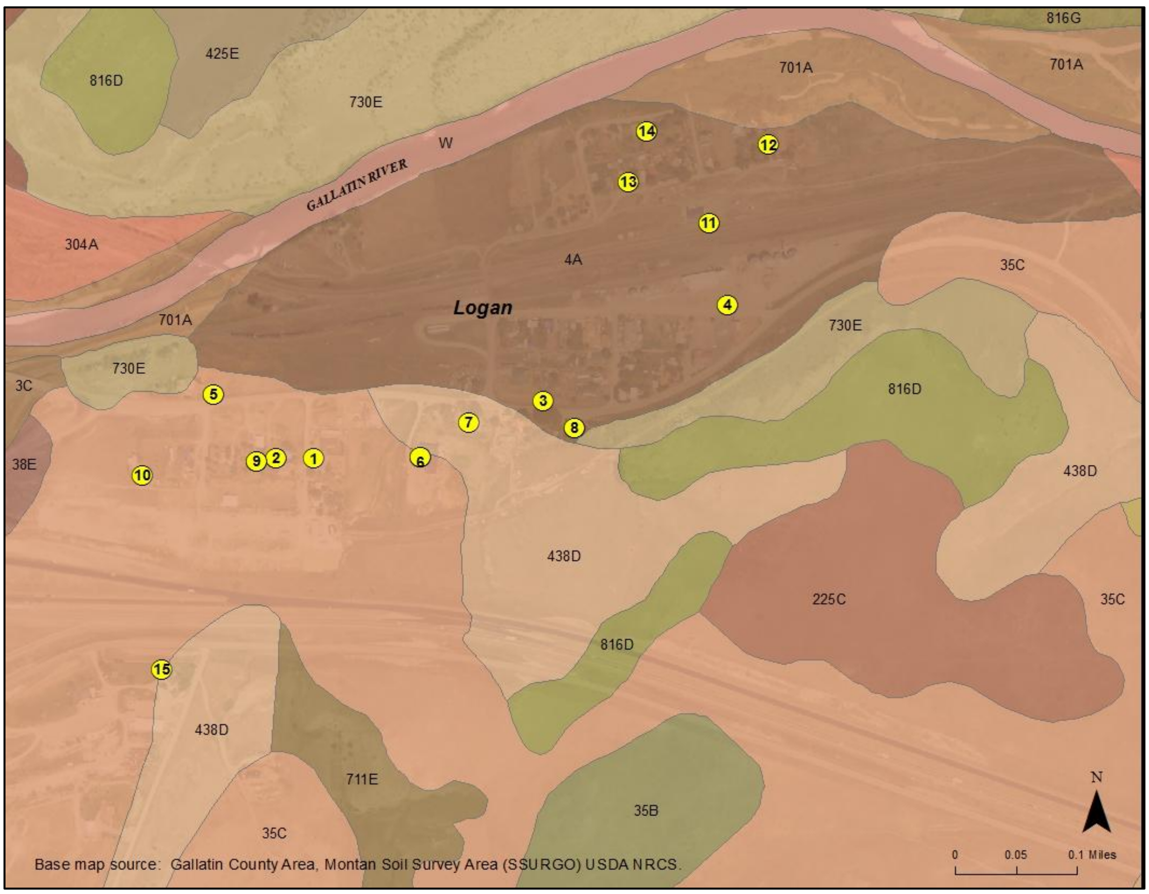


Figure 2. Soils of the Logan area from the Montana Soil Survey for Gallatin County, Montana. Soils in the area of the sampled wells (yellow dots) consist mainly of Ryell silt loam with 0 to 2 percent slopes (4A), Kalsted sandy loam with 4 to 8 percent slopes (35C) and Chinook-Kalsted sandy loams with 8 to 15 percent slopes (438D). (USDA NRCS Web Soil Survey, 2002).

Figure 2. - LEGEND

Soils - Soil Map Unit Index (MUSYM)

- 225C - Musselshell cobbly loam 8-15% slopes
- 304A - Ryell-Rivra-Fairway complex, 0-2% slopes
- 32C - Amesha loam, 4-8% slopes
- 35B - Kalsted sandy loam, 0-4% slopes
- 35C - Kalsted sandy loam, 4-8% slopes
- 35D - Kalsted sandy loam, 8-15% slopes
- 38B - Chinook fine sandy loam, 0-4% slopes
- 38E - Chinook fine sandy loam, 15-35% slopes
- 3C - Glendive sandy loam, 2-8% slopes
- 425E - Musselshell-Pensore, stony complex, 15-35% slopes
- 438D - Chinook-Kalsted sandy loams, 8-15% slopes
- 4A - Ryell silt loam, 0-2% slopes
- 701A - Rivra-Mccabe-Bonebasin complex, 0-2% slopes
- 711E - Blacksheep-Kalsted-Scravo complex, 15-45% slopes
- 730E - Crago-Pensore-Rock outcrop complex, 15-45% slopes
- 816D - Pensore-Rock outcrop complex, 4-15% slopes
- 816G - Pensore-Rock outcrop complex, 45-70% slopes
- W - water
- (1) Sample Well 2013

The Soil Survey for Gallatin County (Brooker and others, 2002) contains information that affects land use planning and predictions of soil behavior based upon various land uses. For sanitary facilities, such as septic tank absorption fields, soil properties and their limitations for that particular use are rated as *slight, moderate* or *severe*. Therefore, soil surveys can be a useful tool in land use planning for onsite wastewater treatment. Overall, the Soil Survey indicates somewhat unfavorable soil properties for a majority of Logan with regard to septic tank absorption fields. The ratings for the three main soil types in Logan are shown in **Table 1**.

Table 1. Soil Type and Limitation Rankings for Septic Tank Absorption fields in Logan

Map Symbol and Soil Name	**Ranking**
4A – Ryell	Severe: poor filter
35C – Kalsted sandy loam	Slight
438D – Chinook-Kalsted sandy loams	Moderate: slope

Source: Soil Survey for Gallatin County, 2002.

3.2 Land and Water Use, General Demographics

Land use in the unincorporated Logan community is residential. Outlying land use is predominantly rural with areas of grazing for horses and other livestock. The Gallatin River flows along the northern boundary of the community. Like many suburban and rural areas of Gallatin County, residents rely on individual wells for drinking water and groundwater use is predominantly for domestic purposes. There is one public water supply for a restaurant in Logan. Established in 1889, Logan was an important railroad station along the Northern Pacific Railroad, now Montana Rail Link. Today, the population is 99 residents (2010 Census). Many of the homes in Logan are rental properties and consist of a mix of single family homes, duplexes and mobile homes.

3.3 Hydrogeology

The Gallatin Valley is an intermontane basin of southwest Montana and is roughly 540 square miles (Kendy and Tresch 1996). It is bounded to the east by the Bridger Range, to the south by the Gallatin and Madison Ranges with the Horseshoe Hills and the Camp Creek Hills (Madison Plateau) serving as the northern and western boundaries, respectively. The Gallatin Valley is part of the Three Forks structural basin formed during Tertiary time. Valley fill consists of Tertiary and Quarternary sediments consisting of boulders, cobbles, sand, silt, clay and volcanic ash (Vuke and others, 2014). These valley fill deposits are the primary aquifer for groundwater uses.

The West Gallatin River, East Gallatin River and associated tributaries discharging from the Gallatin Range and Bridger Range are the primary sources of groundwater recharge in the Gallatin Valley (Hackett and others, 1960; Slagle, 1995; Kendy and Tresch, 1996). The infiltration of irrigation water from the ditches throughout the valley is also a source of recharge. Groundwater flow in the valley is generally from the southeast to the northwest (**Figure 3**).

