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GROUNDWATER QUANTITY AND QUALITY NEAR HAMILTON, MONTANA

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Front photo: Bitterroot Valley North of Hamilton. Photo by Todd Myse.

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ABSTRACT

Population growth in and around Hamilton, Montana, from 1990 to 2010 gave rise to questions regarding the effects of population growth and development on the groundwater and surface-water systems in the area, including water quality and quantity. To help answer these questions, the Montana Bureau of Mines and Geology Ground Water Investigation Program measured groundwater elevations in wells, and stage and flow (discharge) at streams, irrigation canals, and ditches within a 77-mi^2 study area around Hamilton during 2014–2015. Nitrate samples were collected from wells and streams to develop a baseline characterization of nitrate concentrations in the area and to facilitate comparison with historical concentrations. An annual surface-water budget for the Bitterroot River and a groundwater budget for the eastern portion of the study area were developed for calendar year 2015. Both water budgets indicated the Bitterroot River gained water from the groundwater system throughout the year. Irrigation-related recharge (ditch and canal water lost during conveyance and excess water applied to irrigated fields) accounted for about 35% of the inflows to the groundwater system. Domestic use was one of the smallest groundwater outflow components (3%). Groundwater-level records show an irrigation response pattern of recharge from leaking ditches into the groundwater system, causing groundwater levels to peak at the end of the irrigation season in September and October in certain wells. Nonparametric statistical trend tests indicated changes in groundwater elevations and nitrate concentrations over time were spatially variable. Wells with decreasing groundwater-elevation trends and increasing nitrate-concentration trends typically are completed in less permeable aquifer materials that receive less groundwater recharge than other wells in the study area. Thus, long-term groundwater-elevation and nitrate-concentration trends appear to be more related to local aquifer properties than to regional changes in the groundwater system in the Hamilton area.

INTRODUCTION

The city of Hamilton is located in the Bitterroot Valley in western Montana (fig. 1). It is the largest city in Ravalli County. Over the past several decades, the Hamilton area (approximately a 2-mi radius surrounding the city limits) and Ravalli County have experienced rapid population growth (fig. 2A). For Hamilton specifically, the population was relatively stable between 1940 and 1970 (2,332 to 2,499), followed by a slight increase in population from 1970 to 1990 (228), and a sharp increase from 1990 to 2010. Specifically, between 1990 and 2000 there was a population increase of 35% (978) and from 2000 to 2010 the population increased another 17% (727). In 2010, the Hamilton area constituted 26% of the Ravalli County population. Population growth of Hamilton and Ravalli County slowed from 2010 to 2020 (City of Hamilton, 2015; United States Census Bureau, 2020; fig. 2A).

With increased population, the number of housing units have also increased. Between 2000 and 2010, the number of housing units within Ravalli County increased by 23% (3,637 units, United States Census Bureau, 2010). Consequently, the number of wells installed in Ravalli County and the Hamilton area has also increased with population growth (fig. 2A). Conversely, the farmland acreage in Ravalli County has decreased over time. This decrease in farmland acreage is concurrent with an increase in the number of farms (fig. 2B; USDA, 2020). This indicates that there has been a decrease in individual farm size and an overall shift to less agricultural land use and more residential land use. Residential growth in the Hamilton area is similar to residential growth in Ravalli County (City of Hamilton, 2015).

Overall, these changes in population and land use can ultimately affect groundwater and surface-water use and quality. For example, the reduction of agricultural land to accommodate additional residential development can potentially decrease the amount of groundwater recharge from irrigation, which is mostly sourced from surface water. Furthermore, septic systems can be a source of nutrients such as nitrate (NO_3) that could enter groundwater in the study area; thus, additional septic systems could potentially lead to more nitrate loading to the system. As the demand on groundwater increases and if recharge decreases in response to potential irrigation decreases, questions regarding groundwater availability and the effects to surface water are coupled with the county's concerns of potential water-quality changes due to land-use modifications.

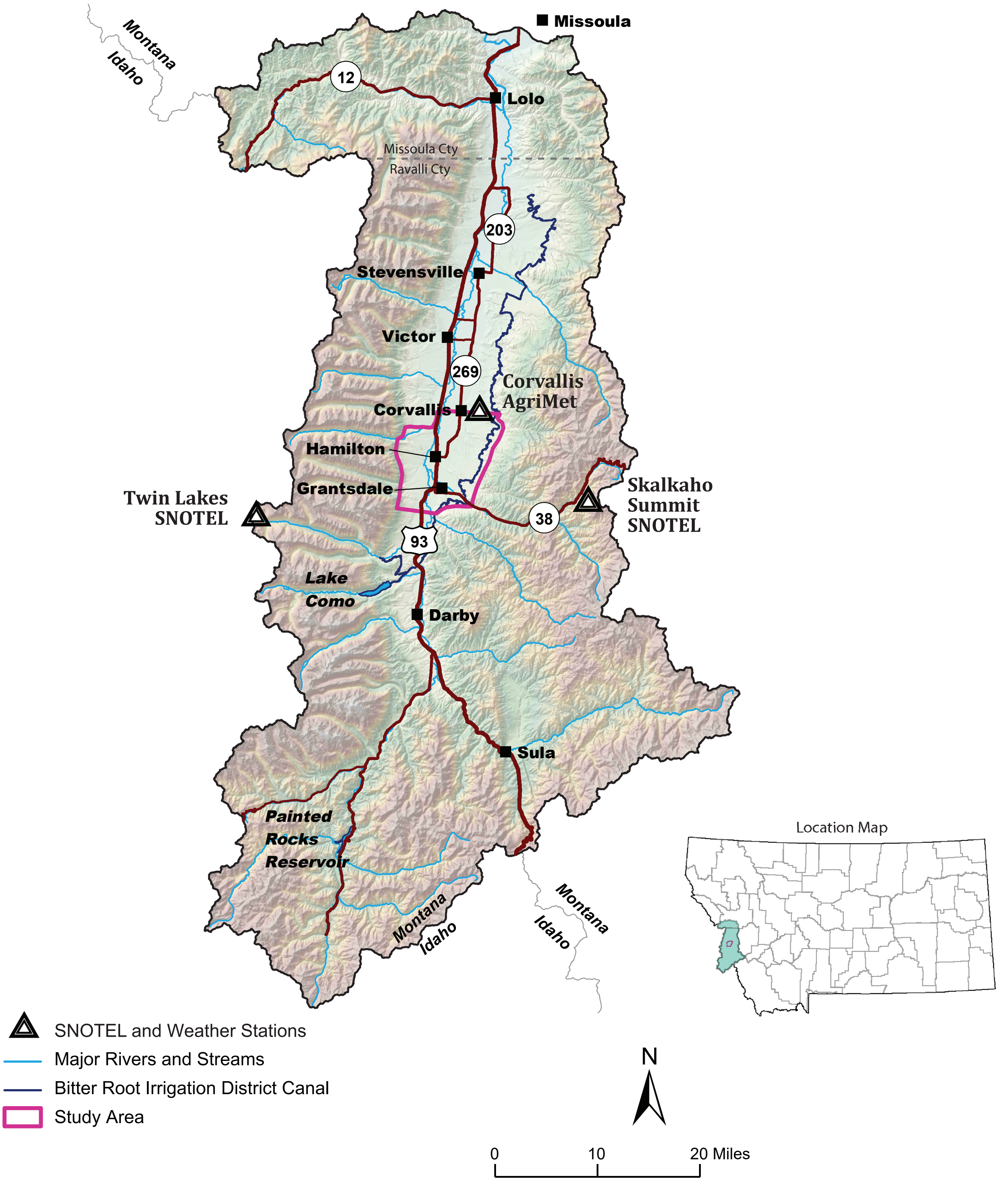
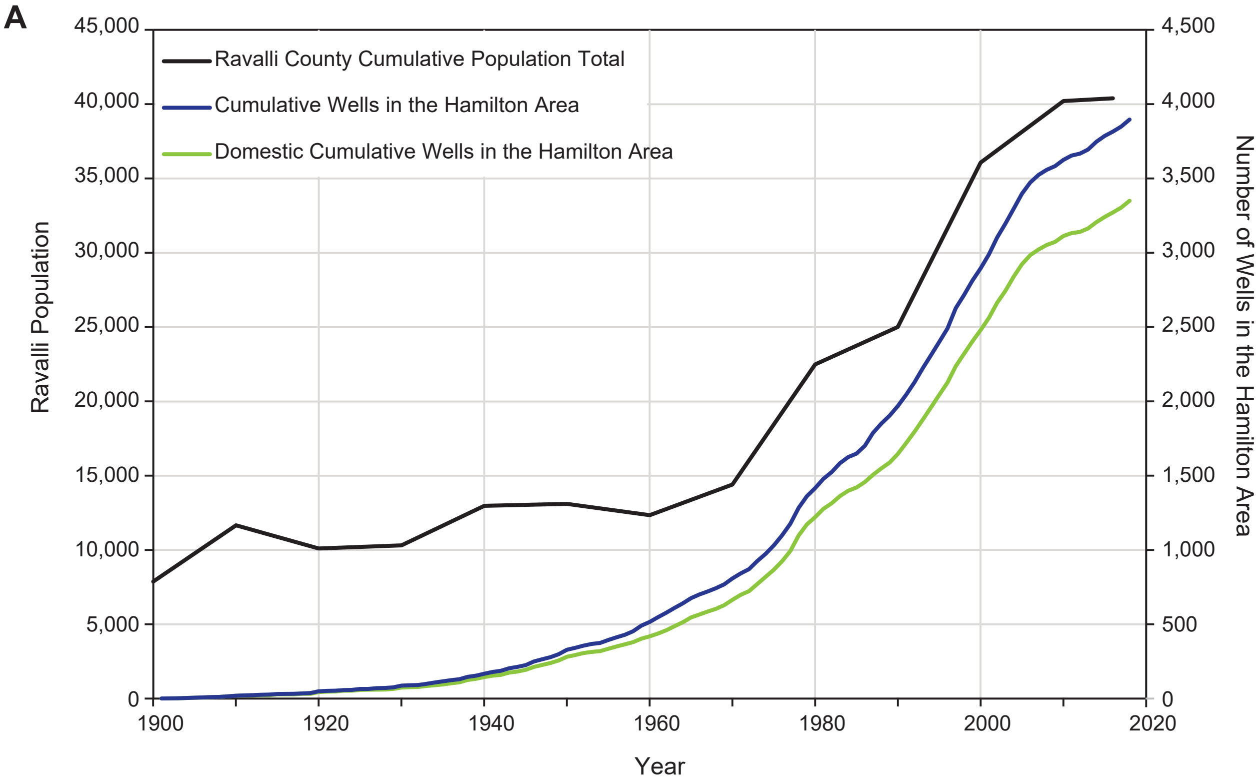


Figure 1. Map of the Bitterroot Valley Watershed in western Montana. The study area is approximately 77 square miles.



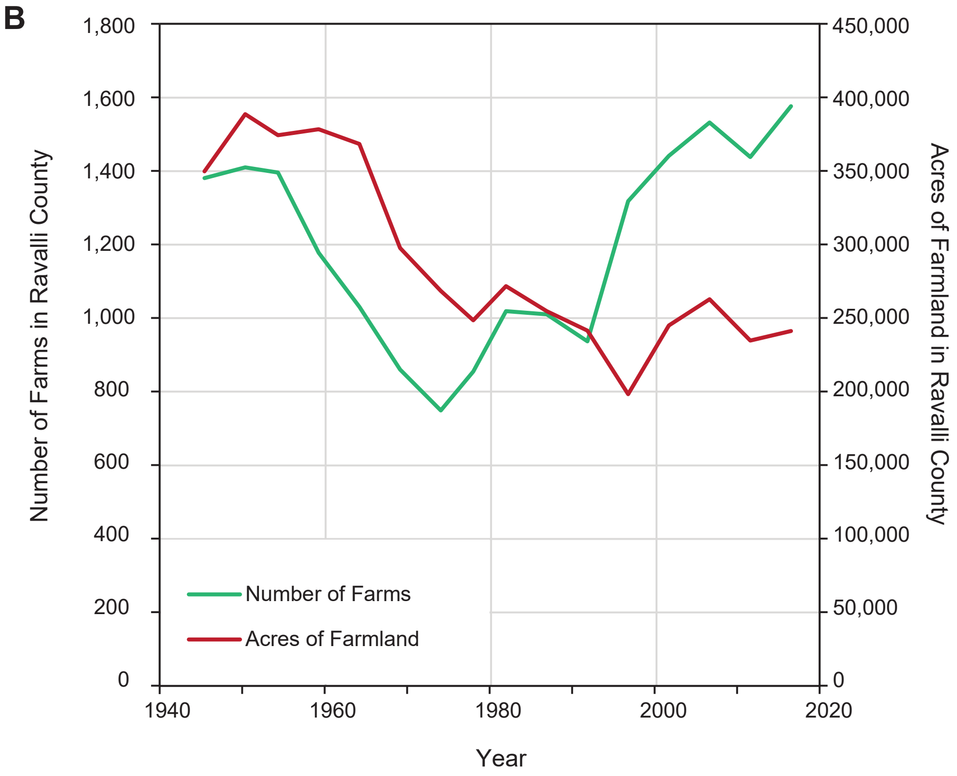


Figure 2. (A) Graph of the population growth in Ravalli County and increase in wells in the Hamilton area. Note the large increase in population size during 1990–2000 (U.S. Census Data, 2010). (B) Graph of the number of farms in Ravalli County and total acreage of farmland. Although the total number of farms have increased in Ravalli County, the total acreage of farmland has decreased, indicating that the size of individual farms has also decreased (USDA, 2020).

Purpose and Scope

The purpose of this investigation is to provide a quantitative evaluation of the groundwater and surface-water systems in the study area and to evaluate potential changes in groundwater elevations and nitrate concentrations in response to increased population. Additionally, this study provides a comprehensive dataset that can be used as a starting point for future hydrogeologic studies.

The scope of the project included the following:

- development of an annual (2015) surface-water budget for the Bitterroot River and a groundwater budget for the groundwater system in the eastern portion of the study area;
- investigation of historical and recent groundwater-level elevation trends, including evaluation of potential spatial patterns; and
- characterization of nitrate concentrations in groundwater and surface water in the study area, including spatial extent and historical and recent trends.

The study area encompasses approximately 77 mi^2 in the center portion of the Bitterroot River watershed (fig. 1) and includes the city of Hamilton. The study area extends about 8 mi north–south from Corvallis to about 3 mi south of Skalkaho Highway (Montana Highway 38). The valley floor is approximately 3 mi wide, and the study focused on the area of the valley that is on the east side of the Bitter Root River to the Bitterroot Irrigation District (BRID) Canal.

Groundwater and surface-water monitoring and water-quality sampling were mainly conducted during a 23-mo period in 2014 and 2015. Aquifer testing was conducted in the spring of 2016. These data were combined with published research, geologic information, historical water-level measurements, and public water system (PWS) annual water-quality analyses to better understand the hydrogeologic setting of the study area.

Previous Investigations

Previous investigations in the Bitterroot Valley and near Hamilton include geologic studies (e.g., Lonn and Sears, 2001), pre-population-growth hydrogeologic studies (McMurtrey and others, 1959, 1972), regional hydrogeologic studies (e.g., Norbeck, 1980; Kendy and Tresch, 1996; Briar and Dutton, 2000; Carstarphen and others, 2003; LaFave, 2006a; Smith, 2006a,b,c; Smith and others, 2013), and water-quality studies (e.g., Briar and Dutton, 2000; LaFave, 2006b; PBS&J, 2008; Smith and others, 2013). Many of these study areas encompassed the entire Bitterroot Valley or larger areas, which are substantially larger than the focus of this study.

Briar and Dutton (2000) investigated three focus areas in the Bitterroot Valley, two of which (Hamilton West and Hamilton Heights) overlap portions of the study area discussed within this Montana Bureau of Mines and Geology (MBMG) Ground Water Investigation Program (GWIP) report. Additionally, two University of Montana master's theses (Finstick, 1986; Uthman, 1988) investigated aquifer properties, created potentiometric surfaces, and collected water chemistry near Victor and Hamilton/Corvallis, respectively. This GWIP study utilized information from these and other earlier hydrogeologic and water-quality investigations, but expanded upon them by developing detailed groundwater and surface-water budgets and statistically evaluating groundwater-elevation and nitrate-concentration trends through 2017. The following sections summarize previous investigations that are directly relevant to this study. Readers are referred to the publications listed above for additional background information.

Physiography

Hamilton is in the Bitterroot Valley, which is an intermontane basin that trends north–south (fig. 1). The Bitterroot Mountains parallel the valley on the west, with high, glaciated peaks reaching elevations of 9,000 to 10,000 ft above mean sea level (amsl). The Bitterroot Mountain front is a well-defined, linear feature. The Sapphire Mountains, east of the valley, are lower in elevation, reaching 8,000 to 9,000 ft amsl, and are further from the valley floor.

The Bitterroot Valley has three broad surficial features: high terraces, alluvial fans, and the valley floor (fig. 3). High terraces (McMurtrey and others, 1972) or high benches (Briar and Dutton, 2000) flank the valley floor. In this report, these features will be called high terraces (cf. McMurtrey and others, 1972). The high terraces are dissected by alluvial fans. On the eastern side, the high terraces typically abut the valley floor with scarps of 50–150 ft (McMurtrey and others, 1972; Briar and Dutton, 2000). The valley floor

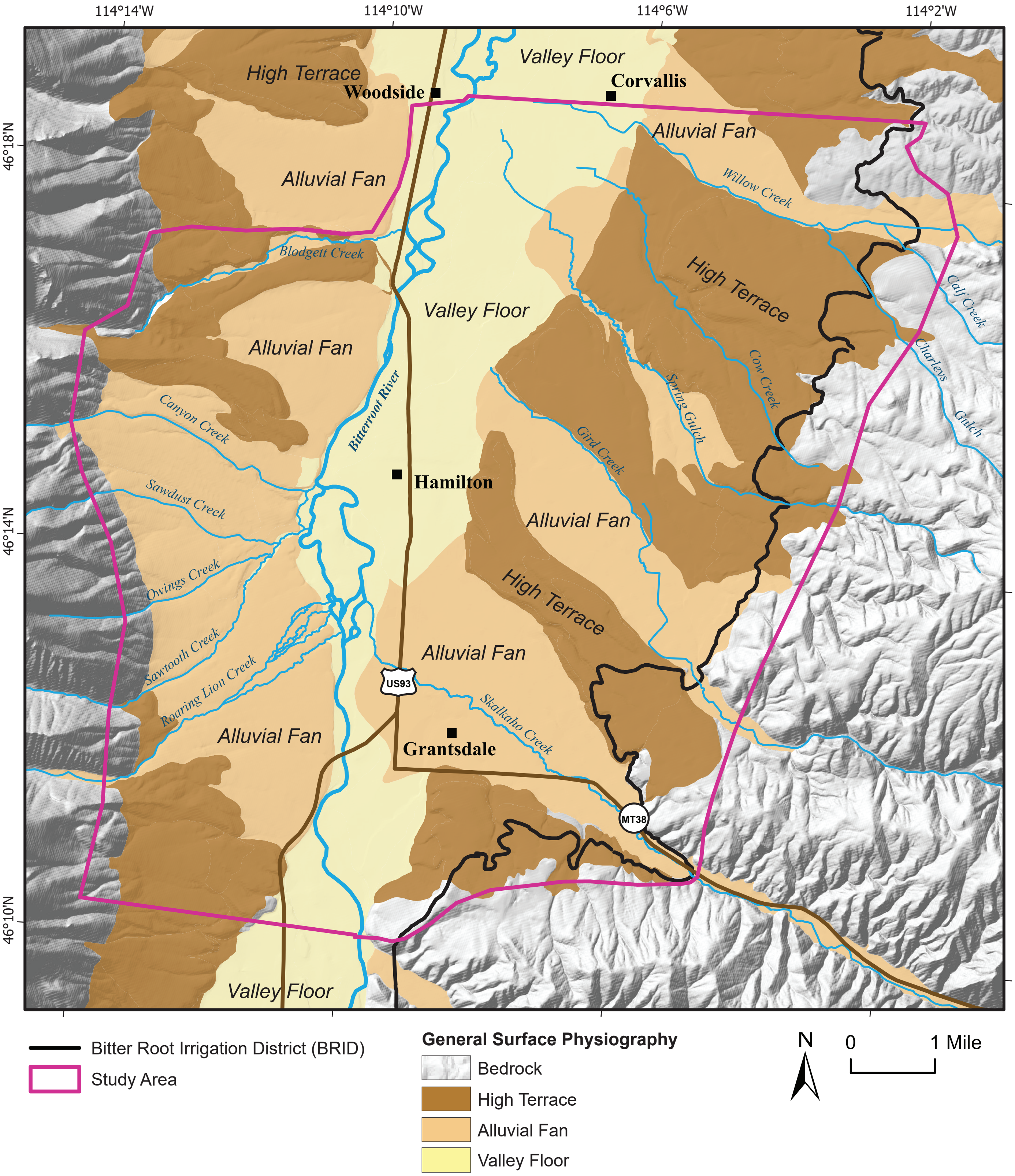


Figure 3. General physiography of the study area: the Bitterroot Mountains are to the west and the Sapphire Mountains are to the east. High terraces and alluvial fans flank the approximately 3-mi-wide valley floor. Adapted from Lonn and Sears (2001).

consists of the present-day floodplain and subtle, low terraces (fig. 3; Lonn and Sears, 2001). Between Corvallis and the Skalkaho Creek, the valley floor is about 3 mi wide, relatively flat, and dips northward slightly with approximately 220 ft of relief.

Climate

Total precipitation varies among the Bitterroot Mountains, Bitterroot Valley, and Sapphire Mountains. This is largely due to the rain-shadow effect and changes in elevation. Precipitation is sourced predominantly from maritime storm systems from the west. As storms travel eastward across the Bitterroot Mountains, less precipitation falls on the Sapphire Mountains compared to the Bitterroot Mountains (rain-shadow effect). Furthermore, less precipitation falls in the valley than in either the Bitterroot Mountains or the Sapphire Mountains (because of elevation differences). Most of the precipitation falls as snow in higher elevations during November–April. During 2014 and 2015, snowmelt occurred primarily from March to June, with smaller melt events during January and February.

Two SNOTEL stations are located near the study area, one in the Bitterroot Mountains at Twin Lakes (elevation of 6,400 ft amsl) and the other in the Sapphire Mountains at Skalkaho Summit (elevation of 7,250 ft amsl; fig. 1). In addition to the two SNOTEL stations, an AgriMet station (elevation of 3,597 ft amsl; fig. 1) is located in the Bitterroot Valley at Corvallis. Data provided from these stations include inches of total accumulated precipitation for the water year (SNOTEL and AgriMet stations) and inches of total accumulated snow water equivalent (SWE; indication of snowmelt; SNOTEL stations only).

Mountain Range Precipitation

The average total precipitation (snow and rain) for the Twin Lakes SNOTEL station [37-yr period of record (POR), 1979–2015] is 64.6 in. In 2014 and 2015, the total precipitation was 70.9 and 59.6 in, respectively. For the POR, 2014 was the 8th wettest year, whereas 2015 was the 29th wettest year. The Twin Lakes station reports an average SWE of 47.7 in. In 2014, the SWE was 64.4 in (2nd highest SWE) and in 2015 the SWE was 44.2 in (20th highest SWE; fig. 4A; NRCS-NWCC, 2017).

The average total precipitation for the Skalkaho Summit SNOTEL station (35-yr POR, 1981–2015) is 37.2 in. In 2014 and 2015, the total precipitation was 39.6 and 33.1 in, respectively. For the POR, 2014 was the 9th wettest year, whereas 2015 was the 26th wettest year for this station. The station reports an average SWE of 28.0 in. In 2014, the SWE was 35.8 in (5th highest SWE) and in 2015 the SWE was 23.3 in (29th highest SWE; fig. 4B, NRCS-NWCC, 2017).

From these data, the average annual total precipitation at both SNOTEL stations was above average in 2014 and below average in 2015 (fig. 4). In addition, as a result of the rain-shadow effect discussed above, the average total precipitation and SWE in the Bitterroot Mountains (west side of the valley) is almost twice as much as in the Sapphire Mountains (east side of the valley), even though the SNOTEL station in the Sapphire Mountains is 850 ft amsl higher.

Valley Floor Precipitation

Average monthly temperature and precipitation for the Corvallis AgriMet Station are shown in table 1. The monthly temperature is highest in July (67.8°F) and lowest in December (26.6°F). The monthly precipitation is highest in May and June (1.51 and 1.55 in, respectively) and lowest in February (0.52 in).

Table 1. Monthly temperature and precipitation averages for the Corvallis, MT AgriMet station (USBR, 2016).

	Average Monthly Temperature (°F)	Average Monthly Precipitation (in)
January	28.2	0.56
February	30.5	0.52
March	38.3	0.66
April	44.7	0.89
May	52.6	1.51
June	59.6	1.55
July	67.8	0.69
August	65.1	0.77
September	56.3	0.77
October	44.9	0.66
November	33.8	0.78
December	26.6	0.72

Note. Average calculated from a 27-yr period of record (POR) from water years 1988-2015; water year 1989 was excluded due to missing data.

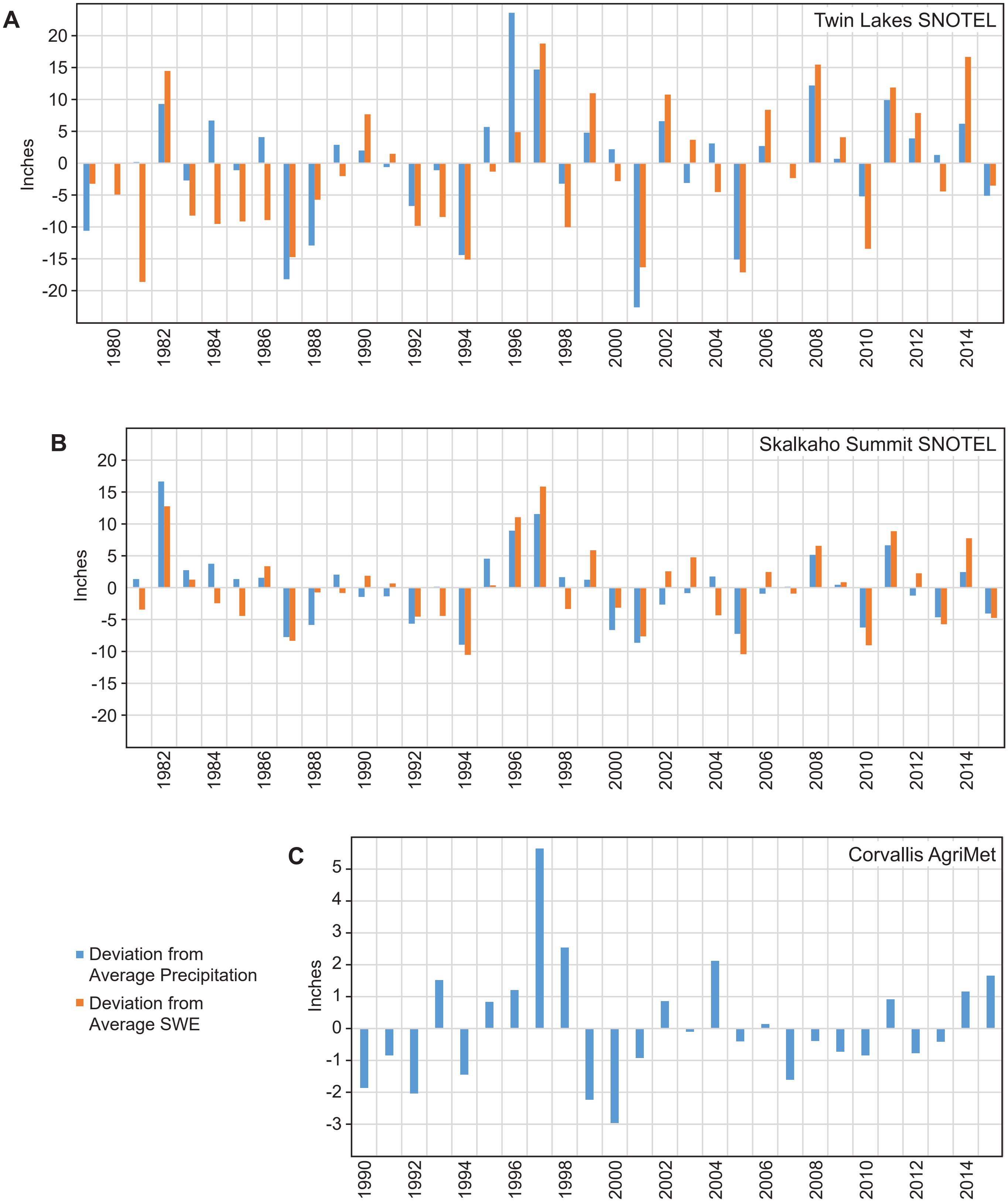


Figure 4. Deviation from average annual precipitation and snow water equivalent (SWE) for SNOTEL stations Twin Lakes (A), Skalkaho Summit (B; NRCS, 2017), and deviation from average annual precipitation for AgriMet station in Corvallis (C; USBR, 2016). Note that the period of records vary for each station. For yearly comparison, x-axis is at the same scale and aligned with the other graphs. See text for average annual precipitation and average SWE for each site.

The average annual precipitation for the Corvallis AgriMet Station (25-yr average for 1900–2015) is 10.0 in. In 2014 and 2015, the total precipitation was 11.2 in and 11.7 in, respectively (fig. 4C). For the POR, 2014 was the seventh wettest year and 2015 was the fourth wettest year (USBR, 2016). From these data, the average annual total precipitation at the Corvallis AgriMet Station was above average for both 2014 and 2015.

Geologic Setting

The Bitterroot Valley is a structural graben, in which the valley is displaced downward relative to the Bitterroot Mountains and the Sapphire Mountains. This structural basin was formed by faulting beginning in the Tertiary, with subsequent sedimentary deposition (McMurtrey and others, 1972; Smith 2006a). The bedrock that bounds the Bitterroot Valley consists of low-grade metamorphosed sedimentary rocks of the Precambrian Belt Supergroup and Cretaceous metamorphic and igneous rocks (TYb; fig. 5; McMurtrey and others, 1972; Smith and others, 2013). Lonn and Sears (2001) mapped the surficial geology of the Bitterroot Valley in great detail. Figure 5 and the following unit descriptions are adapted from their work.

Gravity data and drill cores suggest Tertiary-age sediments are greater than 3,000 ft thick within a sub-basin near Hamilton (Norbeck, 1980; Noble and others, 1982; Smith, 2006a). These Tertiary sediments form the surficial deposits on the high terraces and underlie the valley floor alluvial deposits (figs. 3, 5). They can be broadly divided into two units: the Ancestral Bitterroot River deposits (Tbg, Tbc) and the Tertiary Alluvial and Boulder Fan (Taf) deposits. The Ancestral Bitterroot River sediments were deposited during the Late Eocene to Early Miocene. Unit Tbg generally consists of well-sorted, well-rounded, stratified, light gray to white cobbles, gravel, and sand interbedded with unit Tbc, the "blue clay facies" that consists of light gray clay and silt. The Taf deposits are generally above the Ancestral Bitterroot River (Tbg, Tbc) deposits on the high terraces. Unit Taf consists predominantly of alluvial and boulder fan deposits composed of poorly sorted boulders, cobbles, and sandy-silt deposits.

Deposited stratigraphically above the Tertiary basin-fill are Quaternary surficial deposits. Quaternary deposits, in this study, were broadly grouped into boulder fan (Qbf), alluvial fan (Qaf), and alluvial (Qal) deposits (fig. 5). The boulder fan (Qbf) deposits contain large angular boulders in an unsorted gravel, sand, and silt matrix and are considered glacial in origin (Lonn and Sears, 2001). They are only present on the west side of the valley. The alluvial fan (Qaf) deposits consist of unsorted, boulders, cobbles, gravel, sand, and silt and form the alluvial fans that dissect the high terraces. The alluvial deposits (Qal) generally consist of well-rounded, well-sorted gravel and sand up to 40 ft thick and constitute the Bitterroot River floodplain. Also grouped with alluvial deposits are low terraces deposited as part of former Bitterroot River floodplains that consist of similar deposits.

Hydrogeologic Setting

Surface Water

The main surface-water feature in the study area (and the Bitterroot Valley) is the northward-flowing Bitterroot River. The Bitterroot River enters and exits the study area as one channel. However, the river braids and divides into different branches as it moves through the study area. In general, the Bitterroot River is used for recreation, irrigation, and by wildlife.

Tributaries to the Bitterroot River begin in the Bitterroot Mountains and the Sapphire Mountains. Approximately four times as many streams originate from the west side of the river (Bitterroot Mountains) than from the east side (Sapphire Mountains; Briar and Dutton, 2000). Thus, the Bitterroot Mountains provide more runoff to the Bitterroot River than do the Sapphire Mountains. Within the study area, the tributaries to the Bitterroot River on the west side of the valley include the Blodgett, Canyon, Sawtooth (which includes flow from the Sawdust and Owings Creeks), and Roaring Lion Creeks (fig. 3). On the east side of the study area, Skalkaho Creek is the only natural tributary to the river. Other streams originating from the east side of the river either discharge into ditches (discussed below) that flow north out of the study area or discharge into the Bitterroot River (e.g., Willow Creek) outside the study area.

Groundwater

LaFave (2006a) and Smith and others (2013) indicated the groundwater system in the Bitterroot Valley generally consists of three regional aquifers: the bedrock, deep basin-fill, and shallow basin-fill systems. The bedrock aquifer yields water from fractures

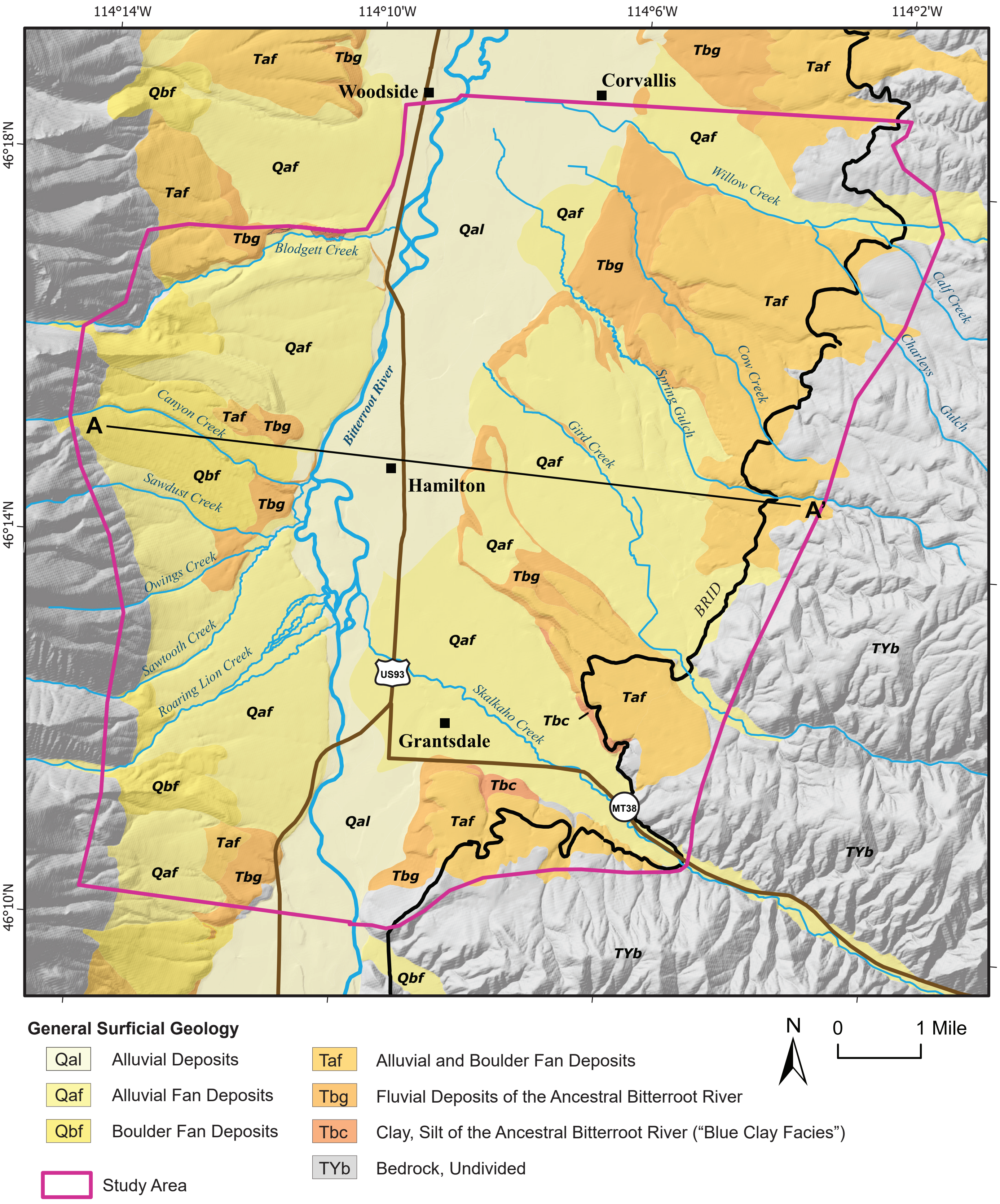


Figure 5. Surficial geology map of study area, generalized from Lonn and Sears (2001). Area consists of deep Tertiary basin-fill sediments (Taf, Tbg, Tbc) that underlie valley floor Quaternary alluvial deposits (Qal, Qaf, Qbfy). Cross-section A–A' is shown in figure 9.

and is currently used only by wells along the perimeter of the valley. The deep basin-fill aquifer consists predominantly of Tertiary deposits, and to a lesser extent Quaternary deposits. Groundwater conditions in the system generally are semi-confined to confined because of interbedded silty and clay-rich layers (Smith and others, 2013). The shallow basin-fill aquifer is unconfined and contains Quaternary deposits typically within 75–80 ft of the ground surface. Groundwater elevations in wells completed in the shallow basin-fill aquifer typically are 5-40 ft below ground surface (bgs; LaFave, 2006a). The shallow basin-fill aquifer is also referred to as the unconfined aquifer, and is the focus of this GWIP report.

