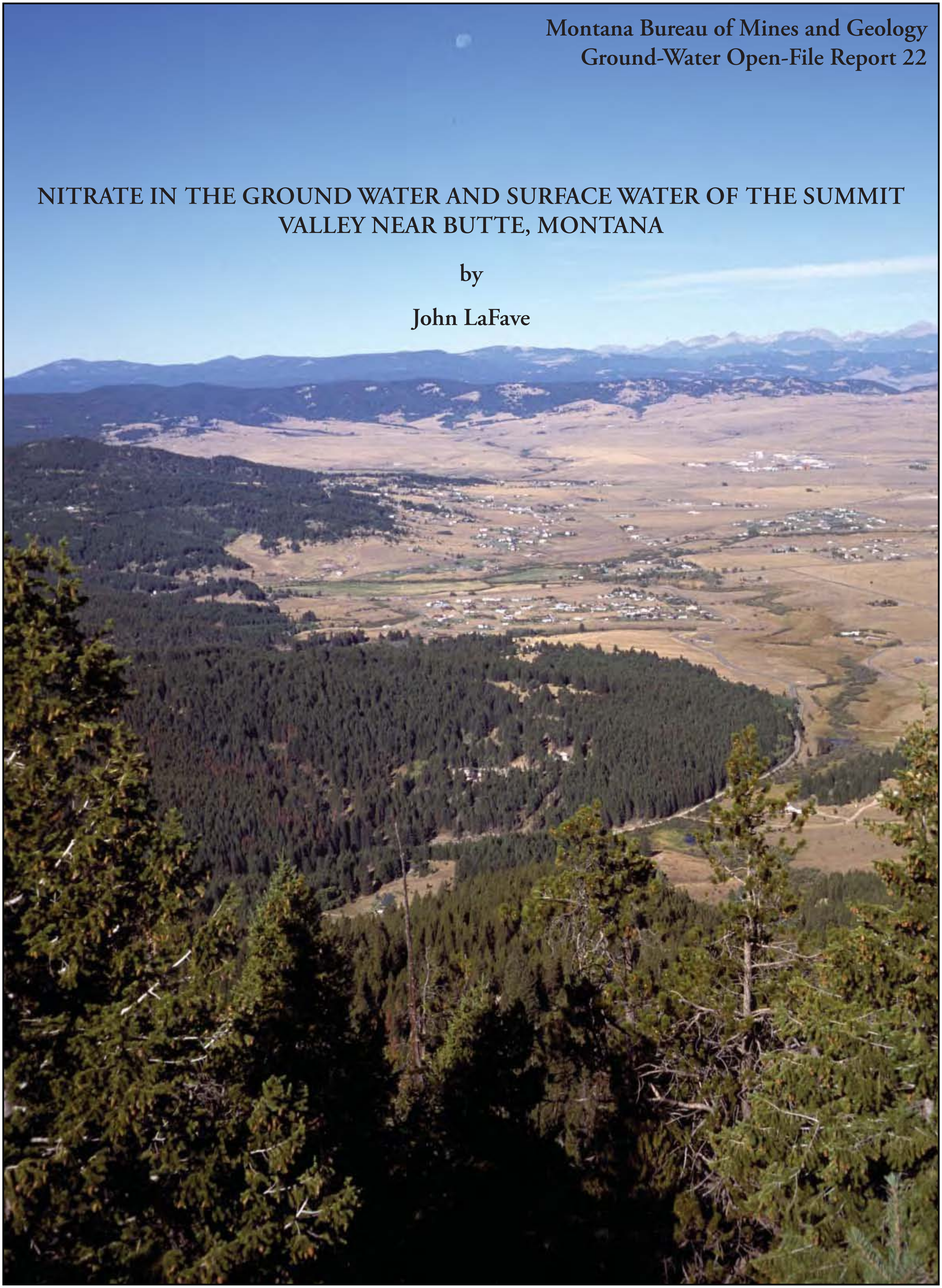
Montana Bureau of Mines and Geology
Ground-Water Open-File Report 22

# NITRATE IN THE GROUND WATER AND SURFACE WATER OF THE SUMMIT VALLEY NEAR BUTTE, MONTANA

by

John LaFave



*Cover photo*: Looking west across the southern part of the Summit Valley, Butte, Montana. Photo by Larry Smith, MBMG.

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# SUMMARY AND CONCLUSIONS

Anomalously high concentrations of nitrate occur in the ground water and surface water in the Summit Valley as compared with other parts of the Clark Fork drainage basin. A data set of 239 samples showed that nitrate concentrations exceed the 10 mg/L health standard in 13 percent of samples, and an additional 51 percent had concentrations exceeding 2 mg/L, suggesting some land-use impact. Concentrations were slightly higher beneath the sewered urban/residential part of the valley than beneath the unsewered part. Concentrations were highest in the sewered residential area in the east side of Butte. Detailed sampling beneath unsewered subdivisions in the southeast part of the valley clearly showed a land-use impact, where median nitrate concentrations were 5 to 9 times higher below unsewered subdivisions than adjacent undeveloped land. Concentrations in the alluvial and bedrock aquifers were similar. The permeable nature of the soils, fractured bedrock, and alluvium has allowed nitrate to penetrate relatively deeply into the ground-water system. Elevated concentrations were commonly detected in wells with a depth to the top open interval, or depth water enters, greater than 100 ft. Similarly, elevated concentrations of nitrate were detected where the water table was relatively deep; 31 percent of the samples with nitrate concentrations greater than 2 mg/L (suggesting a land-use impact) were obtained from areas where the water table was greater than 50 ft below the land surface.

The most likely potential nitrate sources include fertilizers applied to lawns, septic effluent, and/or leaky sewer pipes. Results from limited N and O isotopic analysis of samples from wells completed in different land use and hydrogeologic settings revealed that all the samples were isotopically similar, with the exception of one sample from the Montana Pole site. The isotopic signature suggests an animal waste or human sewage source for all sites except the Montana Pole site, for which the data are indicative of a fertilizer or possibly an explosive source. A few of the samples with somewhat depleted $\delta^{15}N$ values may indicate a mixed lawn fertilizer/sewage source.

For the residents in the Summit Valley who rely on wells for their drinking water, the elevated nitrate concentrations observed throughout the valley are a potential concern for human health. Because of the documented impacts and the vulnerability of the ground-water resources, homeowners that rely on wells for domestic water should be encouraged to regularly test their well water, maintain their septic systems, not over-apply fertilizers, and become aware of the potential risks associated with nitrate contamination of the ground-water resource.

The results suggest that nitrate contamination of the ground water in the Summit Valley is likely to continue as more of the valley becomes developed. The elevated nitrate concentrations that occur at depth, and the occurrence of elevated nitrate in the baseflow of Blacktail and Silver Bow Creeks, suggest that little, if any, natural attenuation of nitrate occurs in the aquifer. Because of the apparent lack of natural attenuation, the only way for nitrate concentrations to be reduced will be through natural flushing concurrent with a reduction in nitrate loading to the aquifer.

## BACKGROUND

Elevated nitrate levels detected in ground water in the Summit Valley have halted some proposed residential developments and raised concern among citizens not currently served by the municipal water and sanitary sewer system (Montana Standard 9/17/2006, Carstarphen and others, 2004). High concentrations of nitrate in ground water generally indicate contamination from anthropogenic activities and are rarely attributable to natural sources. The purpose of this report is to describe nitrate in ground water in the Summit Valley near Butte, Montana and assess the hydrogeologic factors and land uses that may contribute to nitrate contamination.

## INTRODUCTION

Butte occupies the northern part of the Summit Valley in southwest Montana. The Summit Valley, a north–south-oriented intermontane basin, is in the upper part of the Silver Bow Creek drainage at the headwaters of the Clark Fork River system (fig. 1). The basin is bounded on all sides by mountains formed of granite (Butte Quartz Monzonite) that is part of the Boulder Batholith (fig. 2). Near land surface, the granite is fractured and readily weathered. The upland area in the northwestern corner of the valley (near Big Butte) is underlain by lava flows and lesser amounts of volcanic ash (tuff) that are part of the Lowland Creek Volcanics. The valley floor, or the "flat," is an alluvial plain that is about 5 miles long and 3 miles wide; it is drained by the north-flowing Basin and Blacktail Creeks, which join about 2 miles upstream from where Blacktail Creek enters Silver Bow Creek. Silver Bow Creek flows to the west and exits the northwest part of the valley through a narrow gap in the bedrock. The part of Silver Bow Creek that drains the north part of the valley—the Butte hill, south of the Berkeley Pit (between Montana Street and Continental Drive)—was channelized and is now referred to as the Metro Storm Drain (fig. 2).

## GEOLOGIC SETTING

The alluvial basin fill in the interior of the valley is composed of gravels, sands, silts, and clays derived from the weathering (decomposition) of the granitic rocks that form the surrounding mountains. The soils are permeable and well-drained; the NRCS (2007) has mapped most of the soils in the valley as belonging to hydrologic group A or B, meaning that they have a sandy texture with low runoff potential (fig. 2). The thickness of the basin fill is poorly known. A geophysical survey across the flat immediately south of the airport (fig. 2) suggests that bedrock underlying the basin fill is at a depth of 600 to 880 ft in this part of the valley (Botz, 1969). In the northern part of the valley, south of the Berkeley Pit, the alluvium is reported to range up to 600 ft (ARCO, 1994). For more detail regarding the geology of the Summit valley the reader is referred to Berg and Hargrave (2004), Botz (1969), Meinzer (1914), and Smedes (1967, 1968).

## WATER SUPPLY AND WELLS

The city of Butte imports surface water from upland reservoirs and the Big Hole River (located about 20 miles southwest of Butte) for its municipal supply; however, all residences outside of the area serviced by municipal water and sewer rely on individual wells and septic systems. The alluvial basin fill and fractured bedrock along the valley margin are the principal aquifers in the Summit Valley. Infiltration of precipitation, snow melt, and surface water near valley margins provide most of the ground-water recharge. Hydrographs for wells located within the valley show that ground-water levels reach seasonal highs in response to spring runoff and snow melt, followed by declining water levels throughout the rest of the year. Annual water-level fluctuations are generally less than 5 ft, but are more pronounced in the fractured bedrock aquifer (fig. 3). The alluvial aquifer in the valley is largely unconfined. The alluvial basin-fill and bedrock aquifers are generally hydraulically connected; ground water moves from the topographically high valley margins toward the topographically low valley bottoms where it discharges to streams (fig. 3).

Data from the Montana Bureau of Mines and Geology (MBMG) Ground-Water Information Center (GWIC) database shows that within the Summit Valley about 1,300 wells are used for "domestic" purposes. Many "domestic" wells are located within the area served by municipal water and are more likely used for lawn irrigation rather than to supply drinking water. Slightly more than half of the domestic wells (54 percent) use the alluvial basin-fill aquifer; the remainder are completed in the fractured bedrock aquifer along the valley margins (fig. 4). The depth to the top perforated interval, or the

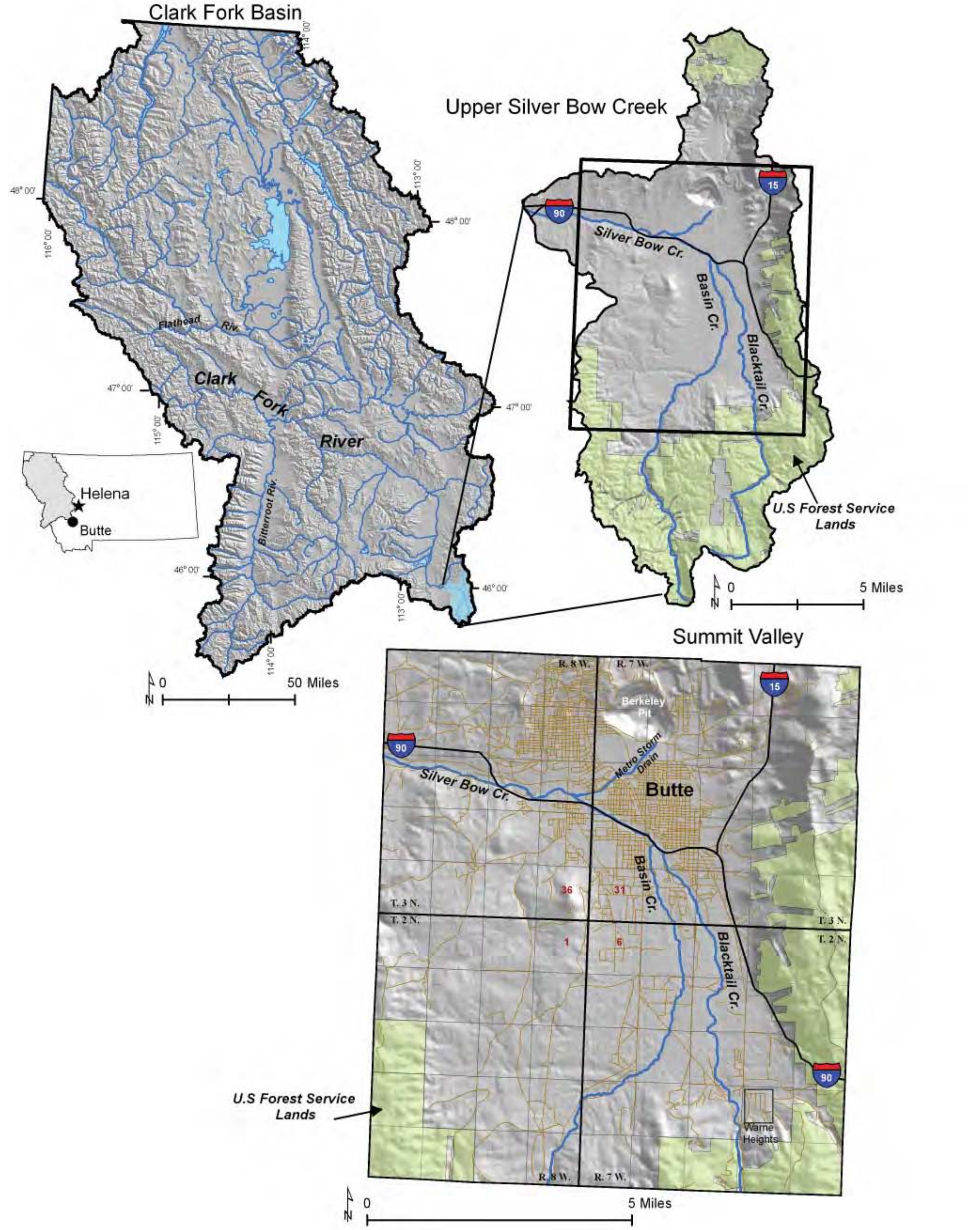


Figure 1. The Summit valley is located in the upper Silver Bow Creek drainage at the headwaters of the Clark Fork basin.

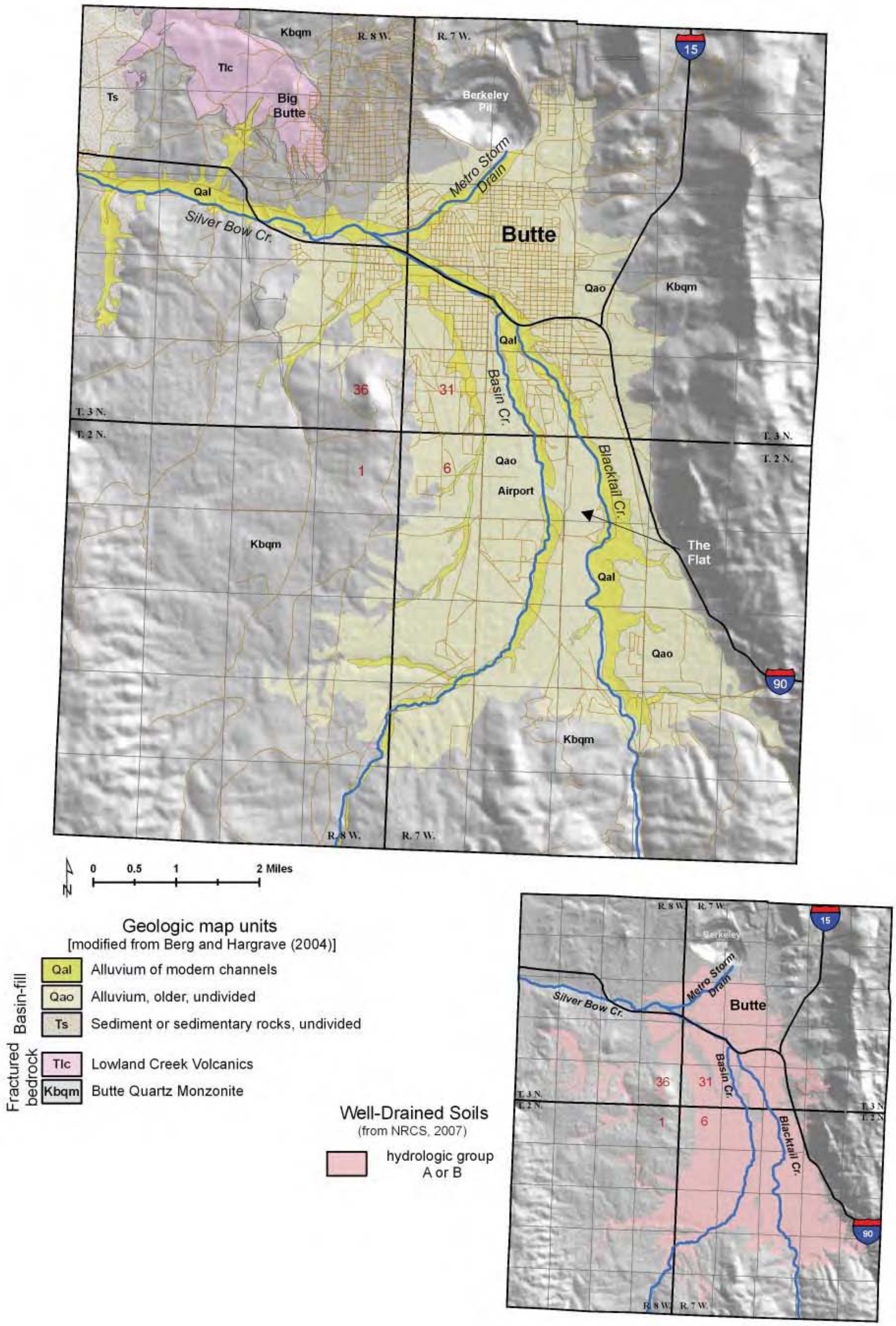


Figure 2. The Summit Valley is an intermontane basin surrounded by mountains composed of Butte Quartz Monzonite (Kbqm). The valley floor is underlain by alluvium (Qal, Qao) with well-drained soils.

depth water enters (DWE), is generally shallower for the alluvial wells; DWEs range from 13 to 398 ft with a median of 76 ft, whereas those for bedrock wells range from 10 to 570 ft, with a median of 100 ft (fig. 4). Over the past 10 years more wells have been developed in the fractured bedrock than in the basin-fill aquifer, reflecting residential development along the valley margins (fig. 4).