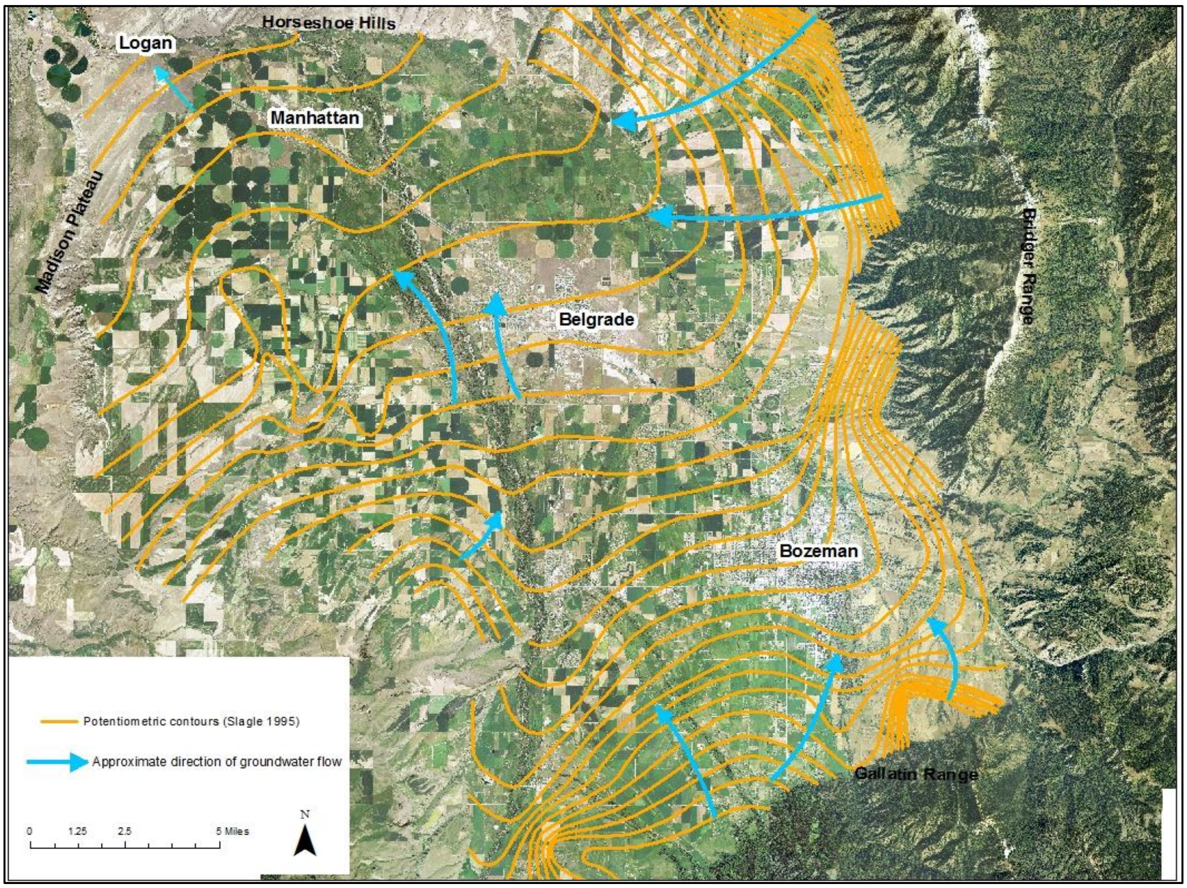


Figure 3. Groundwater flow patterns of the Gallatin Valley, Montana. The approximate direction of groundwater flow is represented by blue arrows. The potentiometric contours show the approximate water level in wells measured August 3-4, 1993 digitized from Slagle (1995).

Geology in the Logan area for the sampled wells consists mainly of alluvium and Dunbar Creek Member formations (**Figure 4**). Logan is the only outlet for surface water from the basin. A natural bedrock "dam" forces groundwater to rise to the surface and discharge into the Gallatin River and has long been considered the location where both groundwater and surface water exit the basin.

Preliminary information from research currently underway by MBMG raises questions about the connection of the Gallatin River to the shallow alluvium at Logan and the water may actually be deeper in the limestone (Michalek, pers. comm., Aug 2014). Bridge layout schematics from boreholes drilled for the Montana Rail Link overpass at Logan by the Montana Department of Transportation note the presence of Karstic limestone (6/14/1999). Preliminary water chemistry from the MBMG monitoring well deep-shallow pairs (LGN1-LGN4, LGN2-LGN3) suggests the well water has a short residence time in the limestone and the groundwater and surface water chemistry appear similar (Michalek, pers. Comm., Aug 2014). Water samples have not been collected from one of these monitoring wells (LGN2, total depth 12 feet) because it has always been dry, even though it was drilled into the shallow alluvium next to the river (**Figure 4**). LGN3 has a total depth of 76 feet and a static water level of 32.22 feet. Deep-shallow well pairs LGN1-LGN4 have total depths of 240 feet and 80 feet, respectively. Static water levels are 34.97 feet and 36.04 feet, respectively. There does not appear to be an upward gradient of groundwater to the river as would be expected in this environment and the flow system in this area is unclear (Michalek, pers. comm., Aug 2014).

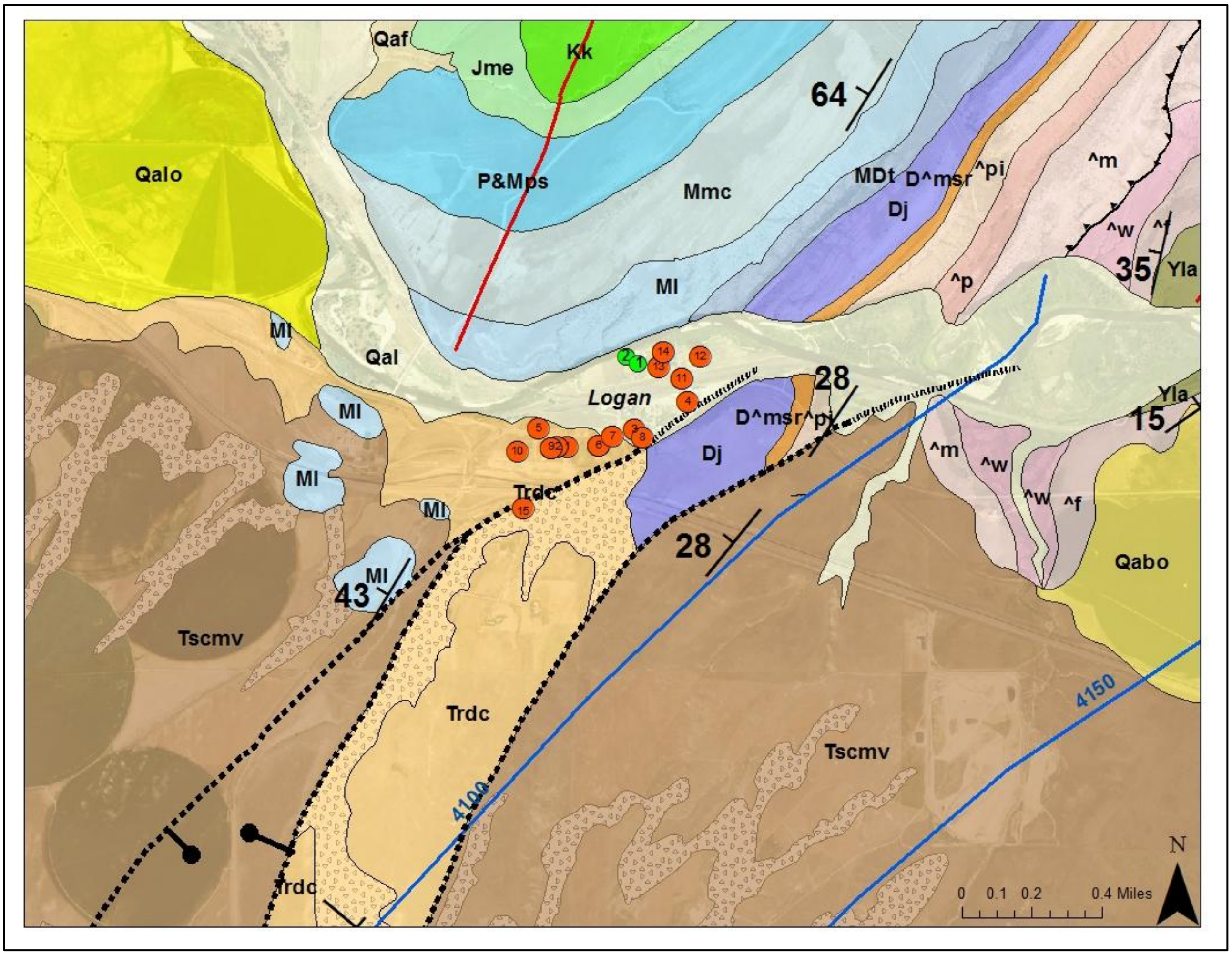


Figure 4. Geology of the greater Logan area (Vuke et al, 2014). Map legend on next page. Orange circles with numbers represent wells sampled for the project in 2013. Green symbols represent MBMG monitoring well deep-shallow pairs. Blue lines represent water-level contours showing approximate altitude of groundwater surface (Slagle 1995). The Cambrian symbol Є could not be typed in ArcGIS and is represented instead by the ^ symbol both in the legend and on the map.