Groundwater Movement

Recharge and discharge of the groundwater among the three aquifers is interconnected in the Bitterroot Valley (Smith and others, 2013). Groundwater flows from the valley margins towards the Bitterroot River, which is the primary location of discharge from the groundwater system in the valley. The horizontal hydraulic gradient is similar to the slope of the land surface, which is relatively flat and tilted northward. Recharge to the bedrock aquifer is from infiltration of precipitation and snowmelt, and discharge from the system is to springs, streams, and to the adjacent unconfined and deep basin-fill aquifers. The deep basin-fill aquifer receives recharge from the bedrock aquifer, leakage from the overlying unconfined aquifer, and/or recharge from losing tributary streams at breaks in slopes along the perimeter of the valley. Discharge from the deep basin-fill aquifer is by upward movement to the unconfined aquifer. The unconfined aquifer can receive recharge from many sources, including the bedrock and deep basin-fill aquifers, infiltration of precipitation, losing streams, irrigation ditch and canal seepage, and excess irrigation water. Ultimately, the groundwater in the unconfined aquifer that is not lost as leakage to the deep basin-fill aquifer is discharged to streams, lost through evapotranspiration, or pumped from wells (LaFave, 2006a). Groundwater-elevation fluctuations in the unconfined aquifer are the result of short-term (e.g., daily pumping, barometric and temperature changes, evapotranspiration), seasonal (e.g., Bitterroot River stage, irrigation), and long-term (e.g., climate variations) trends (McMurtrey and others, 1972; Smith and others, 2013).

Water Infrastructure Development

Irrigation needs are primarily supplied through an extensive canal/ditch system that flows northward (fig. 6). Most of this ditch water is used to irrigate crops; however, some is used to water domestic lawns. The irrigation infrastructure includes the BRID and numerous smaller canals/ditches (fig. 6). The BRID was constructed in the early 1900s and is the largest canal in the valley. It is 72 mi long (16.5 mi are within the study area) and provides water to 16,655 irrigated acres (BRID, 2020). The water source for the BRID is Lake Como Reservoir. The water comes out of Lake Como into Rock Creek and is then diverted into the BRID north of Darby (fig. 1). The principal ditches and canals that divert water from the Bitterroot River are the Republican Ditch, Hedge Ditch, and Corvallis Canal (fig. 6). The Corvallis Canal diverts water from the Bitterroot River northwest of Hamilton town center, whereas the Republican and Hedge Ditches divert water upstream of Hamilton. The Hughes and Ward Ditches divert water from Skalkaho Creek. Several creeks entering the valley floor intermingle with and are dispersed through irrigation ditches (e.g., Gird and Willow Creeks).

Most domestic water use in the study area is supplied by groundwater. In 2016, there were 4,183 groundwater wells within the study area according to the MBMG Ground Water Information Center (GWIC) database. Of these, 3,423 are used for domestic supply and 356 are used for irrigation supply. The remaining well uses include stock water, monitoring, public water supply (PWS), commercial, fire protection, geotechnical, geothermal, industrial, unknown, and other (MBMG, 2016). There are both privately owned PWS wells (subdivisions) and publicly owned City of Hamilton PWS wells. The City of Hamilton PWS began in February 2000 and currently utilizes six wells to supply water to 4,500 people. The system is equipped with 1,799 residential and 393 commercial meters. The Hamilton wastewater department treats about 750,000 gal of water daily (1.16 cubic feet per second, cfs) which is discharged to the Bitterroot River (City of Hamilton, Montana Public Works Department, 2018).

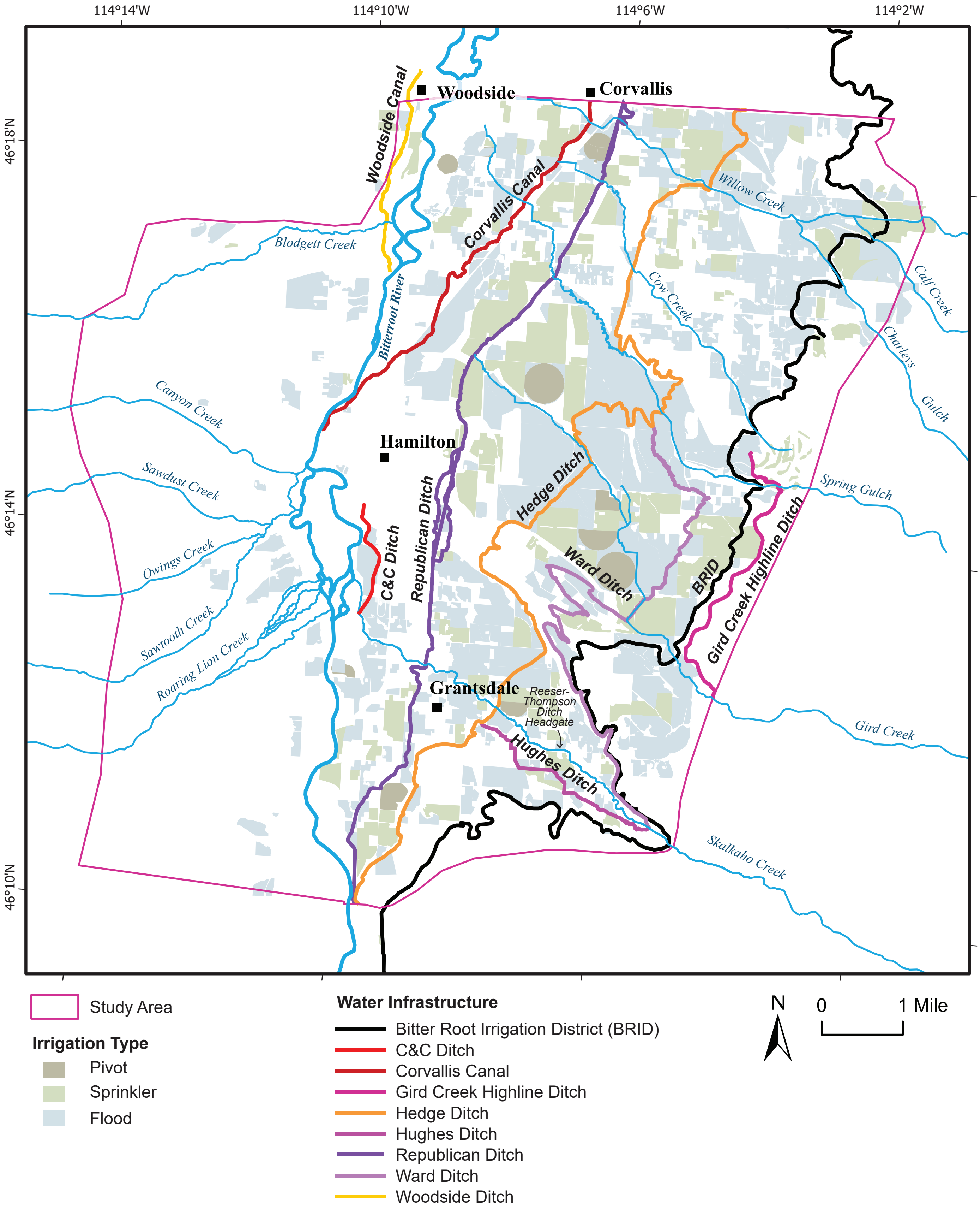


Figure 6. Irrigation water in the study area is conveyed through the canal/ditch system (irrigated lands base layer from MT-DOR, 2015, modified by comparing MT-DOR database with 2015–2017 Google Earth imagery).

Water Quality

Previous studies in the Bitterroot Valley have indicated groundwater quality differs between the west and east sides of the valley (Briar and Dutton, 2000; PBS&J, 2008). In general, most groundwater samples in the Bitterroot Valley are a calcium–bicarbonate water type with relatively low total dissolved solids (<250 mg/L; Smith and others, 2013). Specific conductance measured in groundwater samples on the east side of the Bitterroot Valley near Hamilton is about four times greater than that measured in samples from the west side of the valley. Similarly, nitrate concentrations in samples from the east side of the valley are higher than samples from the west side (Briar and Dutton, 2000). These water-quality differences were attributed, in part, to differences in the quantity of recharge—the east side of the valley has lower precipitation rates and more Tertiary alluvial fan deposits, which are generally less permeable than other sediments in the valley (Briar and Dutton, 2000; PBS&J, 2008). Two studies have noted seasonal variability in nitrate concentrations, but the cause was not determined (Briar and Dutton, 2000; Smith and others, 2013). A water-quality summary for the Bitterroot Valley is described in Briar and Dutton (2000) and Smith and others (2013). In terms of water quality, this study focused on nitrate concentrations in groundwater, with an emphasis on characterizing current nitrate concentrations and evaluating statistical trends in long-term groundwater nitrate concentrations.

Nitrate is a necessary nutrient for plant and animal growth; however, elevated nitrate concentrations in groundwater and surface water can result in undesirable ecological effects (e.g., algae blooms; Dubrovsky and others, 2010) and health effects if ingested (e.g., methemoglobinemia or “blue baby” syndrome in infants; DEQ, 2016). Because of health concerns, the U.S. Environmental Protection Agency (EPA) has established a maximum contaminant level (MCL) for nitrate of 10 mg/L (EPA, 2018), and increased monitoring of nitrate concentrations in PWS water is required once concentrations are greater than 5 mg/L (50% of the MCL; MT-DEQ, 2016; EPA, 2018). Sources of nitrate to groundwater and surface water in excess of what is typically found naturally (typically found to be less than 2 mg/L; USGS, 1999) can include septic effluent, fertilizer, and animal waste. Therefore, higher population density can result in higher nitrate input to local groundwater and surface-water resources (Dubrovsky and others, 2010).

METHODS

Surface-water and groundwater monitoring networks were established within the Hamilton study area to measure streamflow and stage at streams, ditches, and canals, and to collect groundwater levels and samples from 2014 through 2015. Hydraulic characteristics of the aquifers were investigated using three aquifer tests conducted in the spring of 2016 (see Myse and Snyder, 2021). In addition to these field-based datasets, annual PWS water-quality reports and long-term monitoring data were compiled. Collected and compiled data were used to quantitatively characterize various aspects of the groundwater and surface-water systems, including groundwater-elevation and nitrate-concentration trends.

Data Management

Data collected from this study are permanently archived in the MBMG GWIC database. GWIC is accessible at the website http://mbmggwic.mtech.edu/. Within GWIC, data are grouped into project areas to allow easy access to project-specific information. The Hamilton project data are found by going to GWIC’s “Projects” page, then “Groundwater Investigation Program” Project Group, and then “Hamilton.” Groundwater and surface-water monitoring sites are identified in this report by using the site’s GWIC identification number (i.e., well 123456 for wells and site 123456 for surface-water sites).

Monitoring Network

Detailed information about each groundwater and surface-water monitoring site is tabulated in appendix A and can be retrieved from the GWIC website (see Data Management section above). Well-measurement points and surface-water staff gages were surveyed for latitude, longitude, and elevation using survey-grade GPS (Trimble R8 GNSS GPS System & Trimble 5602 Robotic Total Station) by a professional surveyor (Robert Peccia and Associates) in December 2015.

Surface-Water Monitoring Network

Surface-water data were collected on the Bitterroot River, western and eastern tributaries of the Bitterroot River, and canals and ditches east of the Bitterroot

River. The surface-water monitoring network consisted of 37 sites (3 Bitterroot River sites, 9 eastern tributary sites, 7 western tributary sites, and 18 ditch/canal locations) and was established to measure stage and discharge in the study area (fig. 7; appendix A, table A1). Routine measurements at surface-water sites included stage, discharge, specific conductance (SC), and temperature. Discharge at surface-water sites was measured approximately every other week during the irrigation season in 2014 to develop rating curves. During 2015, stage values were recorded monthly using instrumentation (pressure transducers). If a stage reading did not have a corresponding discharge measurement, a discharge measurement was made. Pressure transducers were installed at all surface-water sites, except site 283721, to record hourly stage measurements. Rating curves were developed to calculate discharge for stages recorded with the pressure transducer.

Groundwater Monitoring Network

A monitoring well network consisting of 95 wells was established to collect groundwater elevations and water-chemistry data (fig. 8; appendix A, table A2). The monitoring network consisted of wells used for domestic, irrigation, PWS, stock water, fire protection, monitoring purposes, and unused wells. Wells were selected for monitoring based on hydrogeologic setting, geographic location, historical record, and well-owner permission. Water levels were measured monthly in all wells. During the irrigation season, water levels in a select group of wells were measured every other week (appendix A, table A2). Twenty-two wells were equipped with a pressure transducer programmed to record water levels hourly (fig. 8; appendix A, table A2).

Aquifer Tests

Three aquifer tests were conducted during this study to determine transmissivity and storage capacity for three different hydrostratigraphic units. Aquifer tests were completed in:

1. well 286258, completed in Bitterroot River alluvium (Qal),
2. well 286267, completed in alluvial fan deposits near Skalkaho Creek (Qaf), and
3. well 286280, completed in Ancestral Bitterroot River deposits (Tbgc).

Locations of these wells are shown in figure 8. Wells 286280 and 286267 were pumped for 95 and 96 h, respectively. Well 286258 was pumped longer (121 h) than the other wells to investigate if the cone of depression created by pumping would physically intersect the Bitterroot River. Aquifer test procedures were conducted in accordance with ASTM standards (ASTM International, 2010). Methods, data, and analysis for these three tests are detailed in Myse and Snyder (2021).

Potentiometric-Surface Map

A potentiometric-surface map of the unconfined aquifer for August 2015 was constructed using groundwater elevations measured in 49 wells (appendix A, table A2). All but one measured well had a depth less than or equal to 80 ft bgs, which is considered the maximum depth of the unconfined aquifer in the study area (Smith and others, 2013). All wells from which water levels were used to construct the potentiometric surface were considered unconfined. Well 205674, located on a high terrace in the eastern part of the study area, was 90 ft deep, which is greater than the maximum unconfined aquifer depth indicated in Smith and others (2013). However, the well log for this well did not identify any clays/silts that potentially could indicate confined conditions. Consequently, a water-level measurement from well 205674 was used to help constrain groundwater elevations in the eastern portion of the map. Contouring of groundwater elevations shown in the map was done using the Kriging algorithm in ArcGIS (ESRI, 2021), with manual editing of contours in some areas to better represent "real-world" hydrologic conditions.

Water Budgets

Groundwater and surface-water budgets were developed for the study area using field data collected during 2014–2015. These budgets provide quantitative estimates of the inflow, outflow, and storage components of the groundwater and surface-water systems in the study area. The water budgets were based on the following general equation given in Fetter (1994):

$$\mathit{Inflow} = \mathit{Outflow} \pm \mathit{Changes\ in\ storage}.$$

For both the groundwater and surface-water budgets, this equation was expanded based on the inflow and outflow variables. These variables are discussed below for each water budget type.

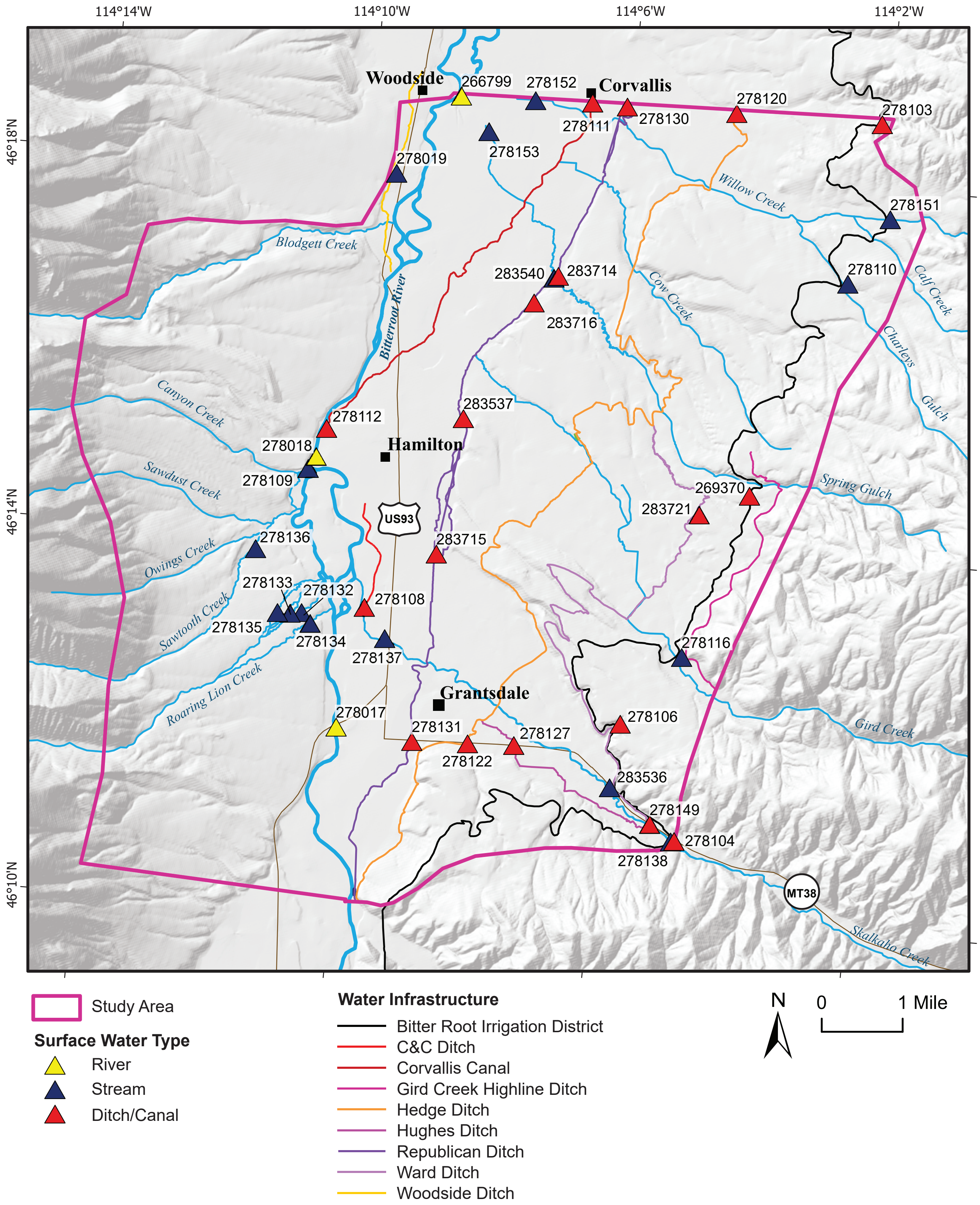


Figure 7. Location of the 37 surface-water monitoring sites: 3 river sites, 16 stream sites, and 18 canal/ditch sites.

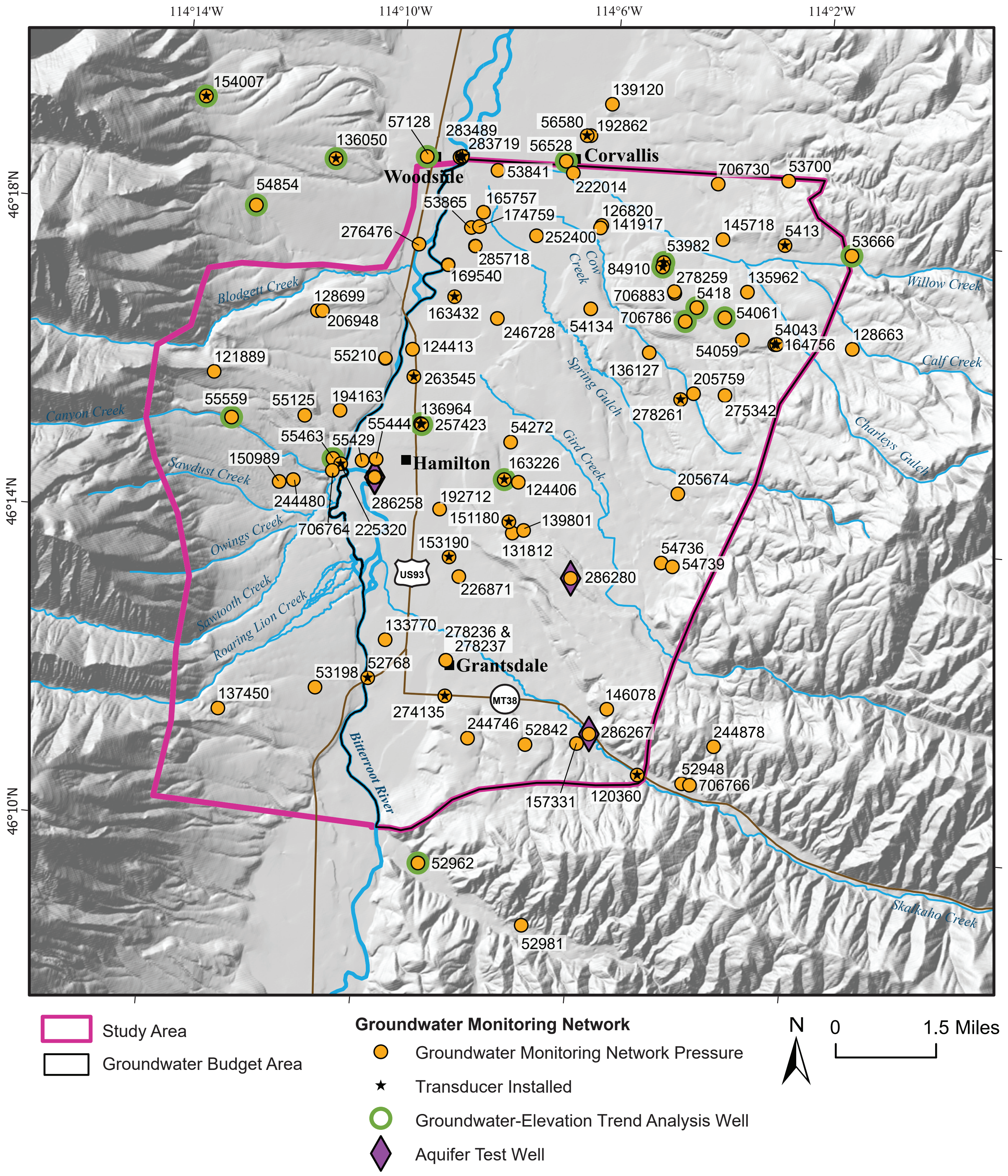


Figure 8. Location of the 95 groundwater monitoring wells with 22 wells equipped with pressure transducers. Aquifer tests were run on three wells. Seventeen wells were analyzed for long-term groundwater-elevation trends.

Surface-Water Budget

A surface-water budget for July 2014 through November 2015 was developed for the Bitterroot River, primarily to quantify streamflow gains from and losses to the groundwater system within the study area. The water budget was developed for the reach between sites 278017 and 266799, a distance of 9.8 mi (fig. 7). River inflows/outflows, tributary inflows, and canal/ditch outflows were measured within the 9.8-mi reach. Manual discharge measurements were made using the Sontek M9 River Surveyor, FlowTracker, Marsh-McBirney, or an Ott MF Pro. Some discharge measurements were calculated from rating curves. Error was estimated for each discharge measurement. All errors calculated for the streamflow gains were less than the calculated gains (with the exception of one month, see Results: Surface-Water Budget section).

The net streamflow gain or loss was calculated as the difference between the inflows and the outflows plus storage. Therefore, the surface-water budget equation can be written as:

$$BR_{in} + Trib_{in} - Canal_{out} - \Delta S - BR_{out} = GW_{in/out},$$

where Br_{in} is inflow of the Bitterroot River at Anglers Roost (278017); $Trib_{in}$ is tributary inflows from Skalkaho (278137), Roaring Lion (28134), Sawtooth (278136), Canyon (278109), and Blodget Creeks (278019); $Canal_{out}$ is outflows from the C&C Ditch (278108), Corvallis Canal (278111), and Woodside Canal; BR_{out} is outflow of the Bitterroot River at Woodside Crossing (266799); ΔS is change in surface-water storage; and $GW_{in/out}$ is groundwater budget component being calculated.

The error for $GW_{in/out}$ was calculated as the square root of the sum of squared discharge errors. Surface-water monitoring sites are shown in figure 7.

Two components of the surface-water budget could not be directly measured and therefore were calculated. First, the discharge of the Bitterroot River to the Woodside Canal (WC_{out}) was estimated on September 15, 2017, by a float method (MT-DNRC, 2018; Rantz, 1982). The discharge is calculated from the width, depth, and velocity (multiplied by 0.85). Second, the change in surface-water storage (ΔS) represents low-elevation surficial features (e.g., old riverbeds) that flood during high flows of the Bitterroot River (March, April, May, and June 2015). A GIS analysis “flooded” these low-elevation features using the monthly average river stage for the high flow months. The calculated water storage during those months was removed from the water budget; an estimated error of 5% was used (Montana Department of Natural Resources and Conservation, 2018).

Groundwater Budget

An annual groundwater budget for 2015 was developed for the unconfined aquifer in the portion of the study area east of the Bitterroot River. Hereafter this is referred to as the groundwater budget area (fig. 8). This area was chosen because it had 88% of the subdivision growth from 2000 to 2020 (Montana State Library, 2022). One of the goals of the groundwater budget was to determine the effect domestic water usage had on the overall groundwater system. By limiting the groundwater budget to the east side of the Bitterroot River, the groundwater budget would be more focused on where most of the subdivision growth is occurring.

The groundwater budget was calculated using monthly estimates of inflows and outflows during January–December 2015. This groundwater budget was constructed using data collected and calculated as part of this study and literature values. The groundwater budget can be written as:

$$GW_{in} + CL_{BRID} + CL_{C/D} + IR + R + SW_{in} = \\ SW_{out} + ET_r + DW + GW_{out} + \Delta S,$$

where GW_{in} is groundwater inflow to the unconfined aquifer from the south and east; CL_{BRID} is canal seepage from the BRID; $CL_{C/D}$ is seepage from the other canals/ditches; IR is irrigation recharge; R is recharge from precipitation on non-irrigated lands; SW_{in} is recharge from Skalkaho Creek; SW_{out} is outflow to Skalkaho Creek; ET_r is riparian evapotranspiration; DW is domestic consumptive use; GW_{out} is groundwater outflow to the Bitterroot River; and ΔS is change in groundwater storage.

The calculations of individual groundwater budget components are summarized below, with additional details provided in appendix B.

Groundwater Inflow (GW_{in}) and Outflow (GW_{out})

Based on the potentiometric-surface map constructed for the unconfined aquifer (see Potentiometric-Surface Map section), groundwater inflow (GW_{in}) was calculated for the eastern and southern boundaries of the groundwater budget area, whereas groundwater outflow (GW_{out}) was calculated for the western and northern boundaries of the groundwater budget area (appendix B, fig. B1). We considered only horizontal groundwater flow within the shallow unconfined aquifer that was perpendicular to the groundwater budget area boundaries. Darcy's Law (Fetter, 1994) was used to calculate inflows and outflows to the groundwater budget area (appendix B, tables B1 and B2):

$$Q = Twi,$$

where T is horizontal transmissivity (in squared feet per day, or ft^2/d) of the aquifer in the vicinity of the flow boundary, w is width of the flow section (ft), and i is approximate horizontal hydraulic gradient across the flow boundary (ft/ft).

Canal Loss (CL_{BRID} and $CL_{C/D}$)

The BRID canal stage and discharge were measured along a 5.8-mi reach of the canal in 2014 and 2015 to estimate canal seepage throughout the irrigation season. We assumed that the total amount of canal seepage recharged groundwater. This 5.8-mi section of the canal had one diversion that was confirmed inactive by MBMG personnel and BRID management. A staff gage, stilling well, and pressure transducer were installed at two sites on the canal (278106 and 269370; fig. 7). The difference in the discharge measurements between sites 278106 and 269370 was used to determine the monthly average seepage rates of the canal per mile (both from rating curves and direct discharge measurements). These seepage rates were then used to calculate the annual water loss from the BRID canal to groundwater (CL_{BRID}).

Canal seepage was also calculated on the Hedge, Hughes, Ward, Gird, and Republican Ditches (fig. 6). Discharge and stage along these ditches were measured as part of the surface-water monitoring network. Seepage losses were calculated as a proportion of discharge using an average discharge-to-seepage ratio calculated using seepage data from the BRID canal. The Corvallis Canal and C&C Ditch were not included in the seepage calculations because they are located in the floodplain. The low hydraulic gradient in the aquifer in the floodplain indicates that these canals are likely in hydraulic connection with the unconfined aquifer, and thus are more likely acting as groundwater drains and/or gaining and losing groundwater as they flow downstream.

Irrigation Recharge (IR) and Non-Irrigated Land Recharge (R)

Irrigated fields receive water from irrigation and precipitation, whereas non-irrigated fields receive water only from precipitation. The water that is not consumed by evapotranspiration (ET) runs off the field or infiltrates into the subsurface. The water that infiltrates into the subsurface and moves past the root zone is assumed to represent recharge to the underlying unconfined aquifer. Therefore, the excess water from irrigated and non-irrigated fields are considered inflows in the groundwater budget and are calculated as irrigation recharge (IR) and non-irrigated land recharge (R).

Irrigation recharge is calculated based on the amount of precipitation plus the irrigation water applied to the crops minus the consumptive use of the crop (ET). Both crop type and irrigation method determine the amount of irrigation water applied to the fields. Similarly, crop type affects the amount of water consumed by the crop. The acreage of each crop type and the associated irrigation method (flood, pivot, and sprinkler) were considered in the groundwater budget area. Data from the Montana Department of Revenue's Final Land Use (FLU) Classification coverage for 2015 was modified based on field observations and aerial photographs (MT-DOR, 2015). Irrigation recharge was calculated for the irrigation season, which typically is May–October in the study area.

Recharge from non-irrigated lands is calculated based on the amount of precipitation minus the amount consumed by the vegetation (ET). Similar to irrigation recharge, the type of vegetation affects the amount of non-irrigated recharge. Acres of each vegetation type were estimated using the LANDFIRE database (USGS, 2010), and ET rates were obtained from the Kimberly Research and Extension Center in Salmon, Idaho (Allen and Robison, 2017). We assumed that groundwater recharge from non-irrigated lands occurred during months with average temperatures above freezing (March–October) and when precipitation exceeded ET. Freezing temperatures were expected to impede infiltration; therefore, we assumed recharge was not occurring during November–February.

Groundwater Interaction with Skalkaho Creek (SW_{in} and SW_{out})

Skalkaho Creek is the only natural tributary on the east side of the Bitterroot River within the groundwater budget area. Skalkaho Creek can either lose water, thereby providing a source of groundwater inflow (recharge, SW_{in}), or it can gain water and act as groundwater outflow or drain (discharge, SW_{out}). Discharge in the creek was measured in a 4.6-mi reach between sites 278138 and 278137 (fig. 7). The difference in discharge between the two creek sites and the amount of water diverted in this reach were used to calculate the monthly groundwater inflow or outflow from Skalkaho Creek.

Riparian Evapotranspiration (ET_r)

Evapotranspiration from riparian vegetation was calculated for cottonwood and willow stands along the Bitterroot River and Skalkaho Creek. The acreage of riparian vegetation was estimated using the LANDFIRE database (USGS, 2010). Monthly ET rates for March–October 2015 were averaged for cottonwoods and willows based on data from the Kimberly Research and Extension Center (Allen and Robison, 2017). Precipitation from the Corvallis Agrimet station (USBR, 2016) was subtracted from the ET to estimate the amount of groundwater withdrawn by the riparian vegetation. Similar to non-irrigated land recharge (R), when precipitation was in excess of ET during November–February, infiltration was assumed to be impeded by frozen ground conditions and not considered further.

Domestic Consumptive Use of Groundwater (DW)

Residential and municipal wells provide water for indoor use and to irrigate lawns and gardens. Most indoor domestic water returns to the subsurface groundwater system by discharge to domestic septic systems or other wastewater systems. Therefore, in the groundwater budget, we accounted for domestic consumptive use by considering it as a groundwater budget outflow.

Calculation of domestic consumptive use (DW) included both indoor domestic use and outdoor lawn use. Indoor domestic consumptive use was based on the estimated number of homes in the study area. The number of homes was multiplied by an average consumptive use of 0.03 acre-ft/yr (according to the MT-DNRC, 2011). Outdoor domestic consumptive lawn use in both PWS and non-PWS areas was estimated by the number and size of watered lawns within the groundwater budget area and the lawn ET rates for March–September 2015 obtained from the AgriMet station in Corvallis (USBR, 2016).

Groundwater Storage (ΔS)

Water levels from 47 unconfined wells (appendix A, table A2) were used to develop a potentiometric surface for each month of 2015, using the Inverse Distance Weighted algorithm in ArcGIS (ESRI, 2021). The wells used in these maps were the same wells used to construct the potentiometric-surface map, except for two wells that had incomplete monthly datasets for 2015 (wells 286258 and 286267). The monthly changes in the potentiometric surface were calculated separately for the valley floor (consisting of Quaternary alluvial deposit sediments) and for the high terraces (consisting predominantly of Tertiary sediments). The change in storage from November 2014 to December 2014 was used to estimate the change in storage for December 2015 because there was an incomplete set of measurements for December 2015. The change in aquifer volume for each month was multiplied by a representative aquifer porosity (n) of 0.20 for the valley floor and 0.15 for the high terraces (Woessner and Poeter, 2020).

Groundwater-Elevation Trend Analysis

Long-term groundwater elevations measured in 16 wells with a POR greater than 15 yr were evaluated statistically to determine if elevations were increasing, were decreasing, or had no trend. These wells are part of the MBMG's Ground Water Assessment Program's statewide monitoring network (MBMG, 2022). The nonparametric seasonal Kendall test (Helsel and others, 2020) was used to evaluate groundwater-elevation trends for the POR and for 2001–2015. This nonparametric approach has the advantage over simple linear regression because it can account for nonlinear relationships and seasonal variability. The wells analyzed for long-term trends are shown in figure 8, and their hydrographs are provided in appendix C.

The seasonal Kendall test computes a test statistic (Kendall's τ) by comparing all observations as pairs in increasing time order. The "seasonal" component of this method evaluates the trends for each season separately using Mann–Kendall trend tests, and then combines those results into a single final test result. In this way, data from each season are compared only to other data collected in the same season. Once calculated, the τ statistic is compared to a standard normal distribution to determine how likely it would be to get that value if there was no trend. The null hypothesis for the seasonal Kendall test was that there was no trend in the groundwater elevation for the period of time evaluated. For this study, a trend (increasing or decreasing groundwater elevation) was considered statistically significant only when the null hypothesis could be rejected at a confidence level of 95% (i.e., using $\alpha = 0.05$). For those wells where a significant increasing or decreasing trend was detected, the magnitude of that trend was quantified using the Sen Slope (Helsel and others, 2020). The Sen Slope is the median of all pairwise slopes between observations.

Because there were variations in monitoring frequency during 2001–2015 (quarterly, monthly, and hourly), quarterly seasons were defined for the seasonal Kendall tests. For those periods where there were more frequent measurements, the observation nearest to the midpoint of the season was used. Trends were not determined for wells with less than 40 quarterly measurements (less than 2/3 of the possible measurements). The trend tests were performed using the XLSTAT add-on package for Excel (Addinsoft, 2018).

Nitrate Sampling and Analysis

Seventy-three groundwater samples collected from 32 wells (16 wells sampled three times, 9 wells sampled twice, and 7 wells sampled once during 2014–2015) and 9 surface-water samples collected from 7 surface-water sites (2 sites sampled twice and 5 sites sampled once during 2014–2015) were analyzed by the MBMG analytical laboratory. The analytes discussed in this report include nitrate + nitrite as nitrogen ($NO_3 + NO_2 - N$), chloride (Cl), and bromide (Br). Chloride and bromide were used to help identify potential sources of nitrate in sampled waters such as septic system effluent, fertilizers, and animal waste (Panno and others, 2006; Katz and others, 2011; Pastén-Zapata and others, 2014; Torres-Martínez and others, 2020). All groundwater and surface-water samples were collected following MBMG standard operating procedures (Gotkowitz, 2022).

Wells were selected for sampling based on availability of historical nitrate analyses, location in areas with no historical samples, proximity to housing projects, and location in areas away from housing projects or irrigated lands to determine background nitrate concentrations in groundwater.

In addition to the nitrate samples collected as part of this study, we also included nitrate samples collected from other studies. Historical nitrate samples from wells 5413 and 126820 were collected by the USGS and the MBMG prior to 2001 (Briar and Dutton, 2000; Smith and others, 2013) and were reviewed as part of this study. Nitrate samples from PWS wells were used to evaluate historical nitrate trends in groundwater within the study area. These PWS datasets consist of nitrate samples collected annually as required by the Montana Department of Environmental Quality (DEQ) and EPA. Collection of nitrate samples from PWS wells began as early as the 1970s. Using the EPA's Safe Drinking Water Information System database, 58 PWS wells were identified in or near the study area (U.S. Environmental Protection Agency, 2017). Water samples from these PWS wells were analyzed for nitrate by accredited labs used by the county health department. Nitrate sample data from these PWS wells compiled for this study are tabulated in appendix D.

Mann–Kendall Trend Test

Annual PWS nitrate samples provide a longer and more consistent dataset to investigate nitrate-concentration trends. For PWS wells with six or more samples, potential monotonic trends in nitrate concentrations were evaluated using the Mann–Kendall test (Helsel and others, 2020). For each well, Mann–Kendall tests were conducted for the POR and for the most recent 10-yr period from 2007 to 2016. A significance level (α-value) of 0.05 was used, so there is a 95% confidence that the detected trends are not due to random variations (i.e., calculated p-values $<\alpha$ were considered to show a statistically significant trend). For wells with statistically significant trends, the Sen Slope (Helsel and others, 2020) was calculated to quantify the magnitude of the trend. The XLSTAT add-on package for Excel (Addinsoft, 2018) was used to perform these tests.

RESULTS

Hydrostratigraphy and Aquifer Properties

Six main hydrostratigraphic units were identified in the study area: (1) bedrock (TYb); (2) Tertiary

Ancestral Bitterroot River deposits (Tbg and Tbc); (3) Tertiary alluvial and boulder fan deposits (Taf); (4) Quaternary boulder fan deposits (Qbf); (5) Quaternary alluvial fan deposits (Qaf); and (6) Quaternary alluvial deposits (Qal; fig. 5). The stratigraphic relationships among the units are shown in a cross-section through the study area (fig. 9).