## NITRATE IN GROUND WATER

Nitrate contamination of ground water results from the combined influence of several factors, including the type and intensity of the nitrate source, and aquifer susceptibility characteristics. Aquifer susceptibility describes the ease with which water (and associated contamination) can enter an aquifer. It is a characteristic of the aquifer, the overlying material, and the hydrologic conditions (Focazio and others, 2002). Factors that contribute to higher susceptibility include soils with rapid infiltration capacities, thin soils with low organic carbon contents, thin unsaturated zones, permeable aquifer materials, and fractured rock settings. In particular, highly permeable, well-drained soils and fractured bedrock have been noted to readily convey even small concentrations of nitrate to the water table (Nolan, 2001).

Nationwide, nitrate is recognized as the most widespread contaminant of ground water (Halberg and Keeney, 1993; Canter, 1997). Nitrate ($NO_3^-$) is a form of dissolved nitrogen in water that is stable over a wide range of environmental conditions and can be readily transported in ground water and streams. There are many natural and anthropogenic sources of nitrate; however, where nitrate contamination of ground water has been identified it is usually related to a surficial nitrogen source (Madison and Brunett, 1984). The primary sources of nitrate contamination are fertilizers, animal manure, human sewage, wastewater, and in rare cases, geologic formations. Naturally occurring, or background, nitrate concentrations in ground water are generally less than 2 milligrams per liter (mg/L); thus, concentrations greater than 2 mg/L may indicate effects of human activities (Mueller and others, 1995; Halberg and Keeney, 1993; U.S. Geological Survey, 1999).

Nitrate is a necessary plant nutrient; however, excessive concentrations in drinking and natural water can pose human health and ecological threats. Elevated concentrations in drinking water can cause methemoglobinemia (or blue-baby syndrome), a potentially fatal oxygen deficiency in infants less than 6 months old. Because of the human health risk, the U.S. Environmental Protection Agency (USEPA) has established a maximum contaminant level (MCL) of 10 mg/L for nitrate in public drinking water supplies. Water with greater than 10 mg/L nitrate should not be used for drinking, cooking, or formula preparation for infants under 6 months of age or pregnant women. Excessive nitrate in surface water can result in eutrophication (nutrient enrichment) and nuisance algal blooms. As a general guideline, a concentration of inorganic nitrogen greater than 0.30 mg/L in surface water is recognized as having the potential to cause eutrophication or algal growth (Mackenthun, 1969). For the Clark Fork River Basin, Dodds and others (1997) recommend total nitrogen levels be maintained at less than 0.35 mg/L to prevent nuisance algal growth. Because ground water is a major component of stream baseflow, elevated nitrate in ground water represents an ecological threat to rivers and streams.

## SUMMIT VALLEY—PREVIOUS STUDIES

Previous hydrogeologic investigations have all recognized the intrinsic susceptibility of the ground-water resources in the Summit Valley. Meinzer (1914), in the first published report on ground-water resources in Butte, noted that “Over most of the flat there is a thin loam soil underlain by very coarse and clean grit,” and that soil on the flat is “low in organic matter.” He recognized the permeable nature of the basin-fill deposits: “Some of the beds of coarse clean grit or gravel, such as underlie the soil in a large part of the flat, probably have a porosity of fully 30 percent.” Meinzer also recognized the high potential for contamination of the ground-water resources: “Waters with large mineral content may be found in exceptional wells, and in some localities, especially in the vicinity of Butte, the ground waters may be polluted by sewage or mine wastes” (Meinzer, 1914).

The next major hydrogeologic investigation of the Butte area also recognized the susceptible nature of the ground-water resources and, more specifically, the threat posed by on-site waste disposal systems. In his concluding remarks Botz (1969) notes that, “The use of septic tanks and wells will undoubtedly aggravate ground-water pollution problems.”

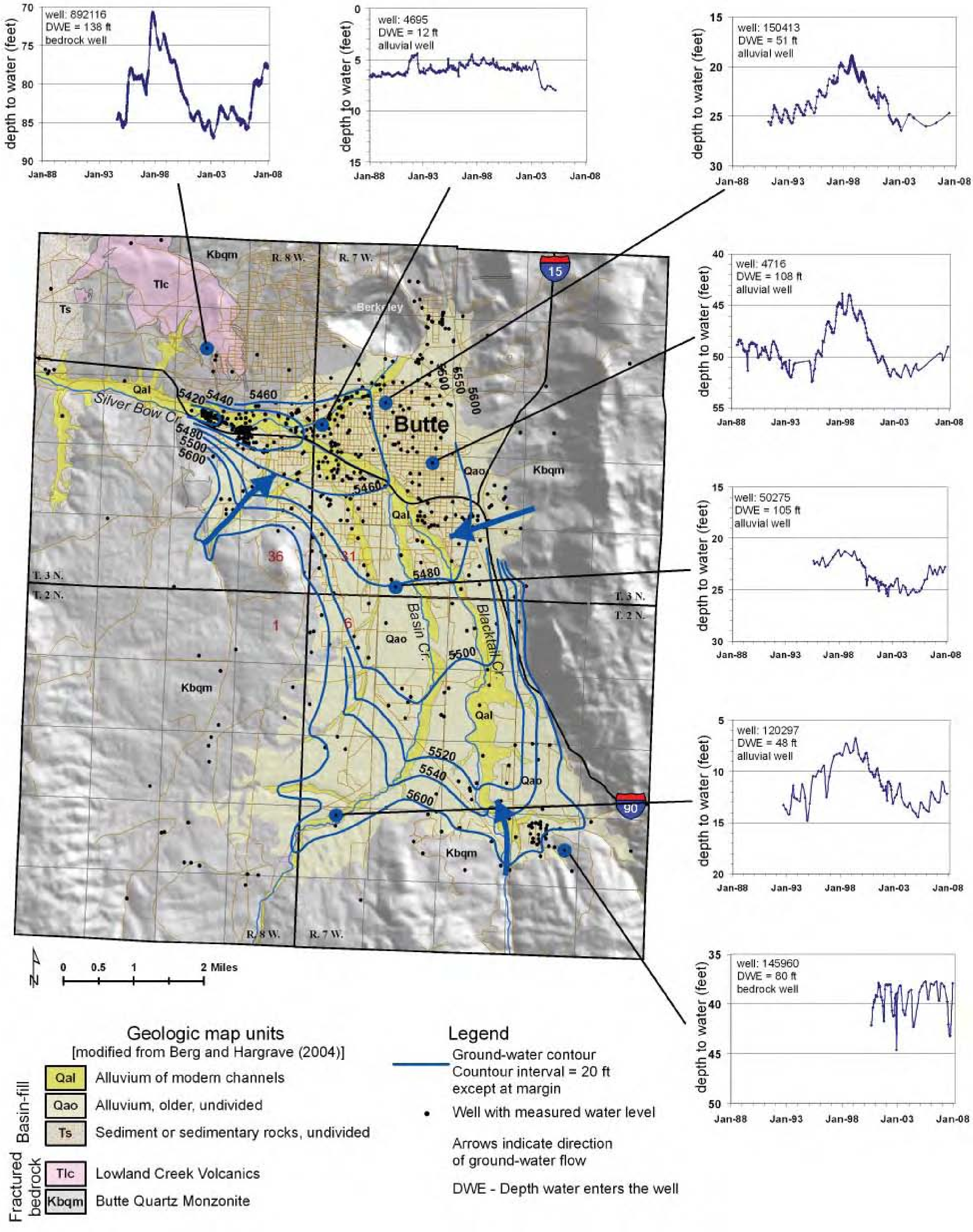


Figure 3. Ground water occurs in the fractured bedrock and the alluvium; ground-water flow is away from the valley margins toward Blacktail and Silver Bow Creeks. Ground-water levels fluctuate seasonally on the order of a few feet.

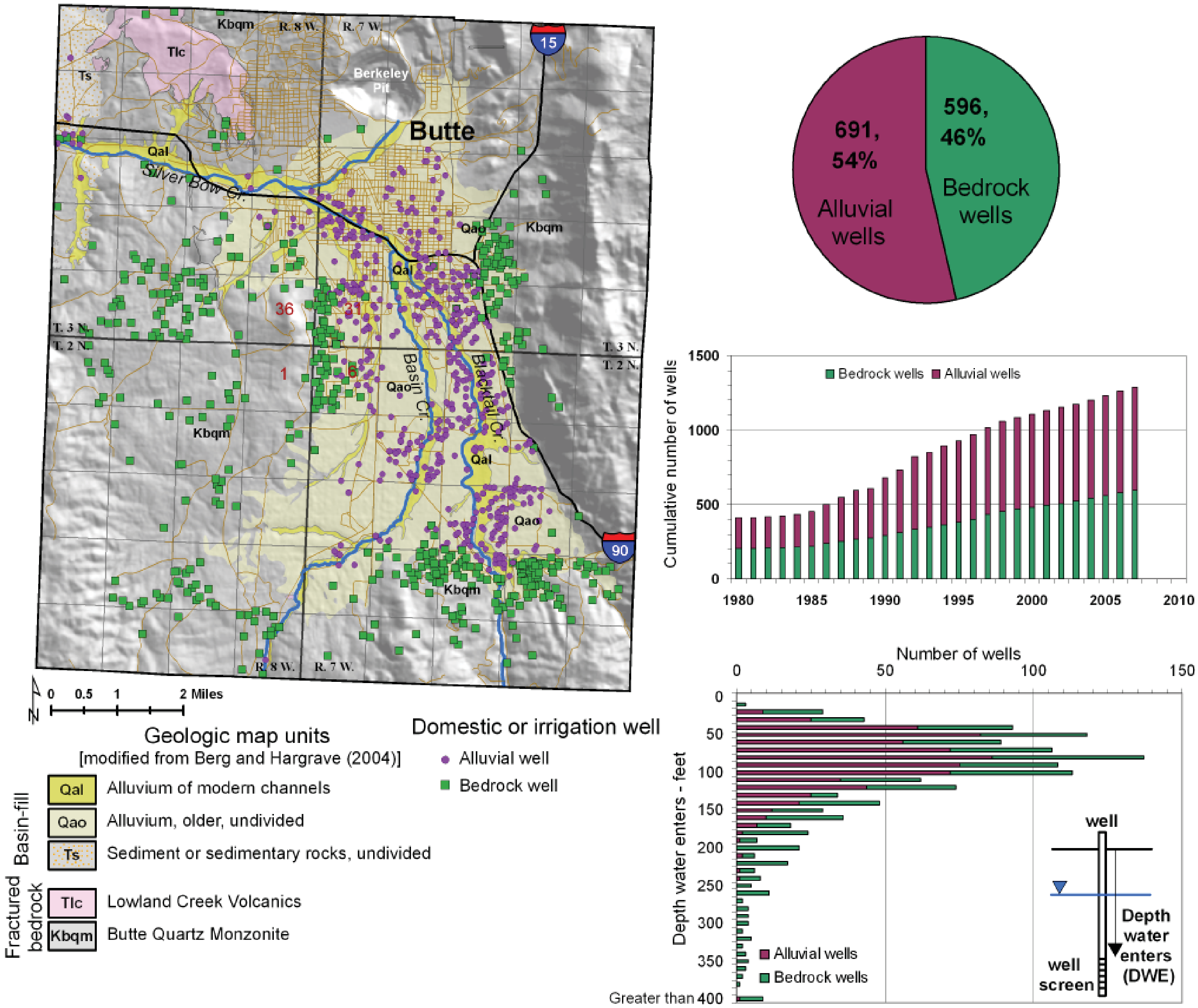


Figure 4. Wells used for domestic and irrigation purposes tap the fractured bedrock and alluvial aquifers. Most of the wells are in the alluvial aquifer, but an increasing number are being completed in the fractured bedrock, reflecting residential development along the valley margin. Well depths in the fractured bedrock aquifer are more variable than well depths in the alluvial aquifer.

A report prepared for the Butte–Silver Bow County City Planning Board at about the same time (Boettcher and Juvan, 1970) also highlighted the potential threat from septic systems, rating most of the valley soils as "severely limited" for septic tank filter sand. A severe rating indicates the limitations are severe enough to make their use questionable.

Straw (1980) authored a report titled, "Geology for Planning in the Butte–Silver Bow Area" and noted, "Of paramount importance is the adequate provision for suitable on-site sewage treatment and disposal facilities and for supplies of potable water. Throughout the country there are many areas where ground-water supplies have been polluted by inappropriately placed or inadequately designed on-site sewage facilities." In a comment on the above-referenced document, the state geologist at the time, S.L. Groff, noted, "Tom Straw's comments on geologic constraints to septic systems are pertinent. Not all populated areas in the planning area can be served by modern-disposal and water distribution systems. Thus, each housing area or subdivision outside the sewage and water systems should be carefully planned to avoid pollution" (Straw, 1980).

Nitrate pollution most likely related to unsewered subdivision development in the southeastern part of the valley was identified by the Butte–Silver Bow Health Department in 1998. The department analyzed water samples from 27 homes in the Warne Heights area (fig. 1). The analytical results were not made publicly available; however, in a letter to participating homeowners the Health Department stated that "15% of the residences had nitrate levels that exceeded the EPA health standard of 10 mg/L" (BSB Health Department, 1998). In response to concerned landowners in the southeastern part of the valley, the MBMG sampled seven sites in Warne Heights (as part of a broader investigation of ground-water resources in the upper Clark Fork Basin), an unsewered subdivision with a high density of septics over a fractured bedrock aquifer. Nitrate was detected in all the sampled wells at concentrations as high as 11.6 mg/L (Carstarphen and others, 2004).

## PURPOSE AND SCOPE

This report compiles and summarizes ground-water nitrate data from the Summit Valley based on samples collected by past and ongoing MBMG investigations (Montana Ground-Water Assessment, Butte Mine Flooding, Montana Pole, Colorado Tailings, Streamside Tailings, Metro Storm Drain, Natural Resource Damage Assessment). These data are publicly available from the GWIC database (http://mbmggwic.mtech.edu/); additional unpublished nitrate data (appendix) were obtained from the files of the Montana Department of Environmental Quality (MDEQ). In addition, this report presents the results of isotopic analyses performed on samples specifically collected to assess nitrate sources (appendix). Some data and interpretations regarding baseflow nitrate concentrations in Blacktail and Silver Bow Creeks are also presented.

This report builds on the previous work by compiling all available data and evaluating the occurrence of nitrate with respect to (1) land use, primarily sewered vs. unsewered areas; (2) aquifer type and setting: fractured bedrock vs. basin fill, and depth to water; and (3) well depth and depth to water.

The analyses from the GWIC database were performed by the Analytical Laboratory at the MBMG; analyses obtained from MDEQ were performed by the MSE Analytical Laboratory. All concentrations are reported as nitrate-N (total nitrate + nitrite as nitrogen).

## WATER QUALITY

The total dissolved solids (TDS) of a water sample provides a general indication of the water quality; the lower the concentration, the better the water quality. The secondary drinking water standard for TDS is 500 mg/L. TDS is calculated from the concentrations of major cations and anions dissolved in a water sample. Dissolved constituents in ground water are a result of the initial chemistry of the recharge water and subsequent interactions of that water with soils and aquifer materials. Increased residence time and physical contact between ground water and the aquifer materials increases the potential for the water to react, resulting in increased dissolution of minerals.

Full chemical analyses of ground water are available for 1,201 sites in the Clark Fork Basin and 123 sites in the Summit Valley from the GWIC database. The sites from the Summit Valley exclude monitoring wells. The results show that the TDS of ground water in the Summit Valley and the rest of the Clark Fork Basin is generally low, indicating good quality water for drinking and other uses; the median concentrations in both areas is less than 250 mg/L (fig. 5). However, there is a difference in the water composition between the two areas. A plot of the relative ionic composition of all the ground-water samples shows that Summit Valley ground water contains relatively more sulfate than the rest of the Clark Fork Basin. The average water composition of the Summit Valley samples is a Ca-$SO_4^{2-}$ type, whereas the average composition of the Clark Fork Basin samples is a Ca-$HCO_3^-$ type (fig. 5).