Figure 4 - LEGEND

Geologic Map Bozeman 30' x 60' Quad SW Montana (Vuke et al, 2014)

MBMG CODE - Description

- D^msr - Maywood and Snowy Range Fms., undivided
- Dj - Jefferson Formation
- Jme - Morrison Formation and Ellis Group, undivided
- Kk - Kootenai Formation
- MDt - Three Forks Formation
- Ml - Lodgepole Limestone
- Mmc - Mission Canyon Limestone
- P&Mps - Phosphoria and Quadrant Fms. and Snowcrest Range Group
- Qabo - Braid plain alluvium, older
- Qaf - Alluvial fan deposit
- Qal - Alluvium
- Qalo - Alluvium, older
- Trdc - Dunbar Creek Member
- Tscmv - Madison Valley Member
- Yla - LaHood Formation, undivided
- ^f - Flathead Formation
- ^m - Meagher Limestone
- ^p - Park Shale
- ^pi - Pilgrim Limestone
- ^w - Wolsey SHale

Conglomerate & Gravel Lenses in Trdc & Tscmv

Strike & Dip of Bedding

Number indicates dip angle in degrees

Faults

- Concealed normal fault
- Inferred normal fault
- Thrust and fault
- Folds
- Potentiometric Contours (Slagle 1995)
- Sampled Well 2013
- MBMG Monitoring Well

NOTE: The Cambrian symbol could not be typed in the ArcGIS program, so it is represented by a ^ symbol in the figure legend and on the map.

The MBMG GWIC database was queried for wells in the immediate Logan area (T2N, R2E, and portions of S35 and S36); with 33 well logs available. Statistics for these wells indicate the average well depth is 147 feet. The minimum depth is 39 feet and maximum depth is 292 feet. The average SWL is 69 feet bgs. The minimum SWL is 8 feet bgs in a well with a total depth of 129 feet. The maximum SWL is 181 feet bgs in a well with a total depth of 263 feet. One well (GWIC 272199 LGN2-MBMG) was not included in the above calculations because it was a dry hole; drilled to a total depth of 12 feet adjacent to the river). A review of the well log lithology information shows these 33 wells are, generally, completed in areas of limestone, fractured limestone, shale and hard rock with some clay and sandstone.

A total of 15 wells in Logan were sampled for this project in January and February 2013. Two duplicate samples were collected. The MBMG GWIC database was queried to try and match well logs to the wells sampled for this project. Only five well logs could be correlated to the wells sampled (wells 3, 4, 5, 13 and 14). The SWL/total depths are 49/260 feet (well 3, GWIC 149116), 46/100 feet (well 4, 243620), 68/140 feet (well 5, GWIC 167340), not recorded/84 feet (well 13, 166801), and 29/65 feet (well 14, GWIC 12704).

4.0 METHODS

4.1 Review of Historical Information

Limited groundwater quality data is available for Logan. Historical water quality data was obtained from the Gallatin County Environmental Health Services (EHS), querying the GLWQD groundwater database and the MBMG Groundwater Information Center (GWIC) database. Available data spanned from 2004 to 2009, with the majority of the groundwater quality data collected between March and June 2008. During this time, numerous complaints were filed with EHS regarding surfacing sewage and failing/non-functioning septic systems in Logan. As a result, 14 homeowners/renters tested their domestic wells for nitrate-N and bacteria. Two of these wells were also tested for chloride and sulfate. Three others additionally tested for arsenic and two for VOCs. Water chemistry data revealed one well with elevated nitrate-N for two sampling events. The nitrate-N levels exceeded the United States Environmental Protection Agency (USEPA) maximum contaminant level (MCL) of 10 mg/L at 32.3 mg/L and 33.6 mg/L. This same well had respective chloride levels of 57 mg/L and 64.9 mg/L and sulfate levels of 90 mg/L and 95.2 mg/L. Six wells had nitrate-N levels above the background of 2 mg/L and ranged from 2.12 – 7.20 mg/L. Three wells were tested for arsenic. Two of these had levels of 0.001 mg/L and 0.002 mg/L, below the MCL of 0.01 mg/L, and the third had non-detectable arsenic. Total coliform bacteria were detected in 6 of the 14 wells. Of those, one also tested positive for *E. coli* bacteria.

In 2009, MBMG collected groundwater samples from a domestic well on Railroad Street for water chemistry and isotope analysis. Nitrate-N levels were <0.5 mg/L. Metals sampling revealed detections for barium (0.0526 mg/L), chromium (0.000079 mg/L) and selenium (0.000372 mg/L). Isotope analysis was done to assist in determining the age of the water. The tritium value was 8.800, the deuterium (^{2}H) value was -143.040 and the oxygen (^{18}O) value was -18.524. A tritium concentration of 8.800 is a clear indication that the water is post-1952, and likely much younger than that (LaFave, pers. comm., Aug 2014). Additional qualitative interpretations would date the water as modern (5-10 years) (Clark & Fritz, 1997).

The Logan Landfill has had anomalous concentrations of perchloroethene (PCE) and related compounds since sampling at the landfill began in the early 1990's. Regulations implemented in 1980 required dry cleaning fluid to be recycled and dumping was illegal. Prior to this, it was common practice for dry cleaning fluid and other chemicals to be disposed of at landfills and was considered the environmentally responsible thing to do. By 1998, PCE levels at the landfill exceeded the MCL of 5 µg/L set by the USEPA. Corrective action involved removing a section of the old waste thought to be the source of the PCE. In 2005, it was determined that this corrective action had not had a positive impact on groundwater quality. Several test wells were drilled in an attempt to identify the presence of PCE in the soils overlying the aquifer. No PCE was found in the soil. In 2007, a pilot program utilizing naturally-occurring bacteria to help facilitate PCE degradation was implemented.

Three springs were sampled for VOCs in January 2008 by Great West Engineering as part of Logan Landfill groundwater monitoring requirements. Miller spring had a detectable level of tetrachloroethene (PCE) at 2.1 µg/L. There were detections for 1,1-dichloroethane, trichloroethane, and trichlorofluoromethane in Miller Spring. However, these values were flagged as estimates since the levels were less than the laboratory reporting limit of 1.0 µg/L. Tetrachloroethene and 1,1-dichloroethane were detected in Evans Spring but flagged as estimated values because the analytes were present below the laboratory reporting limit. Freeway Spring had no detectable levels of VOCs.

4.2 Sample Site Selection

For this project, letters were sent to 57 property owners in the Logan community requesting permission to collect water samples from their wells for analysis. Permission was obtained from 17 homeowners. Two wells could not be sampled due to complications associated with winterization of wells. **Figure 5** shows the location of the wells sampled by GLWQD. MBMG drilled two deep-shallow monitoring well pairs in 2013 and collected water chemistry from these wells in May 2013. The nitrate-N levels for the MBMG samples were below 2 mg/L and ranged from 0.43 mg/L to 1.19 mg/L, chloride values ranged from 4.05 mg/L to 6.56 mg/L and boron values ranged from 0.0188 mg/ L to 0.0223 mg/L (MBMG GWIC database).