Although these hydrostratigraphic units have different hydrogeologic properties, there is sufficient hydraulic connection and groundwater movement among the units so they collectively function as three main aquifers: the bedrock, deep basin-fill, and unconfined shallow basin-fill (LaFave, 2006a; Smith and others, 2013). The characteristics of the hydrostratigraphic units are provided in this section; however, emphasis is placed on the unconfined aquifer because it is the system most likely to be affected by degradation from surface activities. Total well depth, static water level, and yield of wells completed in each hydrostratigraphic unit are statistically summarized in table 2. Hydraulic characteristics of the units determined by aquifer tests (and associated references) are summarized in table 3.

Bedrock (TYb)

Bedrock in the study area (fig. 5) consists of metasedimentary rocks of the Proterozoic Belt Supergroup and Tertiary and Cretaceous igneous rocks of the Idaho Batholith, Willow Creek stock, and Skalkaho Creek stock (Smith, 2006a). Groundwater flows typically through bedrock fractures. The bedrock aquifer is typically penetrated by wells along the valley perimeter. On average, the bedrock aquifer has the deepest wells (182 ft bgs) and the lowest groundwater yields (9.5 gpm; table 2). Transmissivity (T) and storativity (S) determined from an aquifer test in well 5418 were 224 ft^2/d and 0.000048, respectively (table 3; Norbeck, 1980). Bedrock was encountered at a depth of 960 ft in this well, and the storativity value indicates the aquifer is confined. Since bedrock wells are often located above irrigation ditches and irrigated lands, they do not receive irrigation recharge. These wells typically show recharge from snowmelt and large precipitation events.

Tertiary Ancestral Bitterroot River Deposits (Tbg and Tbc)

Sediments constituting the Tertiary Ancestral Bitterroot River deposits can be part of the deep basin-fill aquifer or the shallower unconfined aquifer. The Ancestral Bitterroot River flowed during the late Pliocene or early Pleistocene (McMurtrey and others, 1972) and eroded a broad valley that varied greatly laterally, depositing fine- to coarse-grained sediments. On the high terraces (fig. 3), units Tbg and Tbc are generally part of the unconfined aquifer. Alternatively, units Tbg and Tbc are also found at depths greater than 45–80 ft bgs below Qbf, Qaf, and Qal. At these depths, they are generally part of the deep basin-fill aquifer and are under semi-confined to confined conditions.

Tbg deposits are generally light-colored, well-sorted, and consist of stratified sand, gravel, and large round cobbles (Lonn and Sears, 2001). The Ancestral Bitterroot River deposits can be further divided into coarse-grained (Tbgc) and fine-grained (Tbgf; fig. 9). Tbgc sediments are commonly above Tbgf; however, Tbgc forms lenses within Tbgf and vice versa (fig. 9). Tbc is a finer-grained, light gray clay, silt, and tephra of the "blue clay facies" that interfingers with both Tbgc and Tbgf.

Table 2. Properties of the hydrostratigraphic units based on wells in the study area.

		Total Depth (ft bgs[1])			SWL[2] (ft bgs)			Yield, gpm		
Hydrostratigraphic Unit	*n*	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Quaternary Alluvial deposits (Qal)	19	39	20	58	9	4.5	18	50	15	200
Quaternary Alluvial Fan (Qaf)	17	37	28	47	10	5	17	42	12	100
Quaternary Boulder Fan (Qbf)	2	83	39	126	46	8	83	12	9	15
Tertiary Alluvial Fan (Taf)	54	129	30	340	52	4	238	29	3	325
Tertiary Ancestral Bitterroot River deposits (Tbg, Tbc)[3]	5	107	40	215	64	20	136	26	9	50
Bedrock (TYb)	9	182	77	280	41	9	80	10	1	15

[1] bgs, below ground surface.
[2] SWL, static water level.
[3] Well yields from drillers logs (http://mbmggwic.mtech.edu).

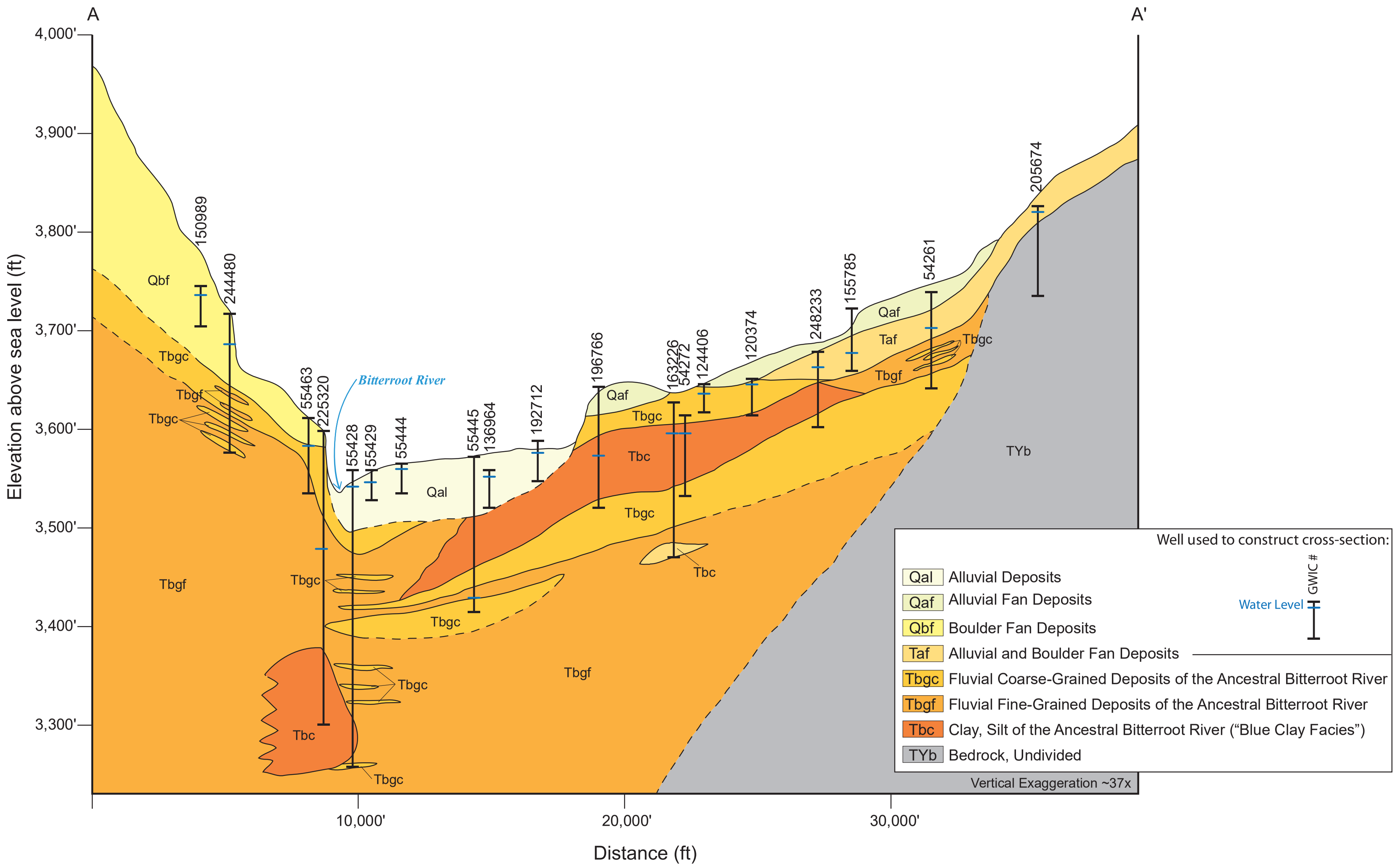


Figure 9. Cross-section A–A' through study area (see figure 5 for location of cross-section). The deep basin-fill aquifer units (generally Tbgc, Tbgf, and Tbc) underlie the shallow basin-fill aquifer units (generally Qal, Qaf, Qbf, Taf). The Ancestral Bitterroot deposits (Tbgc, Tbgf, and Tbc) and Taf can be a part of the shallow or deep basin-fill aquifers depending on the location. The bedrock aquifer (TYb) flanks the valley sediments.

Table 3. Aquifer properties from aquifer tests in the study area.

GWIC	Hydrostratigraphic Unit	T (ft^2/day)	S	Source
278813	Quaternary Alluvial (Qal)	61,930	NA	Water Right # 76H 30069080[1]
183528	Quaternary Alluvial (Qal)	36,000	NA	Water Right # 76H 30001085[1]
192679	Quaternary Alluvial (Qal)	61,200	NA	Water Right # 76H 30001083[1]
286259	Quaternary Alluvial (Qal)	20,320	NA	Myse and Snyder (2021), pumping well 286258
287096	Quaternary Alluvial (Qal)	19,110	NA	Myse and Snyder (2021), pumping well 286258
286256	Quaternary Alluvial (Qal)	29,850	NA	Myse and Snyder (2021), pumping well 286258
203550	Quaternary Alluvial Fan (Qaf)	49,480	0.1	Water Right # 76H 30006845[1]
221697	Quaternary Alluvial Fan (Qaf)	16,680	0.06	Geomatrix Consultants, Inc. (2006)
221698	Quaternary Alluvial Fan (Qaf)	16,700	0.18	Geomatrix Consultants, Inc. (2006)
286266	Quaternary Alluvial Fan (Qaf)	12,170	0.01	Myse and Snyder (2021), pumping well 286267
286270	Quaternary Alluvial Fan (Qaf)	11,210	NA	Myse and Snyder (2021), pumping well 286267
286217	Tertiary Ancestral Bitterroot River deposits (Tbg)	4,500	NA	Myse and Snyder (2021), pumping well 286280
NA	Tertiary Ancestral Bitterroot River deposits (Tbg)	5,299	0.034	Water Right # 76H 30009727[1]
223902/223903	Tertiary Ancestral Bitterroot River deposits (Tbg)	2,478	0.02	Water Right # 76H 30027606[1]
224760	Tertiary Ancestral Bitterroot River deposits (Tbg)	1,610	0.00005	Water Right # 76H 30026378[1]
5418	Bedrock (TYb)	224	0.000048	Norbeck (1980)

Note. NA, not available.

[1] DNRC, oral commun., 2018.

An aquifer test conducted as part of this study in well 286217, completed in the Tbg deposits, yielded 170 gpm (Myse and Snyder, 2020). However, the average well yields from drillers' logs for Tbg is 26 gpm (table 2). Three aquifer tests conducted in the Tbg and Tbc deposits, as part of water rights in Montana, indicated groundwater conditions at these locations were confined and unconfined (storativity values of 0.00005 to 0.034, respectively; table 3). Well logs for the northeastern part of the study area indicate Tbg deposits are finer grained than what is typically described for Tbg in the rest of the study area. Most well yields in the northeastern area yield less than 50 gpm, and many lithologic descriptions include hard, white sand and light gray clay that matches Tbc descriptions. Therefore, Tbc may interfinger with the Tbg deposits in the northeastern part of the study area.

Tertiary Alluvial and Boulder Fan Deposits (Taf)

Similar to the Tertiary Ancestral River deposits, the Tertiary alluvial and boulder fan deposits can be a part of the deep basin-fill aquifer or the unconfined aquifer, depending on the overlying sediments or if they are surficially exposed. Wells that penetrate the Taf have the largest range in depths (30 to 340 ft bgs) and the largest range in yields (3 to 325 gpm; table 2). Taf is a poorly sorted deposit with boulders, cobbles, and sandy silt, and therefore has low permeability (Lonn and Sears, 2001). However, water is found at various depths in thin gravel seams.

Quaternary Boulder Fan Deposits (Qbf)

Quaternary boulder fan deposits are part of the unconfined aquifer. Qbf is only present on the western edge of the study area (fig. 5). It has low yields in the study area (9 and 15 gpm from two wells; table 2), likely due to the highly unsorted sediments (silt to boulders). Aquifer properties are currently unknown for this hydrostratigraphic unit.

Quaternary Alluvial Fan Deposits (Qaf)

Similar to Qbf, Quaternary alluvial fan deposits are a part of the unconfined aquifer. Qaf deposits are on both the west and east sides of the study area (fig. 5). It is the second most productive hydrostratigraphic unit, with an average well yield of 42 gpm (table 2). Transmissivities determined from aquifer tests ranged from about 11,000 to 50,000 ft^2/d, and storativities ranged from 0.01 to 0.18 (table 3). Two transmissivities (about 11,000 and 12,000 ft^2/d) and one storativity value (0.01) determined from the aquifer test conducted in unit Qaf as part of this study (wells 286266 and 286270, table 3) were less than values determined from three previous studies (about 17,000–50,000 and 0.06–0.18, respectively; table 3; well locations shown in fig. 8). The lower transmissivities and storativities may indicate the wells tested as part of this study are completed in finer Qaf sediments than the wells tested as part of the previous studies.

Quaternary Alluvial Deposits (Qal)

Quaternary alluvial deposits form the floodplain of the Bitterroot River (fig. 5) and are part of the unconfined aquifer. Qal generally extends to a depth of 20–60 ft bgs. However, thicker sequences of Qal occur near the mouth of Roaring Lion Creek (up to 100 ft bgs) and the mouth of Blodgett Creek (up to 150 ft bgs; Smith, 2006b). Qal has the lowest average depth to static water level (9 ft bgs; table 2). Qal is also the most productive hydrostratigraphic unit in the study area, with an average yield of 50 gpm (table 2). Multiple aquifer tests estimate transmissivities ranging from about 19,000 to 62,000 ft^2/d (table 3).

Regional Groundwater Flow

Figure 10 shows the potentiometric-surface map of the unconfined aquifer constructed for August 2015. Assuming groundwater flow is perpendicular to the potentiometric contours, groundwater in the study area flows towards the Bitterroot River. The horizontal hydraulic gradient is about 0.02 in the eastern part of the study area, where groundwater flows from the poorly conductive Tertiary sediments (Tbg and Taf) and the moderately conductive Quaternary alluvial fan deposits (Qaf) towards the Bitterroot River (figs. 5, 10). The hydraulic gradient decreases (0.003–0.01) as groundwater flows northward in the more conductive sediments consisting of present-day Bitterroot River deposits (Qal). The hydraulic gradient in the western part of the study area is greater (0.03) than in the eastern part of the study area (about 0.02), corresponding to the steeper topography on the west side of the valley. Similar groundwater-flow directions and hydraulic gradients were reported in Briar and Dutton (2000) and LaFave (2006a).

Water Budgets

Surface-Water Budget

The surface-water budget for the Bitterroot River indicated the river consistently gained groundwater between sites 278017 and 266799, a distance of 9.8 mi (fig. 7). Table 4 and figure 11 compile the inflows, outflows, change in storage (due to low-elevation ponding during high river flows), and the net gain of surface water from groundwater in July–October 2014 and January–November 2015.

Flow in the Bitterroot River ranged from 337 to 4,340 cfs throughout the measured months of 2014 and 2015 (BR_{in} and BR_{out}; table 4). The highest flow occurred during May, when snow melts in the Bitterroot and Sapphire Mountains. Similarly, tributaries to the Bitterroot River show a larger contribution during March–June due to snowmelt. During the high-flow months, low-elevation regions near the river flood and account for 2,800–9,480 acre-ft (46.5–157 cfs) of surface water in the surface-water budget (ΔS). Higher Bitterroot River flows were observed in July–October 2014 compared to July–October 2015, most likely due to greater snowpack and later snowmelt in the Bitterroot Mountains during July 2014 (NRCS-NWCC, 2017; fig. 4). In addition, August and October 2014 had more rain compared to the same months in 2015 (USBR, 2016).

Irrigation canals diverted water from the Bitterroot River during April–October in both years. Depending on the monthly flow in the Bitterroot River, 3–30% of the outflows are to canal/ditches ($Canal_{out}$). The total amount of water (in cfs) diverted to canals and ditches was about the same throughout the summer (about 130 cfs in 2015; table 4; fig. 11), but the percentage of total flow diverted to the canals increased during July–September due to the overall lower flows in the river (fig. 11).

Assuming that groundwater inflows account for the difference between inflows and outflows, the Bitterroot River gained about 43–572 cfs from groundwater (GW_{in}) during 2015 (table 4). River gains from groundwater were highest in May (572 cfs) and June 2015 (214 cfs). These large gains are likely due to snowmelt entering the groundwater system outside the study area and discharging to the river inside the study area. Irrigation recharge and/or canal loss from the BRID increases groundwater elevations and can also increase the groundwater discharge to the river during irrigation season. However, the levels are generally higher during April–September, during the irrigation season, compared to the rest of the year.

Groundwater Budget

A groundwater budget was used to quantitatively estimate the contribution of inflows, outflows, and storage for the study area east of the Bitterroot River. This is useful in understanding the relative importance of different groundwater budget components contributing to the overall groundwater budget. Each component in the groundwater budget equation (see Methods

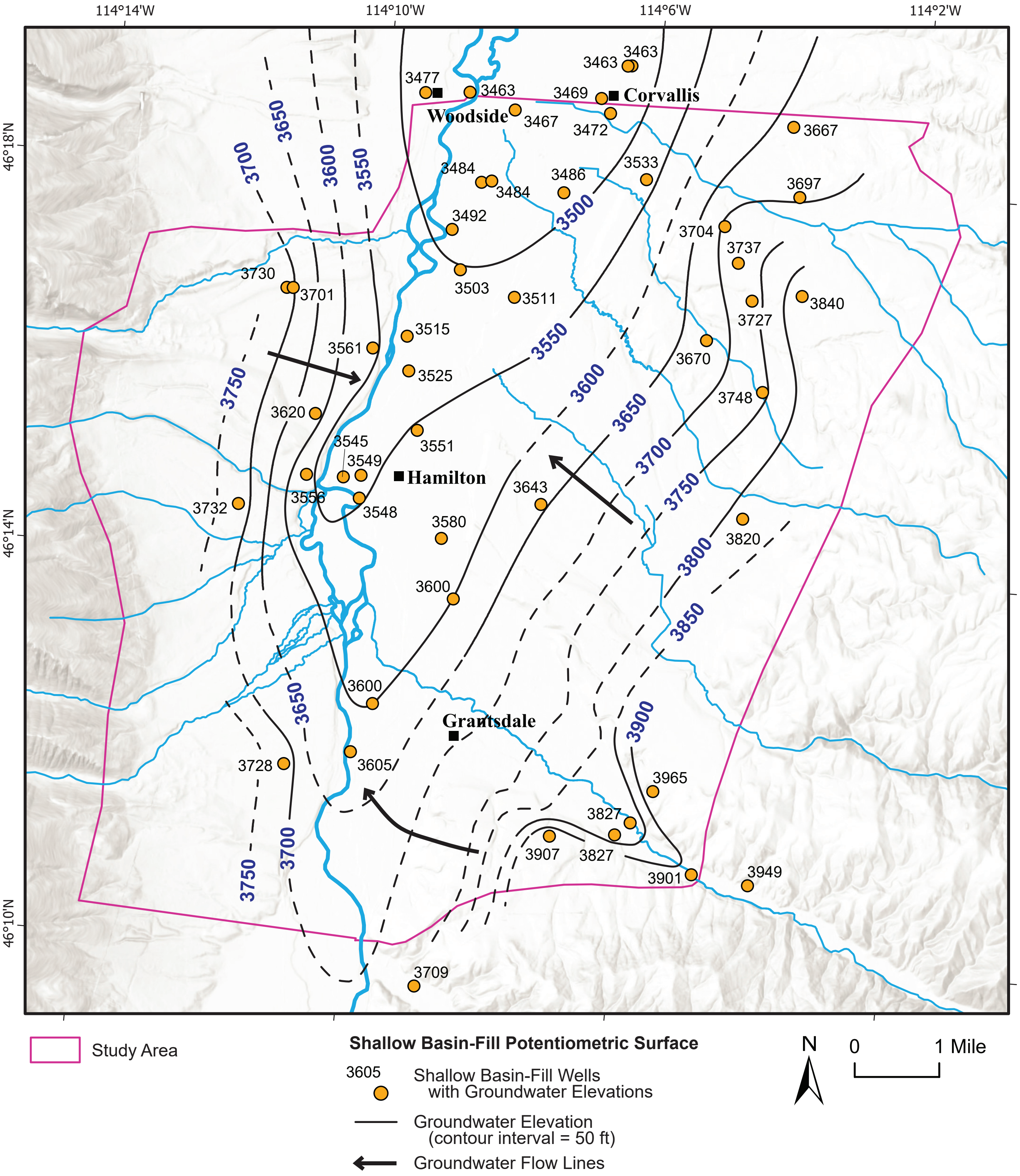


Figure 10. Potentiometric-surface map created using August 2015 water-elevation measurements. Groundwater flows towards the Bitterroot River and northward out of the study area.

Table 4. Bitterroot River surface-water budget.

	Jul-14	Aug-14	Sep-14	Oct-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15
Surface-Water Inflows, cfs															
BR_{in} (278017)	**1,070**	**651**	**374**	**525**	**688^1**	**1,050**	**1,910**	**1,310**	**$3,660^1$**	**1,230**	**432**	**337**	**337**	**337**	**337^1**
Error (+/-)	*32.0*	*19.5*	*11.2*	*15.8*	*20.6*	*31.5*	*57.2*	*39.4*	*109*	*37.0*	*13.0*	*10.1*	*10.1*	*10.1*	*10.1*
Skalkaho Creek (278137)	**32.7**	**35.6**	**8.84**	**33.1**	**14.6^1**	**33.1**	**67.0**	**92.0**	**133^1**	**89.4**	**10.9**	**10.4^1**	**9.67^1**	**6.57^1**	**22.4^1**
Error (+/-)	*1.63*	*1.78*	*0.440*	*1.65*	*0.730*	*1.65*	*3.35*	*4.60*	*6.64*	*4.47*	*0.540*	*0.520*	*0.480*	*0.330*	*1.12*
Roaring Lion Creek (28134)	**2.64**			**4.95**	**3.63^1**	**7.40**	**18.7**	**3.42^1**	**15.8^1**	**11.7**		**0.350^1**	**0.450^1**	**0.340^1**	**0.280^1**
Error (+/-)	*0.130*			*0.250*	*0.180*	*0.370*	*0.940*	*0.170*	*0.790*	*0.580*		*0.020*	*0.020*	*0.020*	*0.010*
Sawtooth Creek (278136)	**27.1**	**7.24**	**3.95^1**	**11.3^1**	**34.7^1**	**53.7**	**88.1**	**46.5**	**119^1**	**46.1**	**6.90**	**4.31^1**	**4.39^1**	**6.48^1**	**13.3^1**
Error (+/-)	*1.36*	*0.360*	*0.200*	*0.560*	*1.73*	*2.69*	*4.40*	*2.32*	*5.93*	*2.30*	*0.350*	*0.220*	*0.220*	*0.320*	*0.670*
Canyon Creek (278109)	**7.65**	**1.33**	**1.81^1**	**4.55^1**	**7.40^1**	**9.30**	**26.6**	**8.05**	**41.3**	**16.1**	**1.33^1**	**0.530^1**	**2.86^1**	**3.26^1**	**1.86^1**
Error (+/-)	*0.380*	*0.070*	*0.090*	*0.230*	*0.370*	*0.470*	*1.33*	*0.400*	*2.06*	*0.810*	*0.070*	*0.030*	*0.140*	*0.160*	*0.090*
Blodget Creek (278019)	**25.7**	**1.03**	**1.05**	**14.7**	**30.6^1**	**64.9**	**161**	**54.0**	**106^1**	**43.7^1**	**2.33^1**	**4.84^1**	**10.0^1**	**4.53^1**	**25.3^1**
Error (+/-)	*1.28*	*0.0500*	*0.0500*	*0.740*	*1.53*	*3.24*	*8.07*	*2.70*	*5.31*	*2.19*	*0.120*	*0.240*	*0.500*	*0.230*	*1.26*
Total Inflows	**1,170**	**696**	**390**	**594**	**779**	**1,220**	**2,270**	**1,510**	**4,080**	**1,440**	**453**	**357**	**364**	**358**	**400**
Surface-Water Outflows, cfs															
C&C Ditch (278108)	**2.71^1**	**3.65^1**	**3.80^1**	**4.09^1**					**8.95**	**6.37**	**7.04^1**	**7.00^2**	**7.00^2**	**7.00^2**	
Error (+/-)	*0.140*	*0.180*	*0.190*	*0.200*					*0.450*	*0.320*	*0.350*	*0.350*	*0.350*	*0.350*	
Corvallis Canal (278111)	**118^1**	**63.2**	**59.1**	**1.59**				**22.5**	**109**	**119**	**91.5**	**91.5^2**	**91.5^2**	**91.5^2**	
Error (+/-)	*5.92*	*3.16*	*2.96*	*0.0800*				*1.12*	*5.44*	*5.93*	*4.57*	*4.58*	*4.58*	*4.58*	
Woodside Canal	**30.0**	**30.0**	**30.0**	**30.0**					**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	
Error (+/-)	*1.50*	*1.50*	*1.50*	*1.50*					*1.50*	*1.50*	*1.50*	*1.50*	*1.50*	*1.50*	
BR_{out} (266799)	**1,110**	**702**	**399**	**622**	**983^1**	**1,280**	**2,240**	**1,550**	**4,340**	**1,450**	**394**	**353**	**305**	**278**	**446^1**
Error (+/-)	*33.2*	*21.1*	*12.0*	*18.7*	*29.5*	*38.5*	*67.1*	*46.6*	*130*	*43.6*	*11.8*	*10.6*	*9.16*	*8.34*	*13.4*
Total Outflows	**1,260**	**799**	**492**	**658**	**983**	**1,280**	**2,240**	**1,570**	**4,490**	**1,610**	**523**	**482**	**434**	**407**	**446**
Storage, cfs															
ΔS							**73.0**	**46.5**	**157**	**46.5**					
Error (+/-)							*3.65*	*2.32*	*7.86*	*2.32*					
Net Gain, cfs															
GW_{in}	**97.4**	**102**	**102**	**64.1**	**204**	**64.6**	**43.3**	**106**	**572**	**214**	**69.1**	**124**	**69.1**	**48.3**	**45.9**
Error (+/-)	*47.0*	*29.0*	*17.0*	*25.0*	*36.0*	*50.0*	*89.0*	*61.0*	*171*	*58.0*	*18.0*	*15.0*	*14.0*	*14.0*	*17.0*

Note. Values may not add to totals due to rounding to three significant figures.

[1] Discharge calculated from rating curve.

[2] Discharge assumed to be the same during the summer irrigation season.

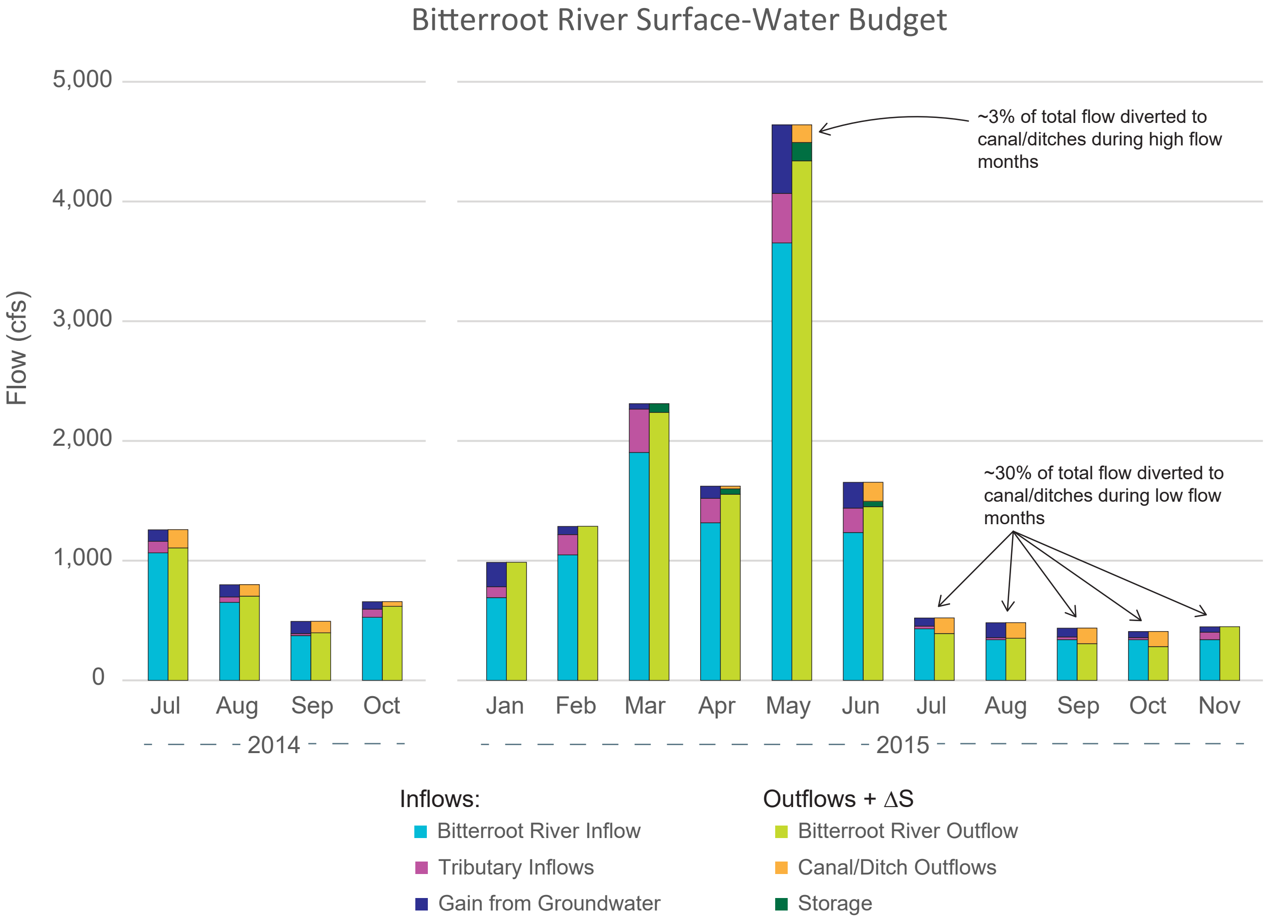


Figure 11. Summary of Bitterroot River surface-water budget. Gain from groundwater was calculated from surface-water outflows plus storage minus surface-water inflows. Therefore, *Inflows* = *Outflows* + ∆*S*. Note that canal/ditch outflow only occurs during irrigation season (April–October) and storage was only calculated for high flows of the Bitterroot River (March–June). The Bitterroot River has the highest flow and greatest gain from groundwater during May when snowmelt is occurring.

section) is quantified below, and calculations for each budget component are described in greater detail in appendix B (appendix B, tables B1–B11). The overall groundwater budget is compiled in table 5.

Groundwater Inflow (GW_{in}) and Outflow (GW_{out})—Appendix B: Tables B1 and B2

The August 2015 potentiometric-surface map indicates groundwater generally flows west–northwest from the eastern and southeastern boundaries toward the Bitterroot River (fig. 10). Groundwater entering the groundwater budget area (GW_{in}) flows through the Tbg, which has transmissivity of 3,123 ft^2/d (geometric mean, $n = 4$; table 3), whereas water exiting the groundwater budget area (GW_{out}) flows through the Qal, with a transmissivity of 25,416 ft^2/d (geometric mean, $n = 4$; table 3). The two 61,000 transmissivities were not included in the geometric mean result because one test was only conducted for 8 h and another has incomplete information. Hydraulic gradients were steeper in the high terraces and gentler in the floodplain (fig. 10). Overall, the total annual groundwater inflow (GW_{in}) was 41,060 acre-ft/yr, whereas the total annual groundwater outflow (GW_{out}) was 80,300 acre-ft/yr (appendix B, tables B1, B2). Therefore, GW_{in} in the groundwater budget area is almost one-half that of GW_{out}.

Canal Loss (CL_{BRID} and $CL_{C/D}$)—Appendix B: Tables B3, B4, and B5

The BRID canal lost water to the groundwater over the 5.8-mi reach in both 2014 and 2015. During both years, upstream site 278106 had greater flow than downstream site 269370 (figs. 12A, 12B). The exception for both years was a brief period in July when flows were higher downstream; however, seepage loss/gain was within the margin of error of the measurements. The loss varies throughout the irrigation season

Table 5. Monthly values for each component of the groundwater budget. See appendix B for additional groundwater budget details.

	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Annual
Inflow, acre-ft													
Groundwater inflow (GW_{in})	3,490	3,150	3,490	3,370	3,490	3,370	3,490	3,490	3,370	3,490	3,370	3,490	41,060
BRID canal loss to groundwater (CL_{BRID})				626	2,430	2,820	1,700	2,630					10,206
Canal/ditch loss to groundwater ($CL_{C/D}$)				343	1,230	1,110	1,190	1,190	957	9			6,029
Irrigation recharge (IR)				174	1,900	2,640	4,250	3,160	1,170	134			13,428
Rain recharge from non-irrigated land (R)					259	1	23	296					579
Skalkaho Creek to groundwater (SW_{in})	1,140	1,190	1,910	2,110	1,940	394				739	1,760	2,180	13,363
Total Inflows	**4,630**	**4,340**	**5,400**	**6,623**	**11,249**	**10,335**	**10,653**	**10,766**	**5,497**	**4,372**	**5,130**	**5,670**	**84,700**
Outflows, acre-ft													
Groundwater to Skalkaho Creek (SW_{out})							1,080	1,440	988				3,508
Riparian ET (ET_r)			47	151	311	608	571	454	343	239			2,724
Domestic consumptive use (DW)	11	11	166	313	404	536	546	459	299	11	11	11	2,778
Groundwater outflow (GW_{out})	6,820	6,160	6,820	6,600	6,820	6,600	6,820	6,820	6,600	6,820	6,600	6,820	80,300
Total Outflows	**6,831**	**6,171**	**7,033**	**7,064**	**7,535**	**7,744**	**9,017**	**9,173**	**8,230**	**7,070**	**6,611**	**6,831**	**89,300**
Storage, acre-ft													
ΔS	**-2,300**	**-3,570**	**-3,130**	**-2,390**	**14,700**	**8,790**	**4,170**	**1,100**	**-2,730**	**-8,040**	**-5,510**	**-3,320**	**-2,230**

Note. Monthly values for each component are calculated in appendix B and are presented in this table rounded to three significant digits. Summations for total monthly inflows, total monthly outflows, and annual values for each component are not rounded. These values are summed to determine annual total inflows and annual total outflows, which were rounded to three significant digits.

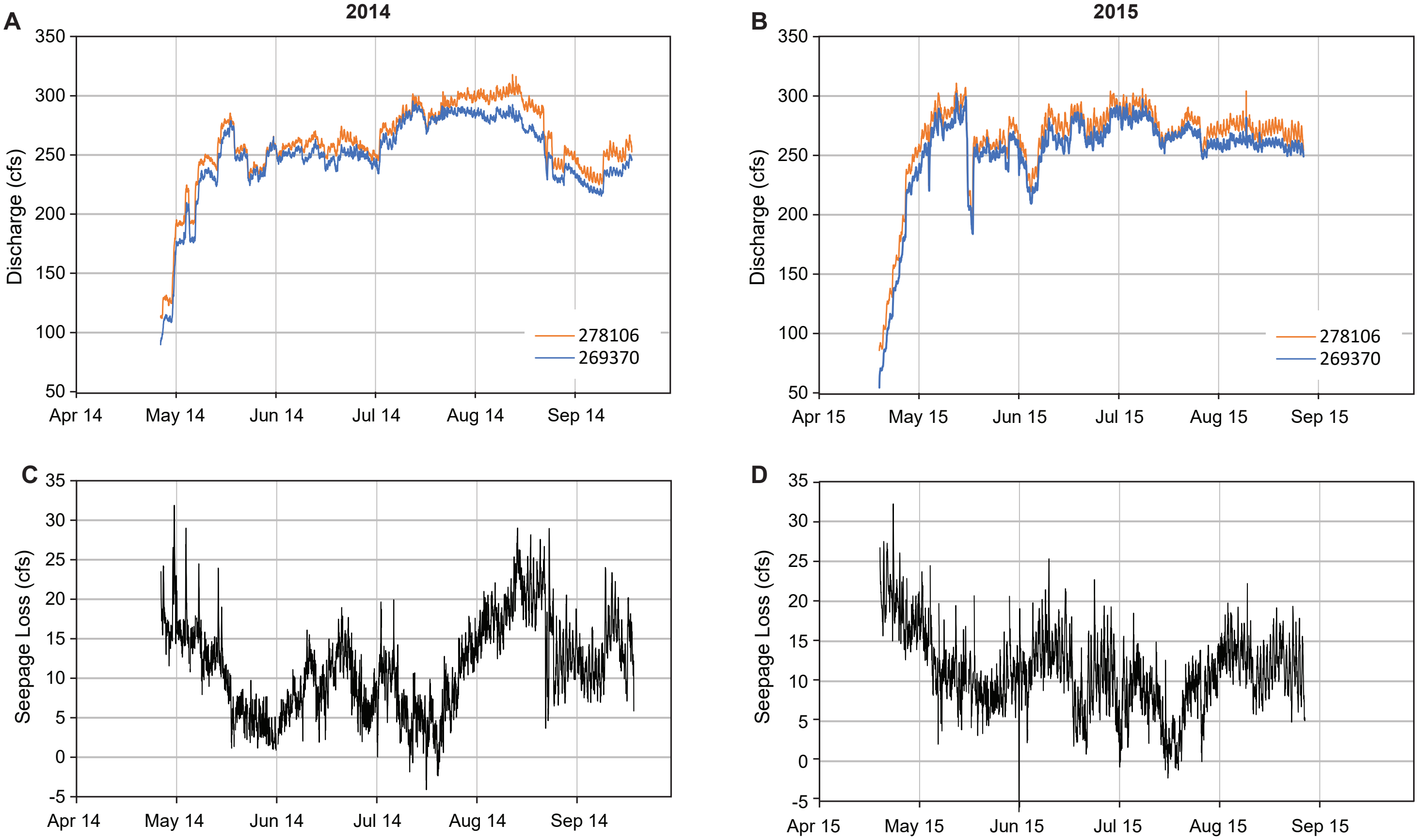


Figure 12. Canal discharge for upstream site 278106 and downstream site 269370 on the BRID canal for 2014 (A) and 2015 (B). The canal discharge is consistently higher upstream, indicating water is seeping to the groundwater. Canal seepage (C, D) varies throughout the irrigation season.

and differs from year to year (figs. 12C, 12 D; table 5). Canal flow and stage, vegetation in the canal, maintenance, and sediments underlying the canal can affect the seepage loss rate. The higher rate of seepage early in the season is attributed to wetting of the sediments underlying the canal once the canal was turned on.