Because the composition of constituents dissolved in water largely depends on the type of rocks and minerals with which it has been in contact, the difference in water chemistry between the Summit Valley and the rest of the Clark Fork Basin probably reflects differences in the geology of the areas. In general, the basin-fill deposits of the Summit Valley are derived from the bedrock that surrounds it, which is composed of granite associated with the Boulder Batholith. The Boulder Batholith hosts rich ore deposits that made Butte a famous mining district. The ore minerals are predominately massive sulfides. These massive sulfide deposits do not occur, or occur to a much lesser extent, in other granitic intrusions within the Clark Fork Basin, for example the Idaho Batholith (Smedes and others, 1988). Therefore, oxidation of the trace sulfide minerals in the bedrock and

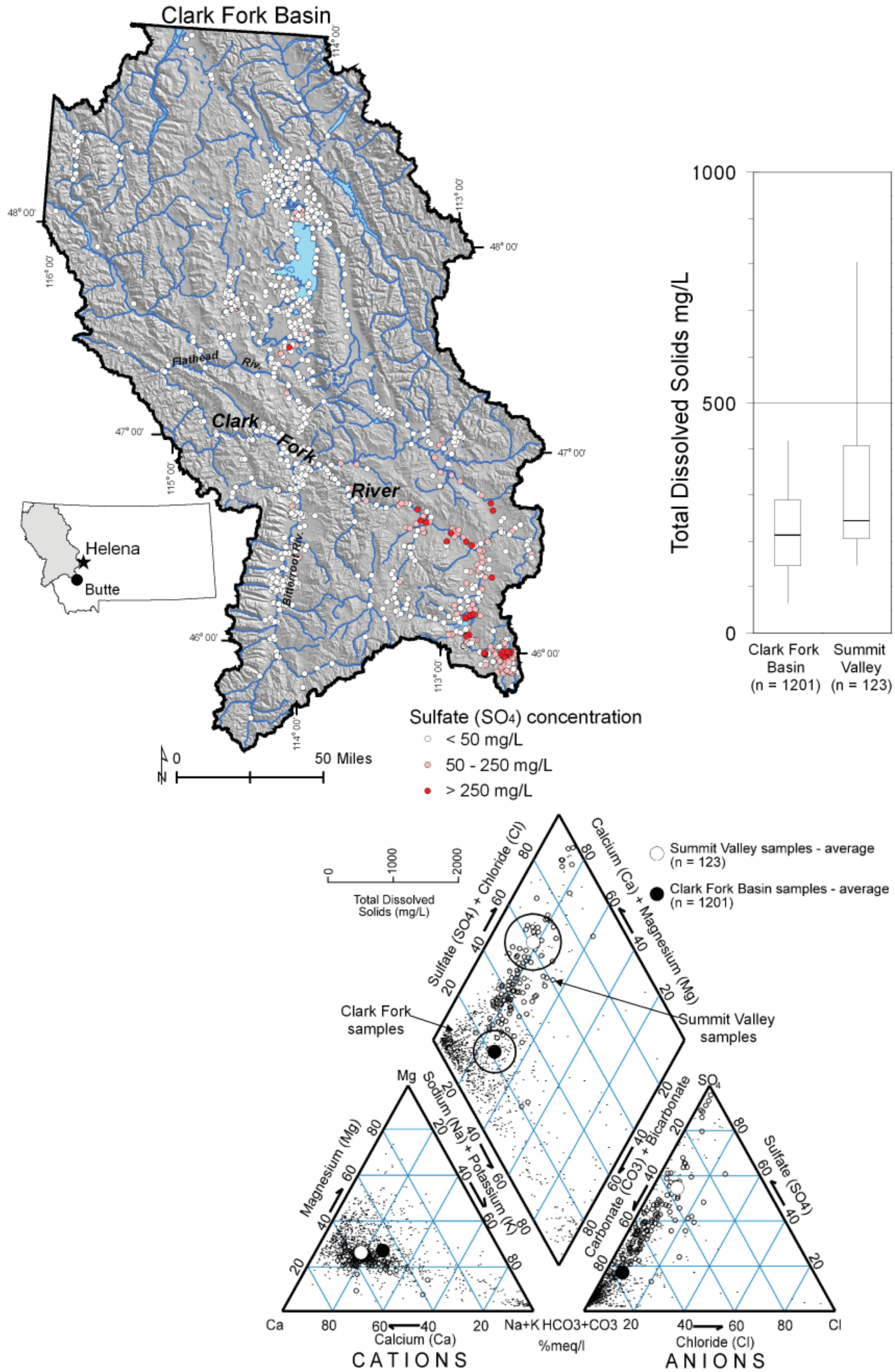


Figure 5. The total dissolved solids concentration of ground water in the Clark Fork Basin is generally well below the secondary health standard of 500 mg/L. However, sulfate concentrations are notably greater in the Silver Bow Creek watershed and the Summit Valley in particular. The sulfate is most likely derived from the massive sulfide deposits that occur within the Boulder Batholith.

basin-fill materials most likely accounts for the larger percentage of sulfate in the Summit Valley ground-water samples.

## SUMMIT VALLEY NITRATE

Ground-water nitrate data are available for 391 sites in the Summit Valley. Those data show that ground water in many parts of the Summit Valley has been impacted by nitrate contamination. A comparison of ground-water nitrate concentrations across the Clark Fork drainage basin shows that nitrate is detected both more frequently and at higher concentrations in the Summit Valley than in other parts of western Montana (fig. 6).

Within the valley there are two areas that have a disproportionate sample density from monitoring wells: (1) the Colorado Tailings/Montana Pole site and (2) the Metro Storm Drain (fig. 5). The Colorado Tailings/Montana Pole site has samples from 124 monitor wells that are mostly completed in the shallow alluvium (average well depth is 25 ft). Of these wells, 120 showed detectable levels of nitrate. The highest concentration was 78.0 mg/L, with a median concentration of 6.5 mg/L and an average of 13.0 mg/L. One well with a nitrate concentration closest to the average (GWIC ID:166775, $NO_3^-$ = 12.9 mg/L) was chosen to represent this area.

Of the 30 sample sites in the Metro Storm Drain area between Montana Street and Continental Drive, 21 showed detectable levels of nitrate. These wells are also completed in the shallow alluvium, and have an average depth of 50 ft. Nitrate concentrations range up to 6.89 mg/L, with a median of 1.25 mg/L and an average of 1.8 mg/L. The well with a nitrate value closest to the average (GWIC ID:4695, $NO_3^-$ = 1.74 mg/L) was chosen to represent this area.

Therefore, for this summary a total of 239 sites were used (appendix). Most of the samples were collected between 1993 and 2008, and were obtained from private domestic wells or monitoring wells. For wells with multiple samples, the result with the greatest nitrate concentration was used for any statistical summary or analysis.

For this summary the nitrate concentrations were grouped into four reporting ranges:

1. less than the detection limit;
2. low level (less than 2.0 mg/L): may reflect natural occurrence or minor land-use impacts;
3. impacted (2.0–10.0 mg/L): elevated concentrations probably reflecting land-use impacts; and
4. MCL exceedance (greater than or equal to 10.0 mg/L): elevated concentrations that represent a human health risk.

Figure 7 shows the distribution of nitrate concentrations in the Summit Valley ground water. Concentrations ranged from below the detection limit to 44.7 mg/L, with a median of 3.18 mg/L. A total of 32 samples (13 percent) exceeded the 10 mg/L health standard; an additional 124 samples (51 percent) had concentrations between 2 and 10 mg/L, suggestive of a land-use impact. Elevated concentrations were observed across the Summit Valley, regardless of aquifer type or presence of sewers (fig. 7).

## LAND USE—SEWERED VS. UNSEWERED

Ground-water contamination by nitrate is typically related to land use overlying the aquifer (Hallberg and Keeney, 1993; Mueller and Helsel, 1996). The land uses within the Summit Valley are primarily mining/industrial, sewered residential, unsewered residential, and undeveloped range land. Given these land uses, the likely sources of nitrate to ground water are (1) septic effluent and animal waste and (2) lawn and agricultural fertilizers. In the sewered residential area, sanitary sewers route household wastewater to the wastewater treatment plant where it is treated and eventually discharged to Silver Bow Creek. Therefore, household wastewater should not be a major source of ground-water nitrate in the sewered area (unless there are leaky sewer lines or older residences that remain on septic systems). However, excessive nitrate leaching related to lawn fertilization and over watering has been documented in residential areas (Morton and others, 1988). In the unsewered residential areas, each home is served by an on-site septic system. Septic systems discharge wastewater to the unsaturated zone where it percolates downward to the water table and becomes part of the shallow ground-water system. Because nitrate is soluble, it is readily transported by the percolating wastewater. Where they occur in high densities, septic systems can be a major local source of nitrate

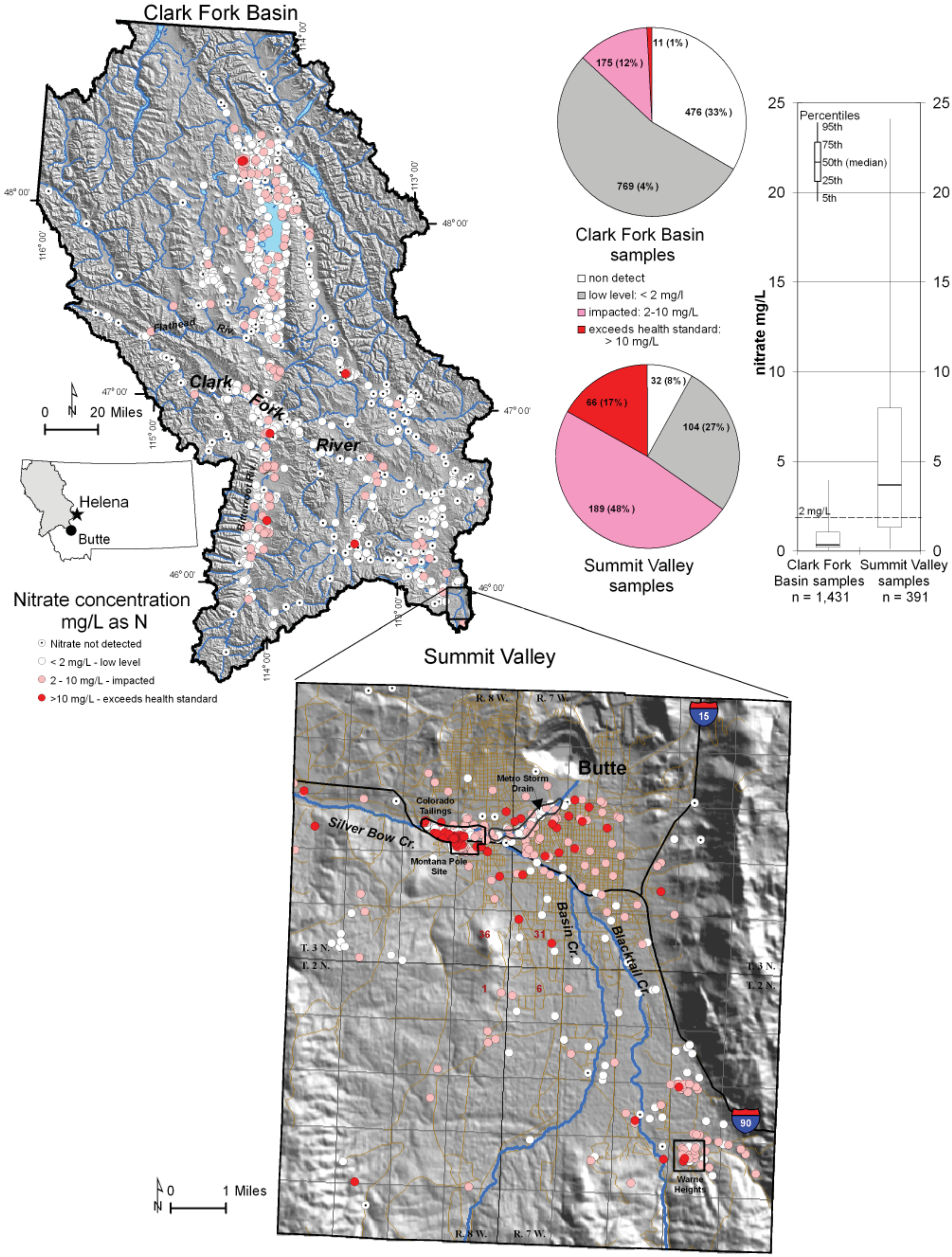


Figure 6. Nitrate is detected more frequently and at higher concentrations in the Summit Valley as compared to the rest of the Clark Fork River Basin.

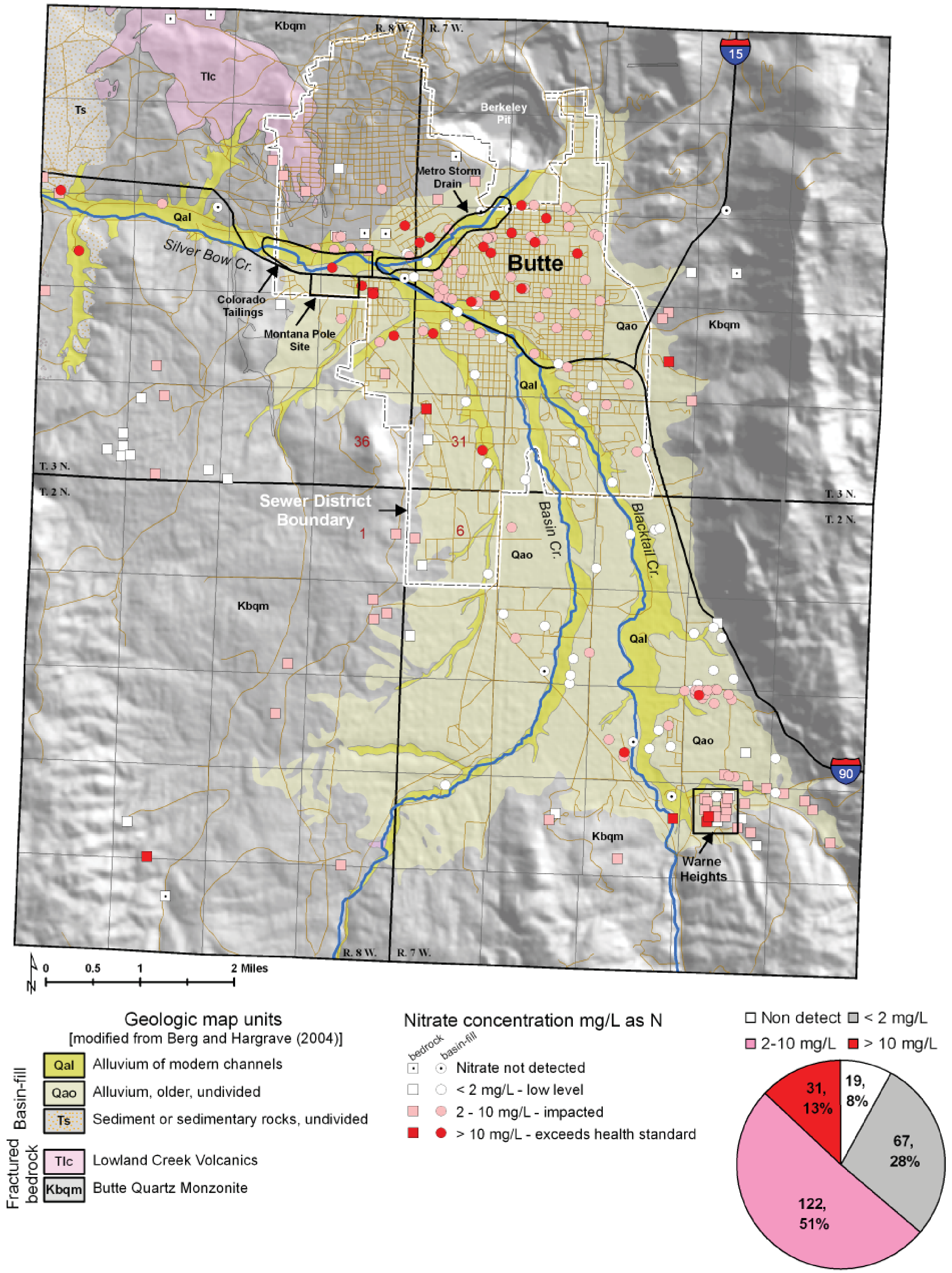


Figure 7. Ground water has been impacted by nitrate in more than 60 percent of the sampled sites in the Summit Valley.

(Hallberg and Keeney, 1993).

For this evaluation, nitrate data from sewered vs. unsewered areas were compared. A GIS coverage of the sewer district boundary provided by the Butte–Silver Bow GIS department was used to differentiate wells completed in and out of the sewer district. Of the available data, 112 samples were obtained from wells in the sewered part of the valley and 127 samples from wells in unsewered areas. Slightly more than half of the sampled wells (64 wells) in the sewered area have a reported use (domestic/commercial/irrigation) that indicates that the well is completed at a residence, business, or city park; the rest of the samples (48 wells) are from dedicated monitoring wells. Samples from the unsewered area are mostly from domestic and a few commercial wells (116 wells); the remainder are from monitoring wells (11 wells).

Figure 8 presents a comparison of the nitrate results in sewered vs. unsewered areas. Both areas show significant nitrate impacts to ground water: 71 percent of the sewered area samples had concentrations greater than 2 mg/L; 19 percent exceeded the health standard. In the unsewered area, 57 percent of the samples had nitrate concentrations in excess of 2 mg/L, with 8 percent exceeding the health standard. Based on overall concentrations, the impacts appear more severe in the sewered part of the valley. The median nitrate concentration from the sewered area samples, 4.8 mg/L, was nearly double that of the unsewered area, 2.5 mg/L (fig. 8).

In the sewered area some of the highest concentrations were clustered in the predominately residential area in the east side of Butte, north of I-90. In this area, the median nitrate concentration was 7 mg/L, with samples from 10 wells exceeding the 10 mg/L health standard.

Of particular concern is the unsewered area in the southeast part of the valley where some proposed housing developments have been delayed (fig. 9). Extensive sampling beneath two unsewered subdivisions with approximately 1- to 2-acre lot sizes shows clear impacts from the developments. The median nitrate concentration from 15 samples obtained from the alluvial aquifer below Lyndale Acres was 4.29 mg/L; approximately a mile south, 15 samples obtained from the bedrock aquifer below Warne Heights had a median nitrate concentration of 6.72 mg/L. In contrast, 5 samples from monitoring or unused wells in adjacent undeveloped land had a median nitrate concentration of 0.76 mg/L.

## AQUIFER: ALLUVIAL VS. FRACTURED BEDROCK

Ground water in the Summit Valley occurs in the alluvial basin-fill sediments and fractured bedrock along the valley margins (figs. 3, 4). Of the 239 sample sites, 150 were wells completed in the alluvial aquifer and 89 were wells completed in fractured bedrock. Roughly two-thirds (103) of the alluvial wells are reported as domestic (with a few commercial or irrigation wells) and one-third (47) are monitoring wells. Of the sampled bedrock wells, 87 percent (77) are reported as domestic (with a few commercial or irrigation wells) and 13 percent (12) are monitoring wells.

Analyses show little difference in the nitrate concentrations between the aquifers. The majority of samples from both aquifers indicate nitrate impacts. Concentrations exceeded 2 mg/L in 66 percent (98) of the alluvial samples and 62 percent (55) of the bedrock samples (fig. 10). The median concentration of alluvial samples was 3.41 mg/L while the median concentration of the bedrock samples was 2.61 mg/L.