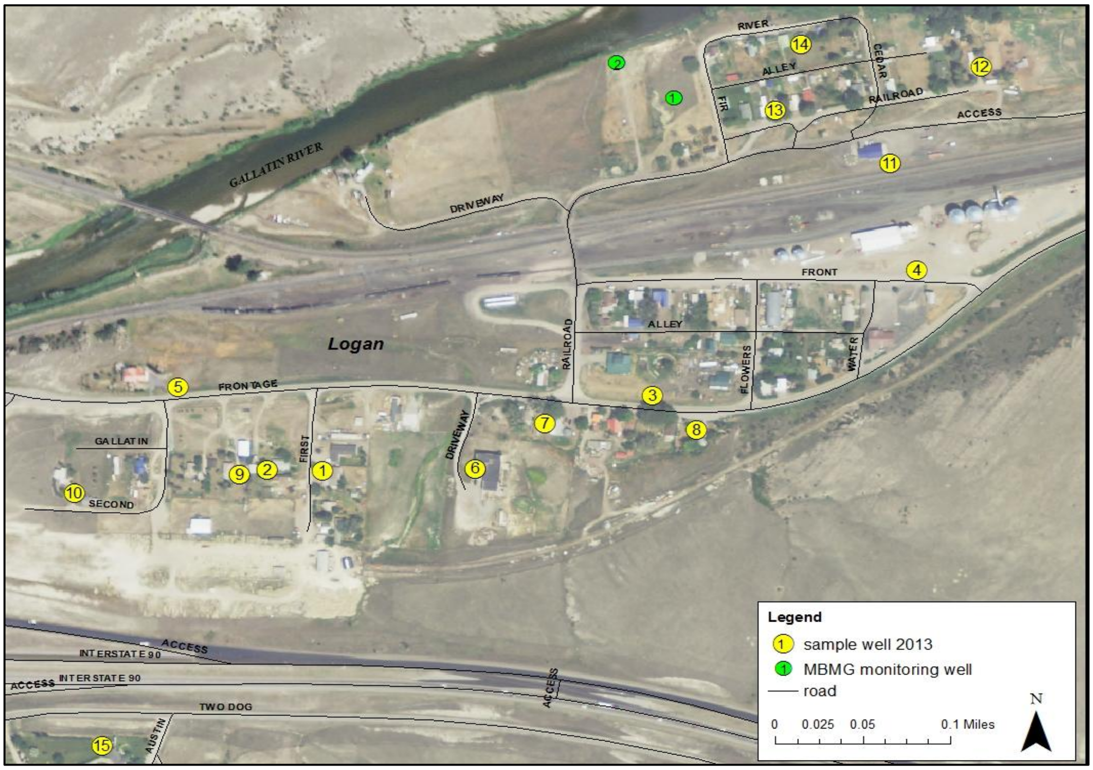


Figure 5. Logan area wells sampled in 2013 by GLWQD. MBMG monitoring wells (green circles) were installed in spring 2013 and water chemistry samples were collected by MBMG personnel in May and September of 2013; several months after GLWQD targeted sampling of domestic wells in the area for this project (yellow circles).

4.3 Well Purging and Measurement of Field Parameters

Following GLWQD standard operating procedures for domestic well sampling, the static water level (SWL) in the well was measured using a water level electronic tape that had been decontaminated with a bleach solution. Static water levels could not be obtained for seven of the wells because the wellhead was inaccessible. Next, three well volumes of water were purged. A YSI ProPlus multiparameter field meter with a flow-through cell connected to a garden hose attached to an outside spigot was used to collect water quality field parameters. Water temperature, pH, specific conductivity (SC), and dissolved oxygen values were recorded on a Site Visit Form every 5 minutes until stabilized using the criteria in **Table 2**. Because of wellhead accessibility issues, one well was unable to be purged (well 8) and wells 1, 2, 9, 12, 13 and 14 were purged from kitchen faucets.

Table 2. Parameter stabilization criteria for well purging

Parameter	Stabilization Criteria	Reference
pH	±0.1	Puls and Barcelona, 1996; Wilde et al., 1998
Specific conductance	±3%	Puls and Barcelona, 1996
Oxidation-reduction potential	±10 millivolts	Puls and Barcelona, 1996
Dissolved oxygen	±0.3 mg/L	Wilde et al, 1998

4.4 Sample Collection, Preservation and Laboratory Analysis

After purging of three well volumes and stabilization of water quality parameters was accomplished, water samples were collected while wearing disposable gloves. The sample was collected directly from an outside spigot that had been disinfected while wearing disposable gloves. For seven of the sample locations (wells 1, 2, 8, 9, 12, 13, and 14), access to an outside spigot was not possible and water samples had to be collected from a tap inside the house. If a water softener was present, samples were collected prior to treatment, if possible. This was noted on the site visit field form. The parameters sampled for are listed in **Table 3**. Sample bottles were provided by Energy Laboratories and Bridger Analytical (total coliform bacteria). Wearing disposable gloves, sample bottle labels were filled out with the appropriate information (sample ID, date, time). Sample bottles were triple rinsed with native water, with the exception of the bottle for total coliform bacteria, and filled. Samples requiring filtration in the field were filtered with a 0.45 micron disposable filter. Samples were preserved, if required, placed in plastic freezer bags, and stored in a cooler on ice. Chain of custody forms were completed and samples were hand-delivered to Bridger Analytical or shipped via overnight delivery to Energy Laboratories.

Table 3. Parameters, analytical methods, sample handling and holding time requirements

Parameter	Analytical Method	Detection Limit	Preservation and Handling	Holding Time
Chloride	E300.0	1 mg/L	Cool, ≤ 6°C	28 days
Nitrate + Nitrite as N	E353.2	0.01 mg/L	H_2SO_4 to pH <2, Cool, ≤ 6°C	28 days
Arsenic	E200.7_8	0.001 mg/L	Filter (0.45 micron), add HNO_3 to pH <2	6 months
Boron	E200.7_8	0.01 mg/L	Filter (0.45 micron), add HNO_3 to pH <2	6 months
Iron	E200.7_8	0.03 mg/L	Filter (0.45 micron), add HNO_3 to pH <2	6 months
Manganese	E200.7_8	0.01 mg/L	Filter (0.45 micron), add HNO_3 to pH <2	6 months
Sodium	E200.7_8	1 mg/L	Filter (0.45 micron), add HNO_3 to pH <2	6 months
VOCs*	E524.2	0.5 µg/L	HCL to pH <2, no air bubbles, store 6°C	14 days
Total coliform bacteria[Ŧ]	SM9223B	1 cfu/mL	Cool, ≤ 6°C	24 hours
E. coli bacteria[Ŧ]	SM9223B	1 cfu/mL	Cool, ≤ 6°C	24 hours

*524-Purgeable Organics, SDWA. 62 compounds.

[Ŧ]Reported as "Present" or "Absent".

4.5 Mapping of Wells and Septic Systems

The individual septic system point data layer generated by GLWQD was used to spatially view the locations of septic systems in Logan. GLWQD used Geographic Information System (GIS) software and several existing septic system data sources to create the data layer. The information compiled to create this spatial data layer is in **Table 4.** The septic data layer was created in 2009 and updated in 2011. Currently, a similar county-wide spatial data layer does not exist for individual wells. However, because Logan does not have a county water and sewer district and there is only one public water supply for a single business in Logan, it is assumed that wherever there is a structure and septic, there is a private well. **Figure 6** illustrates the domestic wells that were sampled for this project along with the individual septic systems in Logan.