During 2015, the average monthly BRID seepage loss ranged from 1.2 to 3.4 cfs/mi (appendix B, tables B3, B4), with an average monthly loss ranging from 626 to 2,820 acre-ft, and an annual total of 10,206 acre-ft (CL_{BRID}; table 5).

Wells 54061 and 52842 (see fig. 8 for location) demonstrate groundwater response to BRID seepage. Wells 54061 and 52842 are about 1,800 ft and 270 ft, respectively, downgradient from the BRID. The rise in groundwater levels in 2014 and 2015 occurs in response to water being conveyed down the canal (fig. 13). Water levels remain elevated throughout the irrigation season and decline late summer/early fall when the canal is shut down (fig. 13).

The discharge-to-seepage ratio (0.8%) calculated for the BRID was applied to the other primary canals (appendix B, table B5). A total of 6,029 acre-ft of water is lost to groundwater from the other canals in the study area ($CL_{C/D}$; table 5).

Irrigation Recharge (IR) and Non-Irrigated Land Recharge (R)—Appendix B: Tables B6 and B7

There are 13,600 irrigated acres within the groundwater budget area. These irrigated acres account for 41% of the total groundwater budget area (about 33,500 acres). Of the irrigated acres, about 48% is flood irrigated, 48% is sprinkler irrigated, and 4% is pivot irrigated (fig. 6). In terms of crop type, 37% was considered alfalfa, 20% was considered grass hay, and 43% was considered pasture grass (see Methods; appendix B, table B6). Irrigation recharge (*IR*) totaled 13,428 acre-ft for April through October 2015 (table 5), and *IR* was largest in August and July. Groundwater levels are noticeably higher (shallower) during irrigation months (figs. 13, 14).

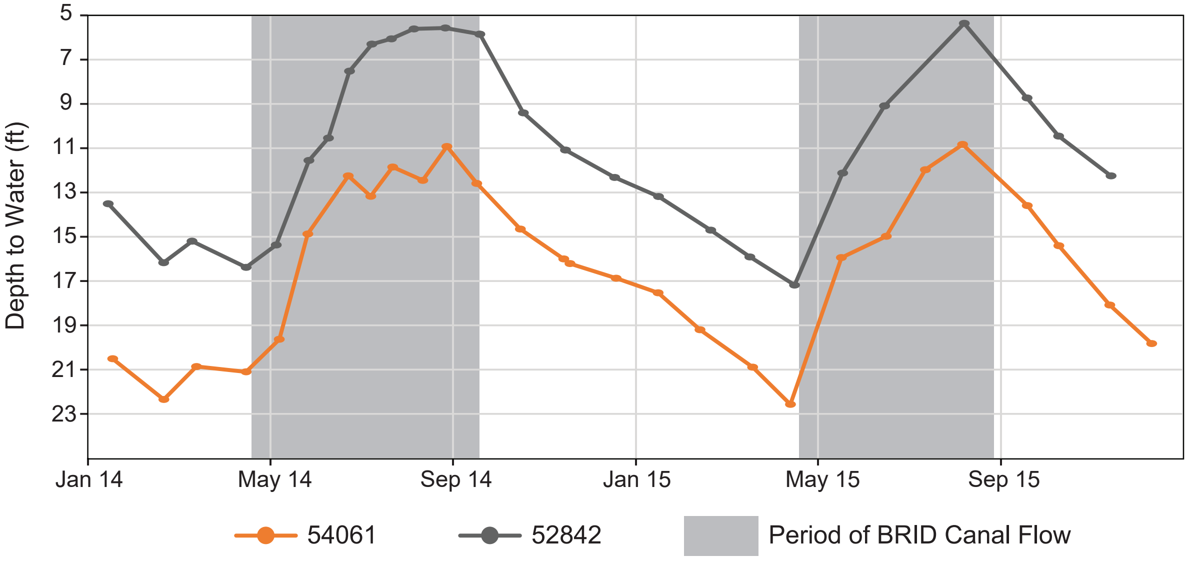
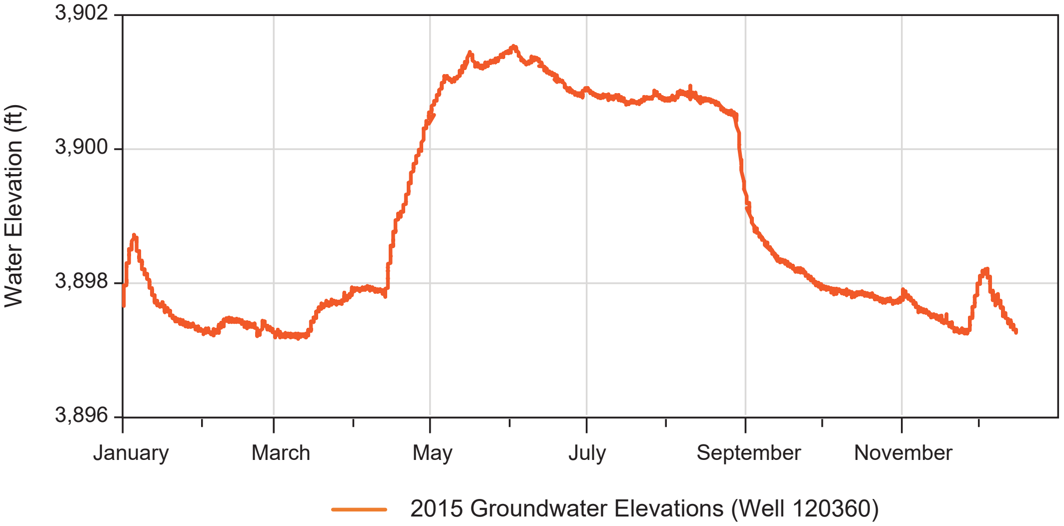


Figure 13. Hydrographs of wells near the BRID Canal. The higher water levels occur throughout the summer, demonstrating the influence of canal seepage on groundwater.



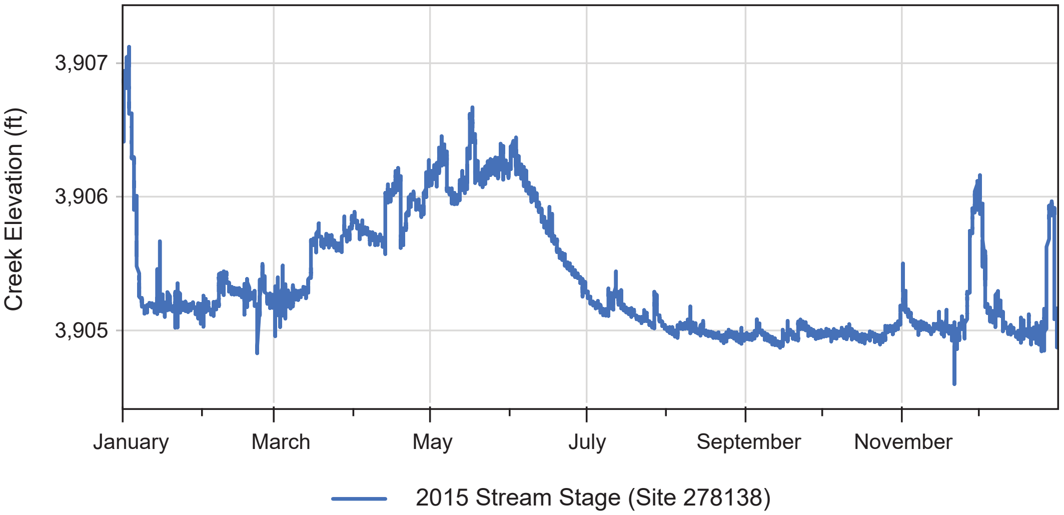


Figure 14. Hydrographs of Skalkaho Creek site 278138 and well 120360 (approximately 300 ft downgradient of the staff gage) demonstrate the fluctuation in water level throughout the year. The creek shows high flows during April–June when there is spring snowmelt. The well shows high water levels during the irrigation season (May–August) because of irrigation recharge. Peaks in both the creek and well hydrograph during November–January are likely caused from rain and/or snowmelt events.

A total of 15,411 acres were classified as non-irrigated land in the groundwater budget area. Of these non-irrigated acres, 9,347 acres were range grass, 3,610 acres were sagebrush, and 2,454 acres were conifers (MT-DOR, 2015). From May through August, precipitation exceeded ET (table 5; appendix B, table B7). The highest non-irrigated land recharge occurred in May and August (259 and 296 acre-ft/mo, respectively). Annual recharge from non-irrigated land (*R*) totaled 579 acre-ft.

Groundwater Interaction with Skalkaho Creek (SW_{in} and SW_{out})—Appendix B: Table B8

Hydrographs for site 278138 on Skalkaho Creek and well 120360, located about 300 ft downgradient, illustrate groundwater/surface-water response. Creek elevations indicate streamflow in Skalkaho Creek is highest during April–June when there is increased runoff, mostly from snowmelt. Groundwater elevations in well 120360 are highest during May–September, reflecting recharge from snowmelt (May–June) and irrigation (May–September). In 2015, there were peaks in both the creek and well hydrographs during January, November, and December, possibly from storms and/or periods of snowmelt.

Discharge measurements on Skalkaho Creek between sites 278138 and 278137 (a 4.6-mi reach) show that the creek loses water to groundwater during October–June (groundwater recharge SW_{in}) and gains from groundwater during July–September (groundwater discharge SW_{out}; table 5). In total, the groundwater system gained 13,363 acre-ft from Skalkaho Creek over 9 mo of the year (SW_{in}) and lost 3,508 acre-ft to Skalkaho Creek over 3 mo of the year (SW_{out}; table 5).

Riparian Evapotranspiration (ET_r)—Appendix B: Table B9

A total of 1,126 acres of cottonwood and willow stands were estimated along the Bitterroot River and Skalkaho Creek within the groundwater budget area (USGS, 2010). Riparian evapotranspiration (ET_r) was greater than precipitation during March–October and resulted in 47 to 608 acre-ft/mo of groundwater outflow (withdrawal). A total of 2,724 acre-ft (equivalent to 29 in) of groundwater was removed by ET_r during 2015 (table 5). As expected, ET_r was highest during the summer months of June, July, and August.

Domestic Consumptive Use of Groundwater (*DW*)—Appendix B: Table B10

With a total of 4,302 households within the groundwater budget area, the total in-house domestic consumptive groundwater use was 129 acre-ft/yr, or about 11 acre-ft/mo (appendix B, table B10). In contrast, the domestic consumptive groundwater use for watering lawns was much larger, about 2,650 acre-ft/yr. The average watered lawn size was 0.14 acres for PWS areas and 0.32 acres for non-PWS areas. Lawn ET rates ranged from 29 to 99 acre-ft/mo (USBR, 2016). Overall, groundwater used for watering lawns dominates the domestic consumptive use of groundwater (*DW*). *DW* totaled 2,778 acre-ft/yr and peaked in June–August when ET rates are highest (table 5).

Groundwater Storage (ΔS)—Appendix B: Table B11

Groundwater storage (ΔS) decreased from January to April, increased during irrigation season from May to August, and decreased from September to December (fig. 15). The changes in groundwater storage throughout 2015 are mostly attributable to snowmelt, canal and ditch losses (*CL*), and irrigation recharge (*IR*). The largest storage increase was in May, during the start of the irrigation season and during spring snowmelt. Figures 13 and 14 illustrate typical groundwater-elevation increases observed in wells in response to increased recharge during irrigation season (May–August), losses due to the BRID and other nearby canals, and Skalkaho Creek inflows (table 5). Increased groundwater elevations (which were used in the groundwater storage calculations) represent the water volume added to groundwater storage during the irrigation season. In 2015, the irrigation canals were shut off on August 28. After the irrigation season (late August–early September), groundwater storage decreases continuously until groundwater recharge occurs the following May. The net groundwater storage for 2015 was calculated to be -2,230 acre-ft (table 5). This is only about 2.5% of the total groundwater outflows. The difference between the annual inflow and outflow was calculated to be -4,600 acre-ft (table 5).

Groundwater-Elevation Trend Analysis

Groundwater-elevation trends in 16 wells were analyzed using the seasonal Kendall test. Table 6 summarizes trend analysis results, including *p*-values and Sen slopes calculated for each of the tested

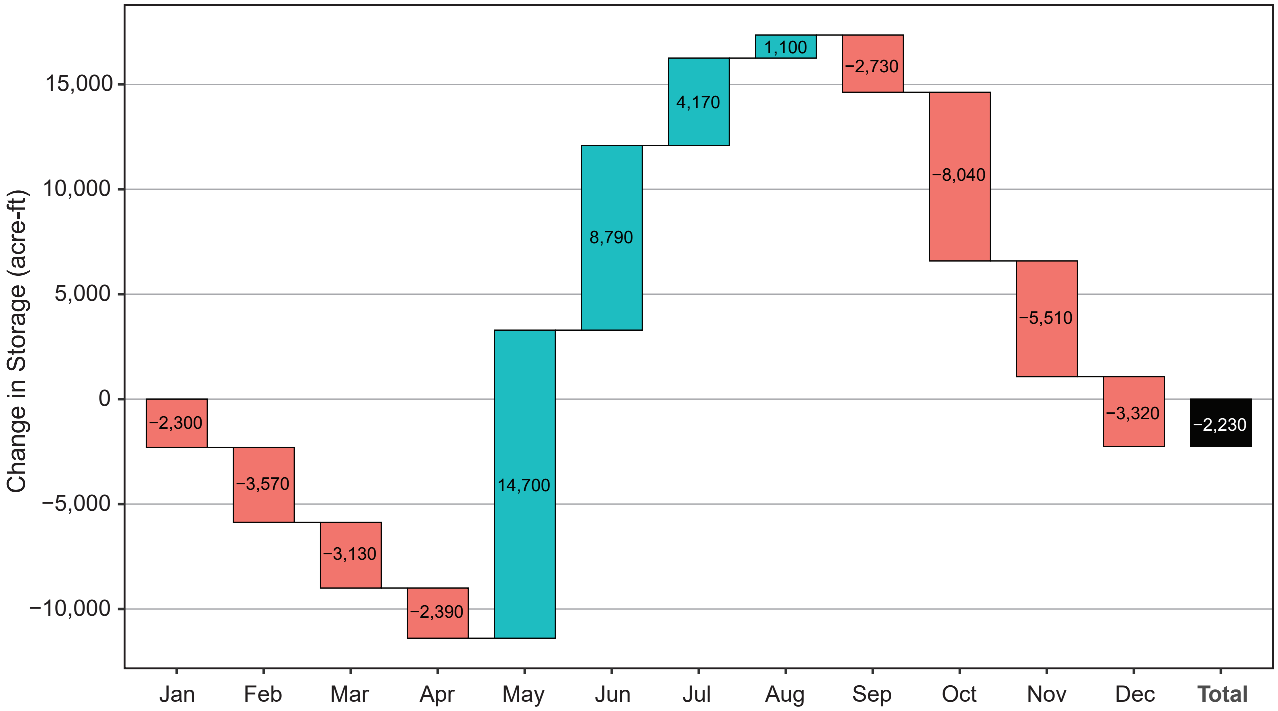


Figure 15. Plot of demonstrating the changes in groundwater storage throughout 2015. Groundwater storage increases during May–August when there is irrigation recharge to the groundwater. Non-irrigation months (September–April) are marked by a decrease in groundwater storage. The total groundwater storage was -2,230 acre-ft for 2015.

Table 6. Results of the seasonal Kendall trend test on long-term groundwater elevation for the POR and for a 15-yr period from 2001 to 2015 of each well.

GWIC ID	POR (year range)	POR (no. of years)	Aquifer	Hydrostratigraphic Unit	Total Depth (ft)	DWE[1] (ft)	Period of Record (POR) *p*-value	Period of Record (POR) Sen Slope (ft/yr)	2001–2015 *p*-value	2001–2015 Sen Slope (ft/yr)
5418	1993–2015	23	Deep basin-fill, Bedrock	Tbg, Tbc, TYb	1,110	209	<0.001	-0.11	0.019	-0.02
52962	1993–2015	23	Shallow basin-fill	Qal	36	26	0.910	NA	0.088	NA
53666	1994–2015	22	Deep basin-fill, Bedrock	Tbg, Tbc, TYb	220	40	0.011	-0.04	0.001	-0.11
53982	2001–2015	15	Shallow basin-fill	Taf	30	22	0.299	NA	0.299	NA
54061	1995–2015	21	Deep basin-fill	Tbg, Tbc	80	50	0.291	NA	<0.001	0.38
54854	1993–2015	23	Bedrock	Tyb	320	320	<0.001	-0.17	insufficient data	
55463	1993–2015	23	Deep basin-fill	Tbg, Tbc	79	74	<0.001	-0.09	0.326	NA
55559	1993–2015	23	Deep basin-fill	Taf, Tbg	126	126	0.090	NA	0.879	NA
56528	1972–2015	44	Shallow basin-fill	Qal	40	40	<0.001	-0.03	0.212	NA
57128	1983–2015	33	Shallow basin-fill	Qal	31	23	0.001	-0.05	0.960	NA
84910	1997–2015	19	Deep basin-fill	Taf, Tbg, Tbc	240	163	<0.001	-0.21	<0.001	-0.11
136050	1993–2015	23	unknown	unknown	84	NR	0.721	NA	0.489	NA
136964	1970–2015	46	Shallow basin-fill	Qal	40	30	<0.001	-0.06	<0.001	-0.11
154007	2000–2015	16	Bedrock	TYb	300	150	0.179	NA	0.694	NA
163226	1997–2015	19	Deep basin-fill	Tbg, Tbc	160	130	0.030	0.02	0.008	0.02
706786	1995–2015	21	unknown	unknown	65	NR	0.508	NA	0.001	0.07

[1] DWE, Depth to Water Entry determined by the top of the highest well screen.

wells. The period of record spanned from 15 to 46 yr. Nine of 16 wells tested for trends over the POR of the well had statistically significant groundwater-elevation trends: 8 wells with decreasing elevation trends and 1 well with an increasing elevation trend (fig. 16). Sen slopes for the 8 wells with decreasing groundwater-elevation trends ranged from -0.03 to -0.21 ft/yr, and the Sen slope for the 1 well with an increasing elevation trend was 0.02 ft/yr (table 6; fig. 16). These yearly changes add up to a few feet of change over the POR of a well. For example, the water elevation in well 136964 decreased about 2.7 ft between 1970 and 2015, while the water elevation in well 84910 decreased about 3.8 ft between 1997 and 2015 (fig. 17).

Seven of fifteen wells tested for trends over the 15-yr period from 2001 to 2015 had statistically significant groundwater-elevation trends: 4 wells with decreasing elevation trends and 3 wells with increasing elevation trends (table 6; fig. 16). Sen slopes for the 4 wells with decreasing groundwater-elevation trends ranged from -0.02 to -0.11 ft/yr, and the Sen slopes for the 3 wells with increasing trends ranged from 0.02 to 0.38 ft/yr (table 6; fig. 16). A seasonal Kendall test was conducted using monthly precipitation from the Corvallis AgriMet station from January 2001 to December 2015 (USBR, 2017) to evaluate whether changes in precipitation might be related to the decreasing groundwater-elevation trends noted for many wells in the study area. No statistically significant trend was found, so changes in precipitation quantity do not appear to be related to the decreasing groundwater elevations observed in some wells in the study area.

Comparison of the *p*-values and Sen slopes calculated for the POR of the well and the 15-yr period from 2001 to 2015 indicated a change in trend depending on the period evaluated for some wells (table 6). Wells 53666 and 136964, which had decreasing groundwater-elevation trends, have steeper Sen slopes (changed more) for the more recent 15-yr period compared to their overall POR. Comparatively, wells 5418 and 84910 had decreasing groundwater-elevation trends, with shallower Sen slopes (changed less) over the 15-yr period compared to their overall POR. Wells 55463, 56528, and 57128 had decreasing groundwater-elevation trends when analyzed over their POR, but no trends over the more recent 15-yr period from 2001 to 2015. Also, no trends were evident for wells 54061 and 706786 during their POR, but groundwater-elevation trends increased over the 15-yr period. Thus, 12 of the 16 wells tested for trends show either no statistical groundwater-elevation trend, a decreasing trend that has lessened in the more recent 15-yr period, or an increasing trend in the more recent 15-yr period (table 6).

The wells with POR greater than 15 yr were poorly distributed across the study area (particularly in the southern half of the study area); however, there is no evident pattern in the spatial distribution of wells with decreasing groundwater-elevation trends. Six of the eight wells with decreasing groundwater-elevation trends over their POR are located along the northern boundary of the study area (fig. 16), but some of the northern wells with decreasing groundwater-elevation trends are near wells with no apparent trends. Well density was also evaluated as a possible explanation for differences in the groundwater-elevation trends. However, the wells with decreasing groundwater-elevation trends do not appear to be associated with well density (fig. 16). Although there are three wells (55463, 136964, and 56528) with decreasing groundwater-elevation trends near high well density areas in and around Hamilton and Corvallis, there also was one well (163226) with an increasing groundwater-elevation trend near the high well density areas. Additionally, three of the wells with decreasing groundwater-elevation trends (54854, 5418, 53666) are on the edges of the valley where there is low well density. It is important to note that the three wells with the largest magnitude decreasing trend over their POR (wells 5418, 54854, and 84910) have the greatest depth to groundwater entry (i.e., depth/elevation of the top of the highest well screen) of the wells analyzed (163–320 ft bgs; table 6) and are screened in deep Tertiary Ancestral Bitterroot River deposits (54854, 84910) or screened at multiple intervals in deep Tertiary Ancestral Bitterroot River deposits and bedrock (5418).

Nitrate Sampling and Analysis

For samples collected as part of this GWIP study, the terms “nitrate” or “nitrate concentrations” refer to nitrate + nitrite as nitrogen concentrations. Nitrite concentrations were expected to be negligible because the sampled groundwater and surface water contained dissolved oxygen and all measured nitrite concentrations were below detection limits. “Nitrate concentrations” reported by the PWS were reported as both

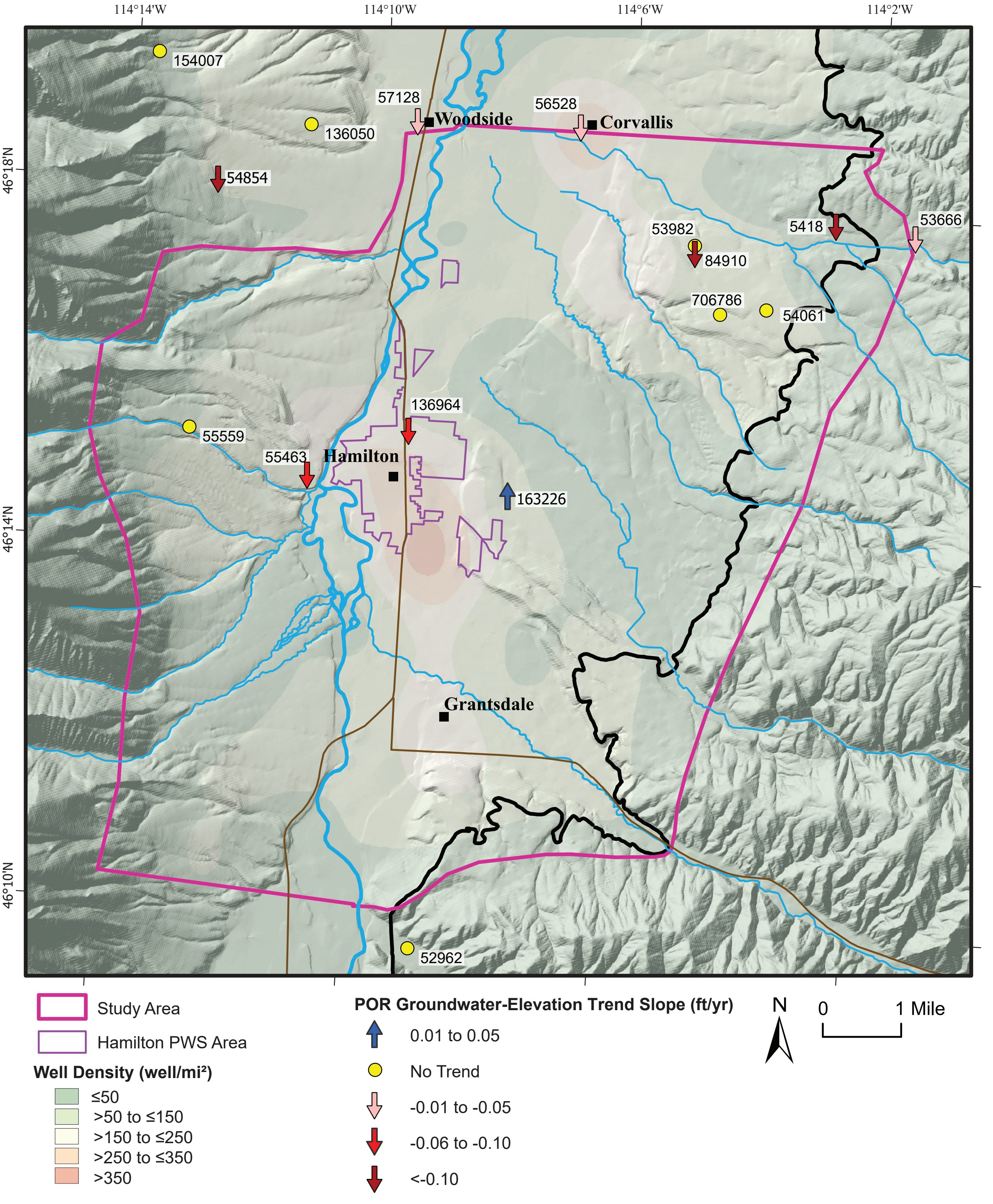
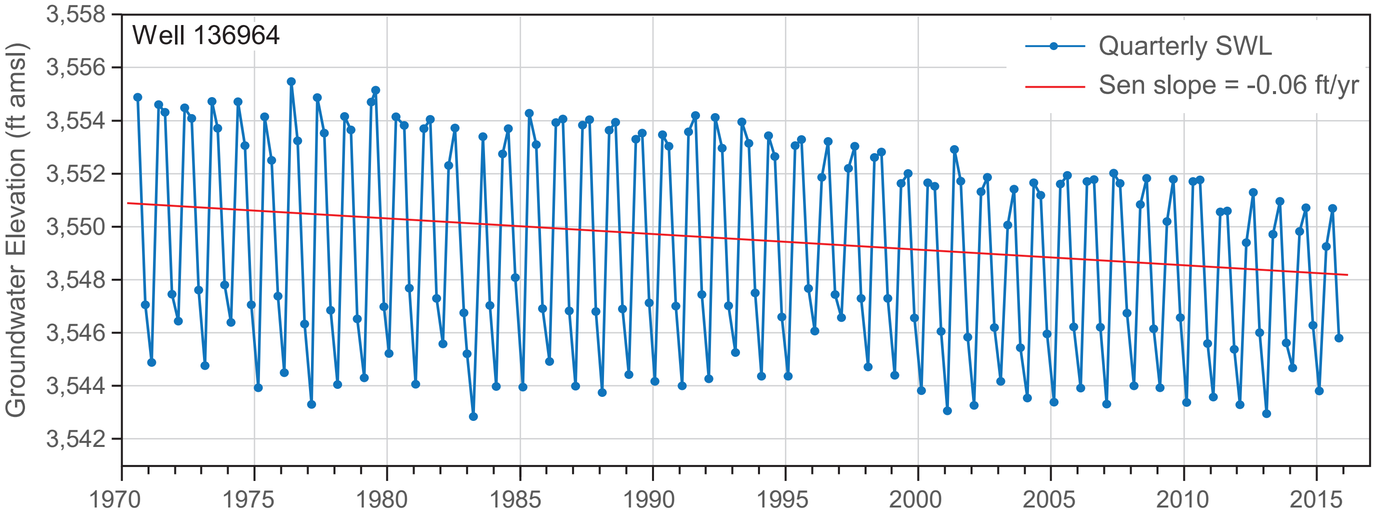


Figure 16. Groundwater-elevation trends for the POR for each well. Multiple wells in the northern part of the map area have decreasing groundwater-elevation trends. The basemap shows well density (determined from the GWIC database) that were completed before or during 2015.



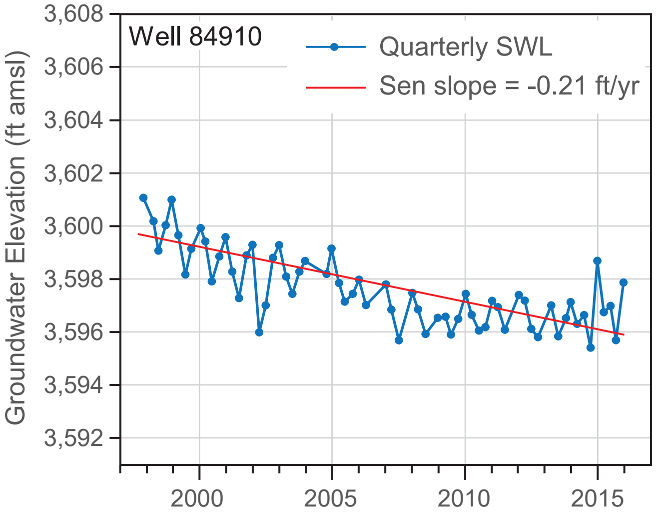


Figure 17. Examples of hydrographs for wells with decreasing water-elevation trends. Well 136964 produces from the shallow basin-fill aquifer. Well 84910 produces from the deep basin-fill aquifer. Additional hydrographs can be found in appendix C.

nitrate as nitrogen and nitrate + nitrite as nitrogen; in this study, both of these reporting methods were considered equivalent in terms of representing the amount of nitrate measured in the water samples.

All nitrate concentrations measured in water samples collected or historical samples compiled for this study were below the EPA PWS drinking water maximum contaminant level of 10 mg/L (U.S. Environmental Protection Agency, 2018). Concentrations of naturally occurring nitrate in Montana groundwater (“background level or concentration”) typically are less than 2 mg/L (USGS, 1999). Surface-water nitrate samples were below the laboratory detection limit (appendix D, table D2) and groundwater nitrate samples ranged from less than the detection limit (0.2 mg/L) to 4.33 mg/L (fig. 18). A relatively high nitrate concentration of 6.06 mg/L was measured in one PWS well (MT0004650; well 258017) sample from October 2015 (appendix D, table D4). The median nitrate concentration for wells 5413 and 126820 increased by 1.17 mg/L and 1.38 mg/L, respectively, between 1996–2001 and 2014–2015 (fig. 19).

Nitrate concentrations in groundwater varied spatially and by aquifer in the study area. Nitrate concentrations generally were higher in wells completed in Tertiary sediments (Tbg, Tbc) or alluvial fan deposits (Taf, Qaf) than in other hydrostratigraphic units (appendix D, table D1). However, nitrate concentrations were low in some wells completed in Tertiary and alluvial fan sediments. Nitrate concentrations tend to be highest (≥2.0 mg/L) in the northeastern part of the study area, and lowest (≤1.0 mg/L) near the Bitterroot River and southern part of the study area (fig. 18).

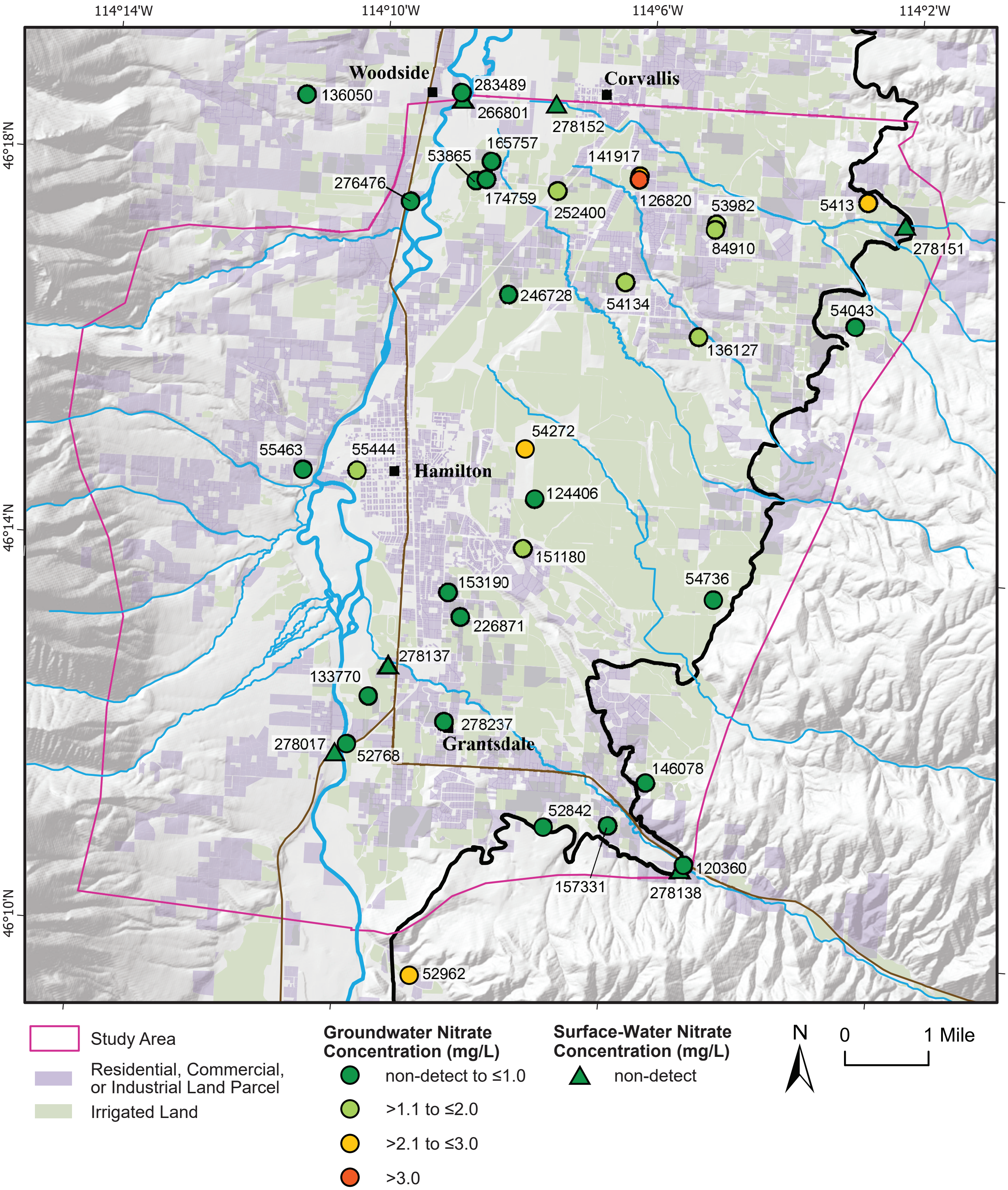


Figure 18. Nitrate concentrations with GWIC numbers for water samples collected in this study. If multiple nitrate samples were taken from one location, the highest nitrate value measured is shown. Note that the northeast portion of the study area has higher nitrate concentrations. Irrigated lands (modified from MT-DOR, 2015) and residential, commercial, and industrial land parcels (Montana State Library, 2022) are shown. Some land parcels overlap with irrigated lands.

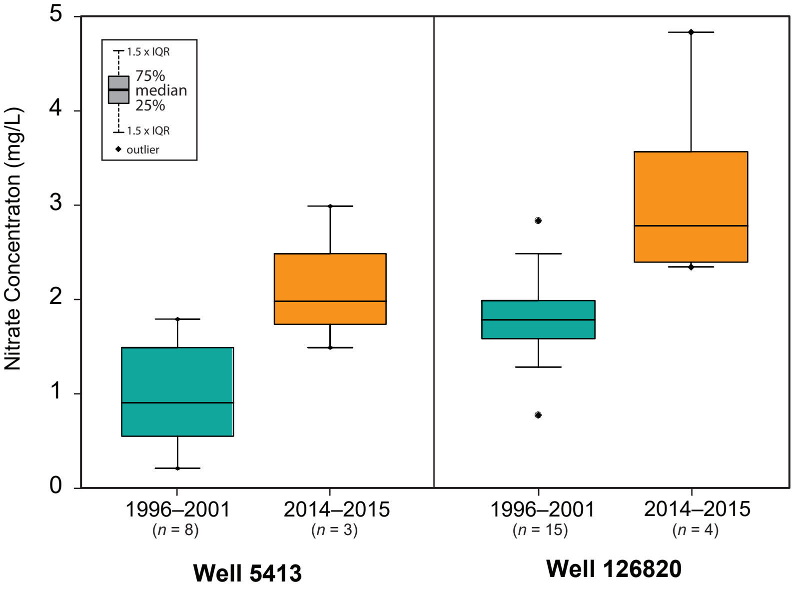


Figure 19. Boxplots demonstrating the difference in nitrate concentrations between samples collected during 1996–2001 and 2014–2015. The number of samples (*n*) in each boxplot is given. The median nitrate concentrations in wells 5413 and 126820 changed by 1.17 mg/L and 1.38 mg/L, respectively. IQR stands for interquartile range.

Nitrate concentrations varied in some wells sampled more than once during the study period. For example, nitrate concentrations in well 126820 in the northeastern part of the study area (fig. 18) varied the most, ranging from 2.40 to 4.85 mg/L in December 2014 and June 2015, respectively. Similarly, nitrate concentrations in well 5413 ranged from 1.5 to 2.99 mg/L in September 2014 and June 2015, respectively.