## WELL DEPTH AND DEPTH TO WATER

Because nitrate sources occur at the land surface, nitrate concentrations will typically be greater at the top of the water table and will decline with depth, resulting in an inverse relationship between nitrate concentration and depth below the land surface. The depth to the top open interval, or depth water enters (DWE), for the sampled wells ranged from 2.8 to 471 ft below the land surface. The alluvial wells tended to be shallower, with DWEs ranging from 2.8 to 260 ft and a median of 60 ft, while DWEs for the bedrock wells ranged from 35 to 471 ft with a median of 120 ft. A plot of nitrate concentrations against the DWE shows very little correlation between concentrations and sample depth (fig. 11). Elevated concentrations (greater than 2 mg/L) were commonly detected in samples from depths up to 200 ft below the land surface. In the alluvium, most of the samples that exceeded the health standard were from shallower wells (DWE <70 ft). In the bedrock aquifer, sample results that exceeded the health standard were from wells with DWEs between 50 and 300 ft deep; five samples with nitrate concentrations greater than 9 mg/L were from wells with DWEs greater than 150 ft (fig. 11). The presence of elevated nitrate at such depths illustrates

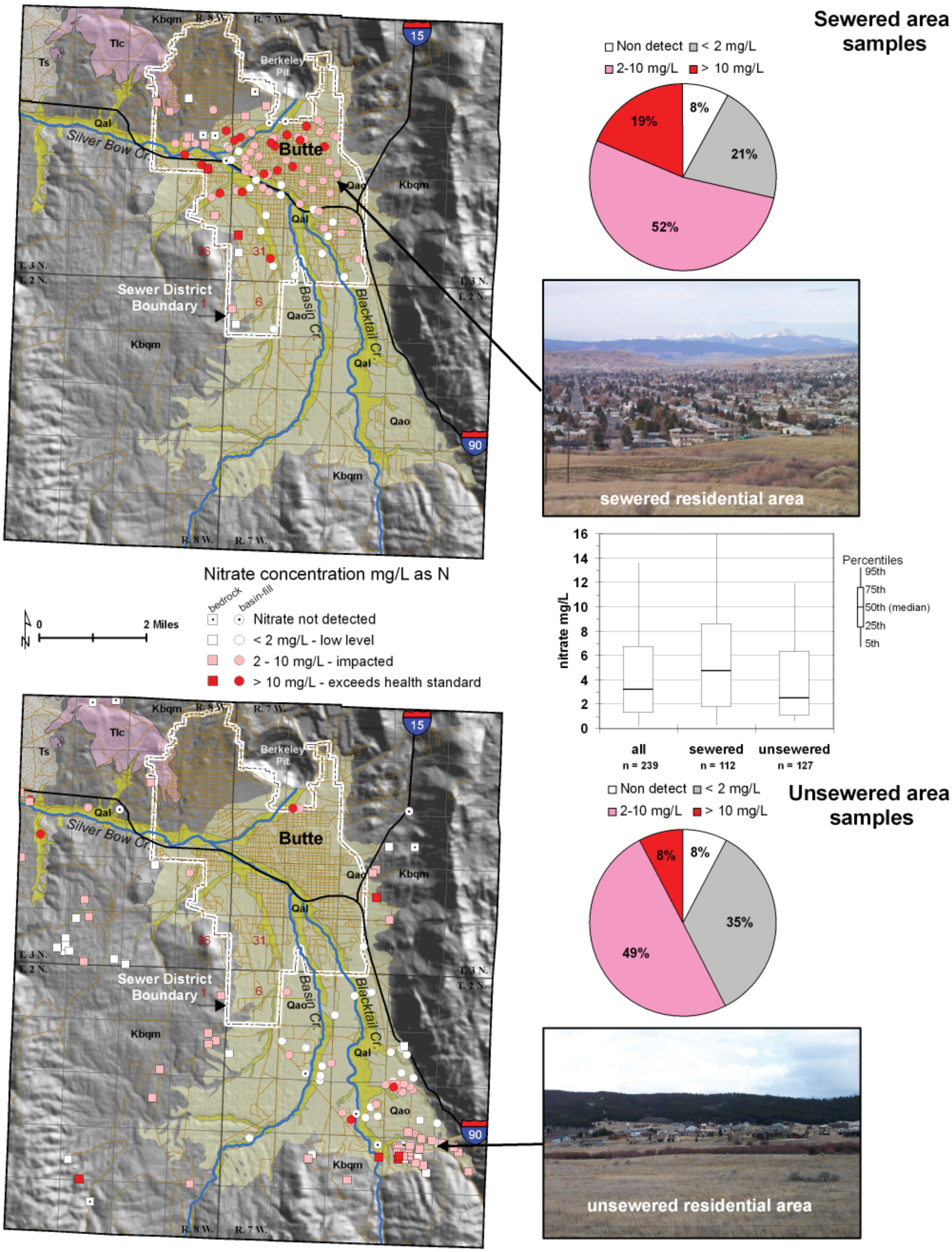


Figure 8. In both sewered and unsewered areas nitrate impacts are widespread; however, the concentration range and median value are greater in the sewered area.

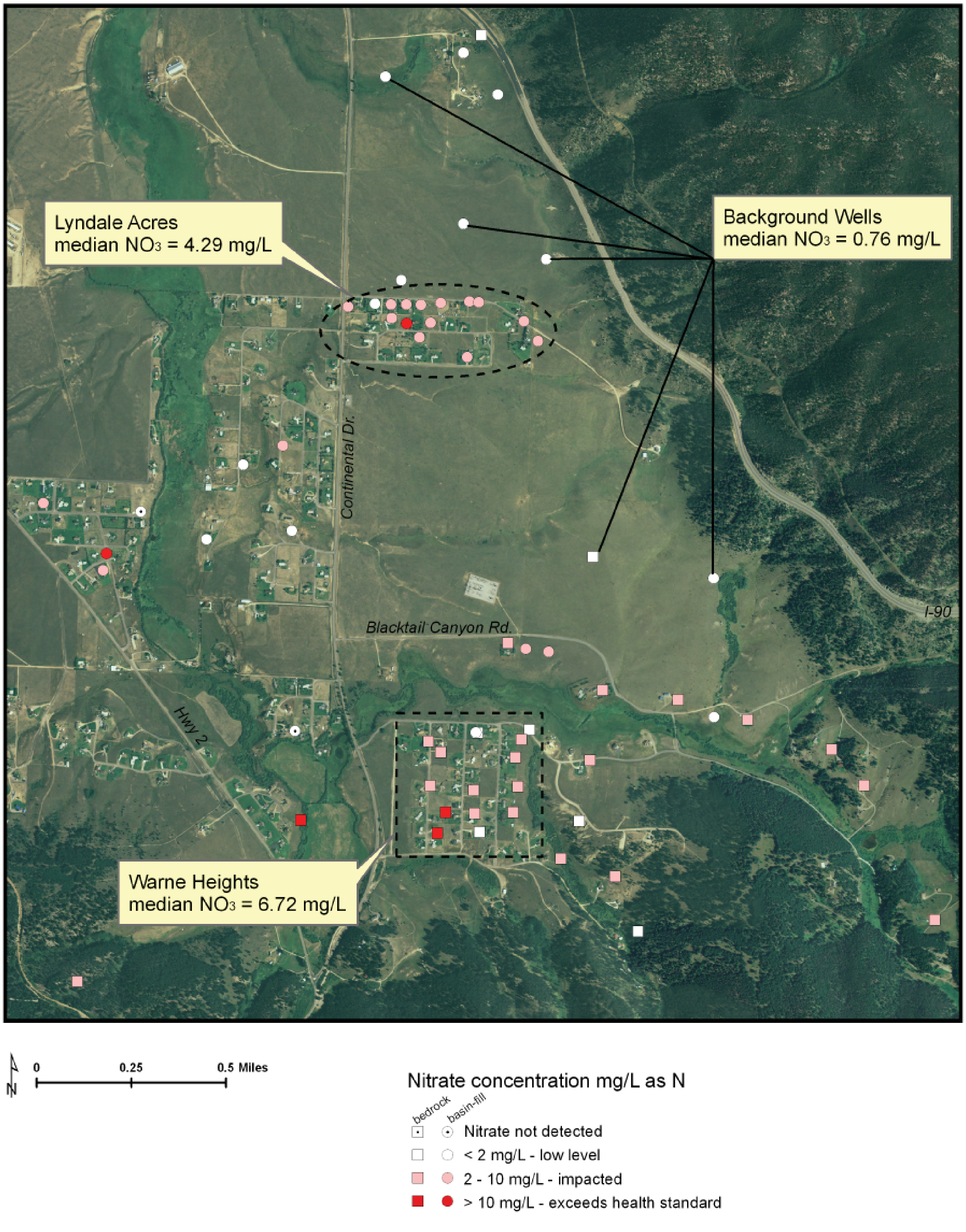


Figure 9. Nitrate concentrations below unsewered subdivisions in the southeast part of the valley are significantly higher than in adjacent undeveloped land.

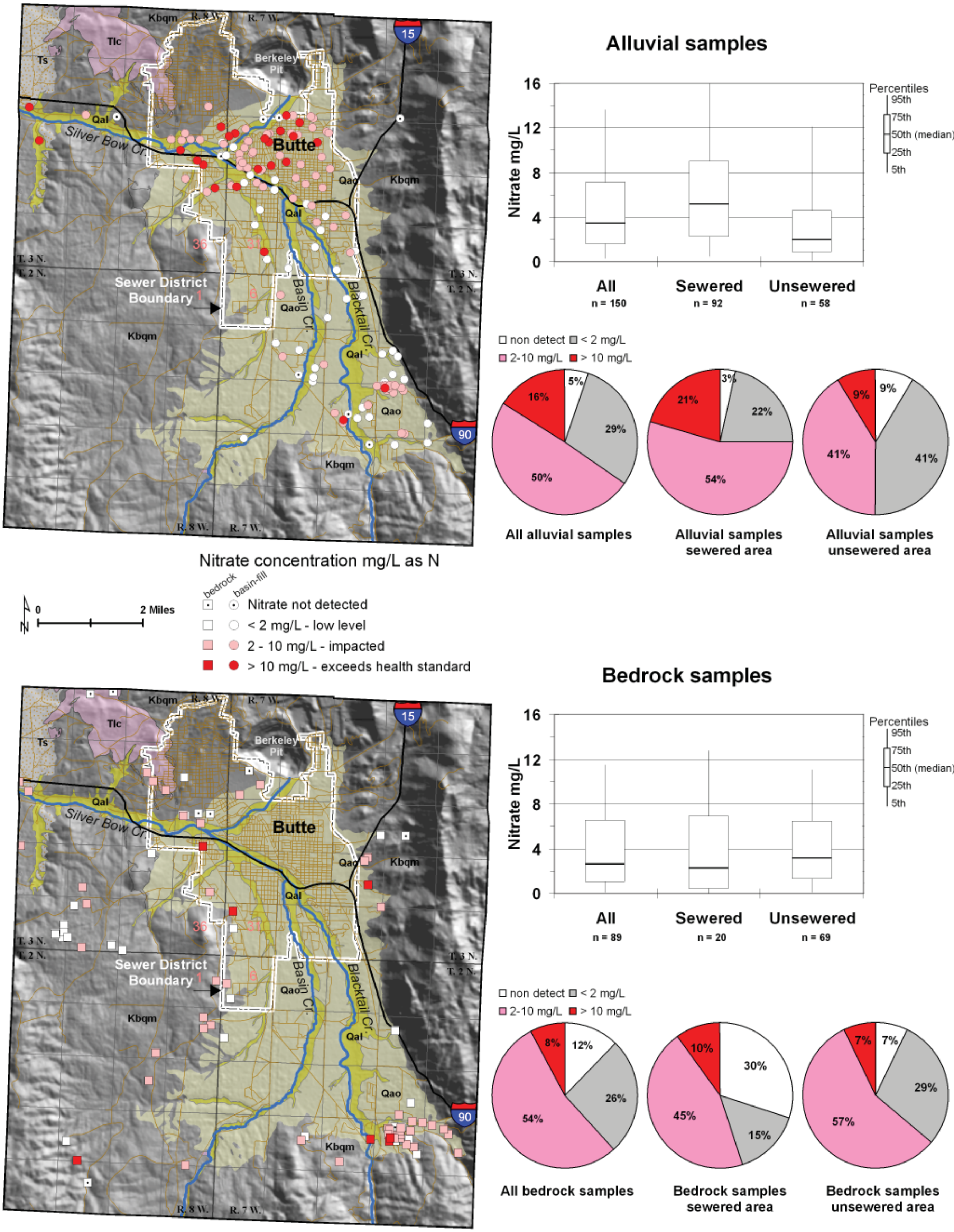


Figure 10. Nitrate concentrations in the alluvial and bedrock aquifers are similar.

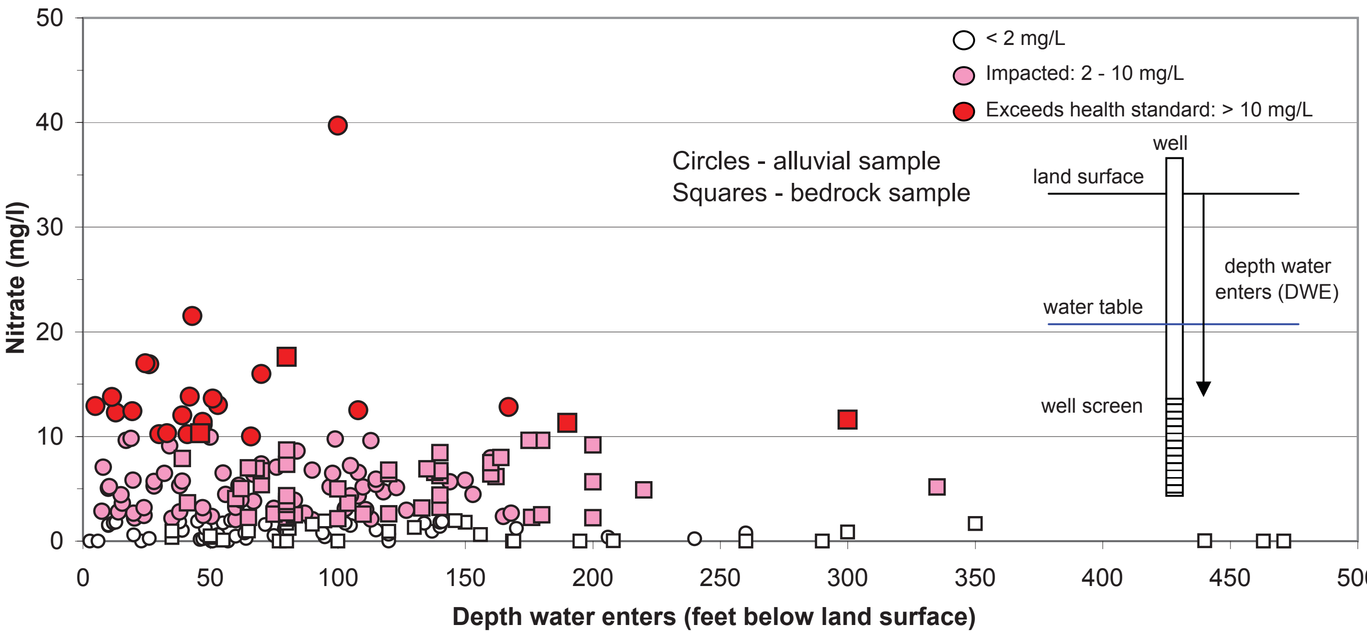


Figure 11. Nitrate concentrations vs. depth water enters (DWE) does not show a clear trend. Samples with nitrate concentrations greater than 2 mg/L (impacted) were obtained from wells at depths greater than 150 ft in both the alluvial and bedrock aquifers. Samples with concentrations greater than 10 mg/L (exceeds health standard) were from shallower wells in the alluvial aquifer; however, samples with health standard exceedances were obtained from wells that ranged from 50 to more than 300 ft deep in the bedrock aquifer.

how fracture porosity (as compared to inter-granular porosity, which characterizes the alluvial aquifer) can facilitate relatively deep transport of water and associated contamination into the subsurface with relatively little dilution (mixing) or dispersion.

The widespread presence of elevated nitrate concentrations at depths greater than 100 ft in both the alluvial and bedrock aquifers can most likely be attributed to the combination of highly permeable, well-drained soils with low organic carbon content and the highly permeable underlying aquifer material. In this environment nitrate is able to move quickly downward without being chemically reduced or inhibited physically.

Areas where the water table is close to the land surface (shallow water table) generally have higher nitrate concentrations than areas where the distance is large (Mueller and others, 1995). The relationship between depth to water and nitrate concentration in samples from the alluvial and bedrock aquifers is shown in figure 12. The results do not show a strong correlation. The depth to the water table ranged from 3 to 158 ft below the land surface in the alluvial wells, with a median of 24 ft. In the bedrock wells the depth to water ranged from 3 to 420 ft, with a median of 45 ft. Elevated concentrations occur near the water table (in the shallow part of the flow system); however, there is not a sharp decline in concentrations with depth (fig. 12). In both the alluvial and bedrock aquifers elevated nitrate concentrations were detected at water table depths greater than 100 ft below the land surface. Samples that exceed the health standard were detected where the water table was as deep as 60 ft in the alluvium and 70 ft in the bedrock aquifer (fig. 12).

## ISOTOPE ANALYSIS: SOURCE IDENTIFICATION

The widespread distribution of nitrate—in the sewered and unsewered areas and in the alluvial and bedrock aquifers—suggests multiple potential sources of nitrate to the ground water. Stable isotope ratios of nitrogen ($^{15}N/^{14}N$) and oxygen ($^{18}O/^{16}O$ of the nitrate) can be helpful in distinguishing between various sources of nitrate. Isotopic ratios are reported relative to a standard in units of parts per thousand, or per mil (‰), using delta (δ) notation (Clark and Fritz, 1997). The reference standard for nitrogen is $N_2$ in atmospheric air, and the reference for oxygen is Vienna Standard Mean Ocean Water [V-SMOW] (Clark and Fritz, 1997). A negative δ value indicates that the sample is depleted in the heavy

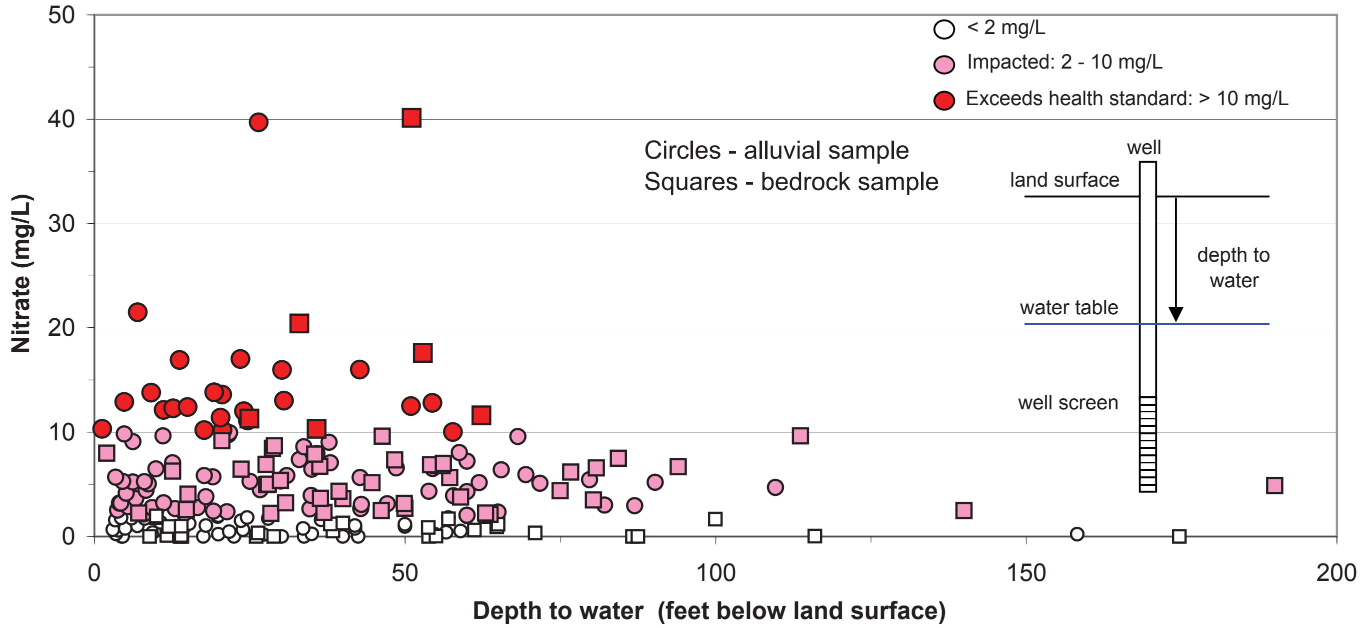


Figure 12. Nitrate concentrations vs. depth to water does not show a pronounced trend. Samples showing impacts were obtained from areas where the water table was more than 100 ft below the land surface in both alluvial and bedrock aquifers.

isotope relative to the standard; a positive value indicates that the sample is enriched in the heavy isotope relative to the standard.