Table 4. Information sources for creating the Gallatin County septic system GIS spatial data layer

Information Reference	Information Type	Information Source
Gallatin County structures database	GIS spatial database	Gallatin County GIS Department
Inspected septic system GPS location	GIS spatial database	EHS Division, Gallatin Co. Health Dept.
Septic systems within GLWQD	GIS spatial database	Custer *et al.,*(2000)
Boundaries for incorporated cities/towns	GIS spatial database	Gallatin County GIS Department
Approved water/sewer district boundary	GIS spatial database	Gallatin County Clerk and Recorder
Public sewage system files	Hard copy files	EHS Division, Gallatin Co. Health Dept.

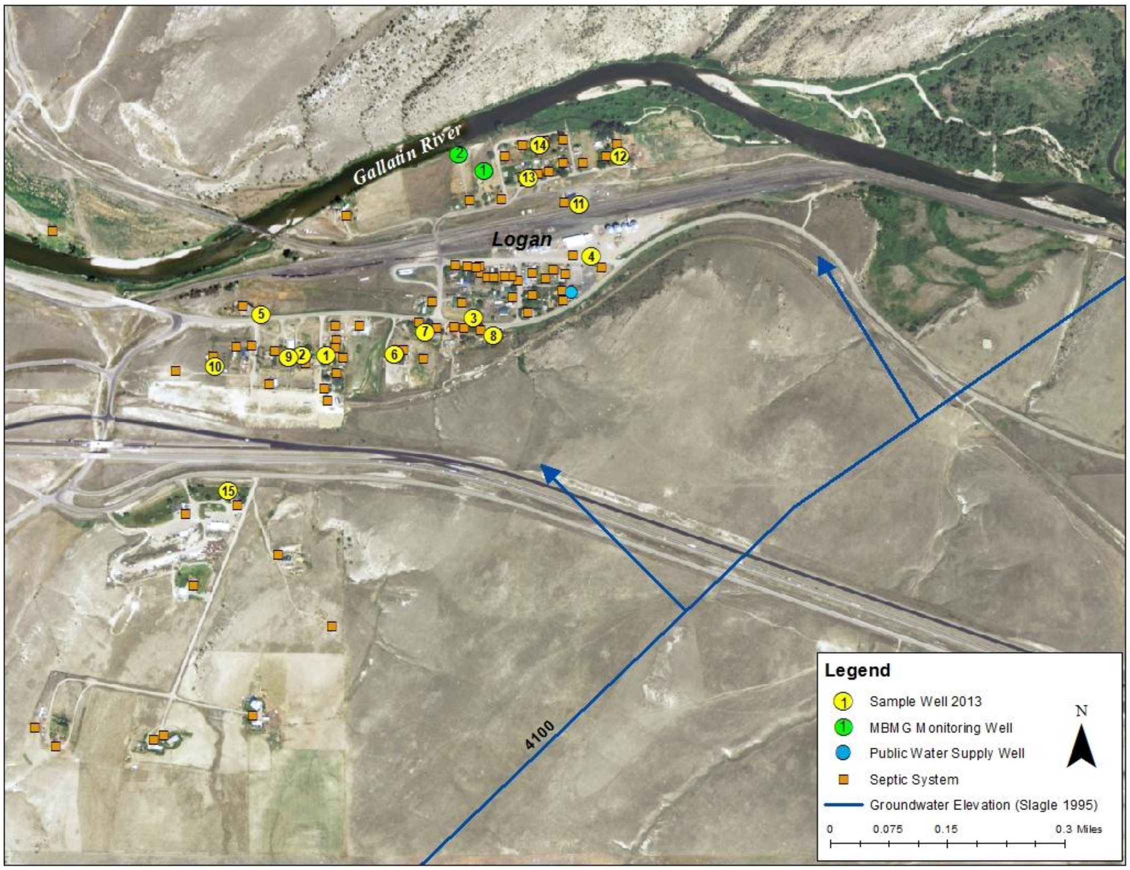


Figure 6. Logan area septic systems and wells. The wells sampled for this project are represented by the yellow circles. The orange squares represent individual septic systems. The blue line indicates the approximate elevation of groundwater and the arrows indicate the approximate direction of groundwater flow based on the potentiometric contours determined by Slagle (1995).

5.0 GROUNDWATER QUALITY ASSESSMENT

Parameters identified for this groundwater quality assessment consisted of typical wastewater pollutants of concern: arsenic, boron, iron, manganese, sodium, nitrate-N, chloride and bacteria (total coliform and *E. coli*). These where chosen because their presence in certain concentrations can have various negative impacts related to drinking water quality. VOCs were also selected for sampling to evaluate potential landfill impacts to groundwater quality. The nitrate-N, chloride, metals and VOC results for the 15 wells sampled in this project are shown in **Table 5**. The bacteria results for these same wells are shown in **Table 6**.

5.1 Metals

Groundwater samples were analyzed for arsenic, boron, iron, manganese and sodium. Arsenic can enter drinking water supplies from naturally occurring deposits in the earth or from agricultural and industrial practices. The USEPA has set a drinking water standard for arsenic at 0.010 mg/L. Arsenic was detected in six samples and concentrations ranged from 0.001 to 0.002 mg/L. The mean arsenic level was 0.001 mg/L.

Boron is naturally found in soils and is a component in many household cleaning products. It can be a useful tracer for sewage sources in conjunction with other indicator parameters since natural concentrations in groundwater are relatively low. Historical boron levels in the Gallatin Valley vary widely and range from 0.01 to 12 mg/L (Hackett et al., 1960, p.163). Several studies indicate natural boron concentrations range from 0.1 to 1.5 mg/L (Banerji 1969 and McQuillan 2004). Water samples with elevated concentrations of boron generally indicate contributions of sewage (Neal et al., 1998). In Logan, boron was detected in five samples and concentrations ranged from 0.07 to 0.36 mg/L. The mean boron level was 0.22 mg/L. There is no USEPA regulatory standard for boron in drinking water.

Iron is an essential nutrient in the human diet. However, high concentrations in drinking water can cause problems in plumbing and aesthetic problems from red staining on fixtures and laundry. The secondary standard for iron established by the USEPA is 0.3 mg/L. This is based on staining and taste considerations. In this study, iron was detected in one sample at 0.04 mg/L.

Manganese naturally occurs in rock and soil and is also a common trace element in the human diet. Manganese is naturally found in groundwater but can also be present as a result of underground pollution sources such as runoff from landfills, compost or chemicals like gasoline. There is no drinking water standard for manganese. However, the USEPA does have a secondary standard of 0.05 mg/L which is based on aesthetics. Manganese was not detected in any of the groundwater samples collected.

Sodium is a common ion in groundwater. It can impart a salty taste at concentrations over 250 mg/L. Human waste is enriched in sodium (and chloride). Road salt can also be a contributor of excess sodium in groundwater. There is no USEPA standard for sodium in drinking water. Sodium was detected in all 15 samples and concentrations ranged from 7 to 113 mg/L. The mean sodium level was 20 mg/L.

5.2 Nitrate-N and Chloride

Naturally occurring nitrate-N concentrations in groundwater are generally less than 2 mg/L (Mueller and others, 1995; Mueller and Helsel , 1996). Groundwater nitrate-N concentrations greater than 2 mg/L can indicate pollution from animal manure, fertilizers, human sewage, and wastewater. Wastewater effluent concentrations can be variable depending on soil type, land use practices and well depth. However, nitrate-N concentrations up to 30 mg/L are typically found in wastewater effluent (Oms et al., 2000). The maximum contaminant level for nitrate-N in drinking water established by the EPA is 10 mg/L. Nitrate-N was detected in all 15 wells sampled for this project. Concentrations ranged from 0.74 mg/L to 21.5 mg/L (**Figure 7**). Forty percent (six wells) of the samples exceeded 2 mg/L. The mean nitrate-N concentration was 5.06 mg/L. Two wells had nitrate-N levels between 5 mg/L and 10 mg/L (8.08 mg/L and 8.75 mg/L) and two other wells had nitrate-N levels that exceeded the MCL at 20.5 mg/L and 21.5 mg/L.