Cl:Br Ratios as an Indication of Nitrate Source

Chloride (Cl) and bromide (Br) concentrations can be used to help identify ("fingerprint") potential sources of nitrate in groundwater. In this study, only 8 of 73 groundwater samples (~11%) contained detectable Br (appendix D, table D1). Therefore, most samples had low to nondetectable Br and low Cl, which is typical of rainwater and/or "pristine" water. For the 8 samples with detectable Br, Cl:Br ratios were plotted against Cl concentrations (fig. 20). The largest Cl:Br ratio for samples collected as part of this study was 139 (well 54134). Figure 20 shows potential source fields and a mixing line (from Pastén-Zapata and others, 2014) representing the Cl:Br ratios and Cl concentrations (in mg/L) that samples will generally have as rainwater recharge is affected by various potential contaminant sources [e.g., agrochemicals (fertilizers), animal waste, septic system effluent, and landfills]. Most samples plot near the agrochemical source field, suggesting fertilizer may have been the source of the nitrate. Another possibility, given the domestic use of most wells, is that the nitrate in the water samples is a mixture between rainwater and septic tank effluent. If this were the case, samples collected from areas with higher nitrate concentrations would be expected to plot closer to the septic tank effluent source field in figure 20.

Long-Term Nitrate Trends in Public Water Supply Wells

Nitrate-concentration trends in 58 PWS wells were evaluated using the Mann–Kendall trend test. For each well, trend tests were conducted for the POR and for the 10-yr period from 2007 to 2016.

Thirty-five of 58 tested PWS wells (60%) did not have statistically significant nitrate-concentration trends using either the POR or the 10-yr period from 2007 to 2016, and were therefore considered to have not changed over time (appendix D, tables D4, D5). The remaining 23 wells had statistically significant concentration trends using either their POR or the 10-yr period from 2007 to 2016 (table 7). Of those 23 wells, 9 showed increasing nitrate trends ranging from 0.01 to 0.59 mg/L per year. The other 14 showed decreasing nitrate trends ranging from -0.02 to -0.08 mg/L per year. Figure 21 shows the nitrate trends for the POR for each well and the PWS location.

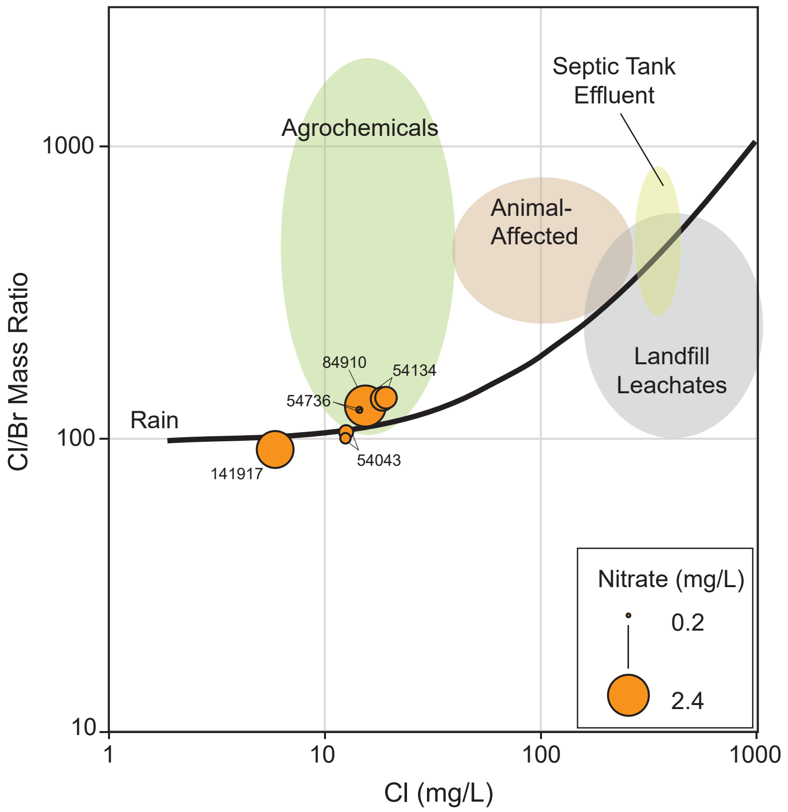


Figure 20. Cl:Br ratios with GWIC numbers from samples in Hamilton that had detectable Cl and Br plotted on a chart designed by Pastén-Zapata and others (2014). The line demonstrates mixing from rainwater to potential sources (agrochemicals, animal-affected, septic tank effluent, and landfill leachates). The circle size of the samples is based on their nitrate concentrations.

Most of the increasing and decreasing nitrate trends are very low values (0.01–0.08 mg/L per year; fig. 21 and appendix D, table D5). These small increases or decreases in nitrate concentrations in a given well could be from improved laboratory equipment and analysis practices over the POR (A. Huft, MBMG Analytical Laboratory Chemist, oral commun., 2022). PWS well MT0004650, completed in Tertiary Ancestral Bitterroot River deposits of the deep basin-fill aquifer, is the only well that showed strong changes in nitrate concentration (0.53 mg/L per year) over its POR from 2009 to 2017 (fig. 22). This well had an initial nitrate concentration of 1.96 mg/L in 2009. It increased to 5.34 mg/L in 2017, with the highest recorded nitrate concentration of 6.06 mg/L in 2015.

Nitrate-concentration trends in PWS wells were mapped in relation to septic system density (fig. 21). As noted previously, septic systems are potential sources of nitrate contamination to shallow groundwater. Many of the PWS wells that are in medium, high, or incorporated city/town septic system density zones had no statistically significant nitrate-concentration trends, indicating septic system density is not related to increasing nitrate concentrations observed in some wells in the study area. Consequently, nitrate concentrations and concentration trends for wells in the study area likely reflect locally varying conditions (e.g., type of aquifer material, amount of groundwater recharge, septic tank system failure, etc.) rather than broader regional conditions. Further discussion of local issues and potential solutions regarding nitrate loading to shallow groundwater in the study area is provided in a later section, Groundwater-Elevation and Nitrate Trends—A Local Consideration.

DISCUSSION

Groundwater Inflow to the Bitterroot River

Groundwater inflow and outflow were the largest components of the groundwater budget (table 5; fig. 23). Groundwater inflow accounted for 48% of all water inflows, whereas groundwater outflow accounted for 90% of the water exiting the area. A total of ap-

Table 7. Results of the Mann-Kendall trend test for the POR and for a 10-yr period from 2007 to 2016.

PWSID	GWIC ID	Aquifer	Hydrostratigraphic Unit	POR (year range)	POR (No. of years)	Period of Record (POR)		2007–2016	
						p-value	Sen Slope[1]	*p*-value	Sen Slope[1]
MT0001046	NA	Unknown	Unknown	1995–2016	22	0.409	NA	0.046	0.03
MT0001059	52679	Shallow basin-fill	Qaf	1994–2016	23	0.034	-0.01	1.000	NA
MT0001067	NA	Unknown	Unknown	1995–2016	22	0.337	NA	0.005	-0.05
MT0001071	55686	Shallow basin-fill	Qal	1994–2017	24	0.004	0.02	0.419	NA
MT0001074	276838	Shallow basin-fill	Qal	1993–2016	24	0.001	-0.02	0.035	-0.04
MT0002799	56636, 56575	Shallow basin-fill	Qal	1993–2016	24	0.014	-0.02	0.371	NA
MT0003003	54701	Deep basin-fill	Tbg, Tbc	1994–2016	23	<0.001	0.01	0.032	0.01
MT0003003	54726	Deep basin-fill	Tbg, Tbc	1994–2016	23	0.002	0.01	0.279	NA
MT0003257	56586	Shallow basin-fill	Qal	1993–2017	25	0.013	-0.03	0.592	NA
MT0003333	NA	Unknown	Unknown	1994–2017	24	0.034	-0.02	0.059	NA
MT0003460	51448	Shallow basin-fill	Qal	1993–2016	24	0.017	-0.03	1.000	NA
MT0003610	53891	Deep basin-fill	Tbg, Tbc	1994–2017	24	<0.001	-0.02	0.009	-0.02
MT0003646	NA	Unknown	Unknown	1994–2017	24	<0.001	0.05	0.174	NA
MT0003861	151177	Deep basin-fill	Tbg, Tbc	1996–2016	21	0.001	-0.01	0.035	-0.02
MT0003898	156242	Shallow basin-fill	Qaf	1996–2016	21	0.070	NA	0.032	-0.04
MT0003982	NA	Unknown	Unknown	1999–2016	18	0.008	-0.03	0.003	-0.06
MT0004041	179092	Shallow basin-fill	Qal	1998–2017	20	0.036	0.01	0.127	NA
MT0004091	NA	Unknown	Unknown	2000–2016	17	0.001	-0.05	0.283	NA
MT0004145	NA	Unknown	Unknown	2002–2018	17	0.030	-0.05	0.419	NA
MT0004369	163430	Shallow basin-fill	Qal	2003–2017	15	0.002	0.04	<0.001	0.05
MT0004425	214124	Deep basin-fill	Tbg, Tbc	2005–2017	13	0.392	NA	0.025	-0.08
MT0004650	258017	Deep basin-fill	Tbg, Tbc	2009–2017	9	0.005	0.53	0.004	0.59
MT0004725	NA	Unknown	Unknown	2010–2016	7	0.020	0.01	0.020	0.01

Note. Only the wells that show statistically significant trends are reported. All analyzed wells are shown in appendix D. NA, not available.

[1] Sen Slope in (mg/L)/yr.

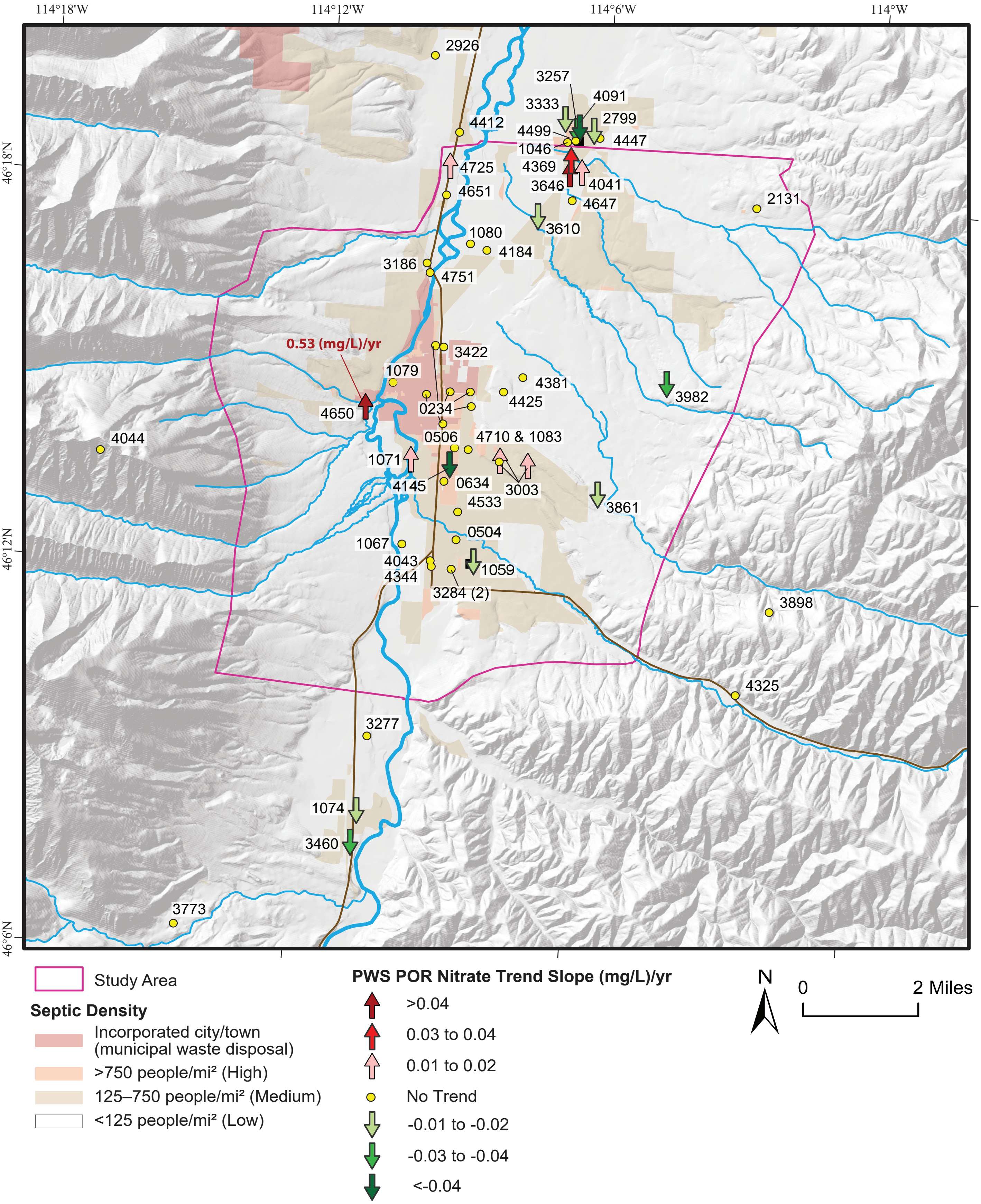


Figure 21. Nitrate trends in PWS for the POR of the well. The wells are labeled with the last four numbers of the MT-PWS ID. Septic density (as of the 2010 census) is shown as a basemap (Montana State Library, 2022).

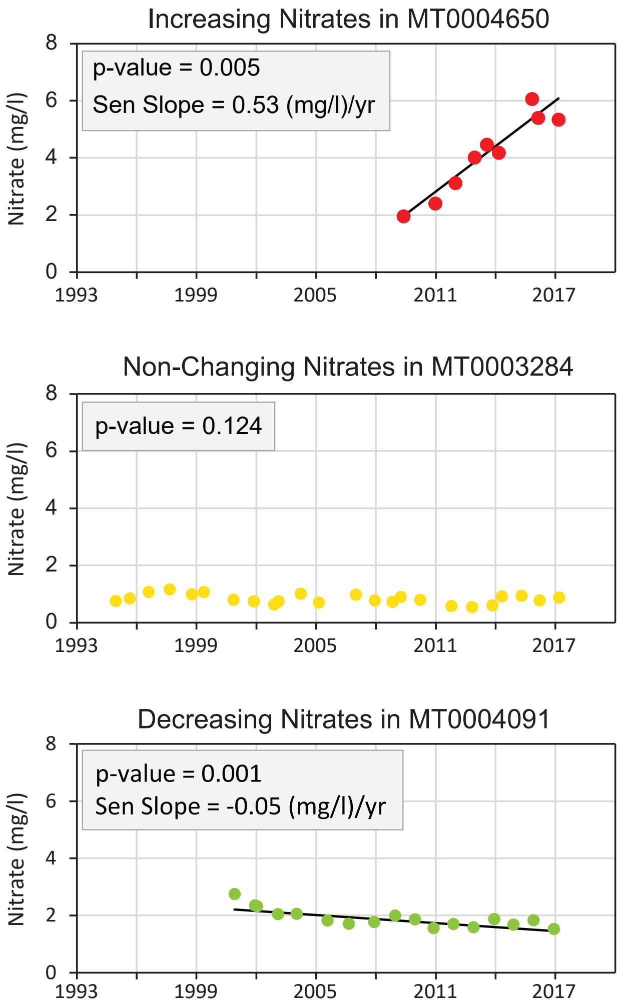


Figure 22. Examples of PWS wells with an increasing nitrate trend, no nitrate trend, or decreasing nitrate trend over their POR. Note that the increasing well is the strongest trend in the dataset.

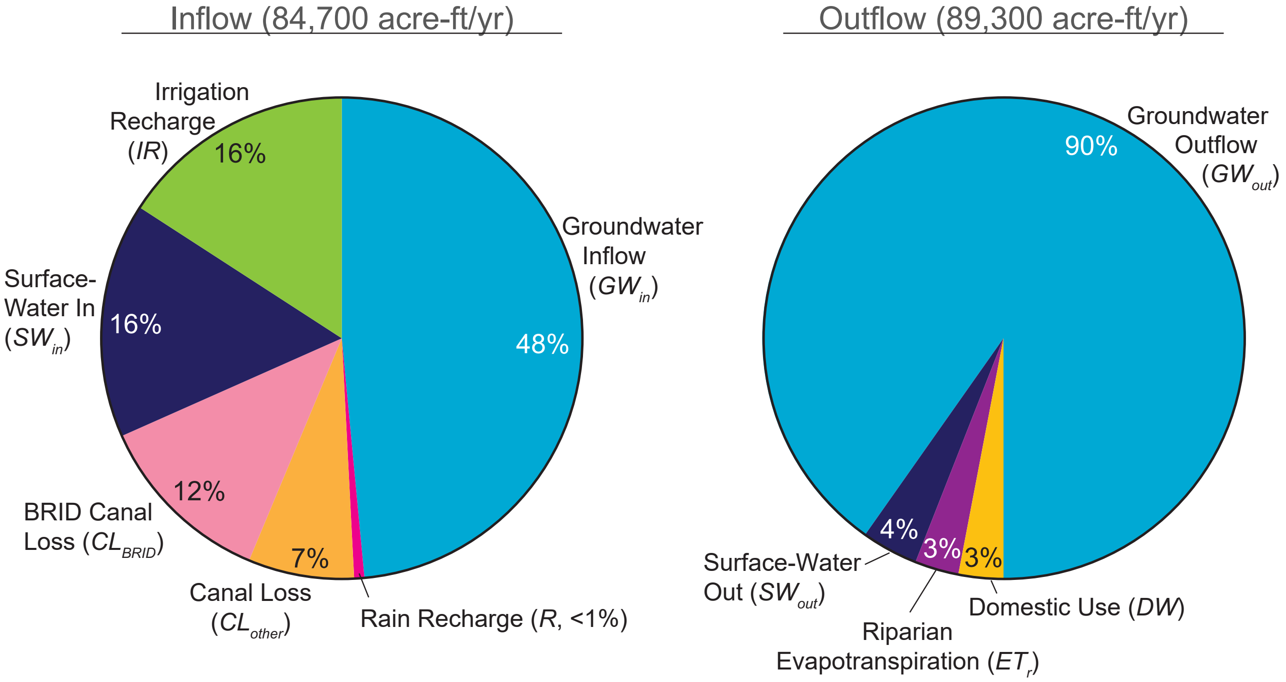


Figure 23. Pie graph summary of the inflow and outflow components in the groundwater budget for 2015. Note that groundwater inflow and outflow are the largest components of the groundwater budget.

proximately 60,000 acre-ft of groundwater discharged to the Bitterroot River from the east side of the valley (appendix B, fig. B1, table B2). In comparison, the groundwater inflow estimated in the Bitterroot River surface-water budget was about 97,000 acre-ft (table 4). This value represents the groundwater inflow from both the east and west sides of the valley. The difference between the groundwater budget and the surface-water budget groundwater inflow to the Bitterroot River suggests that only 37,000 acre-ft of groundwater flow comes from the west side of the valley.

Besides potential error, it is important to note that the western side of the valley contributes twice as much water to the Bitterroot River from tributaries compared to the eastern side. Therefore, groundwater on the west side may be partially discharging to the tributaries rather than directly to the Bitterroot River. If this is the case, the western tributary inputs are already accounted for in the surface-water budget and the western groundwater inflow to the Bitterroot River may be lower based on the assumptions used in this study. Additionally, the western side of the valley has fewer transmissive Quaternary alluvial fan deposits (Qaf) that abut the river. The sediments on the western side of the valley could potentially lower the groundwater inflow to the Bitterroot River from the west side by keeping more water in the west side streams.

The Groundwater Budget in View of Land-Use Changes

Recharge from irrigation (canal and ditch water lost during conveyance and excess water applied to irrigated fields) to groundwater accounts for over one-third of the inflows to the groundwater budget area (fig. 23). Canal loss from the BRID and from other canals and ditches account for 12% and 7% of inflows, respectively (fig. 23). Irrigation recharge from excess water applied to fields accounts for 16% of the inflows. Irrigation-related recharge generally occurs from April to October each year. Figure 15 shows groundwater storage is replenished from May to August during the peak of irrigation season and snowmelt. Domestic use is a small component (about 3%) of the groundwater outflows and is comparable to ET from riparian vegetation. Therefore, long-term land-use changes from agriculture to residential will likely have a larger impact on the groundwater system because of decreased canal loss/irrigated-land recharge rather than increased domestic use.

Because the Bitterroot River is a gaining river throughout the entire year, it is affected by changes to the groundwater system. Decreased groundwater recharge during certain months of the year (e.g., non-irrigation months) or over a period of years could decrease groundwater inflow to the Bitterroot River (e.g., land-use changes from agriculture to residential). Conversely, increased groundwater recharge (e.g., through irrigation-related recharge) could increase groundwater inflow to the Bitterroot River. Similar groundwater/surface-water studies by GWIP have shown that canal loss can recharge groundwater and reduce streamflow depletion (e.g., Abdo and others, 2013; Sutherland and others, 2014; Bobst and Gebril, 2021).

The 2015 groundwater budget showed a net loss of about 2,200 acre-ft in groundwater storage (table 5). This is about 2.5% of the total groundwater outflows. Groundwater budgets have inherent error from assumptions and simplifications made during calculations—error that is not easily quantified. Therefore, a 2.5% difference within the groundwater budget is considered to represent an overall balanced groundwater system with no substantial groundwater loss or gain in 2015.

Groundwater-Elevation and Nitrate Trends—A Local Consideration

Long-term groundwater-elevation and nitrate-concentration trends varied spatially across the study area and with time. This suggests long-term trends or lack of trends are likely explained through local conditions rather than regional trends in the groundwater system.

The largest decreasing groundwater-elevation trends were associated with deep wells in Tertiary sediments or bedrock. This indicates that the groundwater levels in the study area are likely limited by the permeability and recharge rate of the sediments/bedrock around the well. Many of the wells analyzed for long-term groundwater-elevation trends showed a lessening downward trend or an increasing upward trend for the most recent 15-yr period (2001–2015) compared to the POR. This suggests that large population growth (average of 1,105 people/yr) around Hamilton in 1990–2000 (City of Hamilton, 2015) may have resulted in local groundwater drawdown for wells completed in low-permeability sediments/bedrock with low recharge. However, the lessening downward groundwater-elevation trends from 2001 to 2015 during continued growth (376 people/yr from 2000–2015) around Hamilton indicates that the groundwater elevation for low-permeable, low-recharge wells may be equilibrating to a new groundwater elevation.

Similar to groundwater-elevation trends, nitrate-concentration trends will also be affected by low-permeability aquifer materials and low recharge. We found the four wells (52962, 53982, 54272, and 126820) with nitrate concentrations consistently greater than the background level (2 mg/L) were completed either in Quaternary alluvial fan (Qaf) sediments or in Tertiary (Taf, Tbg, and Tbc) sediments. Briar and Dutton (2001) suggested that the eastern side of the Bitterroot Valley is more sensitive to nitrate loading compared to the western side of the valley because the eastern side has comparatively less precipitation and recharge. They also found Tertiary alluvial fan deposits tend to have higher median nitrate concentrations compared to other sediments in the valley because alluvial fan sediments are generally poorly sorted and less permeable (Briar and Dutton, 2001). The nitrate vulnerability assessment by PBS&J (2008) in the Hamilton, Corvallis, and Florence areas showed that areas with coarser sediments and greater recharge are less vulnerable to high nitrate concentrations. This holds true for this GWIP study, in which high nitrate concentrations were commonly found in low-permeability Tertiary Ancestral Bitterroot deposits (Tbg, Tbc) and poorly sorted Quaternary and Tertiary alluvial fan deposits (Qaf, Taf). Wells completed in low-permeability sediments can still have low nitrate concentrations. However, they are at more risk for increasing nitrate trends since recharge tends to be less and therefore cannot dilute nitrate concentrations as fast as permeable sediments.

In addition to low-permeability soils and low recharge limiting the dilution of nitrate concentrations, the source of nitrate concentrations must also be considered. Local monitoring of nitrate concentrations can reveal potential problems. For example, PWS well MT0002131 had increasing nitrate concentrations prior to installation of a treatment system in February 2013 (fig. 24). Following treatment system installation, nitrate concentrations immediately began decreasing. While increasing development and septic systems can increase nitrate concentrations regionally, failing septic systems can increase nitrate concentrations locally, regardless of increased population. About 10–20% of septic tank systems fail annually (U.S. EPA, 2002).

The northeast corner of the study area near Corvallis was one location in particular that appeared to have several wells with decreasing groundwater-elevation trends, higher nitrate concentrations, and slight increase in nitrate-concentration trends [e.g., 0.05

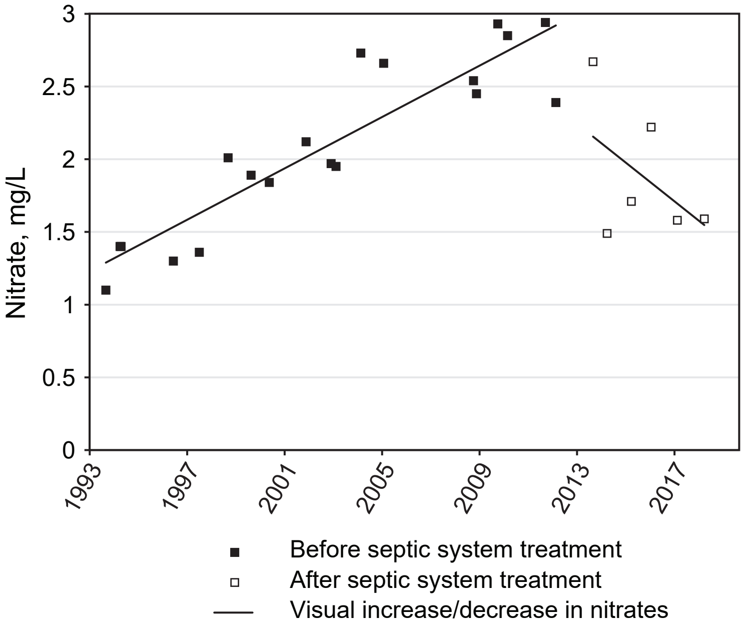


Figure 24. PWS well MT0002131 demonstrating the effectiveness of septic system treatment in lowering nitrate concentrations. Nitrate concentrations increase prior to the septic system treatment (2013) and decrease following septic system treatment.

(mg/L)/yr]. This area has Tertiary Ancestral Bitterroot deposits (Tbg) that are finer grained compared to other Tbg sediments in the study area. Therefore, this area appears to be at higher probability for localized groundwater-elevation decreases and increased nitrate concentrations, likely due to the less permeable aquifer properties of the area.

Finally, since the Bitterroot River is a gaining stream in the study area, nearby groundwater chemistry affects Bitterroot River water quality. Therefore, nitrate concentrations near the river could affect nutrient loading to the Bitterroot River. Consequently, it is important to limit any potential sources of nitrates near the river (e.g., septic systems or fertilizer application). At the time of this study, all nitrate concentrations in surface-water samples collected in the study area were below the Aquatic Life standard for nitrate in Montana streams (0.275 mg/L; Suplee and Watson, 2013) and all nitrate concentrations in water samples from the Bitterroot River were below detection (<0.20 mg/L). Thus, as of 2015, nitrate concentrations are not an issue in the Bitterroot River within the study area.

RECOMMENDATIONS

Groundwater and surface-water monitoring networks provide valuable information needed to evaluate short- and long-term changes in groundwater and surface-water systems. Continued monitoring is recommended to help identify local and regional changes and to provide useful data necessary to answer future water-availability questions. The MBMG's long-term statewide groundwater monitoring network has 13 wells in the study area. It is advantageous to continue monitoring these wells in order to see if any groundwater trends change in the future, especially potential changes to groundwater-elevation levels during population growth periods. This is most important for wells completed in bedrock (TYb) or Tertiary Ancestral Bitterroot deposits (Tbg, Tbc) with low permeability and low recharge. It is also important that USGS gaging stations along the Bitterroot River continue to be funded and operational to monitor changes in stage or discharge due to changes in precipitation, snowpack, or groundwater levels.

This study has provided information and data that could be used to create a groundwater model. A groundwater model can help refine the groundwater budget and evaluate the potential effects of changes in land use and climate conditions to the groundwater and surface-water systems.

Irrigation-related recharge to groundwater can have a large effect on the groundwater system. Therefore, changes to the location and quantity of applied irrigation water should be carefully considered when making legal decisions regarding the location and period of use. Releasing water earlier or later than the current irrigation period could augment groundwater recharge. Additionally, removal of irrigated agricultural lands and/or installation of canal or ditch lining to support additional development should be carefully considered because these changes can decrease groundwater recharge and therefore decrease return flows to nearby streams.

Continued monitoring of nitrate concentrations is valuable in understanding local and regional patterns or trends, as well as identifying individual septic system failures. The small increases in PWS nitrate concentrations are important to watch in subsequent years to see if the trends continue or if the rate of change increases. If an increase in population growth occurs after 2015, more trend analysis may be needed. Additionally, sampling at regular intervals is needed to evaluate annual nitrate concentration variations in the study area. Where practical, future residential developments should be encouraged to utilize centralized PWS and wastewater treatment. These systems enhance the capacity for professional management of water resources. Local water and sewer districts are encouraged to utilize the best available technologies to treat wastewater.

Because the Bitterroot River is a gaining stream within the study area, groundwater storage and water-quality changes should also be evaluated with regard to their potential effects on the Bitterroot River. If population begins to increase steadily on the western side of the valley, it may be valuable to further refine our understanding of groundwater inflow to the Bitterroot River on the western side of the valley.

ACKNOWLEDGMENTS

This study would not have been possible if not for the assistance and cooperation of the many local landowners, too numerous to list. They allowed us access to their wells and their property. Special thanks go to all the area ditch companies that allowed us access to their ditches: C and C Ditch, Darrell Sperry with the Corvallis Canal, Tim Meuchel and Rhonda King with Daly Ditches, and John Crowley with the Bitter Root Irrigation District. Not only did Tim Meuchel, Rhonda King, and John Crowley allow us access to their ditches, but they also provided valuable information and knowledge of irrigation operations within the Bitterroot Valley. Al Pernichele, the Water Commissioner at the time of this study, also was an early advocate of this project and provided additional information and data to enhance this study. Heather Barber at the Bitter Root Water Forum helped us in providing local information about landowners willing to be part of our study and overall support of the project. Stacey Welling at the Natural Resources and Conservation Service provided us irrigation water requirement crop data summary sheets to aid in our water budget.

Montana Tech students Jon Anderson, Mike Chambers, Sara Edinberg, Capri Jensen, Katie Mitchell Boucher, and Charles Shama assisted in data collection, management, and some analysis. Their enthusiasm and energy were much appreciated. MBMG staff Ginette Abdo and Dean Synder helped out with additional field support as well with some aspects of the groundwater budget. Ali Gebril helped with the groundwater flux calculations. Mary Sutherland also aided in some of the water budget storage calculations. Andy Bobst conducted the statistical analysis. Yiwen Li in our GIS department calculated the storage of water during high Bitterroot River stages. MBMG's Ground Water Assessment Program (GWAP) long-term monitoring well data were integral to the trend analysis in this report. The MBMG field staff that services this network is commended for their work in the valley for nearly 30 years.

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APPENDIX A

GROUNDWATER AND SURFACE-WATER MONITORING NETWORKS

Table A1. Surface-water monitoring sites.

GWIC ID	Latitude	Longitude	Ground Surface Elevation (ft)	Type	Site Name	Transducer
266799	46.31277	-114.14548	3473.06	River	Bitterroot Woodside Crossing	Yes
269370	46.24430	-114.06520	3901.00	Ditch/Canal	BRID Tammany	Yes
278017	46.19868	-114.16809	3602.35	River	Bitterroot Anglers	Yes
278018	46.24684	-114.17739	3592.04	River	Bitterroot Demmons	Yes
278019	46.29829	-114.16098	3508.28	Stream	Blodgett Creek	Yes
278103	46.31208	-114.03653	3887.74	Ditch/Canal	BRID Corvallis	Yes
278104	46.18193	-114.07980	3916.00	Ditch/Canal	BRID Skalkaho	Yes
278106	46.20221	-114.09505	3924.00	Ditch/Canal	BRID South	Yes
278108	46.22038	-114.16266	3585.49	Ditch/Canal	C And C Ditch	Yes
278109	46.24460	-114.17925	3543.95	Stream	Canyon Creek	Yes
278110	46.28321	-114.04305	3902.41	Stream	Charlie Gulch	Yes
278111	46.31292	-114.11154	3481.21	Ditch/Canal	Corvallis Ditch-Corvallis	Yes
278112	46.25196	-114.17513	3542.67	Ditch/Canal	Corvallis Ditch-Headgate	Yes
278116	46.21478	-114.08024	3902.62	Stream	Gird BRID	Yes
278120	46.31255	-114.07422	3628.46	Ditch/Canal	Hedge Ditch-Corvallis	Yes
278122	46.19710	-114.13403	3713.21	Ditch/Canal	Hedge Ditch-Skalkaho	Yes
278127	46.19729	-114.12211	3765.00	Ditch/Canal	Hughes Ditch	Yes
278130	46.31258	-114.10252	3513.42	Ditch/Canal	Republican Ditch-Corvallis	Yes
278131	46.19692	-114.14840	3651.12	Ditch/Canal	Republican Ditch-Skalkaho	Yes
278132	46.21880	-114.17875	3640.00	Stream	Roaring Lion Creek-Middle East	Yes
278133	46.21854	-114.18171	3655.00	Stream	Roaring Lion Creek-Middle West	Yes
278134	46.21695	-114.17638	3620.00	Stream	Roaring Lion Creek-South	Yes
278135	46.21854	-114.18495	3667.00	Stream	Roaring Lion Creek-West	Yes
278136	46.22971	-114.19156	3713.00	Stream	Sawtooth Creek	Yes
278137	46.21412	-114.15576	3604.45	Stream	Skalkaho 93	Yes
278138	46.18170	-114.08031	3916.00	Stream	Skalkaho-BRID	Yes
278149	46.18459	-114.08596	3891.00	Ditch/Canal	Ward Ditch-Skalkaho	Yes
278151	46.29518	-114.03306	3884.33	Stream	Willow Creek-BRID	Yes
278152	46.31275	-114.12627	3467.77	Stream	Willow Creek-Corvallis	Yes
278153	46.30671	-114.13782	3474.79	Stream	Gird Corvallis	Yes
283536	46.19074	-114.09683	3830.00	Stream	Skalkaho-Park	Yes
283537	46.25516	-114.14005	3569.00	Ditch/Canal	Republican-Fairgrounds	Yes
283540	46.28124	-114.11837	3539.00	Stream	Gird-North	Yes
283714	46.28124	-114.11820	3538.00	Ditch/Canal	Republican At Grid	Yes
283715	46.23067	-114.14495	3605.00	Ditch/Canal	Republican At Grantsdale	Yes
283716	46.27658	-114.12360	3544.00	Ditch/Canal	Republican At Olde Road	Yes
283721	46.24044	-114.07788	3813.00	Ditch/Canal	Ward-Lovers	No

Table A2. Groundwater monitoring sites.