Nitrogen isotope values are most useful in differentiating between synthetic fertilizer-derived nitrate and animal waste (including sewage). $\delta^{15}N$ values from fertilizer-derived nitrate range from about -4 to +4 ‰, whereas reported $\delta^{15}N$ values from animal waste range from about +7 to +20 ‰ (Kendall and Aravena, 2000; Fogg and others, 1998; Wassenaar, 1995; Aravena and others, 1993). For oxygen ratios, the $\delta^{18}O_{NO3}$ of nitrate derived from chemical fertilizers is characterized by enriched values (+18 to +22 ‰), whereas nitrate originating from animal and human wastes would be more depleted (Aravena and others, 1993).

Between October 2001 and November 2007, 21 wells in the Summit Valley were sampled for $\delta^{15}N$ and $\delta^{18}O_{NO3}$ analysis (one of the wells was sampled twice), and two additional samples were analyzed for $\delta^{15}N$ only (table 1). HKM Engineering sampled 5 of the wells and the remainder were sampled by the MBMG. All of the isotope analyses were performed by the University of Waterloo Environmental Isotope Laboratory, and all samples were also analyzed for nitrate. Sample sites were chosen to assess potential source variability from different land uses (sewered vs. unsewered), aquifer types (bedrock vs. alluvium), and well depths. The sample sites and results are shown in figure 13.

The nitrate concentrations in the 21 samples ranged from 2.28 to 45.5 mg/L, with a median of 6.6 mg/L; 4 samples exceeded the 10 mg/L health standard. The $\delta^{15}N$ values ranged between +4.29 to +11.1 ‰ with a median of +8.8 ‰. The $\delta^{18}O_{NO3}$ values ranged from -7.43 to +11.86 ‰, with a median of -1.7 ‰. All of the samples, with the exception of one obtained from the Montana Pole site, had a similar isotopic signature. The $\delta^{15}N$ and the $\delta^{18}O_{NO3}$ values are generally consistent with an animal waste or sewage source (fig. 13). It should be noted that nitrate derived from human wastes is indistinguishable isotopically from that derived from animal waste. There was no apparent correlation between $\delta^{15}N$ and nitrate, or between $\delta^{15}N$ and DWE; $\delta^{15}N$ values did not vary significantly between aquifer type or land use. The $\delta^{15}N$ values between +5 and +8 ‰ may reflect a mixture of fertilizer and septic sources, as many of the sample sites were below or near residences with well-maintained, apparently well-fertilized lawns. However, overall the results suggest that fertilizer was not a major contributor to the observed ground-water nitrate.

One sample, obtained from a shallow monitoring well at the Montana Pole site, did have a distinct isotopic signature suggestive of a fertilizer source. The sample

**Table 1.** Nitrate isotopic composition data.

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | $^{15}N$ ‰ | $^{18}O_{NO3}$ ‰ -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 128027 | 2002Q0423 | 10/26/2001 | 45.9943 | -112.5184 | GWIC | sewer | DOMESTIC | ALVM | 38 | 32 | 9.9 | 11.1 | -1.00 | 5.70 |
| 128029 | 2002Q0424 | 10/23/2001 | 45.9990 | -112.5027 | GWIC | sewer | DOMESTIC | ALVM | 76 | 70 | 30.2 | 11.1 | -1.69 | 8.49 |
| 153760 | 2002Q0437 | 10/29/2001 | 45.9667 | -112.5125 | GWIC | sewer | DOMESTIC | ALVM | 56.6 | 47 | 24.7 | 10.93 | -0.91 | 2.57 |
| 158435 | 2002Q0430 | 10/29/2001 | 45.9527 | -112.5266 | GWIC | sewer | DOMESTIC | BDRCK | 61 | 41 | 36.4 | 10.52 | -- | 3.65 |
| 49538 | --- | 9/15/2006 | 45.9166 | -112.4512 | HKM | unsewer | DOMESTIC | BDRCK | 65 | 62 | 28.0 | 10.19 | -1.51 | 4.48 |
| 168216 | 2002Q0434 | 10/27/2001 | 45.9140 | -112.4599 | GWIC | unsewer | DOMESTIC | BDRCK | 95 | 70 | 36.3 | 10.05 | -0.76 | 6.72 |
| 49421 | 2002Q0435 | 10/27/2001 | 45.9211 | -112.4786 | GWIC | unsewer | DOMESTIC | ALVM | 71 | 66 | 57.7 | 10.03 | -2.08 | 10.00 |
| 49551 | 2002Q0436 | 10/27/2001 | 45.9109 | -112.4599 | GWIC | unsewer | DOMESTIC | BDRCK | 340 | 300 | 62.3 | 9.78 | -1.99 | 8.98 |
| 129262 | 2002Q0422 | 10/24/2001 | 45.9975 | -112.4932 | GWIC | sewer | DOMESTIC | ALVM | 116 | 108 | 51.0 | 9.73 | 0.52 | 12.50 |
| 49336 | 2002Q0433 | 10/28/2001 | 45.9362 | -112.4872 | GWIC | unsewer | DOMESTIC | ALVM | 80 | 75 | 47.2 | 9.67 | 1.66 | 2.80 |
| 129387 | 2002Q0432 | 10/27/2001 | 45.9674 | -112.4784 | GWIC | sewer | DOMESTIC | ALVM | 176 | 168 | 42.9 | 8.93 | 0.20 | 2.38 |
| 155514 | 2002Q0593 | 11/13/2001 | 45.9899 | -112.5472 | GWIC | sewer | MONITORING | ALVM | 32.5 | 32.5 | 25.3 | 8.91 | -0.11 | 5.52 |
| 49551 | 2007Q0484 | 9/26/2006 | 45.9109 | -112.4599 | GWIC | unsewer | DOMESTIC | BDRCK | 340 | 300 | 62.3 | 8.8 | -5.18 | 8.67 |
| 49573 | --- | 9/15/2006 | 45.9157 | -112.4432 | HKM | unsewer | DOMESTIC | BDRCK | 162 | 120 | 23.7 | 8.33 | -3.80 | 3.83 |
| 890997 | 2002Q0421 | 10/25/2001 | 46.0055 | -112.5537 | GWIC | sewer | DOMESTIC | BDRCK | 125 | 75 | 14.8 | 8.21 | -2.16 | 2.28 |
| 120304 | 2008Q0173 | 9/19/2007 | 45.9020 | -112.5402 | GWIC | unsewer | DOMESTIC | BDRCK | 245 | 162 | 76.7 | 7.85 | -- | 6.16 |
| 49387 | --- | 9/15/2006 | 45.9181 | -112.4555 | HKM | unsewer | DOMESTIC | ALVM | 120 | 113 | 68.2 | 7.70 | -3.86 | 6.75 |
| 50059 | --- | 9/15/2006 | 45.9147 | -112.4385 | HKM | unsewer | DOMESTIC | BDRCK | 180 | 160 | -- | 7.34 | -4.72 | 6.40 |
| 188434 | --- | 9/15/2006 | 45.9180 | -112.4542 | HKM | unsewer | MONITORING | ALVM | 86 | 76 | 38.0 | 7.20 | -1.68 | 6.32 |
| 50356 | 2002Q0425 | 10/25/2001 | 46.0078 | -112.5588 | GWIC | sewer | DOMESTIC | BDRCK | 175 | 135 | 54.1 | 7.17 | -3.69 | 6.89 |
| 179158 | 2007Q0495 | 9/29/2006 | 45.9117 | -112.4595 | GWIC | unsewer | DOMESTIC | BDRCK | 100 | 80 | 33.0 | 7.1 | -7.43 | 20.40 |
| 50092 | 2002Q0431 | 10/29/2001 | 45.9814 | -112.4721 | GWIC | unsewer | DOMESTIC | BDRCK | 70 | 46 | 35.8 | 6.35 | -1.29 | 9.46 |
| 150276 | 2007Q0486 | 9/26/2006 | 45.9146 | -112.4555 | GWIC | unsewer | DOMESTIC | BDRCK | 160 | 140 | 28.7 | 5.69 | -6.42 | 7.26 |
| 175667 | 2002Q0592 | 11/13/2001 | 45.9933 | -112.5508 | GWIC | sewer | MONITORING | ALVM | 15 | 5 | 11.1 | 4.29 | 11.86 | 45.50 |

Note. Source: GWIC, Ground-Water Information Center; HKM, HKM Engineering.
Unit: ALVM, alluvial aquifer; BDRCK, fractured bedrock aquifer.
‰ - per mil
mg/L: milligrams per liter

also had the greatest nitrate concentration (45.5 mg/L). As noted previously, ground water in the vicinity of the Montana Pole site is heavily impacted by nitrate. The source is not known but may be related to past land-use activities at the site. Fertilizers were applied on one occasion to the bio-piles as part of the remediation efforts at the site, but the piles were located on liners or pads to restrict leaching into the subsurface. A facility that produced explosives (presumably ammonia–nitrate-based) for mining operations, LaVelle Powder, was located at or near the site (personal communication, Ted Duaime). Nitrate is a known byproduct from the production and demolition of ordnance. DiGnazio and others (1998) evaluated the isotopic composition of nitrate derived from a leaking lagoon at a munitions manufacturing facility and observed two distinct ranges of $\delta^{15}N$ values. In the immediate vicinity of the lagoon, values from four samples ranged from +8.9 to +13.5 ‰; however, samples from five wells located further downgradient from the lagoon had $\delta^{15}N$ values that ranged from +2.0 to +4.6 ‰, similar to the value from the Montana Pole site. Whatever the source, the isotope data suggest that it is different from the rest of the valley.

## OCCURRENCE OF NITRATE IN SURFACE WATER

During baseflow conditions all, or most, of the stream flow is sustained by ground-water discharge. To assess the impact of ground-water quality on surface-water quality, Blacktail and Silver Bow Creeks were sampled on two occasions during baseflow conditions for nitrate and specific conductance (a measure of the dissolved solids).

On November 9, 2001 and May 29, 2002, samples were collected over a stretch of about 10 river miles along Blacktail and Silver Bow Creeks. The sample locations are shown in figure 14; the data are presented in table 2. The uppermost station, in Thompson Park, is surrounded by Forest Service land, about a mile upstream from Summit Valley residential development. The second and third stations

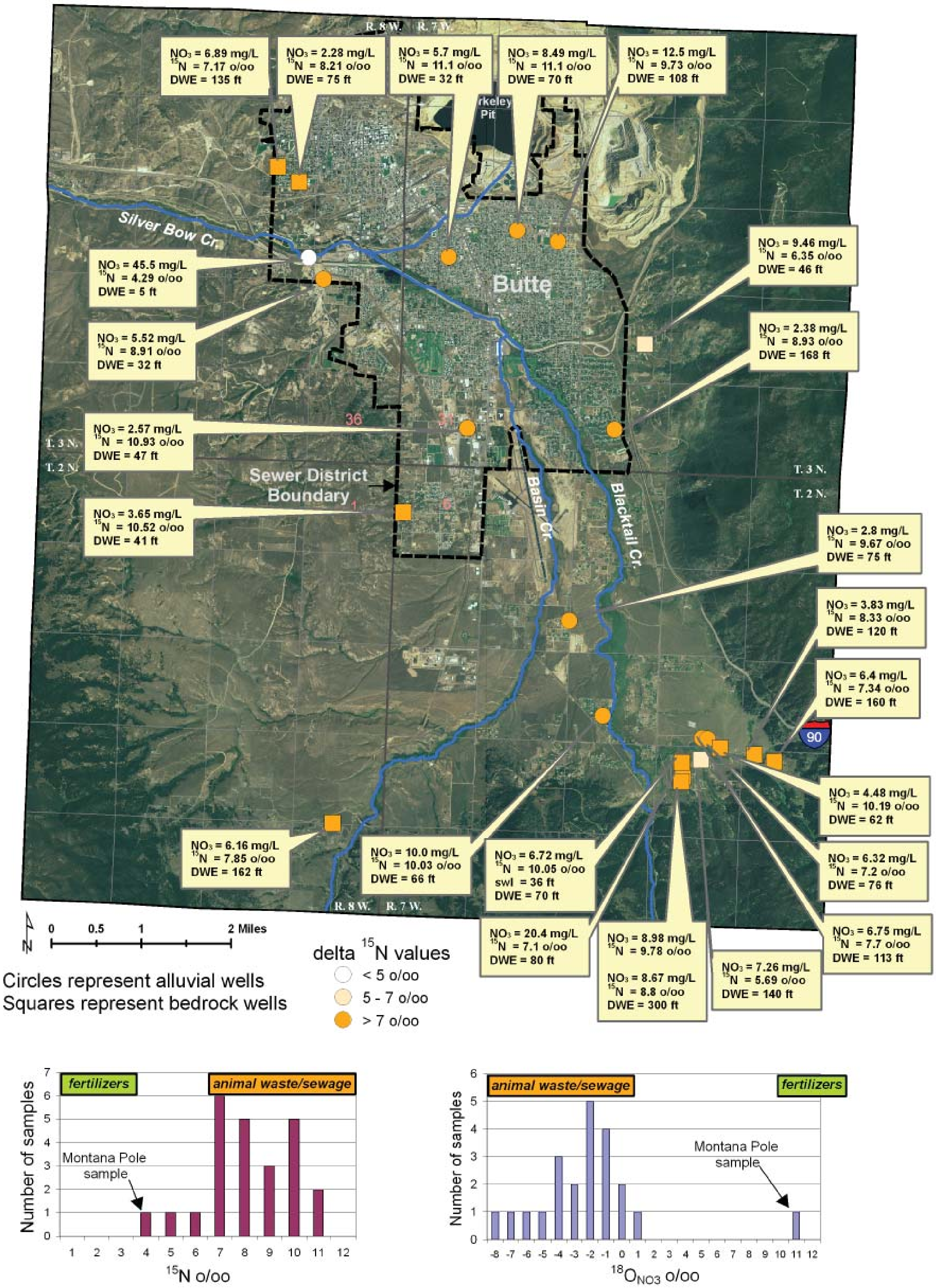


Figure 13. Samples for nitrogen and oxygen isotope analysis were collected from sewered and unsewered areas, and alluvial and bedrock aquifers. The results suggest that most of the nitrate was derived from an animal waste or sewage source.

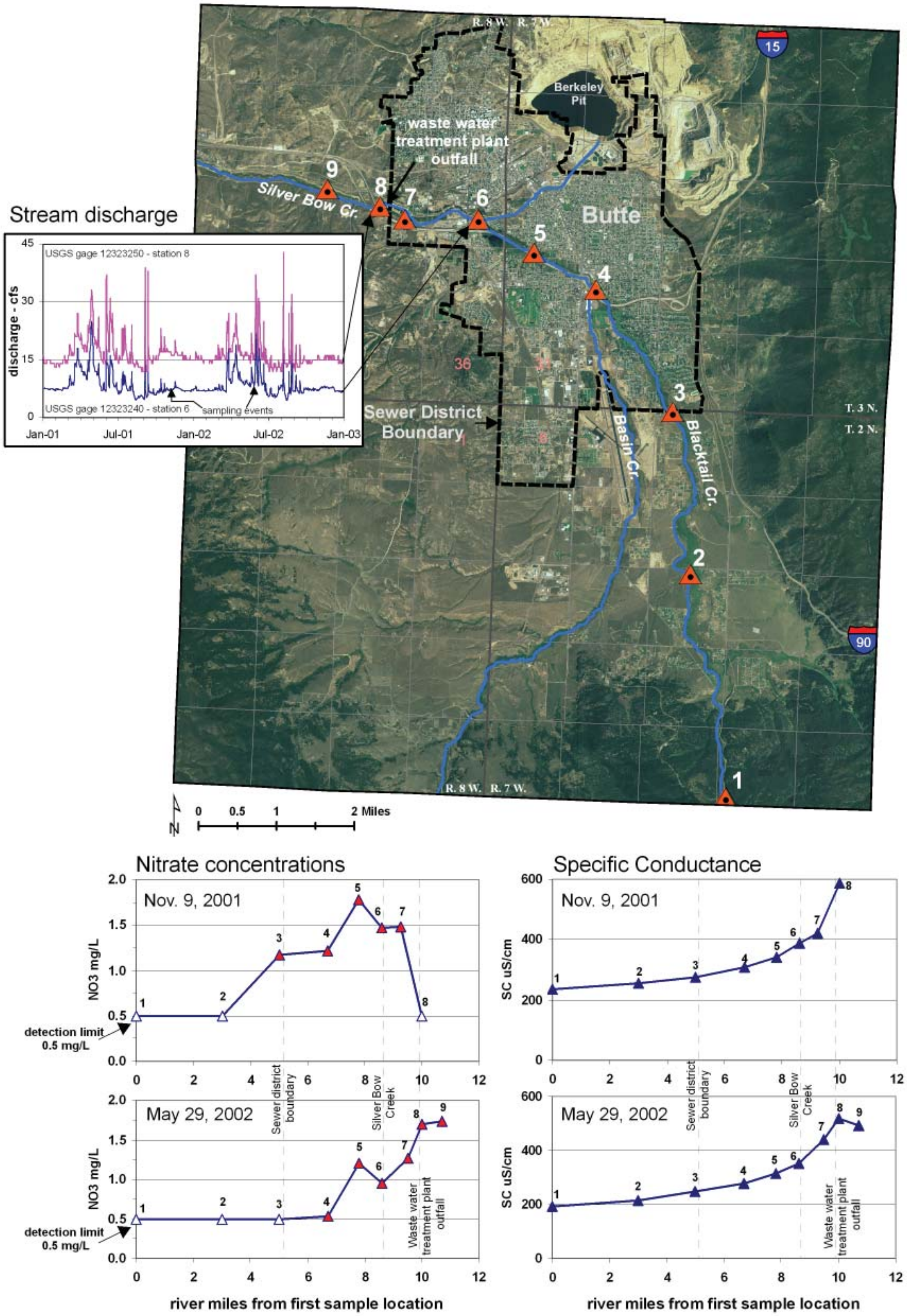


Figure 14. Baseflow samples from Blacktail and Silver Bow Creeks show elevated nitrate concentrations upstream from the wastewater treatment plant, indicating ground-water impacts. The lack of nitrate at station 8 on Nov. 9, 2001, probably indicates that the sample consisted mostly of wastewater treatment effluent and the N was in a reduced state.

are in, and downstream from, unsewered residential developments. Stations 4 and 5 are surrounded by sewered, urban/residential land. Station 6 is located at the U.S. Geological Survey (USGS) gauge 1232340, above the confluence of Blacktail Creek and the Metro Storm Drain. Station 7 is near the Montana Pole/Colorado Tailings sites, station 8 is immediately downstream from the wastewater treatment plant outfall, at USGS gauge 1232350, and station 9 (only sampled in May 2002) is at the first bridge located about 1,000 ft downstream from the wastewater treatment plant outfall.