Chloride is a useful indicator of septic system effluent impacts as it occurs at elevated concentrations in all sewage. Typical concentrations of chloride in septic effluent and sewage range from 37-101 mg/L (Thomas 2000; Hyer 2006). The USEPA secondary standard for chloride is 250 mg/L and is based on aesthetics, not health. Chloride was detected in all 15 wells sampled and concentrations ranged from 5 mg/L to 270 mg/L. The mean chloride concentration was 30 mg/L. Two wells with the highest concentrations of chloride at 89 mg/L and 270 mg/L also had nitrate-N concentrations of 21.5 mg/L and 20.5 mg/L, respectively. While the high chloride in addition to high nitrate-N levels in these two wells appears indicative of wastewater contamination, the overall positive correlation between nitrate-N and chloride concentrations from all samples is relatively weak given the R^2 coefficient of 0.6588 (**Figure** 7).

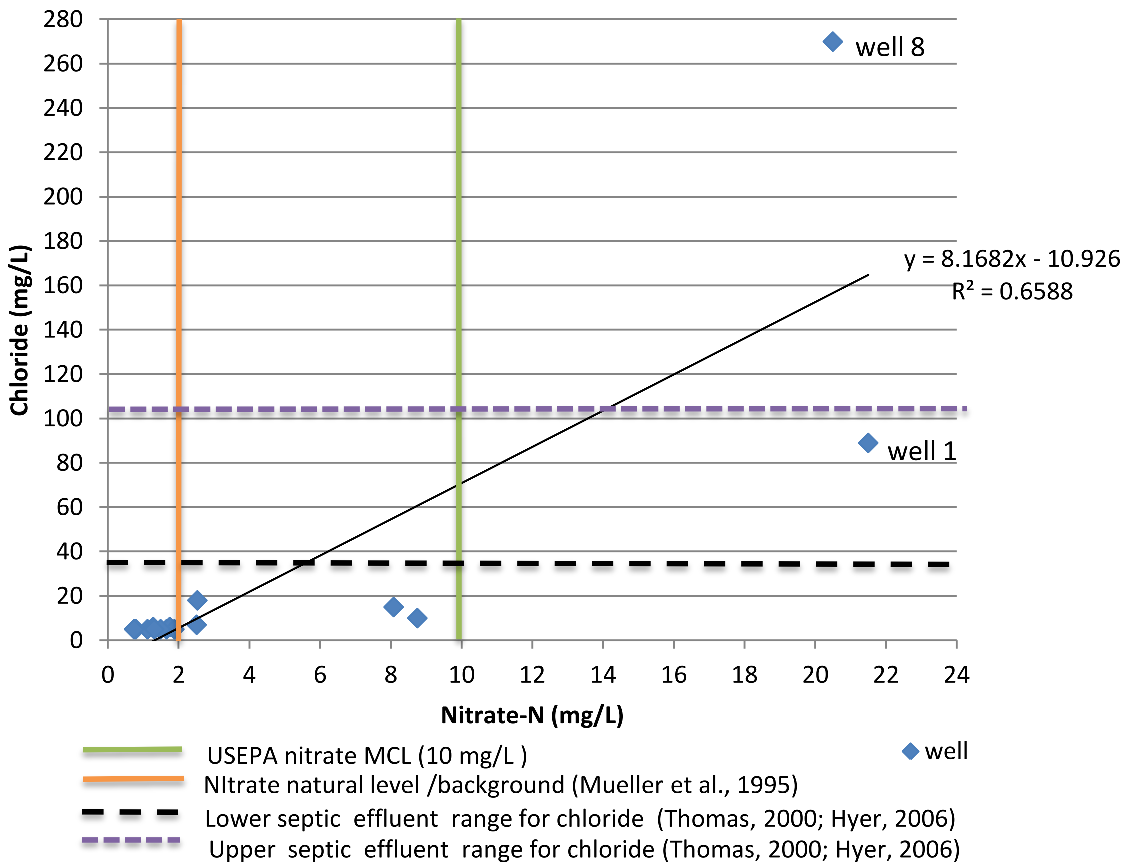


Figure 7. Chloride versus nitrate-N concentrations for 15 domestic wells in Logan, MT. The nitrate-N values are bracketed by solid vertical lines indicating the natural/background level for nitrate (2 mg/L) and the U.S. EPA MCL for nitrate in drinking water (10 mg/L). The chloride values are bracketed by dashed horizontal lines to highlight the typical chloride concentrations in septic effluent (37-101 mg/L). The line of best fit (linear) through the data is shown along with the regression line equation and correlation coefficient (R^2) of 0.6588 indicating a weak positive correlation between nitrate-N concentrations and chloride concentrations.

5.3 Volatile Organic Compounds

VOCs include chlorinated solvents and fuel components. These compounds are widely used in common household products and in industry. The fuel components are found in products such as gasoline and kerosene. Three wells were sampled for VOCs in this project with no detections. A trip blank sample was also analyzed for VOCs with all non-detects (ND).

Table 5. Nitrate-N, chloride, metals and VOC results

Well #	Sample ID	Sample Date	Nitrate-N	Chloride	Arsenic	Boron	Sodium	Iron	Manganese	VOC
1	011613-1	1/16/2013	21.50	89	0.001	0.13	42	ND	ND	Not sampled
2	011613-4	1/16/2013	1.66	5	ND	ND	10	ND	ND	Not sampled
3	011713-1	1/17/2013	1.75	6	ND	0.07	11	ND	ND	ND
4	012913-4	1/29/2013	2.54	7	ND	ND	9	ND	ND	Not sampled
	012913-5 (Duplicate)	*1/29/2013*	*2.47*	*7*	*0.002*	*ND*	*9*	*ND*	*ND*	*Not sampled*
5	011613-3	1/16/2013	0.79	5	ND	ND	9	ND	ND	Not sampled
6	011713-3	1/17/2013	9.00	17	0.001	0.36	25	ND	ND	ND
	011713-4 *(Duplicate)*	1/17/2013	7.15	13	ND	0.36	25	ND	ND	Not sampled
7	012513-7	1/25/2013	8.75	10	ND	0.32	18	ND	ND	Not sampled
8	012913-2	1/29/2013	20.50	270	0.002	0.20	113	ND	ND	Not sampled
9	011613-2	1/16/2013	1.12	5	ND	ND	10	ND	ND	Not sampled
10	012513-5	1/25/2013	0.74	5	ND	ND	8	ND	ND	Not sampled
11	011713-1	1/17/2013	1.28	6	ND	ND	8	ND	ND	Not sampled
12	012913-1	1/29/2013	1.88	5	ND	ND	7	ND	ND	Not sampled
13	012513-2	1/25/2013	1.49	5	0.001	ND	7	ND	ND	Not sampled
14	011713-2	1/17/2013	1.31	5	ND	ND	7	0.04	ND	ND
15	012913-6	1/29/2013	2.53	18	0.001	ND	15	ND	ND	Not sampled

5.4 Total Coliform and *E. coli* Bacteria

Total coliform bacteria are naturally found in the environment (soil and vegetation) and are not a direct health threat. Because coliform bacteria are not naturally occurring in groundwater, their presence in groundwater indicates potential contamination due to some source of entry into the well. *E. coli* (*Escherichia coli*) bacteria are enteric bacteria and are found in the feces of warm-blooded animals. The presence of *E. coli* bacteria in groundwater indicates fecal pollution and disease-causing pathogens such as viruses and protozoans are likely present. The groundwater environment is not conducive to the survival of *E. coli* bacteria with the typical survival time being less than 30 days (US EPA 2002).