GWIC ID	Latitude	Longitude	Elevation (ft)	Use	Total Depth (ft)	SWL[1] from Ground (ft)	SWL (ft)	Date of SWL	Transducer	Select Wells[2]	SWL Trend Analysis	Potentiometric-Surface Map Well
5413	46.29852	-114.04475	3842.06	DOMESTIC	120	5.56	3836.50	8/8/2015	Yes	Only in 2014	No	No
5418	46.28397	-114.07114	3796.14	MONITORING	1110	69.32	3726.82	8/7/2015	No	Only in 2014	Yes	No
52768	46.19977	-114.16691	3615.95	DOMESTIC	42	10.73	3605.02	8/8/2015	Yes	No	No	Yes
52842	46.18734	-114.11669	3910.75	DOMESTIC	43	3.91	3906.84	8/8/2015	No	Only in 2014	No	Yes
52948	46.18085	-114.06722	3983.88	IRRIGATION	80	34.55	3949.33	8/9/2015	No	Yes	No	Yes
52962	46.16036	-114.14784	3729.35	DOMESTIC	36	20.75	3708.60	8/9/2015	No	Yes	Yes	Yes
52981	46.14822	-114.11455	3836.75	DOMESTIC	40	10.51	3826.24	8/9/2015	No	Yes	No	Yes
53198	46.19705	-114.18315	3740.00	DOMESTIC	51	11.60	3728.40	8/8/2015	No	Yes	No	Yes
53666	46.29709	-114.02369	3980.43	DOMESTIC	220	26.48	3953.95	8/7/2015	No	Yes	Yes	No
53700	46.31251	-114.04477	3807.63	DOMESTIC	265	42.98	3764.65	8/7/2015	No	Only in 2014	No	No
53841	46.31115	-114.13570	3473.54	DOMESTIC	72	7.03	3466.51	8/7/2015	No	Yes	No	Yes
53865	46.29844	-114.14294	3491.35	DOMESTIC	80	6.94	3484.41	8/8/2015	No	Yes	No	Yes
53982	46.29332	-114.08227	3714.17	DOMESTIC	30	10.14	3704.03	8/9/2015	Yes	No	Yes	Yes
54043	46.27696	-114.04616	3972.63	DOMESTIC	190	66.84	3905.79	8/7/2015	No	Yes	No	No
54059	46.27757	-114.05633	3883.45	DOMESTIC	120	66.84	3816.61	8/7/2015	No	Yes	No	No
54061	46.28214	-114.06222	3850.00	DOMESTIC	80	9.98	3840.02	8/7/2015	No	Only in 2014	Yes	Yes
54134	46.28238	-114.10420	3632.50	DOMESTIC	180	86.37	3546.13	8/7/2015	No	Yes	No	No
54272	46.25255	-114.12674	3613.81	PWS[3]	85	14.62	3599.19	8/8/2015	No	Yes	No	No
54736	46.22832	-114.07761	3851.65	DOMESTIC	156	5.92	3845.73	8/7/2015	No	Yes	No	No
54739	46.22763	-114.07405	3873.77	DOMESTIC	280	3.91	3869.86	6/24/2014	No	Only in 2014	No	No
54854	46.30053	-114.21044	3851.55	UNUSED	320	36.69	3814.86	8/7/2015	No	Yes	Yes	No
55125	46.25570	-114.19141	3775.09	DOMESTIC	100	44.12	3730.97	8/8/2015	No	Yes	No	No
55210	46.26901	-114.16732	3577.31	DOMESTIC	40	16.54	3560.77	8/8/2015	No	Yes	No	Yes
55429	46.24668	-114.17270	3560.94	PWS	33	15.59	3545.35	8/7/2015	No	Yes	No	Yes
55444	46.24713	-114.16835	3563.50	IRRIGATION	30	14.74	3548.76	8/7/2015	No	Yes	No	Yes
55463	46.24674	-114.18180	3615.69	IRRIGATION	79	59.24	3556.45	8/8/2015	No	Only in 2014	Yes	Yes
55559	46.25436	-114.21419	4044.09	DOMESTIC	126	80.15	3963.94	8/8/2015	No	Only in 2014	Yes	No
56528	46.31398	-114.11453	3476.71	FIRE PROTECTION	40	7.79	3468.92	8/7/2015	No	Only in 2014	Yes	Yes
56580	46.31978	-114.10848	3477.30	PWS	45	14.14	3463.16	8/7/2015	Yes	Only in 2014	No	Yes
57128	46.31322	-114.15802	3488.49	DOMESTIC	31	11.16	3477.33	8/7/2015	No	Only in 2014	Yes	Yes
84910	46.29234	-114.08250	3720.76	DOMESTIC	240	129.29	3591.47	8/29/2015	Yes	No	Yes	No
120360	46.18217	-114.08121	3908.68	DOMESTIC	38	7.93	3900.75	8/8/2015	Yes	Only in 2014	No	Yes
121889	46.26401	-114.22049	4221.93	DOMESTIC	162	131.25	4090.68	8/8/2015	No	Only in 2014	No	No
124406	46.24397	-114.12359	3652.39	DOMESTIC	36	8.93	3643.46	8/7/2015	No	Yes	No	Yes
124413	46.27138	-114.15903	3524.18	DOMESTIC	40	9.20	3514.98	8/7/2015	No	Yes	No	Yes
126820	46.30056	-114.10228	3567.09	DOMESTIC	58	33.77	3533.32	8/8/2015	No	Yes	No	Yes
128663	46.27692	-114.02187	4163.66	DOMESTIC	180	38.44	4125.22	8/7/2015	No	Yes	No	No
128699	46.27850	-114.18939	3740.83	DOMESTIC	48	10.62	3730.21	8/8/2015	No	Only in 2014	No	Yes
131812	46.23289	-114.12455	3741.69	DOMESTIC	195	116.94	3624.75	8/8/2015	No	Only in 2014	No	No
133770	46.20823	-114.16219	3602.96	STOCKWATER	40	3.44	3599.52	8/8/2015	No	Yes	No	Yes
135962	46.28798	-114.05563	3827.67	DOMESTIC	143	56.13	3771.54	8/7/2015	No	Yes	No	No
136050	46.31161	-114.18646	3754.46	DOMESTIC	83.9	45.15	3709.31	8/7/2015	Yes	Only in 2014	Yes	No
136127	46.27365	-114.08516	3689.48	DOMESTIC	59	19.94	3669.54	8/8/2015	No	Only in 2014	No	Yes
136964	46.25539	-114.15517	3560.43	MONITORING	40	9.55	3550.88	8/8/2015	Yes	Only in 2014	Yes	Yes
137450	46.19128	-114.21301	4116.89	DOMESTIC	90	65.51	4051.38	8/8/2015	No	Only in 2014	No	No
139120	46.32690	-114.10120	3479.48	IRRIGATION	198	22.50	3456.98	8/7/2015	No	Only in 2014	No	No

Table A2—*Continued*.

GWIC ID	Latitude	Longitude	Elevation (ft)	Use	Total Depth (ft)	SWL[1] from Ground (ft)	SWL (ft)	Date of SWL	Transducer	Select Wells[2]	SWL Trend Analysis	Potentiometric-Surface Map Well
139801	46.23362	-114.12107	3735.55	DOMESTIC	87	66.12	3669.43	8/8/2015	No	Only in 2014	No	No
141917	46.30086	-114.10212	3566.19	DOMESTIC	140	36.77	3529.42	7/13/2015	No	Yes	No	No
145718	46.29903	-114.06421	3702.52	DOMESTIC	73	5.03	3697.49	8/7/2015	No	Yes	No	Yes
146078	46.19601	-114.09188	4016.05	DOMESTIC	77	51.29	3964.76	8/8/2015	No	Yes	No	Yes
150989	46.24106	-114.19815	3745.29	DOMESTIC	39	13.02	3732.27	8/7/2015	No	Yes	No	Yes
151180	46.23530	-114.12581	3705.69	DOMESTIC	135	63.47	3642.22	8/8/2015	Yes	Yes	No	No
153190	46.22693	-114.14382	3612.47	DOMESTIC	47	12.84	3599.63	8/8/2015	Yes	Only in 2014	No	Yes
154007	46.32345	-114.22810	4220.48	DOMESTIC	300	187.60	4032.88	8/8/2015	Yes	Only in 2014	Yes	No
157331	46.18822	-114.10067	3838.95	DOMESTIC	38	12.15	3826.80	8/8/2015	No	Yes	No	Yes
163226	46.24436	-114.12803	3642.32	TEST WELL	160	37.05	3605.27	8/8/2015	Yes	No	Yes	No
163432	46.28327	-114.14689	3509.08	DOMESTIC	38	6.14	3502.94	8/7/2015	Yes	Only in 2014	No	Yes
164756	46.27698	-114.04617	3972.47	UNUSED	100	73.19	3899.28	8/7/2015	Yes	Yes	No	No
165757	46.30191	-114.13943	3485.50	DOMESTIC	100	6.16	3479.34	8/8/2015	No	Yes	No	No
169540	46.29009	-114.14950	3498.45	IRRIGATION	38	6.18	3492.27	8/7/2015	No	Yes	No	Yes
174759	46.29876	-114.14044	3488.46	DOMESTIC	33	4.35	3484.11	8/8/2015	No	Yes	No	Yes
192712	46.23716	-114.14763	3589.64	DOMESTIC	38	10.07	3579.57	8/8/2015	No	Yes	No	Yes
192862	46.31979	-114.10852	3477.22	MONITORING	75	14.09	3463.13	8/7/2015	Yes	Only in 2014	No	Yes
194163	46.25724	-114.18051	3625.38	DOMESTIC	40	5.85	3619.53	8/8/2015	No	Yes	No	Yes
205674	46.24348	-114.07367	3825.11	DOMESTIC	90	5.58	3819.53	7/16/2015	No	Yes	No	Yes
205759	46.26533	-114.07060	3766.31	DOMESTIC	78	18.03	3748.28	8/8/2015	No	Yes	No	Yes
206948	46.27855	-114.18784	3719.12	DOMESTIC	77	18.10	3701.02	8/8/2015	No	Only in 2014	No	Yes
222014	46.31151	-114.11213	3482.35	DOMESTIC	40	10.04	3472.31	8/8/2015	No	Yes	No	Yes
225320	46.24569	-114.17931	3599.19	DOMESTIC	340	54.31	3544.88	8/8/2015	Yes	Only in 2014	No	No
226871	46.22280	-114.14040	3628.02	DOMESTIC	113	5.56	3622.46	8/8/2015	No	Yes	No	No
244480	46.24165	-114.19379	3715.48	DOMESTIC	140	29.26	3686.22	8/7/2015	No	Only in 2014	No	No
244746	46.18798	-114.13471	3915.95	DOMESTIC	185	94.75	3821.20	8/8/2015	No	Yes	No	No
244878	46.18924	-114.05794	4440.00	DOMESTIC	300	130.24	4309.76	10/18/2014	No	Only in 2014	No	No
246728	46.27911	-114.13316	3531.75	DOMESTIC	58	20.84	3510.91	8/7/2015	No	Only in 2014	No	Yes
252400	46.29749	-114.12247	3495.80	IRRIGATION	38	9.81	3485.99	8/8/2015	No	Only in 2014	No	Yes
257423	46.25521	-114.15479	3560.23	MONITORING	168	9.62	3550.61	8/7/2015	Yes	Only in 2014	Yes	No
263545	46.26546	-114.15812	3527.21	IRRIGATION	20	2.65	3524.56	8/8/2015	Yes	Yes	No	Yes
274135	46.19683	-114.14255	3701.51	PWS	110	53.59	3647.92	8/9/2015	Yes	Yes	No	No
275342	46.26534	-114.06075	3839.34	DOMESTIC	140	21.60	3817.74	8/9/2015	No	Yes	No	No
276476	46.29417	-114.15896	3495.48	DOMESTIC	NA	4.47	3491.01	6/23/2014	No	No	No	No
278236	46.20454	-114.14294	3661.49	DOMESTIC	NA	7.37	3654.12	8/28/2015	No	Yes	No	No
278237	46.20455	-114.14290	3661.27	DOMESTIC	NA	7.16	3654.11	8/28/2015	No	Yes	No	No
278259	46.28679	-114.07826	3759.81	DOMESTIC	NA	30.70	3729.11	1/17/2014	No	Yes	No	No
278261	46.26391	-114.07451	3765.31	DOMESTIC	NA	NA	NA	NA	Yes	Only in 2014	No	No
283489	46.31351	-114.14778	3470.11	PWS	NA	6.76	3463.35	8/8/2015	Yes	No	No	No
283719	46.31373	-114.14709	3467.51	IRRIGATION	9	4.40	3463.11	8/8/2015	Yes	No	No	Yes
285718	46.29450	-114.14138	3494.02	DOMESTIC	NA	NA	NA	NA	No	Yes	No	No
286258	46.24321	-114.16845	3554.67	IRRIGATION	39	6.19	3548.48	10/20/2015	No	No	No	Yes
286267	46.19042	-114.09700	3833.46	TEST WELL	45	6.19	3827.27	10/20/2015	No	No	No	Yes
286280	46.22386	-114.10556	3876.41	DOMESTIC	205	138.27	3738.14	12/23/2015	No	No	No	No
706730	46.31098	-114.06672	3673.28	DOMESTIC	39	6.37	3666.91	8/7/2015	No	Yes	No	Yes
706764	46.24413	-114.18180	3613.48	IRRIGATION	365	49.11	3564.37	8/8/2015	No	Yes	No	No
706766	46.18062	-114.06474	3997.60	DOMESTIC	280	22.86	3974.74	8/29/2015	No	Yes	No	No
706786	46.28085	-114.07450	3757.94	DOMESTIC	65	30.98	3726.96	8/7/2015	No	Only in 2014	Yes	Yes
706883	46.28718	-114.07843	3757.71	DOMESTIC	68	20.71	3737.00	8/8/2015	No	Yes	No	Yes

Note. NA, not available.

[1] SWL, static water level.

[2] Select wells measured every other week during irrigation season.

[3] PWS, public water supply.

APPENDIX B

GROUNDWATER BUDGET

Significant Figures in Calculations

Details regarding calculations of the groundwater budget are described below. Numbers were considered to have three significant figures; however, all numbers are left as-calculated for the reader to follow along with the calculations. Rounding for three significant figures were made for the results, discussion, and tables in the body of the report.

Groundwater Inflow (GW_{in}) and Outflow (GW_{out})

Groundwater inflow from the shallow aquifer (Qal and Tbg, fig. 5 in report) enters the focus area from the south and east (triangles 1 and 2, fig. B1). Outflow occurs to the Bitterroot River along the western boundary (triangles 3 and 4) and to the north (triangle 5). The western half of the southern boundary had potentiometric contours approximately perpendicular to the study boundary, so we assumed that flow does not enter the project area in that location. Similarly, we assumed no outflow on the northeastern boundary based on the potentiometric contours.

The hydraulic gradient was estimated for each triangle based on solving a three-point problem using groundwater elevations from August 2015 and distance between points. Darcy's Law was used to provide the flux through each triangle where:

$$Q = Twi,$$

where T is horizontal transmissivity (in squared feet per day, or ft^2/d) of the aquifer in the vicinity of the flow boundary, w is width of the flow section (ft), and i is approximate horizontal hydraulic gradient across the flow boundary (ft/ft). The total inflows and outflows are summed in tables B1 and B2, respectively.

Table B1. Calculation of the groundwater inflow using figure B1.

Triangle	Width[1] (ft)	Hydraulic Gradient[2]	Transmissivity[3] (ft^2/d)	Inflow (ft^3/d)	Inflow (acre-ft/d)	Inflow (acre-ft/yr)
1	46,800	0.024	3,123	3,467,288	80	29,073
2	7,850	0.058	3,123	1,432,423	33	12,011
Total Inflow					112	41,084

[1] Width is measured for the entire flow section on figure B1.
[2] *i* is calculated hydraulic gradient from the triangle/section seen in figure B1.
[3] Geometric mean of Tbg from table 3.

Table B2. Calculation of the groundwater outflow using figure B.1.

Triangle	Width[1] (ft)	Hydraulic Gradient[2]	Transmissivity[3] (ft^2/d)	Outflow (ft^3/d)	Outflow (acre-ft/d)	Outflow (acre-ft/yr)
3	27,000	0.004	25,416	2,730,398	63	22,894
4	24,600	0.007	25,416	4,393,067	101	36,836
5	8,750	0.011	25,416	2,454,013	56	20,577
Total Outflow					220	80,307

[1] Width is measured for the entire flow section on figure B1.
[2] *i* is calculated hydraulic gradient from the triangle/section seen in figure B1.
[3] Geometric mean for the Qal (excluding exceptionally high values) from table 3.

The average daily inflow and outflow were multiplied by the number of days in each month to determine a monthly inflow and outflow in 2015.

Canal Loss (CL_{BRID} and $CL_{C/D}$)

As discussed in the methods, the seepage amounts for the BRID were based on the difference in discharge between sites 278106 and 269370 (figs. 7, 12 in report). A rating curve was created for each site. The difference in the discharge measurements between sites 278106 and 269370, divided by the distance between sites, resulted in a seepage rate in cubic feet per second (cfs) per mile. The hourly discharge measurements were averaged

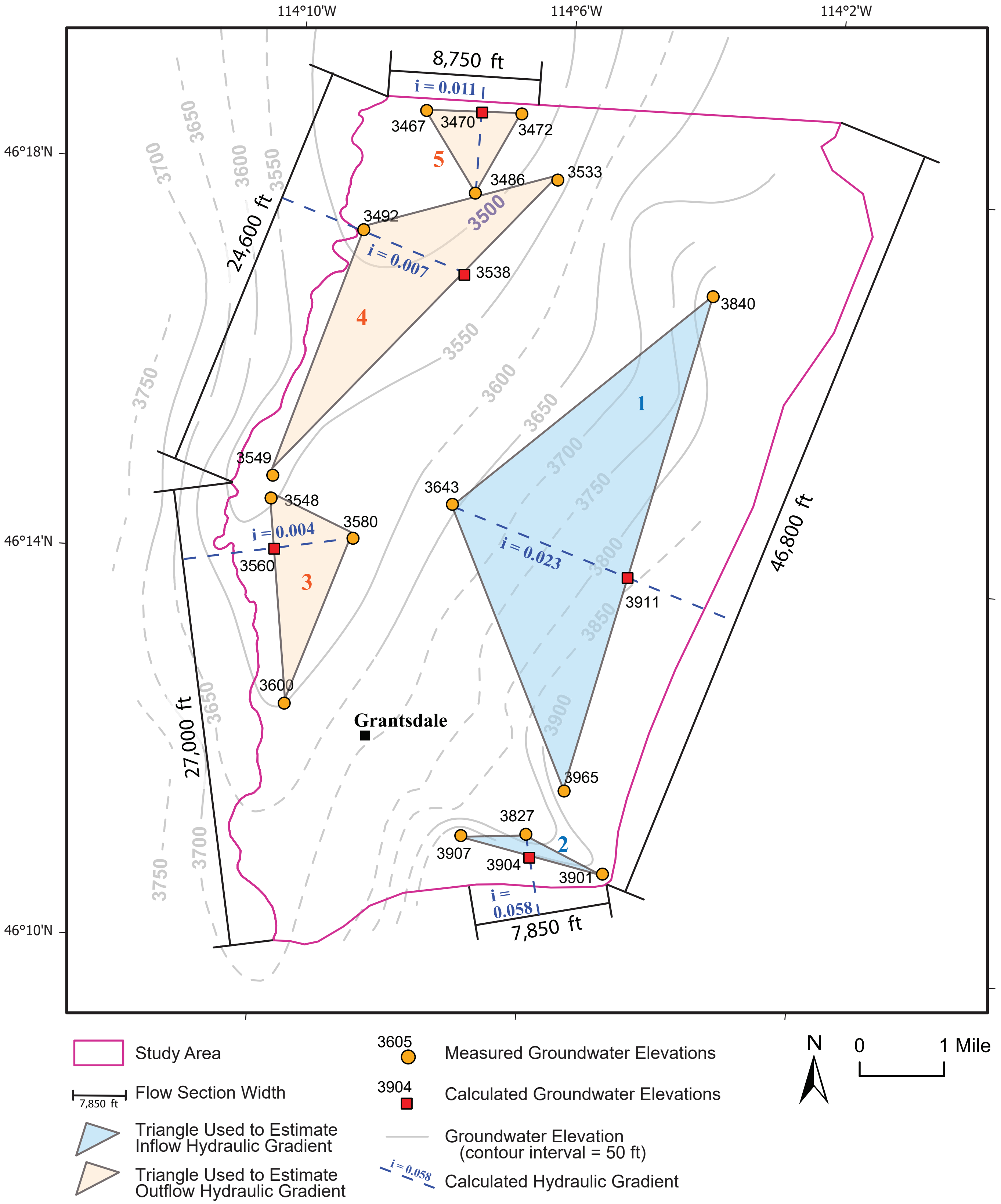


Figure B1. Map demonstrating hydraulic gradients calculated for the groundwater inflow and outflow components for the groundwater budget. The groundwater inflow and outflow takes into account the shallow, unconfined groundwater system. The potentiometric-surface map for the unconfined system is shown for reference.

monthly. The average seepage loss per month (CL_{BRID}, cfs/mi) was then multiplied by the number of days in which the canal was flowing and applied to the 22.9 mi of the BRID canal within the study area.

Tables B3 and B4 include the range in canal loss (minimum and maximum), average monthly loss, and the average annual seepage loss for the irrigation season of 2014 and 2015. The canal was shut down on September 19 in 2014 and was shut down 23 days earlier in 2015 (August 28); this resulted in 12,864 acre-ft total canal loss in 2014 compared to 10,202 acre-ft in 2015.

Table B3. Summary of BRID leakage during 2014.

	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Total
BRID Downgradient Discharge (278106, cfs)							
Minimum	112	158	246	245	235	244	
Average	127	239	258	283	284	244	
Maximum	153	285	274	307	318	267	
BRID Upgradient Discharge (269370, cfs)							
Minimum	90	131	236	234	267	231	
Average	110	229	250	276	267	231	
Maximum	132	279	263	295	292	250	
Average loss (cfs)	17	10	8	7	17	13	
Average loss[1] (cfs/mi)	2.9	1.7	1.4	1.2	2.9	2.2	
No. of days of canal flow	6	31	30	31	31	19	
Average loss[2] (acre-ft/mo)	799	2,427	1,879	1,699	4,126	1,934	12,864

[1]cfs/mile is based on the 5.8-mi distance between sites 278106 and 269370.

[2]Average seepage loss is calculated for the entire canal length (22.9 miles) in the study area.

Table B4. Summary of BRID leakage during 2015.

	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Total
BRID Downgradient Discharge (278106, cfs)						
Minimum	86	195	220	253	254	
Average	172	269	271	279	272	
Maximum	257	311	304	306	304	
BRID Upgradient Discharge (269370, cfs)						
Minimum	39	184	209	247	249	
Average	152	259	259	272	260	
Maximum	240	302	290	298	282	
Average loss (cfs)	20	10	12	7	12	
Average loss[1] (cfs/mi)	3.4	1.7	2.1	1.2	2.1	
No. of days of canal flow	4	31	30	31	28	
Average loss[2] (acre-ft/mo)	626	2,427	2,819	1,699	2,631	10,202

[1]cfs/mile is based on the 5.8-mi distance between sites 278106 and 269370.

[2]Average seepage loss is calculated for the entire canal length (22.9 mi) in the study area.

For the other primary canals and ditches ($CL_{C/D}$), an average discharge to seepage ratio of 0.008 from the BRID was applied to the discharge measurements on the primary canals to estimate seepage loss. The 0.008 ratio was calculated from the 2015 BRID measurements (e.g., the average seepage loss of 2.1 cfs/mi divided by the average discharge of 253 cfs at site 278106).

For ditches with multiple flow measurements along its reach, the ratio was applied to each discharge measurement for that segment of the ditch until all segments were included.

Example estimation of seepage loss from the Ward Ditch (table B5):

1. Discharge at upsteam site 278149 was 19.8 cfs for April 2015.
2. 19.8 cfs was multiplied by 0.008 (0.159 cfs loss) and then multiplied by the length of the segment (7.83 mi - distance from site 278149 and 283721) for a seepage loss of 1.24 cfs.
3. Steps 1 and 2 were repeated for the next segment (from site 283721 to the remaining length of the canal, 2.98 mi)

Table B5. Summary of seepage from the primary canals during 2015.

Canal	Site No.	Length (mi)	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Total Seepage
			Flow (cfs)							Seepage (cfs)							
Hedge																	
	278122	14.20	57.9	113.0	110.0	121.0	122.0	100.0	0	6.57	12.84	12.50	13.75	13.86	11.36	0	
Hughes[1]																	
	278127	0.53	0	2.0	2.3	2.1	2.1	2.1	0	0	0.01	0.01	0.01	0.01	0.01	0	
Ward																	
	278149	7.83	19.8	29.5	27.2	28.9	22.2	18.6	0	1.24	1.85	1.70	1.81	1.39	1.17	0	
	283721	2.98	6.7	6.1	7.0	7.0	6.7	6.7	0	0.16	0.15	0.17	0.17	0.16	0.16	0	
Gird																	
	278116	4.10	13.3	22.0	10.7	10.7	10.7	10.7	10.7	0.44	0.72	0.35	0.35	0.35	0.35	0.35	
	283540	1.30	26.5	37.8	19.5	15.7	15.4	26.6	11.3	0.28	0.39	0.20	0.16	0.16	0.28	0.12	
Republican																	
	278131	3.70	34.0	75.3	64.4	46.1	61.0	45.4	0	1.01	2.23	1.91	1.36	1.81	1.34	0	
	283715[2]	4.68	35.3	35.3	35.3	35.3	33.6	31.8	0	1.32	1.32	1.32	1.32	1.26	1.19	0	
	283714[3]	2.85	22.6	22.6	22.6	16.7	13.1	10.5	0	0.52	0.52	0.52	0.38	0.30	0.24	0	
Total loss (cfs)										11.53	20.02	18.67	19.31	19.29	16.09	0.47	105.39
No. of days of canal flow										15	31	30	31	31	30	10	
Total loss (acre-ft/mo)										**343**	**1,231**	**1,111**	**1,187**	**1,186**	**957**	**9**	**6,024**

Note. Seepage ratio of 0.008 was calculated from BRID.

[1] The pressure transducer data was lost after July for Hughes Canal. Therefore, the July discharge measurement was used for August and September.

[2] A pressure transducer was installed in site 283715 on Republican Ditch in July 2015. Therefore, the July discharge was used to estimate flow for April, May, and June.

[3] Manual discharge measurements were collected for site 283714 on Republican Ditch. However, there were no manual measurements for April and May, so the June data were used for those months.

Where flow was not manually measured, discharge amounts were calculated using rating curves. Since discharge in the primary canals varied through the growing season, monthly seepage rates were calculated using the discharge from the 15th day of each month. The 15th day of the month was on the same days as the manual measured discharges for sites that did not have pressure transducers.

Irrigation Recharge (*IR*) and Recharge from Non-Irrigated Lands (*R*)

The following equation was used to estimate irrigation recharge (*IR*):

$$IR = \text{Applied Irrigation Water} + \text{Precipitation} - \text{ET}.$$

To simplify calculations, the major types of vegetation (alfalfa, grass hay, and pasture grass) were used as the crop type in the study area. The net irrigation requirement and ET for these vegetative types were obtained from the Ravalli County Irrigation Water Requirements (IWR) Crop Data Summary sheet provided by the NRCS (NRCS, written commun., 2015). The IWR considers soil type, crop type, irrigation method, and climate. Table B6 presents the data used to calculate the total monthly recharge amounts for each crop type and factors in the efficiency based on the irrigation method.

The following paragraph describes the calculation steps that are seen in table B6. First, the Net Irrigation Requirement (NIR) for a given month was used from the IWR Crop Data Summary Sheet. Next, an irrigation efficiency was used at 55% for flood, 70% for sprinkler, and 80% for pivot (NRCS, written commun., 2015). The NIR was divided by the efficiency to determine the amount of water needed to be applied to the field ("NIR with efficiency"). Precipitation from the Corvallis Agrimet Station was added to the "NIR with efficiency" to

Table B6. Groundwater recharge from applied irrigation water.

Crop and Irrigation Type	Net Irrigation Req. (NIR, in)	NIR with Efficiency (in)	Precipitation (in)	Total Applied (in)	ET (in)	Recharge (in)	Recharge (ft)	Acres	Total Recharge (acre-ft)
April (starting on the 20th)									
Flood (efficiency 55%)									
Alfalfa	0.00	0.00	0.42	0.42	0.00	0.42	0.04	463	16
Grass Hay	0.00	0.00	0.42	0.42	1.06	-0.64	-0.05	1,293	0
Pasture Grass	0.11	0.20	0.42	0.62	0.78	-0.16	-0.01	4,799	0
Pivot (efficiency 80%)									
Alfalfa	0.00	0.00	0.42	0.42	0.00		0.04	421	15
Grass Hay	0.00	0.00	0.42	0.42	1.06	-0.64	-0.05	57	0
Pasture Grass	0.11	0.14	0.42	0.56	0.78	-0.22	-0.02	30	0
Sprinkler (efficiency 70%)									
Alfalfa	0.00	0.00	0.42	0.42	0.00	0.42	0.04	4,097	143
Grass Hay	0.00	0.00	0.42	0.42	1.06	-0.64	-0.05	1,350	0
Pasture Grass	0.11	0.16	0.42	0.58	0.78	-0.20	-0.02	1,090	0
TOTAL									174
May									
Flood (efficiency 55%)									
Alfalfa	1.27	2.31	1.82	4.13	2.38	1.75	0.15	463	67
Grass Hay	0.00	0.00	1.82	1.82	3.23	-1.41	-0.12	1,293	0
Pasture Grass	2.48	4.51	1.82	6.33	3.37	2.96	0.25	4,799	1,183
Pivot (efficiency 80%)									
Alfalfa	1.27	1.59	1.82	3.41	2.38	1.03	0.09	421	36
Grass Hay	0.00	0.00	1.82	1.82	3.23	-1.41	-0.12	57	0
Pasture Grass	2.48	3.10	1.82	4.92	3.37	1.55	0.13	30	4
Sprinkler (efficiency 70%)									
Alfalfa	1.27	1.81	1.82	3.63	2.38	1.25	0.10	4,097	428
Grass Hay	0.00	0.00	1.82	1.82	3.23	-1.41	-0.12	1,350	0
Pasture Grass	2.48	3.54	1.82	5.36	3.37	1.99	0.17	1,090	181
TOTAL									1,900
June									
Flood (efficiency 55%)									
Alfalfa	4.86	8.84	0.87	9.71	5.81	3.90	0.32	463	150
Grass Hay	3.38	6.15	0.87	7.02	4.72	2.30	0.19	1,293	247
Pasture Grass	3.86	7.02	0.87	7.89	4.75	3.14	0.26	4,799	1,255
Pivot (efficiency 80%)									
Alfalfa	4.86	6.08	0.87	6.95	5.81	1.14	0.09	421	40
Grass Hay	3.38	4.23	0.87	5.10	4.72	0.38	0.03	57	2
Pasture Grass	3.86	4.83	0.87	5.70	4.75	0.94	0.08	30	2
Sprinkler (efficiency 70%)									
Alfalfa	4.86	6.94	0.87	7.81	5.81	2.00	0.17	4,097	684
Grass Hay	3.38	4.83	0.87	5.70	4.72	0.98	0.08	1,350	110
Pasture Grass	3.86	5.51	0.87	6.38	4.75	1.63	0.14	1,090	148
TOTAL									2,639
July									
Flood (efficiency 55%)									
Alfalfa	6.66	12.11	0.86	12.97	7.30	5.67	0.47	463	219
Grass Hay	5.34	9.71	0.86	10.57	5.97	4.60	0.38	1,293	496
Pasture Grass	5.46	9.93	0.86	10.79	6.07	4.72	0.39	4,799	1,887
Pivot (efficiency 80%)									
Alfalfa	6.66	8.33	0.86	9.19	7.30	1.89	0.16	421	66
Grass Hay	5.34	6.68	0.86	7.54	5.97	1.57	0.13	57	7
Pasture Grass	5.46	6.83	0.86	7.69	6.07	1.62	0.13	30	4
Sprinkler (efficiency 70%)									
Alfalfa	6.66	9.51	0.86	10.37	7.30	3.07	0.26	4,097	1,050
Grass Hay	5.34	7.63	0.86	8.49	5.97	2.52	0.21	1,350	283
Pasture Grass	5.46	7.80	0.86	8.66	6.07	2.59	0.22	1,090	235
TOTAL									4,247
August									
Flood (efficiency 55%)									
Alfalfa	5.55	10.09	1.02	11.11	6.24	4.87	0.41	463	188
Grass Hay	2.78	5.05	1.02	6.07	5.17	0.90	0.08	1,293	97
Pasture Grass	4.67	8.49	1.02	9.51	5.33	4.18	0.35	4,799	1,672
Pivot (efficiency 80%)									
Alfalfa	5.55	6.94	1.02	7.96	6.24	1.72	0.14	421	60
Grass Hay	2.78	3.48	1.02	4.50	5.17	-0.68	-0.06	57	0
Pasture Grass	4.67	5.84	1.02	6.86	5.33	1.53	0.13	30	4
Sprinkler (efficiency 70%)									
Alfalfa	5.55	7.93	1.02	8.95	6.24	2.71	0.23	4,097	925
Grass Hay	2.78	3.97	1.02	4.99	5.17	-0.18	-0.01	1,350	0
Pasture Grass	4.67	6.67	1.02	7.69	5.33	2.36	0.20	1,090	214
TOTAL									3,161

Table B5—*Continued*.

	September								
Flood (efficiency 55%)									
Alfalfa	1.75	3.18	0.64	3.82	2.65	1.17	0.10	463	45
Grass Hay	0.00	0.00	0.64	0.64	2.07	-1.43	-0.12	1,293	0
Pasture Grass	2.46	4.47	0.64	5.11	3.01	2.10	0.18	4,799	841
Pivot (efficiency 80%)									
Alfalfa	1.75	2.19	0.64	2.83	2.65	0.18	0.01	421	6
Grass Hay	0.00	0.00	0.64	0.64	2.07	-1.43	-0.12	57	0
Pasture Grass	2.46	3.08	0.64	3.72	3.01	0.71	0.06	30	2
Sprinkler (efficiency 70%)									
Alfalfa	1.75	2.50	0.64	3.14	2.65	0.49	0.04	4,097	167
Grass Hay	0.00	0.00	0.64	0.64	2.07	-1.43	-0.12	1,350	0
Pasture Grass	2.46	3.51	0.64	4.15	3.01	1.14	0.10	1,090	104
TOTAL									1,165
	October								
Flood (efficiency 55%)									
Alfalfa	0.00	0.00	0.21	0.21	0.00	0.21	0.02	463	8
Grass Hay	0.00	0.00	0.21	0.21	0.00	0.21	0.02	1,293	23
Pasture Grass	0.34	0.62	0.21	0.83	1.07	-0.24	-0.02	4,799	0
Pivot (efficiency 80%)									
Alfalfa	0.00	0.00	0.21	0.21	0.00	0.21	0.02	421	7
Grass Hay	0.00	0.00	0.21	0.21	0.00	0.21	0.02	57	1
Pasture Grass	0.34	0.43	0.21	0.64	1.07	-0.44	-0.04	30	0
Sprinkler (efficiency 70%)									
Alfalfa	0.00	0.00	0.21	0.21	0.00	0.21	0.02	4,097	72
Grass Hay	0.00	0.00	0.21	0.21	0.00	0.21	0.02	1,350	24
Pasture Grass	0.34	0.49	0.21	0.70	1.07	-0.37	-0.03	1,090	0
TOTAL									134

get total water applied to the field (“Total Applied”). ET from the NRCS Crop Data Summary sheets was removed from the “Total Applied” to get the inches of “Recharge” after crop consumptive use. A negative recharge indicates that ET exceeds the total amount of water applied. The negative values were not factored into the recharge. The inches of “Recharge” was multiplied by the number of acres for that crop with that irrigation method to get the “Total Recharge.”

Three main vegetation types (range grass, sagebrush, and conifers) were considered for the non-irrigated land recharge calculations. As mentioned in the methods, acres of each vegetation type were estimated using LANDFIRE database (USGS, 2010) and ET rates were obtained from the Salmon, Idaho research station (Allen and Robison, 2012). Recharge from non-irrigated lands was calculated by:

$$R = \text{Precipitation} - \text{ET}.$$

Table B7 presents the data used to calculate the total monthly recharge for each vegetation type.

Table B7. Groundwater recharge from non-irrigated lands.

	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15
Range Grasses (9,347 acres)								
ET (in/d)	0.0276	0.0587	0.0618	0.0528	0.0268	0.0228	0.0224	0.0142
ET (acre-ft/mo)	665	1,371	1,493	1,233	646	551	524	342
Precipitation (acre-ft/mo)	203	389	1,418	678	670	794	499	156
GW Recharge (acre-ft/mo)	NA	NA	NA	NA	23	243	NA	NA
Sage Brush (3,610 acres)								
ET (in/d)	0.0252	0.0354	0.0512	0.0575	0.0386	0.0299	0.0264	0.0150
ET (acre-ft/mo)	235	320	477	519	360	279	238	140
Precipitation (acre-ft/mo)	78	150	548	262	259	307	193	60
GW Recharge (acre-ft/mo)	NA	NA	70	NA	NA	28	NA	NA
Conifer (2,454 acres)								
ET (in/d)	0.0085	0.0181	0.0289	0.0289	0.0289	0.0289	0.0289	0.0181
ET (acre-ft/mo)	54	111	183	177	183	183	177	115
Precipitation (acre-ft/mo)	53	102	372	178	176	209	131	41
GW Recharge (acre-ft/mo)	NA	NA	189	1	NA	25	NA	NA
Total	0	0	259	1	23	296	0	0

Note. NA, not applicable. The evapotranspiration is greater than precipitation, and therefore, no groundwater recharge occurs.

Groundwater Interaction with Skalkaho Creek (SW_{in} and SW_{out})

Hourly stage was recorded from Skalkaho Creek at sites 278138 (upstream) and 278137 (downstream) and on Hughes Ditch (278127) and Ward Ditch (278149) with a transducer (fig. 7 in report). The transducer stage data were converted to discharge by developing a rating curve. The Float Method was used to estimate discharge for the Reese–Thompson Ditch and this observation was applied throughout the irrigation season. The gains/losses of Skalkaho Creek were calculated from the following equation:

$$\mathit{Gain/Loss} = \text{Inflow at site 278138} - \text{Ditch outflow} - \text{Outflow at site 278138}.$$

Table B8 shows the average monthly discharge of Skalkaho Creek and ditch sites that were applied to the groundwater budget. When Skalkaho Creek was losing water to groundwater, it was considered a groundwater inflow (SW_{in}). When Skalkaho Creek was gaining water from groundwater, it was considered a groundwater outflow (SW_{out}).

Table B8. Calculated gains and losses for Skalkaho Creek in 2015.

	Site No.	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Skalkaho Creek	278138	35.1	39.7	66.9	126	207	122	31.1	20.1	19.4	19.7	37.7	40.9
Reeser-Thompson[1]	NA	0	0	0	1.10	9.00	9.00	9.00	9.00	7.32	0	0	0
Hughes Ditch[2]	278127	0	0	0	0.57	4.64	4.64	4.64	4.64	3.78	0	0	0
Ward Ditch	278149	0	0	0	7.65	25.5	29.9	28.4	20.0	13.8	0	0	0
Skalkaho Creek	278137	16.6	18.3	35.9	81.6	137	71.9	6.53	9.92	11.1	7.71	8.17	5.44
Gains		18.5	21.4	31.0	35.5	31.5	6.6				12.0	29.6	35.4
Losses								17.5	23.4	16.6			
Monthly Gains (acre-ft/mo)		1,139	1,189	1,907	2,111	1,938	394				739	1,760	2,179
Monthly Losses (acre-ft/mo)								1,077	1,440	988			

Note. NA, not available. Numbers are average monthly cfs unless noted otherwise.

[1] Reeser-Thompson discharge was measured using the Float Method and was applied for the whole irrigation season. For April and September, the ditch was not on for the whole month.

[2] Hughes Ditch was measured using an MF Pro in May. The stage did not change for the rest of the irrigation season. For April and September, the ditch was not on for the whole month.

Riparian Evapotranspiration (ET_r)

Table B9 presents the data used to calculate the total monthly riparian evapotranspiration (ET_r). ET_r was calculated for a total of 1,126 acres of riparian vegetation by:

$$ET_r = \text{ET} - \text{Precipitation}.$$

Table B9. Groundwater outflow from riparian vegetation (Et_r).

	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15
Monthly ET (mm/d)	0.62	1.79	4.21	6.22	5.69	4.8	3.64	2.25
ET (in/d)	0.024	0.070	0.166	0.245	0.224	0.189	0.143	0.089
ET (acre-ft/mo)	71	198	482	689	652	550	403	258
Precipitation (acre-ft/mo)	24	47	171	82	81	96	60	19
Et_r (acre-ft/mo)	47	151	311	608	571	454	343	239

Note. Cottonwood and willow ET values from Allen and Robison (2012) were averaged and used for the riparian acreage (1,126 acres).