Although the stream flow at station 8, below the wastewater treatment plant outfall, is nearly double that at station 6 on Blacktail Creek, the discharge patterns are similar (fig. 14). The measured discharge during the first sampling event at Blacktail Creek on November 9, 2001 was 7.5 cubic feet per second (cfs). The second sampling event on May 29, 2002 occurred during a baseflow period between runoff events; the measured discharge at Blacktail Creek was 8.1 cfs.

The baseflow concentrations of specific conductance (SC) increased in the downstream direction along Blacktail and Silver Bow

**Table 2.** Nitrate data for baseflow sampling in Nov. 2001 and May 2002.

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | - - | Nitrate (mg/L) | specific conductance (µS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 191284 | 2002Q0587 | 11/9/2001 | 45.8892 | -112.4646 | GWIC | unsewered | < | 0.50 | 234 |
| 191285 | 2002Q0595 | 11/9/2001 | 45.9303 | -112.4763 | GWIC | unsewered | < | 0.50 | 254 |
| 191286 | 2002Q0596 | 11/9/2001 | 45.9603 | -112.4827 | GWIC | unsewered | | 1.17 | 275 |
| 123162 | 2002Q0588 | 11/9/2001 | 45.9825 | -112.5044 | GWIC | sewered | | 1.21 | 308 |
| 191287 | 2002Q0589 | 11/9/2001 | 45.9889 | -112.5212 | GWIC | sewered | | 1.78 | 342 |
| 127593 | 2002Q0590 | 11/9/2001 | 45.9947 | -112.5363 | GWIC | sewered | | 1.47 | 387 |
| 158214 | 2002Q0597 | 11/8/2001 | 45.9948 | -112.5484 | GWIC | sewered | | 1.48 | 421 |
| 4930 | 2002Q0598 | 11/8/2001 | 45.9965 | -112.5628 | GWIC | sewered | < | 0.50 | 588 |
| | | | | | | | | | |
| 191284 | 2002Q1316 | 5/29/2002 | 45.8892 | -112.4646 | GWIC | unsewered | < | 0.50 | 194 |
| 191285 | 2002Q1320 | 5/29/2002 | 45.9303 | -112.4763 | GWIC | unsewered | < | 0.50 | 213 |
| 191286 | 2002Q1318 | 5/29/2002 | 45.9603 | -112.4827 | GWIC | unsewered | < | 0.50 | 250 |
| 123162 | 2002Q1314 | 5/29/2002 | 45.9825 | -112.5044 | GWIC | sewered | | 0.53 | 276 |
| 191287 | 2002Q1323 | 5/29/2002 | 45.9889 | -112.5212 | GWIC | sewered | | 1.20 | 313 |
| 127593 | 2002Q1322 | 5/29/2002 | 45.9947 | -112.5363 | GWIC | sewered | | 0.95 | 353 |
| 164317 | 2002Q1321 | 5/29/2002 | 45.9942 | -112.5560 | GWIC | sewered | | 1.26 | 439 |
| 4930 | 2002Q1317 | 5/29/2002 | 45.9964 | -112.5627 | GWIC | sewered | | 1.70 | 518 |
| 195673 | 2002Q1315 | 5/29/2002 | 45.9992 | -112.5770 | GWIC | unsewered | | 1.74 | 494 |

Note. Source: GWIC, Ground-Water Information Center; MDEQ, Montana Department of Environmental Quality.
Unit: ALVM, alluvial aquifer; BDRCK, fractured bedrock aquifer
mg/L: milligrams per liter
µS/cm: microsiemens per centimeter at 25 degrees Celsius

Creeks. However, on both sampling events, the rate of increase was much greater downstream from station 5, reflecting the more mineralized inputs from the urban area and the wastewater treatment plant (fig. 14). The drop in SC between station 8 (wastewater treatment plant) and 9 on the May 29th sampling event most likely represents mixing of the high-SC wastewater treatment plant effluent with the lower-SC receiving water.

The baseflow concentrations of nitrate reflect the land use and ground-water concentrations. In November 2001, nitrate was not detected at the farthest upstream stations (1 and 2). At station 3, just upstream from the sewered area, concentrations exceeded 1 mg/L (fig. 14). Between stations 3 and 7 (within the sewered area), nitrate concentrations were between 1 and 2 mg/L. Nitrate was not detected immediately downstream of the wastewater treatment plant most likely because the sample was primarily undiluted discharge from the plant, and not mixed well with the receiving water, and the nitrogen was in a reduced state.

In May 2002 nitrate was not detected at stations 1 through 3; however, by station 5 concentrations were generally greater than 1 mg/L and sites further downstream showed progressively higher concentrations, except at station 6 (fig. 14).

Wastewater treatment plants in the Clark Fork Basin are recognized as major contributors of nutrients to surface water (Tri-State Implementation Council, 1998). In the Summit Valley ground-water contamination is the most probable nitrate source to the streams above the wastewater treatment plant. Nitrate concentrations measured in streams throughout the Clark Fork Basin during water years 1999–2003 were generally less than 0.05 mg/L; the maximum concentration detected in the 14 streams that were monitored was 0.26 mg/L (Lambing and Cleasby, 2006). The sampling results from the Summit Valley show that along a 4- to 6-mile reach above (upstream of) the wastewater treatment plant, nitrate concentrations are well above that of other streams in the watershed.

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# APPENDIX

## Nitrate Data from Wells in the Summit Valley

**Appendix.** Nitrate data from wells in the Summit Valley.

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4364 | 1976Q1077 | 9/3/1976 | 45.9950 | -112.6033 | GWIC | unsewered | DOMESTIC | ALVM | -- | -- | 11.2 | | 12.11 |
| 4483 | 1988Q1093 | 8/2/1988 | 45.9550 | -112.5054 | GWIC | unsewered | IRRIGATION | ALVM | 72 | 62 | 34.9 | | 3.92 |
| 4486 | 1976Q1667 | 4/13/1977 | 45.9416 | -112.5065 | GWIC | unsewered | DOMESTIC | ALVM | 134 | 134 | 65.0 | | 1.72 |
| 4490 | 1980Q2081 | 9/3/1980 | 45.9113 | -112.4933 | GWIC | unsewered | DOMESTIC | BDRCK | 120 | 80 | 65.0 | | 1.18 |
| 4491 | 1986Q0869 | 1/1/1900 | 45.9083 | -112.4325 | GWIC | unsewered | DOMESTIC | BDRCK | 140 | 120 | -- | | 2.61 |
| 4492 | 1980Q2739 | 11/6/1980 | 45.9075 | -112.5877 | GWIC | unsewered | DOMESTIC | BDRCK | 460 | 440 | 55.0 | | 0.03 |
| 4604 | 2001Q1120 | 1/4/2001 | 46.0046 | -112.5059 | GWIC | unsewered | MONITORING | ALVM | 65 | 53 | 30.5 | | 13.00 |
| 4611 | 1996Q0649 | 4/4/1996 | 46.0046 | -112.4961 | GWIC | sewered | MONITORING | ALVM | 68.4 | 55 | 54.5 | | 6.50 |
| 4644 | 1989Q1471 | 11/7/1989 | 46.0050 | -112.5244 | GWIC | sewered | IRRIGATION | BDRCK | 300 | 140 | 30.8 | | 3.22 |
| 4647 | 1989Q1466 | 11/8/1989 | 46.0080 | -112.5164 | GWIC | sewered | DOMESTIC | BDRCK | 500 | 175 | 113.7 | | 9.63 |
| 4672 | 1988Q0887 | 7/22/1988 | 45.9971 | -112.5123 | GWIC | sewered | IRRIGATION | ALVM | 53 | 41 | 17.7 | | 10.20 |
| 4673 | 1988Q1422 | 9/28/1988 | 45.9980 | -112.5140 | GWIC | sewered | IRRIGATION | ALVM | 57 | 47 | 20.3 | | 11.40 |
| 4675 | 1988Q0492 | 6/10/1988 | 46.0005 | -112.5218 | GWIC | sewered | MONITORING | ALVM | 17 | 17 | 11.1 | | 9.63 |
| 4687 | 1988Q0496 | 6/10/1988 | 45.9971 | -112.5205 | GWIC | sewered | MONITORING | ALVM | 15.5 | 15.5 | 6.7 | | 3.61 |
| 4695 | 1988Q0268 | 4/27/1988 | 45.9953 | -112.5264 | GWIC | sewered | MONITORING | ALVM | 17 | 12 | 6.0 | | 1.74 |
| 4702 | 2002Q0671 | 12/7/2001 | 46.0003 | -112.4887 | GWIC | sewered | MONITORING | ALVM | 103 | 97 | 90.3 | | 5.18 |
| 4708 | 1988Q1421 | 9/29/1988 | 45.9918 | -112.5052 | GWIC | sewered | IRRIGATION | ALVM | 48 | 30 | 20.7 | | 10.20 |
| 4709 | 1988Q1441 | 10/5/1988 | 45.9918 | -112.5046 | GWIC | sewered | IRRIGATION | ALVM | 109 | 99 | 21.6 | | 9.76 |
| 4714 | 1987Q0767 | 9/17/1987 | 45.9777 | -112.4809 | GWIC | sewered | IRRIGATION | ALVM | 120 | 110 | 62.0 | | 5.17 |
| 4716 | 1988Q1092 | 8/1/1988 | 45.9883 | -112.4933 | GWIC | sewered | IRRIGATION | ALVM | 119 | 108 | 48.6 | | 6.57 |
| 4718 | 1988Q0885 | 7/22/1988 | 45.9895 | -112.5162 | GWIC | sewered | IRRIGATION | ALVM | 40 | 33 | 1.3 | | 10.30 |
| 4719 | 1988Q1091 | 8/1/1988 | 45.9783 | -112.5148 | GWIC | sewered | IRRIGATION | ALVM | 75 | 65 | 10.7 | | 1.34 |
| 4721 | 1980Q1270 | 7/14/1980 | 45.9680 | -112.5247 | GWIC | sewered | DOMESTIC | BDRCK | 100 | 35 | 71.0 | | 0.34 |
| 4722 | 1988Q1402 | 9/26/1988 | 45.9733 | -112.4905 | GWIC | sewered | DOMESTIC | ALVM | 98 | 90 | 28.0 | | 1.72 |
| 4723 | 2006Q0395 | 10/19/2005 | 45.9744 | -112.4855 | GWIC | sewered | DOMESTIC | ALVM | 105 | 98 | 35.0 | | 6.46 |
| 4725 | 1988Q1624 | 11/30/1988 | 46.0372 | -112.5430 | GWIC | unsewered | MONITORING | BDRCK | 156 | 156 | 61.2 | | 0.61 |
| 4773 | 1989Q1311 | 9/9/1989 | 46.0092 | -112.5465 | GWIC | sewered | IRRIGATION | BDRCK | 700 | 300 | 53.8 | | 0.86 |
| 4819 | 1988Q1549 | 11/1/1988 | 46.0063 | -112.5369 | GWIC | sewered | IRRIGATION | ALVM | 200 | 160 | 35.9 | | 7.94 |
| 4986 | 1989Q0606 | 5/8/1989 | 45.9983 | -112.5281 | GWIC | sewered | MONITORING | ALVM | 26 | 26 | 13.7 | | 16.90 |
| 4993 | 1987Q0564 | 7/29/1987 | 45.9986 | -112.5463 | GWIC | sewered | MONITORING | BDRCK | 68 | 68 | 27.7 | | 6.92 |
| 5002 | 1989Q0663 | 5/12/1989 | 45.9970 | -112.5434 | GWIC | sewered | MONITORING | ALVM | 34 | 24 | 4.1 | | 3.18 |
| 5004 | 1989Q1468 | 11/9/1989 | 45.9970 | -112.5433 | GWIC | sewered | MONITORING | ALVM | 30 | 10 | 3.4 | | 1.56 |
| 5007 | 1989Q0667 | 5/11/1989 | 45.9967 | -112.5469 | GWIC | sewered | MONITORING | ALVM | 29.5 | 20 | 13.0 | | 2.66 |
| 5018 | 2007Q0964 | 4/25/2007 | 45.9961 | -112.5303 | GWIC | sewered | MONITORING | ALVM | 31 | 19 | 4.9 | | 9.81 |
| 5023 | 1988Q1435 | 10/4/1988 | 45.9965 | -112.5309 | GWIC | sewered | MONITORING | ALVM | 18 | 13 | 4.3 | | 1.79 |
| 34689 | 1994Q0870 | 11/30/1993 | 45.9411 | -112.5322 | GWIC | unsewered | DOMESTIC | BDRCK | 175 | 133 | 49.9 | | 3.16 |
| 49260 | 2001Q1731 | 6/23/2001 | 45.9546 | -112.4792 | GWIC | unsewered | DOMESTIC | ALVM | 134 | 120 | 24.0 | | 0.65 |
| 49306 | 1994Q0868 | 11/29/1993 | 45.9477 | -112.5102 | GWIC | sewered | DOMESTIC | ALVM | 101 | 95 | 56.7 | | 0.41 |
| 49333 | 1994Q0883 | 12/1/1993 | 45.9380 | -112.5036 | GWIC | unsewered | DOMESTIC | ALVM | 91 | 83 | 57.9 | | 3.91 |
| 49336 | 2001Q1727 | 6/24/2001 | 45.9362 | -112.4872 | GWIC | unsewered | DOMESTIC | ALVM | 80 | 75 | 47.2 | | 3.12 |
| 49421 | 2002Q0435 | 10/27/2001 | 45.9211 | -112.4786 | GWIC | unsewered | DOMESTIC | ALVM | 71 | 66 | 57.7 | | 10.00 |
| 49493 | 2001Q1593 | 5/21/2001 | 45.9146 | -112.4679 | GWIC | unsewered | DOMESTIC | ALVM | 58 | 51 | 33.8 | < | 0.50 |
| 49537 | 2007Q0483 | 9/26/2006 | 45.9148 | -112.4579 | GWIC | unsewered | DOMESTIC | BDRCK | 87 | 77 | 26.1 | < | 0.25 |
| 49539 | 2004Q0379 | 2/10/2004 | 45.9148 | -112.4580 | GWIC | unsewered | DOMESTIC | ALVM | 48 | 38 | 24.6 | | 1.82 |
| 49551 | 2001Q1601 | 5/18/2001 | 45.9109 | -112.4599 | GWIC | unsewered | DOMESTIC | BDRCK | 340 | 300 | 62.3 | | 11.60 |