All 15 wells were sampled for coliform bacteria. Of those, 10 were positive for coliform bacteria (wells 1, 2, 4, 6, 9, 11, and 12-15) and were further tested for *E. coli* bacteria. Of those 10, five (wells 2, 4, 11, 13 and 14) tested positive for *E. coli* and were retested. An additional well (well 6) which did not show *E. coli* bacteria presence was also resampled to test whether a sample with total coliform bacteria could be replicated. Well 6, when resampled and tested showed neither total coliform bacteria nor *E. coli* bacteria and confirmed that total coliform is simply a test that suggests further testing is needed. One of the five wells (well 11) that tested positive for *E. coli* bacteria tested positive upon retesting. One month later that well was retested and was negative for total coliform bacteria and *E. coli* bacteria. Well 13 which tested positive for *E. coli* bacteria was not retested by GLWQD as part of this project. It is assumed the well was retested at a later date and was negative for *E. coli* bacteria. In summary, of 15 wells sampled, 10 showed the presence of coliform bacteria and five showed the presence of *E. coli* bacteria (wells 2, 4, 11, 13 and 14). All wells ultimately tested negative for *E. coli* bacteria.

Table 6. Total coliform and *E. coli* bacteria results

Well #	Sample ID	Sample Date	Total Coliform Bacteria	*E. coli* Bacteria
1	011613-1	1/16/2013	+	-
2	011613-4	1/16/2013	+	+
	012513-4	1/25/2013	+	-
3	011713-1	1/17/2013	-	-
4	012913-4	1/29/2013	+	+
	012913-5 (Duplicate)	*1/29/2013*	*+*	*+*
	022613-1	2/26/2013	+	-
5	011613-3	1/16/2013	-	-
6	011713-3	1/17/2013	+	-
	012513-6	1/25/2013	-	-
7	012513-7	1/25/2013	-	-
8	012913-2	1/29/2013	-	-
9	011613-2	1/16/2013	+	-
	012513-3	1/25/2013	+	-
10	012513-5	1/25/2013	-	-
11	011713-5	1/17/2013	+	+
	012513-1	1/25/2013	+	+
	022613-2	2/26/2013	-	-
12	012913-1	1/29/2013	+	-
13	012513-2	1/25/2013	+	+
14	011713-2	1/17/2013	+	+
	012913-3	1/20/2013	+	-
15	012913-6	1/29/2013	+	-

The presence of bacteria in a well indicates that it should be disinfected. When a private domestic well tests positive for *E. coli* bacteria, there is an immediate health risk and the water should not be consumed until it can be treated. Well disinfection, often referred to as "shock chlorination" should be performed as soon as possible. Retesting of the water can then occur 72 hours after the chlorine solution is no longer detectable in the home plumbing system. In Logan, where the residential lots are small and wells are in close proximity to septic systems, annual testing for coliform bacteria is recommended. Wells that routinely test positive for *E. coli* bacteria are most at risk for health concerns and unless the source of contamination can be removed, the problem will remain.

5.5 Well Depth and Depth to Water

Since nitrate-N sources often occur at or very near the land surface as a result of human-related activities, nitrate-N concentrations will typically be higher in the shallow portion of the aquifer and decrease with depth below the ground surface. As mentioned previously, attempts to accurately identify and associate well logs in the Logan area with the wells sampled for this project were generally unsuccessful. Five well logs could be confirmed out of the fifteen wells sampled. These wells, total well depths along with nitrate-N and other wastewater indicator values are shown in **Table 7**. This small sample set does not appear to reveal any correlation between well depth and these parameters.

Table 7. Total well depth and corresponding nitrate-N, chloride, boron and sodium values for five sampled wells

Well #	Total Depth	Nitrate-N (mg/L)	Chloride (mg/L)	Boron (mg/L)	Sodium (mg/L)
3	260	1.75	6	0.07	11
4	100	2.54	7	ND	9
5	140	0.79	5	ND	9
13	84	1.49	5	ND	7
14	65	1.31	5	ND	7

5.6 Field Measurements Discussion

The field parameter data measured for this project are shown in **Table 8**. Specific conductivity levels of 502 µS/cm, 690 µS/cm, 692 µS/cm, and 920 µS/cm were measured in well, 15, well 6, well 7 and well 1, respectively. These may be the result of septic system influence on groundwater as these samples also had nitrate-N values above 2.0 mg/L (three with nitrate-N between 8.75 mg/L – 21.5 mg/L). However, water temperature, dissolved oxygen (DO) and pH levels were variable and do not suggest impacts from septic effluent.

Table 8. Field measurements recorded at time of water chemistry sample collection

Well #	Sample ID	Water Temp (C°)	SC (µS/cm)	DO (% Sat)	DO (mg/L)	pH
1	011613-1	10.94	**920**	73.5	Not recorded	6.61
2	011613-4	9.52	426	77.2	8.80	7.26
3	011713-1	9.05	434	39.3	4.52	7.32
4	012913-4	10.03	483	74.6	8.40	6.67
5	011613-3	9.31	390	75.8	8.69	7.25
6	011713-3	10.20	**690**	58.6	6.60	7.07
7	012513-7	9.96	**692**	31.3	3.52	6.96
8	012913-2	Field parameter data not collected due to well access issues.				
9	011613-2	10.52	410	80	Not recorded	7.36
10	012513-5	10.44	379	52.8	5.90	7.24
11	011713-5	9.50	408	87.5	9.99	7.42
12	012913-1	8.09	446	82.1	9.69	6.19
13	012513-2	8.26	423	80.4	9.45	6.61
14	011713-2	10.82	414	94.2	10.42	7.37
15	012913-6	9.48	**502**	68.6	7.82	6.81

6.0 DISCUSSION

Results from the targeted sampling indicate some wells in Logan appear to be impacted from septic systems. Six of the fifteen wells sampled had nitrate-N levels above 2 mg/L indicating possible anthropogenic activities (Mueller and others, 1995; Mueller and Helsel, 1996) are likely impacting groundwater quality to some extent. **Figure 8** provides a data summary of the wastewater parameters collected for the sampled wells along with available well depths.

The influence of septic system effluent on well 1 and well 8 is possible based on the data collected. These two wells had elevated nitrate-N (well 1 at 21.5 mg/L, well 8 at 20.5 mg/L) and chloride levels (well 1 at 89 mg/L, well 8 at 270 mg/L) (**Figure 7, Figure 8**). As stated earlier, sewage and septic system effluent typically have chloride concentrations in the range of 37-101 mg/L (Thomas, 2000; Hyer, 2006).