Domestic Consumptive Use of Groundwater (DW)

The total number of lawns was estimated by counting Non-Vacant Residential Urban and Non-Vacant Residential Rural land classes from the Ravalli County Cadastral database (Montana State Library, 2022). There were 1,467 and 2,835 parcels in the PWS and non-PWS areas, respectively. Lawn size was digitized for a random selection of 5% of all parcels in the study area. The average lawn size was determined separately for the PWS and non-PWS areas based on the random sample of parcels. The average lawn size in the PWS area was 0.14 acre and 0.32 acre for the non-PWS area. Therefore, the total acreage of lawn used in the calculation was 205 and 907 acres for PWS and non-PWS lawns, respectively. Lawn evapotranspiration rates were obtained from the Corvallis AgriMet station (USBR, 2016).

In-house domestic consumptive use was calculated using 4,302 households in the groundwater budget area and the groundwater consumptive use of 0.03 acre-ft/yr per household (DNRC, 2011).

Table B10 tabulates the monthly *DW* in the groundwater budget.

Table B10. Domestic lawn and indoor consumptive use based on lawn acreage total of 205 and 907 acres in the PWS and non-PWS areas, respectively.

	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
Lawn consumptive use												
Lawn ET (in/mo)	0	0	1.67	3.26	4.24	5.66	5.77	4.83	3.11	0	0	0
PWS lawn consumptive use (acre-ft/mo)	0	0	29	56	73	97	99	83	53	0	0	0
Non-PWS lawn consumptive use (acre-ft/mo)	0	0	126	246	321	428	436	365	235	0	0	0
Total lawn consumptive use (acre-ft/mo)	0	0	155	302	393	525	535	448	288	0	0	0
In-house consumptive use (acre-ft/mo)	11	11	11	11	11	11	11	11	11	11	11	11
Total domestic consumptive use (acre-ft/mo)	11	11	166	313	404	536	546	459	299	11	11	11

Groundwater Storage (ΔS)

Table B11 shows the total volume change for each month calculated in ArcGIS. Original calculations were in m^3/month and were converted to acre-ft/month. The high terraces and valley floor were considered to have different porosities in the storage calculations.

Table B11. Calculated storage changes from ArcGIS.

	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15[1]
High Terraces Storage (n = 0.15)												
Volume change (m^3)	13,731,541	25,369,114	21,751,300	17,634,749	-81,588,104	-56,452,072	-31,933,495	-11,614,847	17,139,671	48,573,037	31,876,023	21,582,779
Storage change (m^3)	-2,059,731	-3,805,367	-3,262,695	-2,645,212	12,238,216	8,467,811	4,790,024	1,742,227	-2,570,951	-7,285,956	-4,781,403	-3,237,417
Total storage change in high terraces (acre-ft/mo)	-1,670	-3,085	-2,645	-2,145	9,922	6,865	3,883	1,412	-2,084	-5,907	-3,876	-2,625
Qal storage (n = 0.20)												
Volume change (m^3)	3,883,311	2,988,666	2,996,633	1,515,310	-29,326,115	-11,903,196	-1,743,028	1,941,860	3,954,673	13,137,219	10,104,808	4,309,482
Storage change (m^3)	-776,662	-597,733	-599,327	-303,062	5,865,223	2,380,639	348,606	-388,372	-790,935	-2,627,444	-2,020,962	-861,896
Total storage change in valley floor (acre-ft/mo)	-630	-485	-486	-246	4,755	1,930	283	-315	-641	-2,130	-1,638	-699
Total storage change (acre-ft/mo)	-2,300	-3,570	-3,131	-2,390	14,677	8,795	4,166	1,098	-2,726	-8,037	-5,515	-3,323

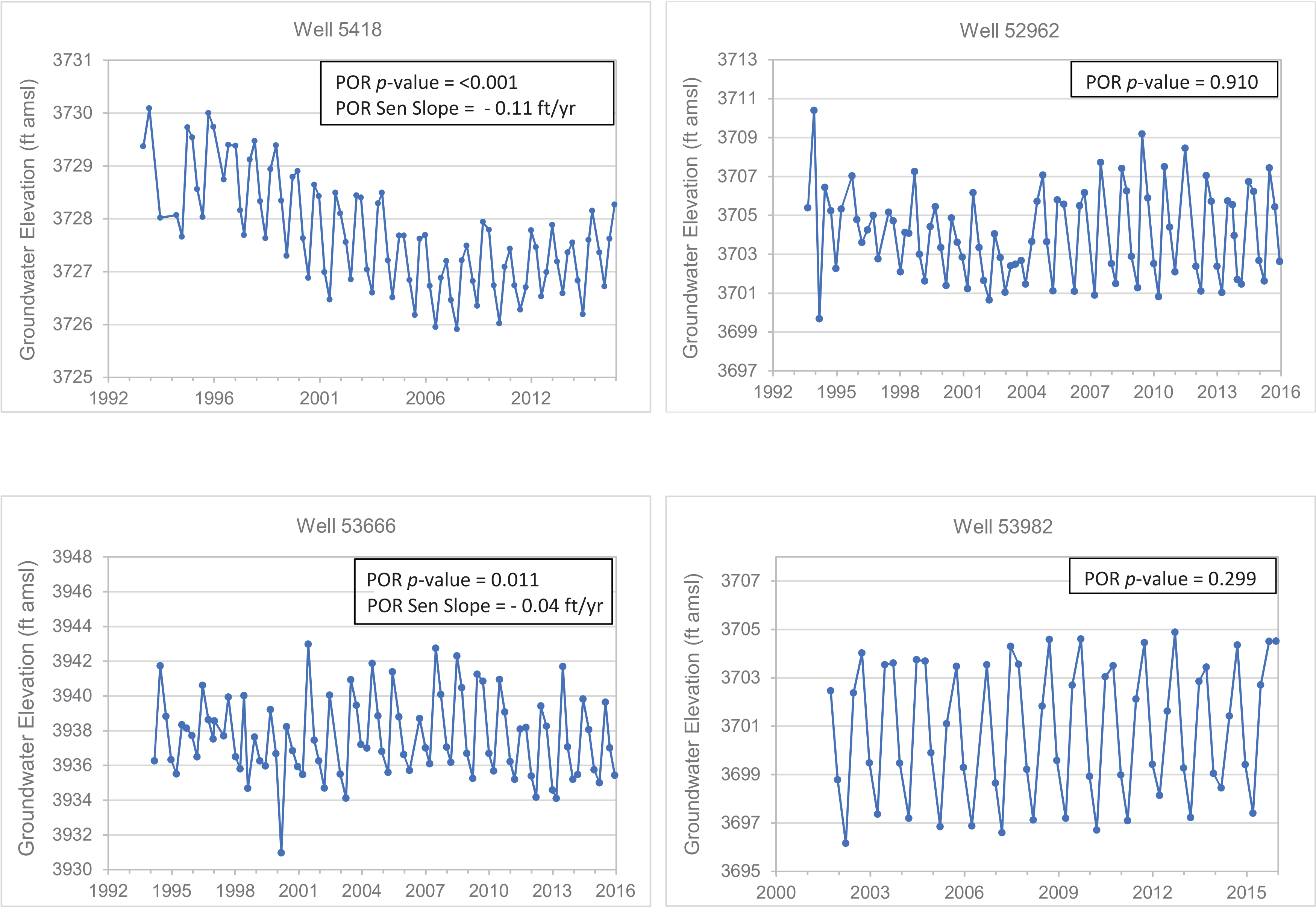
Note. Different porosities were estimated for the high terraces (0.15) and for the valley floor (0.20).

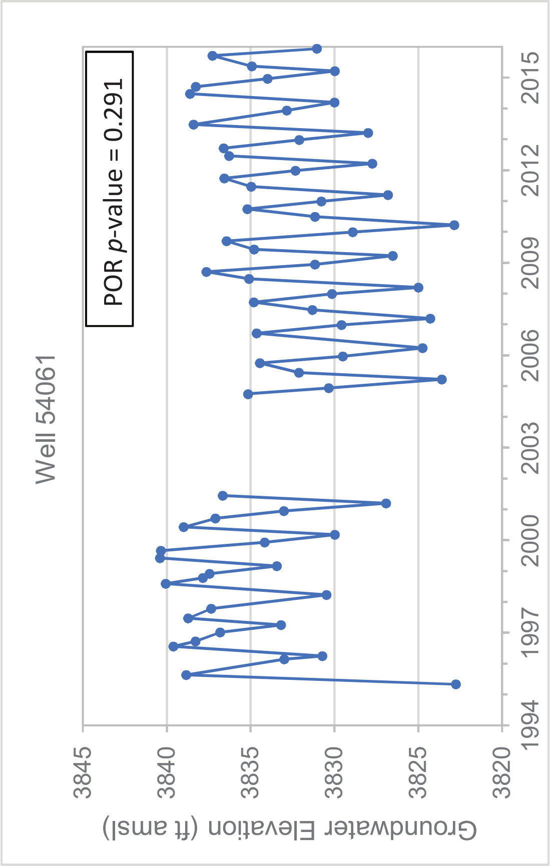
[1] Dec-15 was estimated using the change in storage from November 2014 to December 2014, since December 2015 had an incomplete water-level dataset.

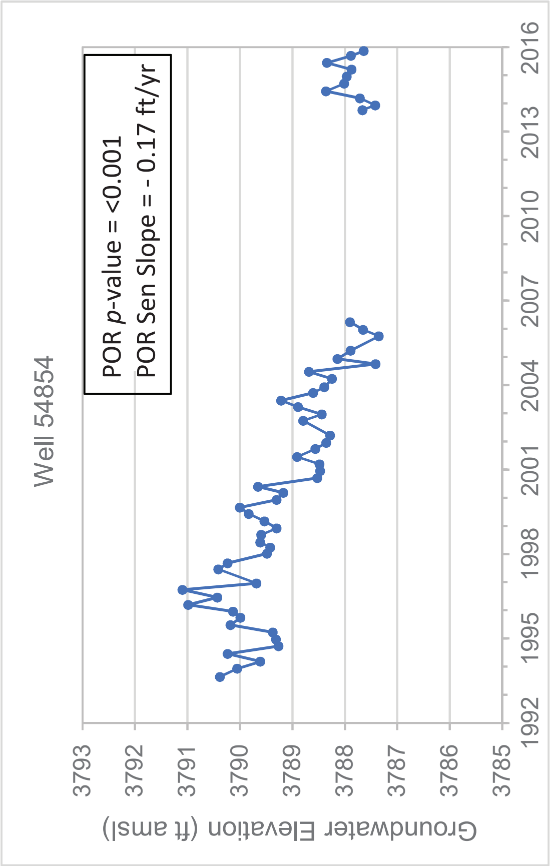
APPENDIX C

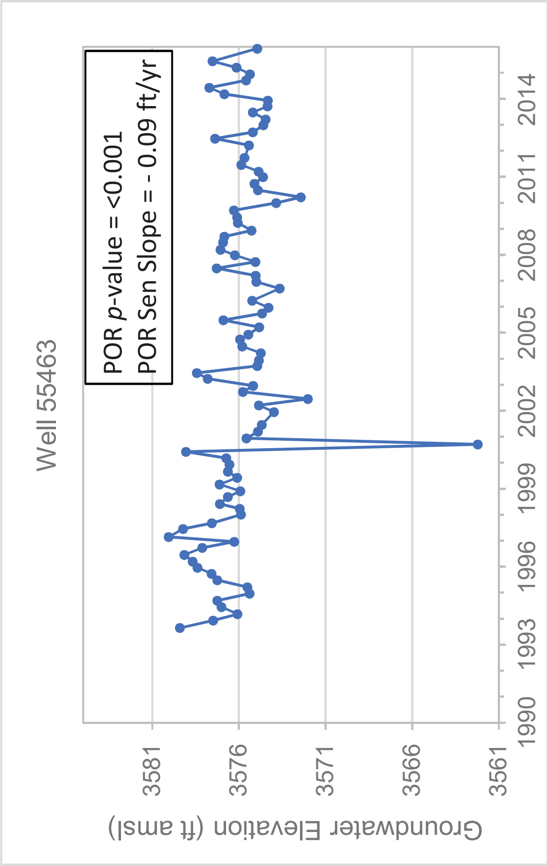
GROUNDWATER-ELEVATION TRENDS

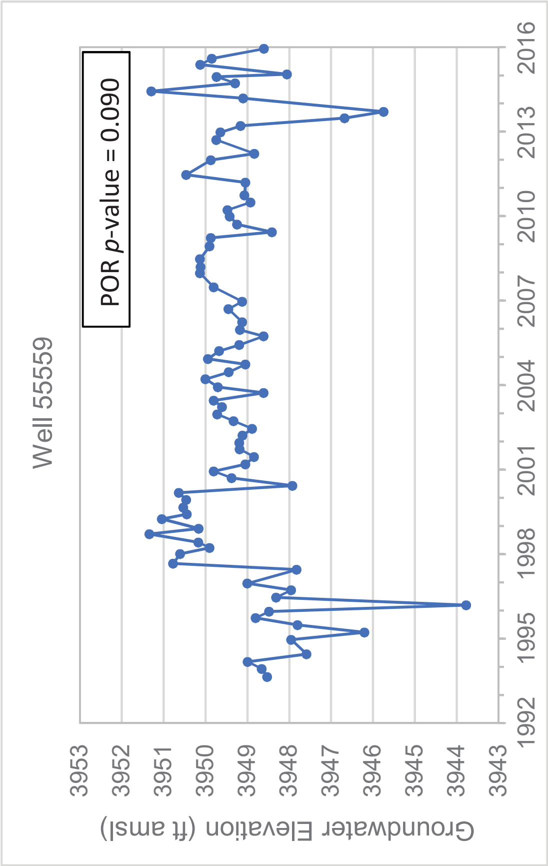
Appendix C. Hydrographs of wells analyzed for long-term groundwater-elevation trends.

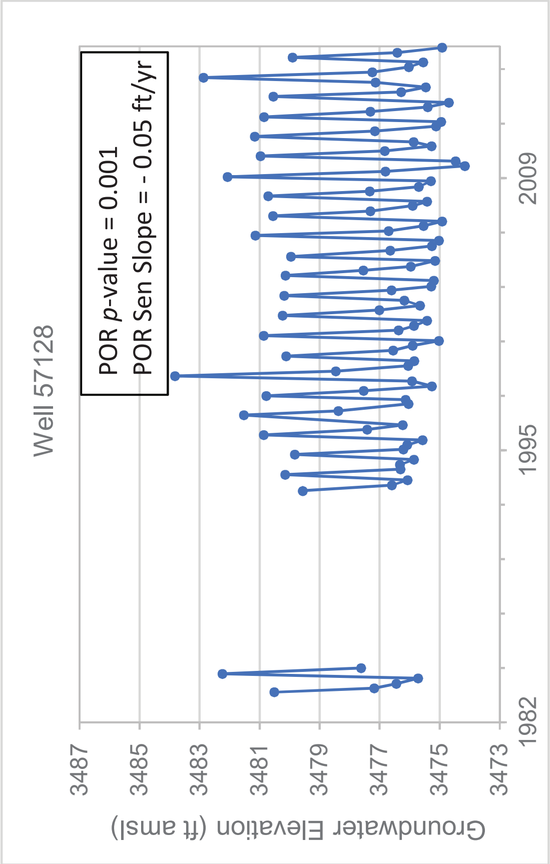


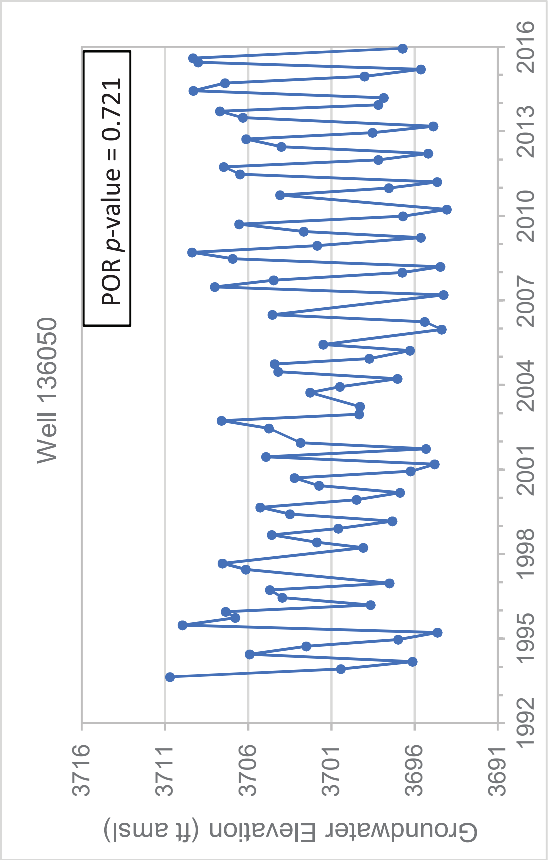

Well 54061
POR *p*-value = 0.291
Groundwater Elevation (ft amsl)
3845
3840
3835
3830
3825
3820
1994
1997
2000
2003
2006
2009
2012
2015

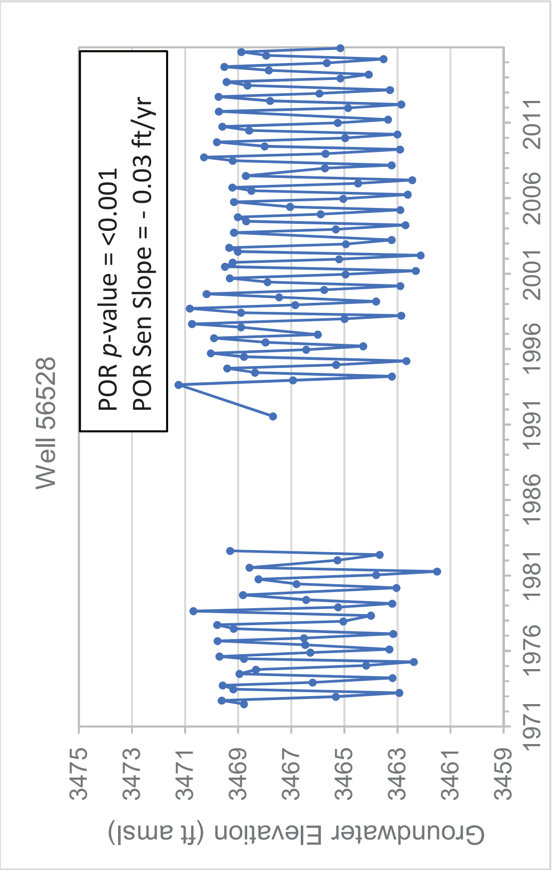

Well 54854
POR *p*-value = <0.001
POR Sen Slope = - 0.17 ft/yr
Groundwater Elevation (ft amsl)
3793
3792
3791
3790
3789
3788
3787
3786
3785
1992
1995
1998
2001
2004
2007
2010
2013
2016

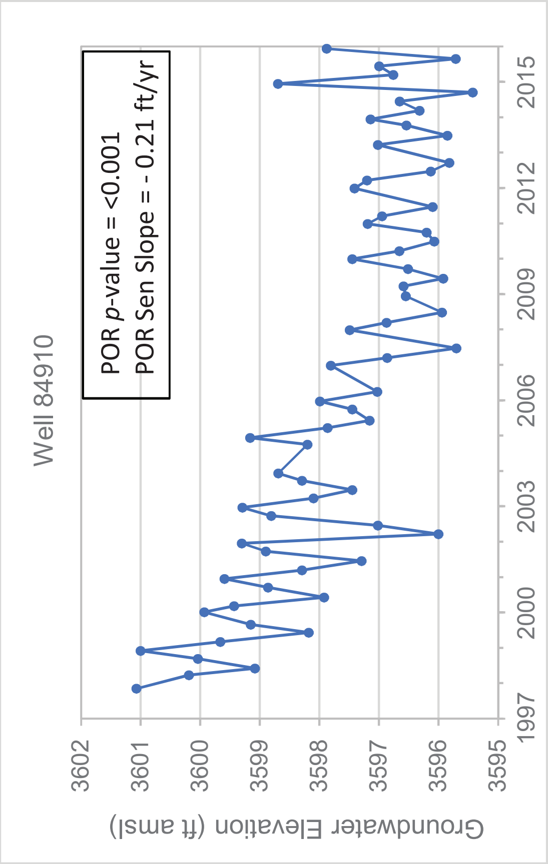

Well 55463
POR *p*-value = <0.001
POR Sen Slope = - 0.09 ft/yr
Groundwater Elevation (ft amsl)
3581
3576
3571
3566
3561
1990
1993
1996
1999
2002
2005
2008
2011
2014

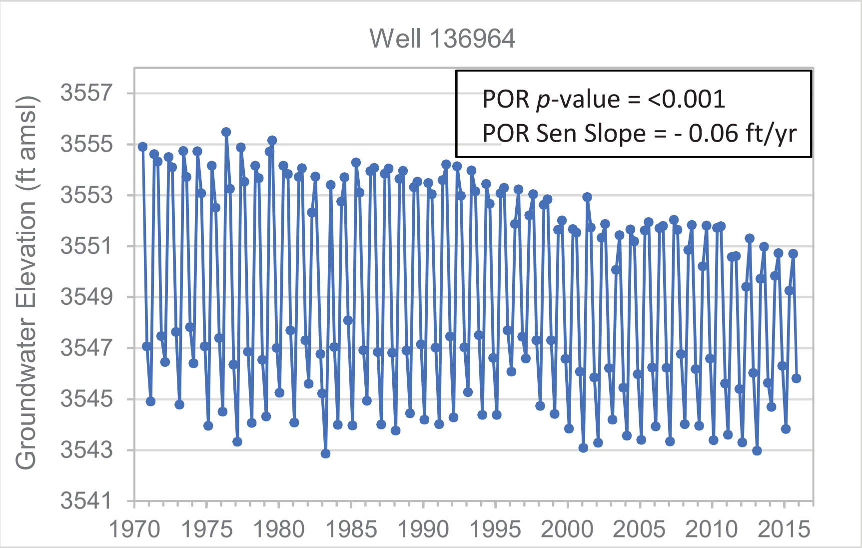

Well 55559
POR *p*-value = 0.090
Groundwater Elevation (ft amsl)
3953
3952
3951
3950
3949
3948
3947
3946
3945
3944
3943
1992
1995
1998
2001
2004
2007
2010
2013
2016

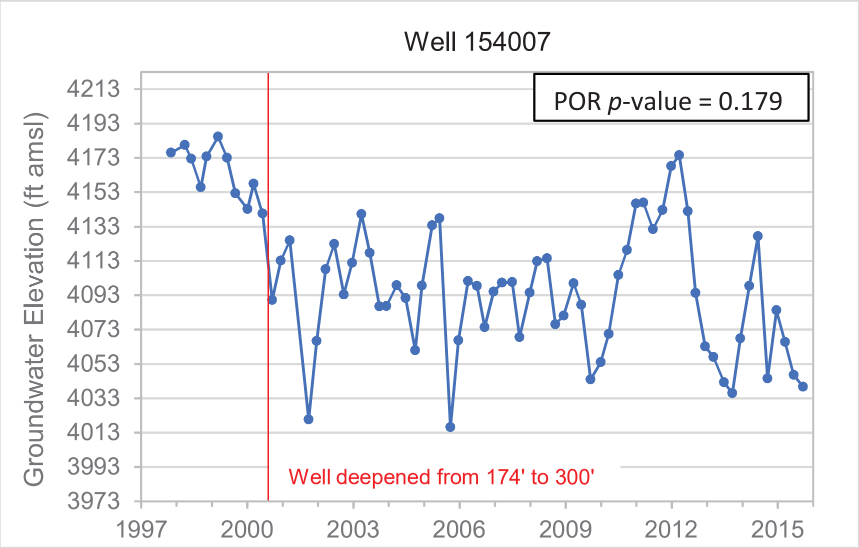

Well 57128
POR *p*-value = 0.001
POR Sen Slope = - 0.05 ft/yr
Groundwater Elevation (ft amsl)
3487
3485
3483
3481
3479
3477
3475
3473
1982
1995
2009

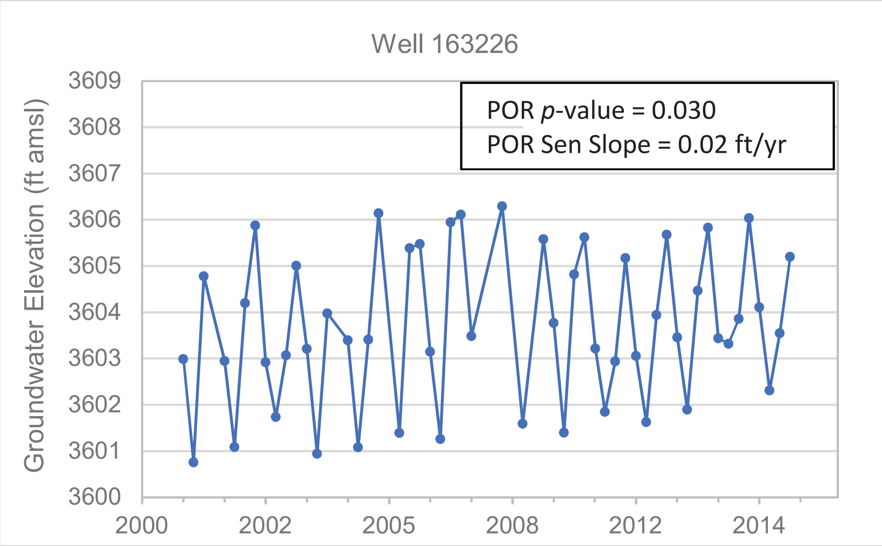

Well 136050
POR *p*-value = 0.721
Groundwater Elevation (ft amsl)
3716
3711
3706
3701
3696
3691
1992
1995
1998
2001
2004
2007
2010
2013
2016

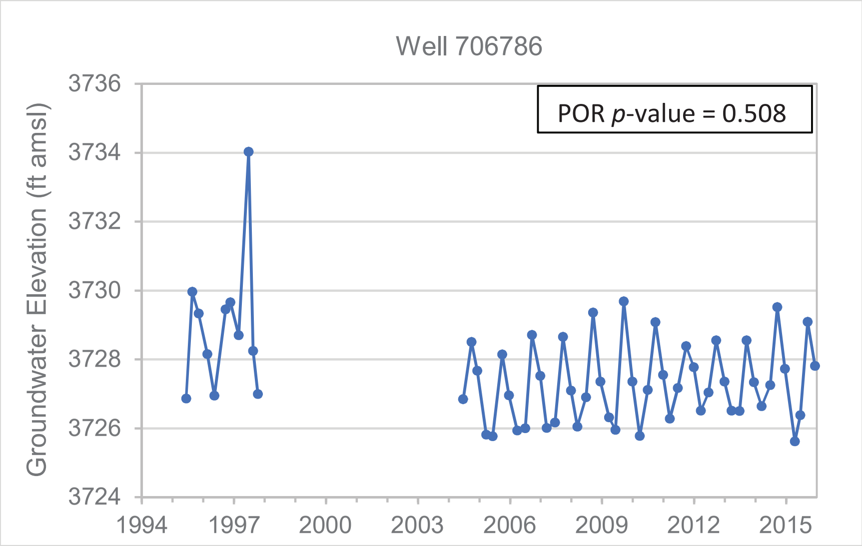

Well 56528
POR *p*-value = <0.001
POR Sen Slope = - 0.03 ft/yr
Groundwater Elevation (ft amsl)
3475
3473
3471
3469
3467
3465
3463
3461
3459
1971
1976
1981
1986
1991
1996
2001
2006
2011


Well 84910
POR *p*-value = <0.001
POR Sen Slope = - 0.21 ft/yr
Groundwater Elevation (ft amsl)
3602
3601
3600
3599
3598
3597
3596
3595
1997
2000
2003
2006
2009
2012
2015


Well 136964
POR p-value = <0.001
POR Sen Slope = - 0.06 ft/yr
Groundwater Elevation (ft amsl)
3557
3555
3553
3551
3549
3547
3545
3543
3541
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015


Well 154007
POR p-value = 0.179
Well deepened from 174' to 300'
Groundwater Elevation (ft amsl)
4213
4193
4173
4153
4133
4113
4093
4073
4053
4033
4013
3993
3973
1997
2000
2003
2006
2009
2012
2015


Well 163226
POR p-value = 0.030
POR Sen Slope = 0.02 ft/yr
Groundwater Elevation (ft amsl)
3609
3608
3607
3606
3605
3604
3603
3602
3601
3600
2000
2002
2005
2008
2012
2014


Well 706786
POR p-value = 0.508
Groundwater Elevation (ft amsl)
3736
3734
3732
3730
3728
3726
3724
1994
1997
2000
2003
2006
2009
2012
2015

APPENDIX D

NITRATE DATA AND NITRATE TRENDS

Table D1. Groundwater chemistry samples collected for nitrate ($NO_3 + NO_2$ –N), Cl, Br, and field measurements.

GWIC ID	Aquifer	Hydrostratigraphic Unit	Sample Date	Water Temp	Field pH	Field SC	Field DO (mg/L)	Cl (mg/L)	Br (μg/L)	NO_3+NO_2-N (mg/L)
5413	Bedrock	TYb	9/16/2014	11.0	7.4	300	NR	3.4	<10 U	1.5
			12/17/2014	10.6	6.3	374	6.00			1.99
			6/16/2015	11.9	7.7	429	NR	5.96	<10 U	2.7
52768	Shallow basin-fill	Qal	4/3/2015	11.8	6.5	121	4.80	2.09	<10 U	0.66
			7/14/2015	11.8	6.7	125	NR	2.38	<10 U	0.71
52842	Deep basin-fill	Taf	9/19/2014	11.5	8.0	121	7.23	0.410 J	<10 U	<0.2 U
			12/18/2014	11.2	8.3	107	5.10			<0.2 U
			6/16/2015	11.0	8.3	126	5.63	0.450 J	<10 U	<0.2 U
52962	Shallow basin-fill	Qal	9/17/2014	10.9	6.7	209	7.05	7.8	<10 U	3.41
			12/18/2014	11.2	6.6	199	4.83			2.6
			6/3/2015	10.6	6.7	194	9.00	7.94	<10 U	2.38
53865	Shallow basin-fill	Qal	12/18/2014	12.1	NR	316	3.21			1.28
			6/2/2015	11.8	7.3	323	8.61	1.86	<10 U	0.53
53982	Shallow basin-fill	Tbg	9/18/2014	10.0	7.5	449	9.86	2.19	<10 U	2.75
			12/17/2014	10.8	NR	427	8.90			2.68
			6/15/2015	10.8	7.9	422	NR	2.24	<10 U	1.81
54043	Deep basin-fill	Tbg	9/18/2014	11.8	7.5	554	7.43	12.53	124	0.6
			12/18/2014	11.9	7.5	526	6.62			0.62
			6/2/2015	12.0	7.6	506	6.13	12.62	119	0.81
54134	Deep basin-fill	Tbg,Tbc	9/17/2014	11.7	7.4	390	10.58	19.33	139	1.26
			12/18/2014	12.0	7.6	364	7.87			1.35
			6/2/2015	12.1	7.7	359	8.10	18.61	135	1.38
54272	Deep basin-fill	Tbg	9/16/2014	11.7	7.2	382	NR	3.36	<10 U	2.06
			12/17/2014	10.6	6.7	385	7.09			2
			6/1/2015	11.9	7.4	365	6.04	3.31	<10 U	2.11
54736	Deep basin-fill	Tbg,Tbc	9/17/2014	11.5	7.9	607	NR	14.65	117	<0.2 U
			12/16/2014	10.6	8.0	589	3.96			0.26
			6/3/2015	11.4	8.1	613	3.77	14.53	115	0.34
55444	Shallow basin-fill	Qal	9/17/2014	14.7	7.2	310	NR	7.55	<10 U	1.24
			6/17/2015	12.7	7.3	302	7.94	5.89	<10 U	1.27
55463	Deep basin-fill	Tbg,Tbc	9/17/2014	10.9	6.8	167	NR	4.7	<10 U	0.78
			6/16/2015	10.6	7.1	162	1.07	5.01	<10 U	0.88
84910	Deep basin-fill	Tbg,Tbc	9/18/2014	12.8	7.2	413	8.68	15.5	119	2.42
			12/16/2014	11.4	7.3	360	7.09			1.05
120360	Shallow basin-fill	Qaf	7/14/2015	7.6	7.5	327	2.02	3.7	<10 U	0.25
124406	Shallow basin-fill	Qaf	6/16/2015	9.5	7.3	201	3.17	1	<10 U	<0.2 U
126820	Shallow basin-fill	Tbg	9/18/2014	12.0	7.3	417	9.89	5.21	<10 U	3.16
			12/19/2014	12.2	7.6	349	7.52			2.43
			6/2/2015	12.5	7.7	463	8.25	11.47	<10 U	4.33
133770	Shallow basin-fill	Qal	9/17/2014	11.0	7.4	335	NR	2.7	<10 U	0.58
			6/3/2015	10.3	7.5	340	9.56	2.58	<10 U	0.79
136050	unknown	Qaf	12/17/2014	11.1	6.3	74.0	8.08			1.08
			6/15/2015	10.8	6.6	69.2	10.72	0.88	<10 U	0.91
136127	Shallow basin-fill	Tbc	9/16/2014	10.5	7.3	667	9.05	6.28	<10 U	1.81
			12/17/2014	10.8	7.5	627	6.67			1.88
			6/15/2015	11.2	7.6	657	NR	4.67	<10 U	1.43
141917	Deep basin-fill	Tbg	6/16/2015	13.2	7.7	443	NR	5.92	64	2.17
146078	Bedrock	TYb	7/14/2015	11.9	7.7	556	9.43	2.7	<10 U	0.61
151180	Deep basin-fill	Tbg	9/19/2014	11.6	7.6	416	9.14	3.01	<10 U	1.68
			12/18/2014	11.6	7.8	403	7.98			2.15

Table D1—*Continued.*

GWIC ID	Aquifer	Hydrostratigraphic Unit	Sample Date	Water Temp	Field pH	Field SC	Field DO (mg/L)	Cl (mg/L)	Br (μg/L)	NO_3+NO_2-N (mg/L)
153190	Shallow basin-fill	Qal	9/17/2014	9.9	7.5	439	0.90	2.19	<10 U	<0.2 U
			12/18/2014	10.0	NR	405	6.14			<0.2 U
			6/17/2015	9.2	7.5	421	2.18	2.6	<10 U	<0.2 U
157331	Shallow basin-fill	Qaf	7/14/2015	8.9	7.9	231	10.35	0.79	<10 U	<0.2 U
165757	Deep basin-fill	Tbg,Tbc	9/17/2014	12.2	6.9	228	2.63	2.88	<10 U	0.5
			12/17/2014	11.9	6.3	220	3.85			0.58
			6/3/2015	12.6	7.1	215	2.04	2.82	<10 U	0.7
174759	Shallow basin-fill	Qal	12/18/2014	11.2	NR	254	7.83			0.37
			6/2/2015	10.5	6.9	196	8.21	4.04	<10 U	0.88
226871	Deep basin-fill	Tbc	9/19/2015	10.2	7.8	338	3.45	1.2	<10 U	<0.2 U
246728	Shallow basin-fill	Qal	9/16/2014	11.9	7.2	324	6.15	2.25	<10 U	1.47
			12/19/2014	11.6	7.2	343	5.75			0.92
			6/16/2015	12.2	7.4	143	NR	0.99	<10 U	<0.2 U
252400	Shallow basin-fill	Qaf	9/18/2014	9.8	6.9	413	7.87	4.08	<10 U	2.11
			6/17/2015	10.0	7.2	377	NR	2.9	<10 U	1.85
276476	NR	NR	9/18/2014	10.7	6.4	140	0.30	6.97	<10 U	<0.2 U
			12/17/2014	10.3	7.9	118	0.91			<0.2 U
			6/1/2015	10.6	6.5	132	0.28	6.82	<10 U	<0.2 U
278237	NR	NR	9/17/2014	11.7	7.4	263	NR	1.91	<10 U	0.34
			12/18/2014	11.7	8.4	260	4.08			0.28
			6/16/2015	10.4	7.5	287	NR	2.4	<10 U	0.83
283489	NR	NR	7/14/2015	NR	NR	NR	NR	1.82	<10 U	<0.2 U

Note. NR, not recorded. U, Undetected quantity below detection limit.

Table D2. Water chemistry samples collected from streams in the study area that have reported nitrate (NO_3 + NO_2 – N), Cl, Br, and field measurements.

GWIC ID	Sample Date	Water Temp	Field pH	Field SC	Cl (mg/L)	Br (μg/L)	NO_3+NO_2-N (mg/L)
266799	9/15/2014	15.2	NR	98	2.01	<10 U	<0.2 U
266801	7/14/2015	NR	NR	NR	1.86	<10 U	<0.2 U
278017	9/15/2014	14.5	NR	89.6	1.27	<10 U	<0.2 U
	7/14/2015	20.2	7.83	67.6	1.09	<10 U	<0.2 U
278137	9/18/2014	14.5	NR	183	1.82	<10 U	<0.2 U
278138	9/18/2014	13	NR	209.3	1.38	<10 U	<0.2 U
	7/14/2015	17.4	8.63	202.2	1.02	<10 U	<0.2 U
278151	9/15/2014	8.5	NR	279.8	1.19	<10 U	<0.2 U
278152	9/15/2014	11.1	NR	174	2.15	<10 U	<0.2 U

Note. NR, not recorded. U, Undetected quantity below detection limit.

Table D3. Reported nitrate concentrations collected from two long-term sampled wells (5413 and 126820).

GWIC: 5413		
Sample Date	Nitrate (mg/L)	Source
11/19/1996	0.6	Briar and Dutton (2000)
1/7/1997	0.9	Briar and Dutton (2000)
2/26/1997	1.5	Briar and Dutton (2000)
4/3/1997	1.8	Briar and Dutton (2000)
5/20/1997	1.5	Briar and Dutton (2000)
6/24/1997	0.94	Briar and Dutton (2000)
8/19/1997	0.23	Briar and Dutton (2000)
10/5/1997	0.47	Briar and Dutton (2000)
9/16/2014	1.5[1]	This Study
12/17/2014	1.99[1]	This Study
6/16/2015	2.99	This Study

Note. Data were used in Mann-Kendall trend test.