**Appendix.** Nitrate data from wells in the Summit Valley

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49553 | 2001Q1603 | 5/18/2001 | 45.9128 | -112.4556 | GWIC | unsewered | DOMESTIC | BDRCK | 85 | 65 | 56.2 | | 6.99 |
| 49591 | 1998Q0024 | 7/14/1997 | 45.9327 | -112.5536 | GWIC | unsewered | DOMESTIC | BDRCK | 220 | 83 | 46.2 | | 2.50 |
| 49619 | 1992Q0132 | 5/20/1992 | 45.9022 | -112.5830 | GWIC | unsewered | DOMESTIC | BDRCK | 240 | 200 | -- | | 44.70 |
| 50032 | 1994Q0029 | 7/14/1993 | 46.0041 | -112.4951 | GWIC | sewered | DOMESTIC | ALVM | 76 | 67 | 65.5 | | 6.38 |
| 50044 | 1999Q0266 | 9/4/1998 | 45.9898 | -112.5205 | GWIC | sewered | DOMESTIC | ALVM | 34 | 28 | 3.4 | | 5.69 |
| 50045 | 1999Q0269 | 9/11/1998 | 45.9911 | -112.5224 | GWIC | sewered | DOMESTIC | ALVM | 40 | 34 | 6.2 | | 9.09 |
| 50051 | 1994Q0023 | 7/13/1993 | 45.9998 | -112.5036 | GWIC | sewered | DOMESTIC | ALVM | 78 | 70 | 33.0 | | 7.36 |
| 50053 | 1994Q0032 | 7/15/1993 | 45.9935 | -112.5078 | GWIC | sewered | DOMESTIC | ALVM | 45 | 39 | 19.1 | | 5.72 |
| 50058 | 1994Q0030 | 7/14/1993 | 45.9953 | -112.4679 | GWIC | unsewered | DOMESTIC | BDRCK | 75 | 55 | 11.7 | | 0.09 |
| 50092 | 1994Q0885 | 12/2/1993 | 45.9814 | -112.4721 | GWIC | unsewered | DOMESTIC | BDRCK | 70 | 46 | 35.8 | | 10.30 |
| 50094 | 1994Q0019 | 7/13/1993 | 45.9818 | -112.5019 | GWIC | sewered | IRRIGATION | ALVM | 140 | 113 | -- | | 2.09 |
| 50099 | 1994Q0026 | 7/14/1993 | 45.9859 | -112.4971 | GWIC | sewered | DOMESTIC | ALVM | 94 | 84 | 33.7 | | 8.59 |
| 50118 | 1994Q0028 | 7/14/1993 | 45.9800 | -112.4945 | GWIC | sewered | DOMESTIC | ALVM | 100 | 87 | 34.7 | | 2.65 |
| 50128 | 1994Q0020 | 7/13/1993 | 45.9867 | -112.5094 | GWIC | sewered | DOMESTIC | ALVM | 106 | 94 | 5.0 | | 0.76 |
| 50141 | 1994Q0058 | 7/16/1993 | 45.9890 | -112.5153 | GWIC | sewered | DOMESTIC | ALVM | 28 | 20 | 3.9 | | 0.58 |
| 50176 | 1994Q0879 | 11/30/1993 | 45.9741 | -112.5166 | GWIC | sewered | DOMESTIC | ALVM | 65 | 60 | 21.7 | | 0.47 |
| 50202 | 1994Q0880 | 12/1/1993 | 45.9727 | -112.5252 | GWIC | sewered | DOMESTIC | BDRCK | 104 | 74 | 51.1 | | 40.12 |
| 50233 | 1994Q0886 | 12/2/1993 | 45.9647 | -112.5113 | GWIC | sewered | DOMESTIC | ALVM | 46 | 46 | 27.3 | | 0.17 |
| 50275 | 1996Q0239 | 8/17/1995 | 45.9624 | -112.5028 | GWIC | sewered | MONITORING | ALVM | 105 | 105 | 23.6 | | 1.50 |
| 50356 | 2002Q0425 | 10/25/2001 | 46.0078 | -112.5588 | GWIC | sewered | DOMESTIC | BDRCK | 175 | 135 | 54.1 | | 6.89 |
| 50452 | 1994Q0877 | 11/30/1993 | 45.9827 | -112.5361 | GWIC | sewered | DOMESTIC | ALVM | 45 | 38 | 16.6 | | 2.77 |
| 50461 | 2002Q0084 | 8/8/2001 | 45.9778 | -112.5346 | GWIC | sewered | DOMESTIC | BDRCK | 295 | 200 | 20.6 | | 9.19 |
| 120297 | 2001Q1728 | 6/24/2001 | 45.9150 | -112.5178 | GWIC | unsewered | DOMESTIC | ALVM | 54 | 48 | 11.2 | | 0.52 |
| 120303 | 2002Q0083 | 8/8/2001 | 45.9250 | -112.5559 | GWIC | unsewered | DOMESTIC | BDRCK | 120 | 80 | 80.4 | | 3.51 |
| 120304 | 2008Q0173 | 9/19/2007 | 45.9020 | -112.5402 | GWIC | unsewered | DOMESTIC | BDRCK | 245 | 162 | 76.7 | | 6.16 |
| 120321 | 1994Q0874 | 11/30/1993 | 45.9625 | -112.4836 | GWIC | sewered | DOMESTIC | ALVM | 45 | 39 | 14.7 | | 1.01 |
| 120998 | 1994Q0031 | 7/15/1993 | 46.0037 | -112.6081 | GWIC | unsewered | DOMESTIC | BDRCK | 160 | 140 | 12.6 | | 6.25 |
| 121185 | 1990Q0494 | 11/7/1990 | 46.0042 | -112.6078 | GWIC | unsewered | MONITORING | ALVM | 19.4 | 19.4 | 15.1 | | 12.40 |
| 122652 | 1991Q0644 | 7/31/1991 | 45.9875 | -112.5011 | GWIC | sewered | DOMESTIC | ALVM | 203 | 150 | 31.0 | | 5.83 |
| 122864 | 1991Q1021 | 9/25/1991 | 45.9938 | -112.5188 | GWIC | sewered | DOMESTIC | ALVM | 66 | 60 | 11.2 | | 3.22 |
| 123052 | 2007Q0491 | 9/28/2006 | 45.9118 | -112.4558 | GWIC | unsewered | DOMESTIC | BDRCK | 375 | 335 | 44.7 | | 5.17 |
| 123304 | 2003Q0288 | 8/20/2002 | 45.9901 | -112.5379 | GWIC | sewered | MONITORING | ALVM | 50 | 42 | 19.3 | | 13.80 |
| 123306 | 1994Q0867 | 11/29/1993 | 45.9772 | -112.4888 | GWIC | sewered | COMMERCIAL | ALVM | 51 | 45 | 19.9 | | 1.90 |
| 124358 | 1994Q0035 | 7/15/1993 | 45.9840 | -112.5094 | GWIC | sewered | DOMESTIC | ALVM | 307 | 206 | 9.4 | | 0.37 |
| 125214 | 1991Q1167 | 12/12/1991 | 45.9533 | -112.5308 | GWIC | unsewered | DOMESTIC | BDRCK | 90 | 70 | 30.0 | | 5.37 |
| 125794 | 1994Q0037 | 7/15/1993 | 45.9913 | -112.4995 | GWIC | sewered | DOMESTIC | ALVM | 160 | 144 | 42.8 | | 5.66 |
| 125814 | 2003Q0128 | 7/23/2002 | 45.9400 | -112.4973 | GWIC | unsewered | DOMESTIC | ALVM | 84 | 75 | 59.0 | | 0.53 |
| 126150 | 1995Q0280 | 10/5/1994 | 45.9967 | -112.5393 | GWIC | sewered | MONITORING | BDRCK | 100 | 65 | 7.2 | | 2.25 |
| 126151 | 1995Q0281 | 10/10/1994 | 45.9967 | -112.5393 | GWIC | sewered | MONITORING | BDRCK | 200 | 176 | -- | | 2.25 |
| 127062 | 1994Q0038 | 7/15/1993 | 46.0016 | -112.4954 | GWIC | sewered | DOMESTIC | ALVM | 98 | 90 | 54.6 | | 6.77 |
| 127641 | 1998Q1162 | 6/24/1998 | 45.9856 | -112.5215 | GWIC | sewered | DOMESTIC | ALVM | 47 | 39 | 6.9 | | 1.01 |
| 127992 | 1994Q0004 | 7/12/1993 | 45.9930 | -112.5291 | GWIC | sewered | IRRIGATION | ALVM | 32 | 26 | 3.5 | | 0.26 |
| 128027 | 1994Q0003 | 7/12/1993 | 45.9943 | -112.5184 | GWIC | sewered | DOMESTIC | ALVM | 38 | 32 | 9.9 | | 6.48 |
| 128029 | 1994Q0021 | 7/13/1993 | 45.9990 | -112.5027 | GWIC | sewered | DOMESTIC | ALVM | 76 | 70 | 30.2 | | 15.96 |
| 128065 | 1994Q0078 | 7/27/1993 | 46.0321 | -112.5762 | GWIC | unsewered | DOMESTIC | BDRCK | 220 | 195 | 87.5 | < | 0.01 |

**Appendix.** Nitrate data from wells in the Summit Valley

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 128109 | 1992Q0306 | 7/1/1992 | 45.9755 | -112.4922 | GWIC | sewered | IRRIGATION | ALVM | 63 | 56 | 26.7 | | 4.47 |
| 128499 | 1992Q0683 | 8/4/1992 | 45.9913 | -112.5405 | GWIC | sewered | MONITORING | ALVM | 51 | 43 | 7.0 | | 21.50 |
| 128728 | 1994Q0881 | 12/1/1993 | 45.9557 | -112.4727 | GWIC | unsewered | DOMESTIC | ALVM | 115 | 115 | 42.0 | | 1.05 |
| 129259 | 1994Q0075 | 7/22/1993 | 45.9935 | -112.4912 | GWIC | sewered | DOMESTIC | ALVM | 123 | 115 | 69.5 | | 5.91 |
| 129262 | 2002Q0422 | 10/24/2001 | 45.9975 | -112.4932 | GWIC | sewered | DOMESTIC | ALVM | 116 | 108 | 51.0 | | 12.50 |
| 129263 | 1994Q0036 | 7/15/1993 | 45.9904 | -112.4878 | GWIC | sewered | DOMESTIC | ALVM | 123 | 115 | 79.7 | | 5.43 |
| 129265 | 1994Q0027 | 7/14/1993 | 45.9850 | -112.4904 | GWIC | sewered | DOMESTIC | ALVM | 113 | 105 | 53.9 | | 4.32 |
| 129268 | 1994Q0064 | 7/19/1993 | 45.9805 | -112.4965 | GWIC | sewered | DOMESTIC | ALVM | 54 | 48 | 15.3 | | 1.22 |
| 129387 | 1992Q1021 | 8/25/1992 | 45.9674 | -112.4784 | GWIC | sewered | DOMESTIC | ALVM | 176 | 168 | 42.9 | | 2.67 |
| 130887 | 1992Q1441 | 10/9/1992 | 46.0050 | -112.4607 | GWIC | unsewered | MONITORING | ALVM | 28 | 23 | 17.6 | < | 0.10 |
| 131146 | 2007Q0482 | 9/26/2006 | 45.9126 | -112.4580 | GWIC | unsewered | DOMESTIC | BDRCK | 220 | 200 | 57.2 | | 5.65 |
| 131298 | 1992Q1979 | 10/27/1992 | 46.0025 | -112.5730 | GWIC | unsewered | MONITORING | ALVM | 7.8 | 2.8 | 4.4 | < | 0.10 |
| 133452 | 1993Q0797 | 6/17/1993 | 45.9352 | -112.4907 | GWIC | unsewered | DOMESTIC | ALVM | -- | -- | 54.9 | | 0.20 |
| 134087 | 1994Q0001 | 7/8/1993 | 45.9686 | -112.4925 | GWIC | sewered | DOMESTIC | ALVM | -- | -- | -- | | 0.92 |
| 137595 | 2001Q1254 | 2/22/2001 | 45.9953 | -112.5219 | GWIC | sewered | MONITORING | ALVM | 23.5 | 8 | 12.6 | | 7.05 |
| 142004 | 1994Q1021 | 5/25/1994 | 46.0061 | -112.6118 | GWIC | unsewered | PUBLIC WATER SUPPLY | BDRCK | 154 | 110 | -- | | 2.56 |
| 144011 | 1991Q1166 | 12/17/1991 | 45.9492 | -112.4864 | GWIC | unsewered | DOMESTIC | ALVM | 128 | 64 | 35.0 | | 0.24 |
| 145960 | 2001Q1275 | 3/5/2001 | 45.9095 | -112.4501 | GWIC | unsewered | DOMESTIC | BDRCK | 100 | 80 | 39.4 | | 4.32 |
| 149205 | 2007Q0492 | 9/28/2006 | 45.9127 | -112.4604 | GWIC | unsewered | DOMESTIC | BDRCK | 240 | 180 | 46.4 | | 9.61 |
| 150276 | 2002Q0771 | 1/7/2002 | 45.9146 | -112.4555 | GWIC | unsewered | DOMESTIC | BDRCK | 160 | 140 | 28.7 | | 8.45 |
| 150389 | 2001Q1259 | 2/23/2001 | 45.9927 | -112.5311 | GWIC | sewered | MONITORING | ALVM | 12.5 | 6 | 4.6 | < | 0.50 |
| 150395 | 2001Q1253 | 2/22/2001 | 45.9991 | -112.5259 | GWIC | sewered | MONITORING | ALVM | 50 | 39 | 24.1 | | 12.00 |
| 150402 | 2003Q0929 | 4/11/2003 | 46.0034 | -112.5149 | GWIC | sewered | MONITORING | ALVM | 61.5 | 50.5 | 30.2 | < | 12.50 |
| 150409 | 2007Q0960 | 4/23/2007 | 45.9993 | -112.5132 | GWIC | sewered | MONITORING | ALVM | 30 | 19.7 | 17.7 | | 5.83 |
| 150410 | 2001Q1245 | 2/21/2001 | 45.9993 | -112.5131 | GWIC | sewered | MONITORING | ALVM | 61 | 47.3 | 19.2 | | 2.44 |
| 150411 | 2003Q0941 | 4/10/2003 | 45.9995 | -112.5122 | GWIC | sewered | MONITORING | ALVM | 64 | 50.4 | 21.4 | | 2.35 |
| 150412 | 2006Q1087 | 5/4/2006 | 46.0003 | -112.5079 | GWIC | sewered | MONITORING | ALVM | 30 | 24.5 | 23.6 | | 17.00 |
| 150413 | 2006Q1085 | 5/4/2006 | 46.0003 | -112.5079 | GWIC | sewered | MONITORING | ALVM | 62 | 51 | 20.6 | | 13.60 |
| 153760 | 2001Q1596 | 5/22/2001 | 45.9667 | -112.5125 | GWIC | sewered | DOMESTIC | ALVM | 56.6 | 47 | 24.7 | | 11.10 |
| 153761 | 1997Q0001 | 7/1/1996 | 46.0458 | -112.5473 | GWIC | unsewered | DOMESTIC | BDRCK | 180 | 140 | 94.0 | | 6.70 |
| 154868 | 2007Q0490 | 9/28/2006 | 45.9110 | -112.4576 | GWIC | unsewered | DOMESTIC | BDRCK | 390 | 350 | 100.0 | | 1.66 |
| 156155 | 2007Q0265 | 8/14/2006 | 45.9903 | -112.5380 | GWIC | sewered | COMMERCIAL | BDRCK | 260 | 190 | 25.0 | | 11.30 |
| 157638 | 1997Q0274 | 9/10/1996 | 46.0117 | -112.5208 | GWIC | sewered | MONITORING | BDRCK | 290 | 290 | 86.6 | < | 0.05 |
| 158224 | 1998Q0841 | 3/18/1997 | 45.9987 | -112.5455 | GWIC | sewered | MONITORING | BDRCK | 496 | 471 | 53.8 | < | 0.25 |
| 158225 | 2002Q0669 | 12/5/2001 | 45.9987 | -112.5456 | GWIC | sewered | MONITORING | ALVM | 61 | 38 | 25.1 | | 5.28 |
| 158226 | 2002Q0668 | 12/5/2001 | 45.9994 | -112.5404 | GWIC | sewered | MONITORING | BDRCK | 174 | 169 | 13.8 | < | 0.50 |
| 158230 | 1997Q0675 | 2/28/1997 | 46.0117 | -112.5209 | GWIC | sewered | MONITORING | BDRCK | 600 | 600 | 420.6 | < | 2.50 |
| 158231 | 1997Q0568 | 12/6/1996 | 45.9994 | -112.5357 | GWIC | sewered | MONITORING | BDRCK | 168.5 | 168.5 | 8.9 | < | 0.05 |
| 158435 | 2002Q0430 | 10/29/2001 | 45.9527 | -112.5266 | GWIC | sewered | DOMESTIC | BDRCK | 61 | 41 | 36.4 | | 3.65 |
| 160113 | 2002Q0257 | 9/19/2001 | 46.0312 | -112.5851 | GWIC | unsewered | DOMESTIC | BDRCK | 260 | 260 | 174.7 | < | 0.50 |
| 163580 | 2001Q1594 | 5/19/2001 | 45.9047 | -112.4793 | GWIC | unsewered | DOMESTIC | BDRCK | 120 | 100 | 63.7 | | 2.12 |
| 164443 | 2001Q1146 | 1/8/2001 | 46.0008 | -112.5315 | GWIC | sewered | MONITORING | ALVM | 192 | 167 | 54.4 | | 12.80 |
| 165216 | 2007Q0487 | 9/26/2006 | 45.9117 | -112.4579 | GWIC | unsewered | DOMESTIC | BDRCK | 180 | 160 | 84.4 | | 7.48 |
| 165704 | 2007Q0494 | 9/28/2006 | 45.9101 | -112.4531 | GWIC | unsewered | DOMESTIC | BDRCK | 120 | 100 | 27.7 | | 4.98 |
| 166182 | 2004Q0511 | 5/6/2004 | 46.0047 | -112.5032 | GWIC | unsewered | MONITORING | ALVM | 50 | 50 | 21.8 | | 9.94 |