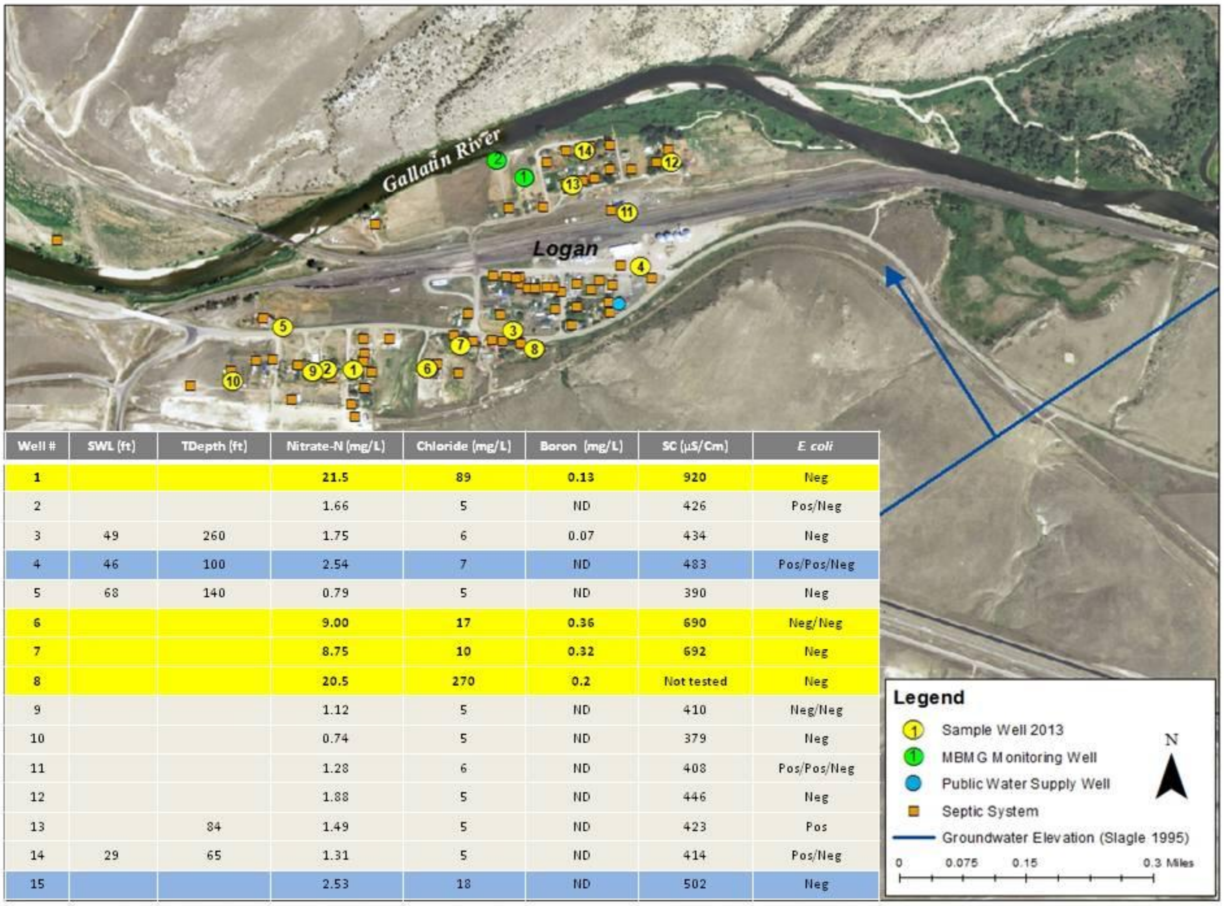
The chloride value for well 8 exceeded the upper limit of this range. Water softener backwash can increase chloride concentrations in wastewater effluent to more than 1,500 mg/L (Kinsley and others, 2005). The site visit form completed for well 8 indicated that the home is on a water treatment system, but the water sample was collected before treatment. Well 1 also had elevated SC (SC data unable to be collected for well 8). One would expect *E. coli* bacteria to be present in these wells providing further evidence of septic system influence given the elevated nitrate-N and chloride levels. However, both well 1 and well 8 tested negative for *E. coli* bacteria. This is somewhat perplexing. Even though *E. coli* bacteria are not known to survive for extended periods of time in groundwater, if there were a continuous source of septic effluent it is conceivable that *E. coli* bacteria would be persistently present. A better understanding of localized groundwater flow patterns and knowing well depths would be valuable information to assist in answering this question.

In addition to wells 1 and 8, three other wells (6, 7 and 15) may be influenced by septic systems. These wells had SC levels ranging from 502 mg/L to 692 mg/L and nitrate-N results from 2.53 mg/L to 9.00 mg/L. While well 4 had a nitrate-N result greater than 2 mg/L (2.54 mg/L), all other indicators for wastewater contamination were anomalous.

Interestingly, wells that had *E. coli* bacteria present (well 2, 4, 11, 13 and 14) were not associated with the high nitrate-N and chloride concentrations seen in well 1 and well 8. The presence of total coliform in 10 of the 15 wells sampled is likely correlated to unsanitary well conditions rather than septic system effluent. Information provided on the site visit forms when samples were collected indicate wells without sanitary well caps, damaged well cap seals, and/or the presence of spiders and other insects inside the well cap. Additionally, the general condition of several wells could not be assessed since they are located in underground pits or under the house. Therefore, a multi-parameter approach to determining septic system effluent influence on groundwater using a suite of wastewater tracers is likely necessary; especially in areas with complex geology.

Several wells were sampled for VOCs with no detectable levels found, suggesting that railroad and landfill activities may not be directly impacting wells in Logan. Additional data collection and analysis from several more wells for VOCs would be useful in confirming this.

Based on the available information, the groundwater flow system in Logan is unclear at this time. While well logs were unavailable for the majority of the wells sampled for this project, lithology information for the area from GWIC indicates wells are completed in fractured limestone and shale; further complicating groundwater flow paths. In addition to lack of information regarding well completion depths in the area, borehole evidence of underground karst features in the area complicates groundwater data interpretation.



Well #	SWL (ft)	TDepth (ft)	Nitrate-N (mg/L)	Chloride (mg/L)	Boron (mg/L)	SC (µS/Cm)	*E coli*
1			21.5	89	0.13	920	Neg
2			1.66	5	ND	426	Pos/Neg
3	49	260	1.75	6	0.07	434	Neg
4	46	100	2.54	7	ND	483	Pos/Pos/Neg
5	68	140	0.79	5	ND	390	Neg
6			9.00	17	0.36	690	Neg/Neg
7			8.75	10	0.32	692	Neg
8			20.5	270	0.2	Not tested	Neg
9			1.12	5	ND	410	Neg/Neg
10			0.74	5	ND	379	Neg
11			1.28	6	ND	408	Pos/Pos/Neg
12			1.88	5	ND	446	Neg
13		84	1.49	5	ND	423	Pos
14	29	65	1.31	5	ND	414	Pos/Neg
15			2.53	18	ND	502	Neg

Figure 8. Data summary for Logan area sampled wells. Yellow highlighted rows show the wells with nitrate-N values greater than 5 mg/L. Blue highlighted rows show the wells with nitrate-N values greater than 2 mg/L.

7.0 CONCLUSIONS

- Six of 15 wells appear to show some evidence of impact from septic systems, with nitrate-N above 2.0 mg/L. Interestingly, few wells showed both *E. coli* bacteria and high nitrate-N. Some of these wells showed high SC and/or chloride which are consistent with such contamination, but not all showed this relationship.

- There was only a weak positive correlation between nitrate-N concentrations and chloride concentrations.

- Some of the *E. coli* bacteria and total coliform bacteria positive results could come from poor sanitary seals on well caps.

- There were no VOCs found in the domestic wells, which suggests direct contamination from the landfill is relatively unlikely.

- More work is needed to correlate well logs with sample sites, and better knowledge of the groundwater flow system would help with interpretations.

8.0 RECOMMENDATIONS

The Logan community consists of a mix of older and some newer wells and septic systems. As a result of several complaints received by Gallatin County Environmental Health Services, some failing septic systems have been replaced as recently as 2012. However, many septic systems may not be regularly maintained and residents should have their septic systems pumped every 3-5 years based on system size and use. Property owners in the Logan area are encouraged to work with Environmental Health Services at the Gallatin City-County Health Department to identify existing failing septic systems so that solutions for the installation of replacement systems can begin. Gallatin County recently applied for grant funds from the MT Department of Natural Resources Renewable Resource Grant and Loan Program. If funded, a revolving loan program would be implemented that would provide financial assistance to homeowners with failed septic systems who, otherwise, do not have the financial means to do so. It is recommended that the initial focus of this program, once created, be targeted in the Logan area.

Residents with wells that consistently test positive for coliform bacteria are encouraged to examine the condition of their well for cracks in the well cap or casing and holes or areas of depression on the ground next to the well casing since these conditions make the well susceptible to contamination from insects. Well caps, especially old or damaged ones, should be replaced with sanitary well caps that have a rubber seal to reduce or eliminate insect problems. Wells located in pits can be especially vulnerable to unsanitary conditions. Well owners should take extra precautions to ensure the pit area is clean and free of insects and rodents. If possible, the well casing should be extended above ground surface and have a sanitary well cap installed.

Wells that test positive for *E. coli* bacteria should be shock chlorinated and tested again before anyone resumes drinking the water. It is unclear why a well may sporadically test positive for *E.* coli bacteria. In this situation, the well owner should make sure they are having their septic tank pumped regularly and also survey their property for other sources of animal or human waste that may be impacting their drinking water.

Residents are encouraged to test their drinking water annually for nitrate-N and bacteria at a minimum. While the three wells tested for VOCs for this project had non-detect results, residents should consider testing for VOCs annually given the proximity to the landfill. The GLWQD can provide education materials and Well Educated test kits to residents and provide assistance with interpreting their test results.

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