**Appendix.** Nitrate data from wells in the Summit Valley

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 166775 | 2002Q0175 | 8/16/2001 | 45.9939 | -112.5472 | GWIC | sewered | MONITORING | ALVM | 15 | 5 | 4.8 | | 12.90 |
| 168176 | 1999Q0267 | 9/4/1998 | 45.9918 | -112.5234 | GWIC | sewered | IRRIGATION | ALVM | -- | -- | 5.2 | | 4.15 |
| 168177 | 1999Q0261 | 9/4/1998 | 45.9909 | -112.5234 | GWIC | sewered | IRRIGATION | ALVM | -- | -- | 3.8 | | 2.52 |
| 168178 | 1999Q0268 | 9/4/1998 | 45.9900 | -112.5234 | GWIC | sewered | IRRIGATION | ALVM | -- | -- | 4.6 | | 5.29 |
| 168216 | 2002Q0434 | 10/27/2001 | 45.9140 | -112.4599 | GWIC | unsewered | DOMESTIC | BDRCK | 95 | 70 | 36.3 | | 6.72 |
| 169068 | 1999Q0355 | 10/27/1998 | 45.9878 | -112.5192 | GWIC | sewered | MONITORING | ALVM | 15 | 10 | -- | | 1.50 |
| 171279 | 2002Q0086 | 8/8/2001 | 45.9838 | -112.5330 | GWIC | sewered | IRRIGATION | ALVM | 100 | 100 | 26.5 | | 39.70 |
| 171285 | 2004Q0067 | 8/11/2003 | 45.9861 | -112.5448 | GWIC | unsewered | COMMERCIAL | ALVM | 61.3 | 61.3 | 30.0 | | 5.32 |
| 171287 | 1999Q0448 | 12/30/1998 | 45.9906 | -112.5111 | GWIC | sewered | MONITORING | ALVM | 18 | 13 | 12.7 | | 12.27 |
| 171288 | 1999Q0449 | 12/29/1998 | 45.9899 | -112.5216 | GWIC | sewered | MONITORING | ALVM | 19 | 15 | 8.3 | | 4.42 |
| 171289 | 1999Q0766 | 6/10/1999 | 45.9857 | -112.5165 | GWIC | sewered | MONITORING | ALVM | 12.5 | 7.5 | 5.4 | | 2.84 |
| 171290 | 1999Q0765 | 6/11/1999 | 45.9847 | -112.5140 | GWIC | sewered | MONITORING | ALVM | 15.4 | 10.4 | 6.2 | | 5.21 |
| 171291 | 1999Q0767 | 6/10/1999 | 45.9844 | -112.5244 | GWIC | sewered | MONITORING | ALVM | 16.5 | 11.5 | 9.2 | | 13.77 |
| 171292 | 1999Q0764 | 6/11/1999 | 45.9895 | -112.5147 | GWIC | sewered | MONITORING | ALVM | 15 | 10 | 8.7 | | 5.05 |
| 171294 | 1999Q0354 | 10/27/1998 | 45.9935 | -112.5238 | GWIC | sewered | MONITORING | ALVM | 19 | 14 | 9.3 | | 2.77 |
| 174040 | 2000Q0341 | 10/4/1999 | 45.9968 | -112.5511 | GWIC | sewered | DOMESTIC | ALVM | 32 | 24 | 9.9 | | 2.43 |
| 175710 | 2000Q1155 | 5/22/2000 | 45.9954 | -112.4579 | GWIC | unsewered | DOMESTIC | BDRCK | 100 | 100 | 28.9 | < | 0.50 |
| 179106 | 2006Q0156 | 8/8/2005 | 45.9879 | -112.5583 | GWIC | unsewered | DOMESTIC | BDRCK | 70 | 50 | 26.4 | | 0.34 |
| 179158 | 2007Q0495 | 9/29/2006 | 45.9117 | -112.4595 | GWIC | unsewered | DOMESTIC | BDRCK | 100 | 80 | 33.0 | | 20.40 |
| 179162 | 2002Q0143 | 8/15/2001 | 45.9755 | -112.4667 | GWIC | unsewered | DOMESTIC | BDRCK | 80 | 60 | 15.1 | | 4.05 |
| 180512 | 2003Q0797 | 12/30/2002 | 45.9139 | -112.4517 | GWIC | unsewered | DOMESTIC | BDRCK | 100 | 80 | 28.4 | | 2.20 |
| 184068 | 2003Q0998 | 4/23/2003 | 46.0027 | -112.5853 | GWIC | unsewered | MONITORING | ALVM | 20.3 | 20.3 | 14.5 | | 2.20 |
| 184133 | 2001Q0698 | 9/28/2000 | 45.9989 | -112.5467 | GWIC | sewered | MONITORING | BDRCK | 498 | 463 | -- | < | 0.50 |
| 188524 | 2002Q0032 | 7/9/2001 | 45.9608 | -112.5684 | GWIC | unsewered | DOMESTIC | BDRCK | 160 | 120 | 64.8 | | 0.93 |
| 188843 | 2002Q0123 | 8/14/2001 | 45.9886 | -112.6104 | GWIC | unsewered | DOMESTIC | BDRCK | 220 | 220 | 190.0 | | 4.89 |
| 189232 | 2002Q0205 | 8/22/2001 | 45.8962 | -112.5786 | GWIC | unsewered | DOMESTIC | BDRCK | 80 | 80 | 14.1 | < | 0.50 |
| 190733 | 2007Q0489 | 9/28/2006 | 45.9139 | -112.4558 | GWIC | unsewered | DOMESTIC | BDRCK | 140 | 80 | 48.4 | | 7.34 |
| 207686 | 2005Q0333 | 12/14/2004 | 45.9778 | -112.5851 | GWIC | unsewered | DOMESTIC | BDRCK | 220 | 200 | 63.0 | | 2.24 |
| 215790 | 2005Q0266 | 10/26/2004 | 45.9972 | -112.5204 | GWIC | sewered | MONITORING | ALVM | 55 | 55 | 8.2 | | 1.73 |
| 218848 | 2006Q0429 | 10/22/2005 | 45.9680 | -112.4765 | GWIC | unsewered | IRRIGATION | ALVM | 97.5 | 71.5 | 36.5 | | 1.59 |
| 222920 | 2007Q0949 | 3/27/2007 | 46.0040 | -112.5086 | GWIC | sewered | MONITORING | ALVM | -- | -- | 22.5 | < | 2.50 |
| 222921 | 2007Q0757 | 11/6/2006 | 46.0028 | -112.5004 | GWIC | sewered | MONITORING | ALVM | -- | -- | 42.8 | | 16.00 |
| 224152 | 2006Q0862 | 2/7/2006 | 45.9994 | -112.5010 | GWIC | sewered | MONITORING | ALVM | -- | -- | 37.8 | | 9.01 |
| 224153 | 2006Q1006 | 4/25/2006 | 46.0006 | -112.4896 | GWIC | sewered | MONITORING | ALVM | 123 | 123 | 71.8 | | 5.10 |
| 230013 | 2007Q0493 | 9/28/2006 | 45.9144 | -112.4606 | GWIC | unsewered | DOMESTIC | BDRCK | 124 | 104 | 40.0 | | 3.63 |
| 236994 | 2008Q0033 | 7/20/2007 | 45.9074 | -112.4487 | GWIC | unsewered | DOMESTIC | BDRCK | 166 | 146 | 10.0 | | 1.96 |
| 237861 | 2007Q1134 | 6/11/2007 | 45.9555 | -112.4738 | GWIC | unsewered | DOMESTIC | ALVM | 145 | 137 | 50.0 | | 0.94 |
| 890802 | 1989Q1173 | 8/24/1989 | 45.9970 | -112.5396 | GWIC | sewered | COMMERCIAL | ALVM | 35 | 28 | 8.1 | | 5.26 |
| 890975 | 1989Q1452 | 11/13/1989 | 45.9102 | -112.4947 | GWIC | unsewered | DOMESTIC | BDRCK | 52 | 39 | 35.5 | | 7.90 |
| 890997 | 1994Q0006 | 7/12/1993 | 46.0055 | -112.5537 | GWIC | sewered | DOMESTIC | BDRCK | 125 | 75 | 14.8 | | 2.58 |
| 891015 | 1989Q1551 | 12/19/1989 | 45.9112 | -112.4674 | GWIC | unsewered | DOMESTIC | BDRCK | 140 | 80 | 52.9 | | 17.60 |
| 892032 | 1990Q0052 | 3/29/1990 | 45.9972 | -112.5208 | GWIC | sewered | IRRIGATION | ALVM | 41 | 35 | 8.0 | | 2.16 |
| 892039 | 1990Q0094 | 4/24/1990 | 45.9847 | -112.5266 | GWIC | sewered | DOMESTIC | ALVM | 53 | 47 | 4.3 | | 3.19 |
| 892116 | 2000Q0876 | 4/20/2000 | 46.0101 | -112.5613 | GWIC | unsewered | MONITORING | BDRCK | 206.5 | 138 | 80.8 | | 6.56 |

**Appendix.** Nitrate data from wells in the Summit Valley

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4487 | --- | 12/22/2006 | 45.9247 | -112.4713 | MDEQ | unsewered | DOMESTIC | ALVM | 71 | 65 | 18.0 | | 1.03 |
| 49308 | --- | 6/7/2007 | 45.9377 | -112.5269 | MDEQ | unsewered | DOMESTIC | BDRCK | 62 | 35 | 14.0 | | 0.97 |
| 49359 | --- | 6/15/2006 | 45.9408 | -112.4601 | MDEQ | unsewered | DOMESTIC | ALVM | -- | -- | -- | | 1.04 |
| 49361 | --- | 6/15/2006 | 45.9392 | -112.4581 | MDEQ | unsewered | DOMESTIC | ALVM | 85 | 79 | 50.0 | | 1.17 |
| 49365 | --- | 8/15/2006 | 45.9304 | -112.4613 | MDEQ | unsewered | DOMESTIC | ALVM | 112 | 105 | 60.0 | | 7.20 |
| 49368 | --- | 6/15/2006 | 45.9311 | -112.4619 | MDEQ | unsewered | DOMESTIC | ALVM | 108 | 108 | 60.0 | | 4.29 |
| 49369 | --- | 6/15/2006 | 45.9299 | -112.4554 | MDEQ | unsewered | DOMESTIC | ALVM | 153 | 153 | -- | | 4.44 |
| 49374 | --- | 8/15/2006 | 45.9298 | -112.4619 | MDEQ | unsewered | DOMESTIC | ALVM | 165 | 165 | 65.0 | | 2.34 |
| 49375 | --- | 6/15/2006 | 45.9313 | -112.4593 | MDEQ | unsewered | DOMESTIC | ALVM | 116 | 111 | 82.2 | | 3.01 |
| 49377 | --- | 8/5/2005 | 45.9310 | -112.4644 | MDEQ | unsewered | DOMESTIC | ALVM | 103 | 103 | -- | | 1.70 |
| 49378 | --- | 6/15/2006 | 45.9305 | -112.4635 | MDEQ | unsewered | DOMESTIC | ALVM | 121 | 60 | 60.0 | | 2.03 |
| 49387 | --- | 5/15/2000 | 45.9181 | -112.4555 | MDEQ | unsewered | DOMESTIC | ALVM | 120 | 113 | 68.2 | | 9.58 |
| 49409 | --- | 3/29/2007 | 45.9255 | -112.4692 | MDEQ | unsewered | DOMESTIC | ALVM | 72 | 67 | 18.0 | | 3.81 |
| 49423 | --- | 1/9/2007 | 45.9229 | -112.4822 | MDEQ | unsewered | DOMESTIC | ALVM | 87 | 80 | 58.8 | | 8.05 |
| 49436 | --- | 1/9/2007 | 45.9228 | -112.4768 | MDEQ | unsewered | DOMESTIC | ALVM | 64 | 57 | 42.5 | < | 0.05 |
| 49437 | --- | 12/22/2006 | 45.9218 | -112.4732 | MDEQ | unsewered | DOMESTIC | ALVM | 54 | 47 | 20.0 | | 0.21 |
| 49538 | --- | 5/30/2006 | 45.9166 | -112.4512 | MDEQ | unsewered | DOMESTIC | BDRCK | 65 | 62 | 28.0 | | 5.01 |
| 49573 | --- | 4/18/2006 | 45.9157 | -112.4432 | MDEQ | unsewered | DOMESTIC | BDRCK | 162 | 120 | 23.7 | | 6.44 |
| 50059 | --- | 9/15/2006 | 45.9147 | -112.4385 | MDEQ | unsewered | DOMESTIC | BDRCK | 180 | 160 | -- | | 6.40 |
| 120296 | --- | 9/21/2007 | 45.9486 | -112.5247 | MDEQ | sewered | DOMESTIC | BDRCK | 80 | 65 | 12.0 | | 0.96 |
| 131144 | --- | 6/15/2006 | 45.9309 | -112.4659 | MDEQ | unsewered | DOMESTIC | ALVM | 103 | 103 | 43.0 | | 3.08 |
| 131442 | --- | 8/15/2006 | 45.9291 | -112.4593 | MDEQ | unsewered | DOMESTIC | ALVM | 137 | 127 | 87.0 | | 2.94 |
| 134928 | --- | 1/9/2007 | 45.9205 | -112.4788 | MDEQ | unsewered | DOMESTIC | ALVM | 98 | 90 | 60.0 | | 2.03 |
| 137291 | --- | 8/5/2005 | 45.9306 | -112.4562 | MDEQ | unsewered | DOMESTIC | ALVM | 125 | 118 | 109.7 | | 4.70 |
| 158774 | --- | 3/15/2007 | 45.9880 | -112.4739 | MDEQ | unsewered | DOMESTIC | BDRCK | 160 | 140 | 75.0 | | 4.40 |
| 162606 | --- | 9/28/2006 | 45.9889 | -112.4726 | MDEQ | unsewered | DOMESTIC | BDRCK | 340 | 180 | 140.0 | | 2.50 |
| 163589 | --- | 9/30/2005 | 45.9732 | -112.5832 | MDEQ | unsewered | DOMESTIC | BDRCK | 100 | 80 | 50.0 | | 2.70 |
| 163590 | --- | 9/30/2005 | 45.9620 | -112.5728 | MDEQ | unsewered | DOMESTIC | BDRCK | 101 | 81 | 38.0 | | 1.20 |
| 163954 | --- | 6/15/2006 | 45.9415 | -112.4592 | MDEQ | unsewered | DOMESTIC | BDRCK | 118 | 95 | 63.0 | | 1.91 |
| 166093 | --- | 12/22/2006 | 45.9222 | -112.4685 | MDEQ | unsewered | DOMESTIC | ALVM | 66 | 58 | 20.0 | | 1.98 |
| 169825 | --- | 9/30/2005 | 45.9611 | -112.5846 | MDEQ | unsewered | DOMESTIC | BDRCK | 121 | 80 | 37.0 | | 2.30 |
| 185742 | --- | 12/1/2005 | 45.9326 | -112.4912 | MDEQ | unsewered | DOMESTIC | ALVM | 148 | 140 | 65.0 | | 1.40 |
| 188434 | --- | 5/30/2006 | 45.9180 | -112.4542 | MDEQ | unsewered | MONITORING | ALVM | 86 | 76 | 38.0 | | 7.05 |
| 188439 | --- | 5/30/2006 | 45.9210 | -112.4453 | MDEQ | unsewered | MONITORING | ALVM | 74 | 64 | 42.0 | | 0.78 |
| 188446 | --- | 6/22/2006 | 45.9157 | -112.4450 | MDEQ | unsewered | DOMESTIC | ALVM | 63 | 53 | 3.0 | | 0.63 |
| 201467 | --- | 1/9/2007 | 45.9331 | -112.4970 | MDEQ | unsewered | DOMESTIC | ALVM | 140 | 120 | 40.0 | < | 0.05 |
| 206625 | --- | 6/22/2006 | 45.9164 | -112.4470 | MDEQ | unsewered | DOMESTIC | BDRCK | 224 | 164 | 2.0 | | 7.98 |
| 211273 | --- | 7/9/2007 | 45.9401 | -112.5350 | MDEQ | unsewered | DOMESTIC | BDRCK | 100 | 80 | 59.0 | | 3.76 |
| 211274 | --- | 7/9/2007 | 45.9431 | -112.5353 | MDEQ | unsewered | DOMESTIC | BDRCK | 100 | 80 | 29.0 | | 8.68 |
| 217903 | --- | 9/15/2006 | 45.9150 | -112.4551 | MDEQ | unsewered | DOMESTIC | BDRCK | 100 | 55 | 14.0 | | 0.09 |
| 218030 | --- | 5/30/2006 | 45.9183 | -112.4564 | MDEQ | unsewered | DOMESTIC | BDRCK | 140 | 120 | 56.0 | | 6.79 |
| 218686 | --- | 9/30/2005 | 45.9646 | -112.5952 | MDEQ | unsewered | DOMESTIC | BDRCK | 120 | 80 | 57.0 | | 1.70 |
| 218691 | --- | 9/30/2005 | 45.9727 | -112.5882 | MDEQ | unsewered | DOMESTIC | BDRCK | 110 | 50 | 38.4 | | 0.51 |
| 219743 | --- | 9/30/2005 | 45.9638 | -112.5902 | MDEQ | unsewered | DOMESTIC | BDRCK | 180 | 150 | 10.0 | | 1.80 |
| 219748 | --- | 9/30/2005 | 45.9672 | -112.5919 | MDEQ | unsewered | DOMESTIC | BDRCK | 160 | 130 | 40.0 | | 1.30 |

**Appendix.** Nitrate data from wells in the Summit Valley

| GWIC ID number | GWIC sample number | Sample date | Latitude | Longitude | Source | Area | Well use | Unit | Total depth (ft) | Depth water enters (ft) | Static water level (ft) | -- | Nitrate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 225226 | --- | 6/15/2006 | 45.9320 | -112.4630 | MDEQ | unsewered | DOMESTIC | ALVM | 149 | 141 | 60.0 | | 1.87 |
| 225668 | --- | 3/22/2006 | 45.9217 | -112.4520 | MDEQ | unsewered | MONITORING | BDRCK | 240 | 208 | 116.0 | | 0.02 |
| --- | --- | 6/15/2006 | 45.9330 | -112.4551 | MDEQ | unsewered | DOMESTIC | ALVM | 280 | 240 | 158.3 | | 0.23 |
| --- | --- | 9/30/2005 | 45.9636 | -112.5922 | MDEQ | unsewered | DOMESTIC | BDRCK | -- | -- | -- | | 0.45 |
| --- | --- | 6/15/2006 | 45.9397 | -112.4643 | MDEQ | unsewered | DOMESTIC | ALVM | 280 | 260 | 33.6 | | 0.76 |
| --- | --- | 12/1/2005 | 45.9314 | -112.4914 | MDEQ | unsewered | DOMESTIC | ALVM | 170 | 170 | -- | | 1.20 |
| --- | --- | 7/18/2006 | 45.9116 | -112.4522 | MDEQ | unsewered | DOMESTIC | BDRCK | -- | -- | -- | | 1.48 |
| --- | --- | 9/30/2005 | 45.9651 | -112.5918 | MDEQ | unsewered | DOMESTIC | BDRCK | -- | 90 | -- | | 1.60 |
| --- | --- | 6/15/2006 | 45.9342 | -112.4598 | MDEQ | unsewered | DOMESTIC | ALVM | 160 | 140 | 57.0 | | 1.80 |
| --- | --- | 6/15/2006 | 45.9310 | -112.4635 | MDEQ | unsewered | DOMESTIC | ALVM | -- | -- | -- | | 3.07 |
| --- | --- | 7/18/2006 | 45.9133 | -112.4367 | MDEQ | unsewered | DOMESTIC | BDRCK | -- | -- | -- | | 3.30 |
| --- | --- | 6/15/2006 | 45.9311 | -112.4627 | MDEQ | unsewered | DOMESTIC | ALVM | -- | -- | -- | | 6.65 |
| --- | --- | 6/15/2006 | 45.9312 | -112.4608 | MDEQ | unsewered | DOMESTIC | ALVM | -- | -- | -- | | 7.51 |
| --- | --- | 6/15/2006 | 45.9312 | -112.4587 | MDEQ | unsewered | DOMESTIC | ALVM | -- | -- | -- | | 7.52 |
| --- | --- | 6/15/2006 | 45.9303 | -112.4626 | MDEQ | unsewered | DOMESTIC | ALVM | -- | -- | -- | | 13.40 |

Abbreviations
Source: GWIC, Ground-Water Information Center; MDEQ, Montana Department of Environmental Quality
Unit: ALVM, alluvial aquifer; BDRCK, fractured bedrock aquifer
mg/L: milligrams per liter