[1] Nitrate + nitrite as nitrogen analyses were used because nitrate as nitrogen analyses were unavailable. Nitrite as nitrogen was minimal in the study area; therefore nitrate + nitrite as nitrogen analyses are representative of nitrate as nitrogen analyses.

GWIC: 126820		
Sample Date	Nitrate (mg/L)	Source
9/14/1995	1.3	Briar and Dutton (2000)
1/7/1997	1.7	Briar and Dutton (2000)
1/7/1997	1.7	Briar and Dutton (2000)
2/26/1997	1.9	Briar and Dutton (2000)
4/3/1997	1.6	Briar and Dutton (2000)
5/20/1997	1.8	Briar and Dutton (2000)
6/24/1997	0.79	Briar and Dutton (2000)
8/19/1997	2	Briar and Dutton (2000)
10/15/1997	1.6	Briar and Dutton (2000)
6/7/1999	2.85	Smith and others (2013)
8/31/1999	2.01	Smith and others (2013)
5/11/2000	2.5	Smith and others (2013)
7/16/2000	1.86	Smith and others (2013)
9/16/2000	1.47	Smith and others (2013)
3/3/2001	2.24	Smith and others (2013)
9/18/2014	3.16[1]	This Study
12/19/2014	2.36[1]	This Study
12/19/2014	2.43[1]	This Study
6/2/2015	4.85	This Study

Tables D4. Historic public water supply (PWS) nitrate values used in Mann-Kendall Trend Test.

PWSID:	MT0000234	PWSID:	MT0000234	PWSID:	MT0000234	PWSID:	MT0000234	PWSID:	MT0000234
GWIC_ID:	136335	GWIC_ID:	54276	GWIC_ID:	55295	GWIC_ID:	54443	GWIC_ID:	55251
Report_ID:	City of Hamilton	Report_ID:	City of Hamilton	Report_ID:	City of Hamilton	Report_ID:	City of Hamilton	Report_ID:	City of Hamilton
Well_ID:	Well 1	Name_ID:	Well 2	Name_ID:	Well 4	Name_ID:	Welll 5	Name_ID:	Well 6
Latitude:	46.2394	Latitude:	46.2478	Latitude:	46.2468	Latitude:	46.2443	Latitude:	46.2596
Longitude:	-114.1547	Longitude:	-114.1528	Longitude:	-114.1613	Longitude:	-114.1448	Longitude:	-114.1591
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
2/9/2016	1.06	2/9/2016	0.75	1/26/2004	0.92	3/1/2016	0.92	2/9/2016	1.32
8/27/2015	1.17	8/27/2015	0.88	9/8/2003	1.08	10/22/2015		8/27/2015	2.26
8/4/2014	1.26	8/4/2014	0.96	2/4/2003	0.72	8/4/2014	0.67	8/4/2014	2.38
2/25/2013	0.89	2/25/2013	0.70	3/5/2002	0.74	9/3/2013	0.55	2/25/2013	1.52
3/12/2012	0.97	3/12/2012	0.64	9/11/2001	0.79	8/20/2012	0.55	3/12/2012	1.02
7/20/2011	1.00	7/20/2011	0.88	5/15/2000	0.98	7/20/2011	0.63	7/20/2011	1.60
3/9/2010	1.01	3/9/2010	0.67	4/3/2000	1.30	11/18/2010	0.54	3/9/2010	0.98
7/14/2009	1.22	7/14/2009	0.93	8/3/1999		7/14/2009	0.59	7/14/2009	1.91
7/14/2008	0.94	7/14/2008	1.01	8/10/1998	1.15	7/14/2008	0.60	7/14/2008	1.00
7/18/2007	1.06	7/18/2007	0.86	7/16/1997	1.14	7/18/2007	0.47	7/18/2007	1.75
7/19/2006	1.19	1/22/2007	0.64	11/7/1996	0.91	7/19/2006	0.36	1/22/2007	
1/10/2005	0.90	7/19/2006	0.96	12/21/1994	0.76	1/10/2005	0.90	7/19/2006	2.44
1/26/2004	0.89	1/10/2005	0.65	8/26/1993	0.87	1/26/2004	0.91	1/10/2005	0.99
9/8/2003	0.96	1/26/2004	0.74			9/8/2003	0.23	1/26/2004	1.25
2/4/2003	0.71	9/8/2003	0.72			2/4/2003	0.67	9/8/2003	
3/5/2002	0.70	2/4/2003	0.66			3/5/2002	0.70	2/4/2003	1.81
9/11/2001	0.73	3/5/2002	0.71			9/11/2001	0.36	3/22/2002	0.92
5/15/2000	0.90	9/11/2001	0.53			5/15/2000	0.90	9/11/2001	1.59
4/3/2000	1.16	5/15/2000	0.98			4/3/2000	1.08	5/15/2000	
8/3/1999	1.08	4/3/2000	1.20			8/3/1999	0.38	4/3/2000	1.35
8/10/1998	1.08	8/3/1999	0.99			8/10/1998	0.48	8/3/1999	3.06
7/16/1997	1.63	8/10/1998	0.73			7/16/1997	0.73	8/10/1998	2.61
11/7/1996	0.80	7/16/1997	1.21			8/26/1993	0.45	7/16/1997	3.90
12/21/1994	0.69	11/7/1996	0.790					11/7/1996	0.85
8/26/1993	1.03							12/21/1994	0.75
								8/26/1993	2.86

Table D4—*Continued* .

PWSID:	MT0000234	PWSID:	MT0000504	PWSID:	MT0000506	PWSID:	MT0000634
GWIC_ID:	173150	GWIC_ID:	52638	GWIC_ID:	Unknown	GWIC_ID:	52557, 52555
Report_ID:	City of Hamilton	Report_ID:	Big Sky Trailer Court	Report_ID:	White Bird Community	Report_ID:	Westana Mobile Manor
Name_ID:	Wells 7, 8, 9	Name_ID:	Well 1 and 2	Name_ID:	Well 1 1970	Name_ID:	Well 1 & 2
Latitude:	46.24804	Latitude:	46.20959087	Latitude:	46.233333	Latitude:	46.224528
Longitude:	-114.145479	Longitude:	-114.1473819	Longitude:	-114.15	Longitude:	-114.153056
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
2/9/2016	1.65	4/25/2017	0.47	4/25/2017	0.61	3/9/2017	0.60
8/27/2015	0.95	2/25/2016	0.38	2/25/2016	0.71	2/10/2016	0.57
8/4/2014	0.97	2/18/2015	0.32	2/24/2015	0.80	4/20/2015	0.60
2/25/2013	1.83	4/14/2014	0.34	4/1/2014	0.50	4/21/2014	0.57
3/12/2012	1.62	4/16/2013	0.20	4/16/2013	0.57	3/14/2013	0.51
7/20/2011	0.92	1/30/2012	0.25	1/30/2012	0.70	3/15/2012	0.53
3/9/2010	1.46	2/11/2011	0.26	2/11/2011	0.26	10/11/2011	0.55
7/14/2009	1.15	12/9/2010	0.24	12/9/2010	0.60	3/23/2010	0.57
7/14/2008	1.39	12/2/2009	0.29	12/2/2009	0.70	11/24/2009	0.55
4/8/2008		11/12/2008	0.34	11/12/2008	0.83	10/29/2008	0.53
7/18/2007	0.91	9/13/2007	0.80	9/2/2008	0.15	12/7/2007	0.56
7/19/2006	0.81	9/13/2007	0.76	8/31/2008	0.16	12/28/2006	0.59
4/11/2005	1.64	6/26/2006	1.65	5/5/2008	0.71	3/23/2005	0.54
1/10/2005		2/22/2005	0.33	2/13/2008	0.47	3/28/2004	0.54
		12/16/2004	0.38	12/19/2007	0.31	3/13/2003	0.50
		7/16/2003	1.47	9/13/2007	8.02	10/16/2002	0.50
		9/5/2002	0.52	10/19/2006	0.80	12/17/2001	0.51
		12/10/2001	0.39	3/23/2005	0.62	11/7/2000	0.51
		6/27/2000	0.82	3/28/2004	0.55	11/15/1999	0.50
		12/10/1999	0.54	3/13/2003	0.43	12/14/1998	0.64
		4/5/1998	0.27	10/16/2002	0.57	12/31/1997	0.54
		8/22/1997	0.58	12/17/2001	0.49	12/23/1996	0.66
		7/16/1996	0.96	11/7/2000	0.57	1/6/1995	0.52
		3/9/1995	0.31	5/11/1999	0.45		
		12/26/1994	0.23	12/2/1998	0.55		
		2/25/1992	0.27	7/29/1997	0.92		
		4/10/1989	0.23	10/21/1996	0.65		
		6/5/1985	0.33	5/9/1995	0.43		
		10/13/1982	0.71	11/14/1994	0.51		
				8/8/1994	0.60		

Table D4—Continued.

PWSID: MT0001046		PWSID: MT0001059		PWSID: MT0001067		PWSID: MT0001071	
GWIC_ID: Unknown		GWIC_ID: 52679		GWIC_ID: Unknown		GWIC_ID: 55686	
Report_ID: The Wild Mare		Report_ID: Hamilton Christian Academy		Report_ID: Angler's Roost		Report_ID: Motel 6	
Name_ID: Well 1 60		Name_ID: Well 1		Name_ID: Well 1 & 2		Name_ID: Treatment Plant	
Latitude: 46.3141		Latitude: 46.2008		Latitude: 46.2077		Latitude: 46.2331062	
Longitude: -114.1157		Longitude: -114.1403		Longitude: -114.1669		Longitude: -114.1657938	
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
11/28/2016	1.92	9/24/2016	0.78	11/28/2016	0.13	2/18/2017	1.04
8/10/2015	1.39	4/22/2015	0.89	11/16/2015	0.79	2/3/2016	0.88
8/26/2014	1.39	9/25/2014	0.72	12/2/2014	0.80	7/22/2015	1.54
11/21/2013	1.40	12/19/2012	0.78	12/4/2013	0.66	1/21/2014	0.87
12/19/2012	1.20	12/20/2011	0.78	12/6/2012	0.80	3/11/2013	0.91
5/26/2010	1.26	9/29/2010	0.77	12/7/2011	0.78	3/1/2012	0.88
4/29/2008	1.27	12/22/2009	0.71	11/29/2010	0.84	2/9/2011	0.55
12/11/2007	1.17	12/17/2008	0.86	12/14/2009	0.95	3/15/2010	0.65
3/27/2006	1.38	9/24/2007	0.85	12/1/2008	0.92	3/20/2009	1.17
6/27/2000	1.42	12/19/2006	0.75	11/27/2007	1.04	4/7/2008	1.06
1/4/1998	1.53	12/21/2005	0.74	11/27/2006	0.84	2/22/2007	0.31
2/27/1995	1.09	9/21/2004	0.80	12/13/2005	0.93	4/3/2006	1.07
		12/8/2003	0.75	12/8/2004	1.48	2/22/2005	0.84
		11/20/2002	0.76	11/12/2003	1.19	1/5/2004	0.66
		4/23/2002	0.82	12/11/2002	1.53	2/3/2003	0.53
		12/19/2001	0.90	12/10/2001	1.27	5/13/2002	0.67
		11/30/2000	0.95	11/28/2000	1.06	10/1/2001	0.51
		11/9/1999	0.99	11/8/1999	1.04	12/4/2000	0.53
		12/8/1998	1.04	10/5/1998	0.64	11/16/1999	0.61
		12/30/1997	0.96	11/3/1997	0.61	12/1/1998	0.66
		12/16/1996	0.81	10/7/1996	0.61	10/13/1997	0.70
		9/27/1995	0.83	12/11/1995	0.60	1/29/1996	0.49
		1/13/1995	0.94			11/8/1994	0.51
		6/20/1994	0.81				

Table D4—Continued.

PWSID: MT0001074		PWSID: MT0001079		PWSID: MT0001080		PWSID: MT0001083	
GWIC_ID: 276838		GWIC_ID: 127283		GWIC_ID: Unknown		GWIC_ID: 54495	
Report_ID: Bitterroot Valley Rv Park		Report_ID: Hamilton Mobile Village		Report_ID: Honey Lane Court Hamilton		Report_ID: Bluebird Mobile Home	
Name_ID: Well 1		Name_ID: Well 1		Name_ID: Well 1		Name_ID: Well 1	
Latitude: 46.1347		Latitude: 46.2493555		Latitude: 46.286389		Latitude: 46.23309937	
Longitude: -114.1772		Longitude: -114.1737206		Longitude: -114.148694		Longitude: -114.1449845	
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
9/29/2016	0.30	3/9/2017	0.74	4/25/2017	0.63	12/21/2016	0.56
10/28/2015	0.65	2/18/2016	0.80	2/25/2016	0.74	10/22/2015	0.59
6/3/2014	0.32	10/21/2015	1.04	2/24/2015	0.84	9/23/2014	0.70
11/28/2011	0.43	9/23/2014	1.62	4/1/2014	0.59	9/24/2013	0.54
5/18/2010	0.52	12/17/2013	0.74	4/16/2013	0.06	8/21/2012	0.65
4/23/2009	0.56	9/19/2012	0.95	1/30/2012	0.65	11/29/2011	0.46
7/10/2008	0.70	11/14/2011	0.86	2/11/2011	0.55	9/28/2010	0.54
4/23/2007	0.66	3/23/2010	0.69	12/9/2010	0.64	6/16/2009	0.70
8/23/2006	N/A	10/26/2009	1.06	12/2/2009	0.30	3/14/2008	0.54
8/25/2005	0.67	12/9/2008	1.14	11/12/2008	0.84	11/21/2006	0.63
5/27/2004	0.71	12/7/2007	0.79	6/26/2006	0.68	4/5/2005	0.48
2/3/2003	0.58	12/28/2006	0.82	2/22/2005	0.63	12/14/2004	0.66
8/12/2002	0.63	9/13/2006	1.10	12/16/2004	0.73	11/24/2003	0.24
11/27/2000	0.66	3/23/2005	0.66	7/16/2003	0.67	11/21/2002	0.15
11/29/1999	0.67	3/28/2004	0.75	9/5/2002	0.52	12/12/2001	0.16
11/23/1998	0.70	3/13/2003	0.52	12/10/2001	0.40	11/27/2000	0.16
11/24/1997	0.19	12/16/2002	0.53	7/19/2000	0.85	9/20/1999	0.55
11/20/1996	0.75	12/17/2001	0.56	5/11/1999	0.49	12/4/1998	0.59
11/29/1995	0.76	2/9/2001	0.54	10/5/1998	0.83	12/9/1997	0.65
1/2/1995	0.83	5/11/1999	0.69	7/29/1997	0.75	12/17/1996	0.56
11/15/1993	0.91	12/2/1998	0.67	7/30/1996	0.73	1/3/1995	0.78
		7/8/1997	1.19	12/26/1995	0.57	6/21/1993	0.78
		10/16/1996	0.90	6/20/1994	0.52		
		9/1/1995	1.00	8/25/1993	0.70		
		7/9/1993	1.12				

Table D4—Continued.

PWSID:	MT0002131	PWSID:	MT0002799	PWSID:	MT0002926	PWSID:	MT0003003
GWIC_ID:	53705	GWIC_ID:	56636	GWIC_ID:	56980	GWIC_ID:	54701
Report_ID:	Ponderosa Mobile Home Park	Report_ID:	Corvallis Mobile Village	Report_ID:	Town of Pinesdale	Report_ID:	Antigone Acres HOA
Name_ID:	Well 2	Name_ID:	Well 1 & 2	Name_ID:	Well 3 & 4	Name_ID:	Wells 3 & 4
Latitude:	46.2997	Latitude:	46.314	Latitude:	46.33465355	Latitude:	46.234049
Longitude:	-114.0456	Longitude:	-114.106	Longitude:	-114.1656213	Longitude:	-114.1334593
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
3/9/2017	1.58	8/10/2016	1.02	9/14/2016	N/A	6/27/2016	0.92
2/10/2016	2.22	11/17/2015	1.56	10/7/2015	0.33	11/16/2015	0.89
4/20/2015	1.71	12/9/2014	1.57	6/11/2014	N/A	11/30/2014	0.84
4/21/2014	1.49	9/16/2013	0.82	9/24/2013	0.40	3/31/2013	0.79
9/23/2013	2.67	10/23/2012	1.17	6/5/2012	N/A	11/18/2012	0.85
3/15/2012	2.39	3/15/2012	1.21	4/6/2011	0.33	11/27/2011	0.81
10/11/2011	2.94	10/11/2011	1.12	5/20/2010	0.35	3/14/2010	0.80
3/23/2010	2.85	3/23/2010	1.42	2/11/2009	0.36	11/1/2009	0.86
10/26/2009	2.93	3/26/2009	1.50	5/7/2008	0.35	12/2/2008	0.74
12/11/2008	2.45	2/27/2008	1.69	2/10/2007	0.32	6/17/2007	0.77
10/29/2008	2.54	10/1/2007	1.27	7/10/2006	0.30	12/17/2006	0.76
2/28/2007	0.81	12/28/2006	1.68	6/6/2004	N/A	12/18/2005	0.76
9/19/2006	0.85	3/23/2005	1.54	9/1/2003	0.31	3/7/2004	0.74
2/21/2005	2.66	3/28/2004	1.53	3/24/2002	0.28	11/30/2003	0.73
3/15/2004	2.73	3/13/2003	1.59	8/28/2000	0.49	11/25/2002	0.70
3/10/2003	1.95	10/16/2002	0.75	7/4/2000	N/A	8/1/2001	0.71
12/27/2002	1.97	4/26/2000	1.39	7/13/1999	0.39	9/25/2000	0.77
12/17/2001	2.12	11/18/1999	1.24	3/21/1995	0.18	7/22/1999	0.89
6/14/2000	1.84	4/20/1998	1.40			9/14/1998	0.74
9/14/1999	1.89	3/12/1997	1.74			7/22/1997	0.73
10/6/1998	2.01	5/7/1996	1.88			12/31/1996	0.70
7/31/1997	1.36	5/17/1995	1.61			4/3/1995	0.79
7/8/1996	1.30	5/18/1994	1.68			12/13/1994	0.26
5/17/1994	1.40	9/30/1993	2.52				
5/1/1994	1.40						
9/30/1993	1.10						

Table D4—Continued.

PWSID:	MT0003003	PWSID:	MT0003003	PWSID:	MT0003186	PWSID:	MT0003257
GWIC_ID:	54709	GWIC_ID:	54726	GWIC_ID:	54927	GWIC_ID:	56586
Report_ID:	Antigone Acres HOA	Report_ID:	Antigone Acres HOA	Report_ID:	The Word Restaurant	Report_ID:	Corvallis Primary School
Name_ID:	Wells 3 & 4	Name_ID:	Well 2 10-07-1976 Sw	Name_ID:	Treatment Plant	Name_ID:	Well 1
Latitude:	46.230393	Latitude:	46.2331	Latitude:	46.2808	Latitude:	46.3137
Longitude:	-114.1334593	Longitude:	-114.1233	Longitude:	-114.164	Longitude:	-114.1121
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
6/27/2016	0.31	6/27/2016	0.96	11/23/2004	0.59	3/7/2017	1.69
11/16/2015	0.88	11/16/2015	0.90	8/8/2006	0.71	4/16/2016	2.00
11/30/2014	0.82	11/30/2014	0.84	9/22/2005	1.18	5/12/2015	2.06
3/31/2013	0.78	3/31/2013	0.80	11/23/2004	0.59	2/18/2014	1.78
11/18/2012	0.85	11/18/2012	0.84	12/22/2003	1.17	3/19/2013	1.70
11/27/2011	0.83	11/27/2011	0.80	10/7/2009	1.69	2/7/2012	1.75
3/14/2010	0.79	3/14/2010	0.79	12/30/2008	0.89	2/8/2011	1.65
11/1/2009	0.86	11/1/2009	0.86			2/9/2010	1.91
12/2/2008	0.72	12/2/2008	0.74			2/10/2009	1.71
6/17/2007	0.88	6/17/2007	1.18			3/11/2008	1.99
12/17/2006	0.72	12/17/2006	0.75			2/13/2007	1.88
12/18/2005	0.72	12/18/2005	0.76			8/8/2006	1.71
3/7/2004	0.61	3/7/2004	0.73			2/9/2005	2.27
11/30/2003	0.72	11/30/2003	0.73			1/13/2004	2.15
11/25/2002	0.69	11/25/2002	0.73			2/25/2002	2.16
1/16/2002	0.78	8/1/2001	0.78			11/14/2001	2.07
8/1/2001	0.79	9/25/2000	0.80			12/6/2000	2.37
9/25/2000	0.85	7/22/1999	0.97			12/15/1999	1.59
7/22/1999	0.90	9/14/1998	0.73			12/2/1998	3.01
9/14/1998	0.72	7/22/1997	0.87			6/24/1997	3.92
7/22/1997	0.88	12/31/1996	0.70			6/12/1996	2.42
12/31/1996	0.70	4/3/1995	0.70			7/11/1995	2.37
4/3/1995	0.70	12/13/1994	0.27			6/28/1995	1.38
12/13/1994	0.26					12/28/1994	2.60
						9/17/1993	2.26

Table D4—Continued.

PWSID:	MT0003277	PWSID:	MT0003284	PWSID:	MT0003284	PWSID:	MT0003333
GWIC_ID:	53283	GWIC_ID:	52662	GWIC_ID:	52663	GWIC_ID:	Unknown
Report_ID:	Wards Cove Water Users	Report_ID:	Sawtooth Villa	Report_ID:	Sawtooth Villa	Report_ID:	Corvallis Tavern
Name_ID:	Well 1 GWIC 53283	Name_ID:	Well 1 N GWIC 52662	Name_ID:	Well 2 S GWIC 52663	Name_ID:	Well 1
Latitude:	46.1575	Latitude:	46.2019	Latitude:	46.2019	Latitude:	46.316667
Longitude:	-114.1753	Longitude:	-114.1485	Longitude:	-114.1485	Longitude:	-114.116667
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
3/9/2017	0.35	3/9/2017	0.94	3/9/2017	0.87	1/9/2017	1.43
2/10/2016	0.39	2/10/2016	0.77	3/16/2016	0.77	4/13/2016	1.59
4/20/2015	0.31	4/20/2015	0.93	4/20/2015	0.93	1/14/2015	1.56
4/21/2014	0.28	4/21/2014	0.91	4/21/2014	0.91	1/13/2014	1.36
12/5/2013	0.29	9/23/2013	0.65	11/1/2013	0.60	3/10/2013	1.27
3/14/2013	0.30	10/23/2012	0.53	10/23/2012	0.53	2/7/2012	1.25
3/15/2012	0.35	3/15/2012	0.75	3/15/2012	0.76	2/8/2011	1.20
10/11/2011	0.30	10/11/2011	0.58	10/11/2011	0.58	3/9/2010	1.31
3/23/2010	0.73	3/23/2010	0.79	3/23/2010	0.79	4/13/2009	1.22
2/25/2009	0.96	3/26/2009	0.88	3/26/2009	0.89	3/24/2008	1.23
9/25/2008	0.68	10/29/2008	0.82	10/29/2008	0.72	2/20/2007	1.31
11/7/2007	0.57	12/7/2007	0.77	12/7/2007	0.77	3/14/2006	1.30
11/29/2006	0.44	12/28/2006	0.96	12/28/2006	0.97	2/8/2005	1.46
12/28/2005	0.23	2/16/2005	0.90	2/16/2005	0.70	3/22/2004	1.35
12/21/2004	0.80	3/22/2004	1.00	3/22/2004	1.00	4/21/2003	1.48
12/10/2003	0.78	2/11/2003	0.75	2/11/2003	0.74	4/18/2002	1.37
12/10/2002	0.59	11/26/2002	0.60	11/26/2002	0.63	12/4/2000	1.78
12/11/2001	0.57	11/15/2001	0.75	11/15/2001	0.74	12/7/1999	1.89
12/12/2000	0.53	11/7/2000	0.78	11/7/2000	0.79	12/14/1998	2.41
11/22/1999	0.55	5/11/1999	1.05	5/11/1999	1.06	10/22/1997	3.37
8/27/1998	0.24	10/8/1998	1.00	10/8/1998	0.98	11/14/1994	1.44
8/19/1997	0.36	8/26/1997	1.17	8/26/1997	1.16		
7/1/1996	0.60	8/5/1996	1.04	8/5/1996	1.06		
4/3/1995	0.46	8/24/1995	0.82	8/24/1995	0.84		
12/27/1994	0.60	12/14/1994	0.71	12/14/1994	0.75		

Table D4—Continued.

PWSID:	MT0003422	PWSID:	MT0003460	PWSID:	MT0003610	PWSID:	MT0003646
GWIC_ID:	55258	GWIC_ID:	51448	GWIC_ID:	53891	GWIC_ID:	Unknown
Report_ID:	Subway Sandwich Shop	Report_ID:	Rocky Mountain Log Home	Report_ID:	Merc Fresh Market The	Report_ID:	LDS Church Corvallis
Name_ID:	Treatment Plant	Name_ID:	Tp For Main Office S Well 1	Name_ID:	Well 2 At Treatment Plant	Name_ID:	Well 2
Latitude:	46.2593	Latitude:	46.12638	Latitude:	46.29108353	Latitude:	46.3093
Longitude:	-114.1561	Longitude:	-114.1787	Longitude:	-114.1245172	Longitude:	-114.1144
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
3/30/2017	1.10	8/8/2016	1.07	3/17/2017	1.38	3/9/2017	2.21
3/31/2016	1.13	9/28/2015	1.07	10/18/2016	1.21	2/10/2016	2.13
12/3/2015	1.35	9/15/2014	1.16	2/23/2015	1.33	6/16/2015	2.09
9/30/2014	1.86	10/8/2013	1.12	3/24/2014	1.19	7/8/2013	2.00
12/5/2013	0.88	11/7/2012	1.16	4/12/2013	1.29	4/11/2012	2.04
11/13/2012	1.20	3/16/2010	1.59	3/20/2012	1.35	2/8/2012	2.18
3/15/2011	0.87	11/27/2007	1.08	3/22/2011	1.40	12/13/2011	2.02
4/26/2010	1.06	12/29/2004	1.33	3/2/2010	1.40	9/29/2009	1.71
11/18/2009	1.42	10/8/2013	1.12	6/22/2009	1.41	6/17/2009	2.34
6/30/2009	1.12	11/7/2012	1.16	3/20/2008	1.34	2/27/2008	1.65
3/11/2009	1.17	3/12/2012	1.88	3/19/2007	1.46	2/5/2007	1.71
5/22/2008	1.08	3/16/2010	1.59	2/7/2006	1.45	2/6/2006	1.70
4/3/2007	1.14	11/16/2009	0.86	2/22/2005	1.39	2/1/2005	1.45
7/5/2006	1.00	8/27/2008	1.04	2/19/2004	1.50	1/26/2004	1.40
10/3/2005	1.28	11/27/2007	1.08	4/17/2003	1.56	2/4/2003	1.21
10/5/2004	1.69	8/15/2006	1.02	4/29/2002	1.52	10/2/2002	1.31
11/17/2003	1.75	10/4/2005	1.04	12/7/2000	1.62	7/9/2001	1.31
10/1/2002	2.18	12/29/2004	1.33	12/29/1999	1.50	7/25/2000	1.29
10/2/2001	1.30	12/11/2003	1.64	12/14/1998	1.64	8/2/1999	1.24
10/3/2000	1.45	3/22/2001	3.81	11/24/1997	1.74	8/25/1998	1.31
7/12/1999	1.24	11/9/2000	1.91	2/12/1996	1.81	10/7/1997	1.26
10/5/1998	1.29	11/8/1999	1.53	12/20/1994	1.45	7/9/1996	1.37
11/3/1997	1.53	5/27/1998	1.61			12/5/1994	1.35
6/19/1996	0.98	12/29/1997	2.13				
12/20/1994	0.95	12/17/1996	2.04				
		12/29/1994	1.74				
		5/14/1993	1.39				

Table D4—Continued.

PWSID:	MT0003773	PWSID:	MT0003861	PWSID:	MT0003898	PWSID:	MT0003982
GWIC_ID:	51576, 51575	GWIC_ID:	151177	GWIC_ID:	156242	GWIC_ID:	Unknown
Report_ID:	Lost Horse Creek Lodge	Report_ID:	Hamilton Golf Cl. Snack Shop	Report_ID:	Sleeping Child Church	Report_ID:	Stock Farm The
Name_ID:	Common Header 2 & 3	Name_ID:	Treatment Plant Well 1	Name_ID:	Treatment Plant	Name_ID:	Common Header P1-P16
Latitude:	46.1061	Latitude:	46.219917	Latitude:	46.195359	Latitude:	46.24955
Longitude:	-114.2411	Longitude:	-114.096778	Longitude:	-114.032397	Longitude:	-114.074163
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
3/26/2013	0.14	2/25/2016	0.79	3/9/2016	0.69	3/9/2016*	0.79
2/12/2012	0.14	9/29/2014	0.76	12/7/2015	0.65	3/26/2015*	0.87
3/8/2011	0.13	9/26/2013	0.73	1/13/2015	0.57	3/18/2014*	0.93
4/4/2010	0.17	11/19/2012	0.84	1/21/2014	0.64	3/21/2013*	1.00
3/9/2010	0.16	2/10/2011	0.85	1/29/2013	0.74	2/22/2012	0.87
12/21/2009	0.16	3/24/2009	0.90	1/17/2012	0.63	2/21/2011	1.12
10/28/2008	0.16	10/17/2007	0.94	1/16/2011	0.90	2/19/2010	1.05
11/29/2007	0.14	8/21/2006	0.98	1/5/2010	0.94	7/24/2009	1.34
2/17/2006	0.13	10/11/2005	1.00	3/3/2009	0.75	10/21/2008	1.14
2/18/2005	0.26	10/13/2004	0.94	2/5/2008	0.99	10/12/2008	1.20
3/31/2003	0.16	9/4/2003	1.02	2/6/2007	0.84	7/13/2007	1.32
		4/22/2002	0.94	2/7/2006	0.90	8/7/2006	1.50
		8/16/2000	1.02	1/25/2005	0.75	9/2/2005	1.29
		9/14/1999	0.93	1/27/2004	0.31	2/3/2004	1.18
		11/9/1998	0.86	4/15/2003	0.47	8/6/2003	1.02
		10/2/1997	1.04	2/26/2002	0.64	3/14/2002	1.14
		10/2/1996	1.06	7/27/2001	0.98	5/10/2001	1.18
				11/28/2000	0.91	12/5/2000	1.15
				11/16/1999	0.78	5/5/1999	1.48
				12/1/1998	1.33		
				11/10/1997	1.66		
				12/24/1996	0.72		

*Name_ID changed to Storage Facility 1 Intermediate

Table D4—Continued.

PWSID: MT0004041		PWSID: MT0004043		PWSID: MT0004044		PWSID: MT0004091	
GWIC_ID: 179092		GWIC_ID: 53123		GWIC_ID: 167441		GWIC_ID: Unknown	
Report_ID: Corvallis Gym & Middle School		Report_ID: Sonshine Daycare		Report_ID: Lone Pine Store		Report_ID: Memories Café	
Name_ID: Well 1		Name_ID: Treatment Plant		Name_ID: Treatment Plant		Name_ID: Well 1	
Latitude: 46.30985857		Latitude: 46.2038		Latitude: 46.22757167		Latitude: 46.314156	
Longitude: -114.1100711		Longitude: -114.1563		Longitude: -114.2782314		Longitude: -114.11192	
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
3/7/2017	1.56	9/26/2016	0.53	12/5/2016	0.17	12/1/2016	1.53
4/13/2016	1.77	4/22/2015	0.93	9/24/2015	0.57	11/23/2015	1.83
5/12/2015	1.68	8/20/2014	0.94	9/24/2014	0.72	11/24/2014	1.68
2/18/2014	1.59	9/5/2013	0.47	11/6/2013	0.53	12/5/2013	1.87
3/19/2013	1.58	3/15/2012	0.69	10/3/2012	0.52	11/19/2012	1.59
2/7/2012	1.48	4/19/2011	0.62	11/7/2011	0.63	11/21/2011	1.70
2/8/2011	1.55	6/10/2010	0.78	10/5/2010	0.54	11/22/2010	1.56
2/9/2010	1.59	9/14/2009	0.53	10/1/2009	0.53	12/15/2009	1.86
2/10/2009	1.32	6/10/2008	0.86	9/11/2008	0.58	12/17/2008	1.99
3/11/2008	1.52	12/18/2007	0.80	11/5/2007	0.48	11/26/2007	1.77
2/13/2007	1.63	12/28/2006	0.82	11/28/2006	0.62	8/23/2006	1.71
8/8/2006	1.54	10/17/2005	0.44	11/16/2005	0.43	7/27/2005	1.82
2/9/2005	1.52	12/28/2004	0.71	12/28/2004	0.44	1/9/2004	2.06
1/13/2004	2.15	11/20/2003	0.83	8/4/2003	0.47	2/4/2003	2.04
1/13/2004	1.54	11/6/2002	0.97	7/18/2002	0.53	1/15/2002	2.32
2/25/2003	1.52	12/20/2001	0.95	12/28/2000	0.29	12/6/2001	2.35
5/21/2002	1.55	11/1/2000	0.75	8/17/1999	0.42	11/30/2000	2.75
11/14/2001	1.52	12/20/1999	0.90				
12/6/2000	2.80						
12/15/1999	1.48						
6/9/1998	1.32						

Table D4—Continued.

PWSID: MT0004145
GWIC_ID: Unknown
Report_ID: Hamiltion First Baptist Church
Name_ID: Well 1 At Treatment Plant
Latitude: 46.22552
Longitude: -114.151054

Sample Date	Nitrate (mg/L)
1/17/2017	N/A
2/1/2016	0.99
1/19/2015	0.02
1/27/2014	0.55
3/12/2013	0.02
2/13/2012	0.10
2/7/2011	0.54
2/16/2010	0.04
2/17/2009	0.96
2/12/2008	0.65
2/12/2007	0.74
3/28/2006	0.79
7/18/2005	0.86
4/19/2004	0.82
6/17/2003	1.15
1/8/2002	0.53

PWSID: MT0004184
GWIC_ID: 185861
Report_ID: Pharaohplex
Name_ID: Well 1
Latitude: 46.28495
Longitude: -114.14259

Sample Date	Nitrate (mg/L)
5/30/2017	0.32
6/16/2016	0.46
7/21/2015	0.48
5/22/2014	0.45
5/22/2013	0.41
5/16/2012	0.32
4/19/2011	0.36
5/25/2010	0.36
8/26/2009	0.40
4/15/2008	0.34
4/25/2007	0.38
8/8/2006	0.50
8/29/2005	0.47
5/4/2004	0.27
4/15/2003	0.39
7/15/2002	0.56
3/28/2001	0.30

PWSID: MT0004325
GWIC_ID: 221886
Report_ID: Skalkaho Steakhouse
Name_ID: Well 1
Latitude: 46.17338024
Longitude: -114.0429015

Sample Date	Nitrate (mg/L)
11/29/2016	0.09
3/3/2015	0.62
12/10/2014	1.45
9/25/2013	0.02
9/25/2012	
9/27/2011	0.09
12/15/2010	0.09
11/24/2009	0.20
8/28/2008	
12/17/2007	
12/26/2006	
11/30/2005	
5/25/2004	

PWSID: MT0004344
GWIC_ID: 239537
Report_ID: Canyon View Church
Name_ID: Treatment Plant
Latitude: 46.2023149
Longitude: -114.155771

Sample Date	Nitrate (mg/L)
11/14/2016	0.88
11/2/2015	0.92
11/26/2014	0.79
12/10/2013	0.79
12/13/2012	0.78
12/19/2011	0.78
12/14/2010	0.80
5/5/2009	0.71

Table D4—Continued.

PWSID:	MT0004369	PWSID:	MT0004381	PWSID:	MT0004412	PWSID:	MT0004425
GWIC_ID:	163430	GWIC_ID:	54272	GWIC_ID:	219224	GWIC_ID:	214124
Report_ID:	Corvallis Subway	Report_ID:	Hangar Cafe	Report_ID:	La Mas Fina Restaurant	Report_ID:	Canyons Athletic Club The
Name_ID:	Well 1	Name_ID:	Well 1	Name_ID:	Well 1	Name_ID:	Well 1
Latitude:	46.31277	Latitude:	46.25255	Latitude:	46.3151	Latitude:	46.248517
Longitude:	-114.11425	Longitude:	-114.1267364	Longitude:	-114.1551	Longitude:	-114.133429
Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)	Sample Date	Nitrate (mg/L)
3/7/2017	0.91	12/5/2016	1.18	11/28/2016	0.17	12/12/2016	1.04
6/3/2016	1.85	11/2/2015	2.18	10/26/2015	0.43	11/9/2015	2.22
5/12/2015	2.13	10/14/2014	1.92	11/17/2014	0.07	11/24/2014	1.86
5/20/2014	1.81	9/16/2013	2.16	10/29/2013	0.07	11/25/2013	1.95
4/22/2013	1.74	11/1/2012	1.91	10/9/2012	0.55	6/11/2012	1.94
1/19/2012	1.62	4/20/2011	0.39	7/11/2011	0.18	6/27/2011	1.88
2/10/2011	1.59	11/22/2010	1.90	4/27/2010	0.19	7/27/2010	2.28
1/20/2010	1.52	12/2/2009	1.89	4/28/2009	0.17	6/25/2009	2.48
3/10/2009	1.53	1/18/2008	3.00	10/6/2008	0.26	9/29/2008	2.33
5/2/2008	1.48	2/2/2006	2.28	3/13/2007	0.27	5/7/2007	2.33
4/3/2007	1.45	11/29/2004	2.30	2/2/2006	0.22	9/20/2006	1.15
7/5/2006	1.54					10/4/2005	2.44
7/5/2005	1.44						
3/1/2004	1.33						
12/2/2003	1.08						

Table D4—Continued.

PWSID: MT0004447
GWIC_ID: Unknown
Report_ID: Centennial Subdivision
Name_ID: Well 1 & 11
Latitude: 46.3156
Longitude: -114.10402

Sample Date	Nitrate (mg/L)
11/8/2016	1.61
4/22/2015	1.71
8/4/2014	1.63
10/14/2013	1.66
4/13/2012	1.69
5/31/2011	1.6
6/14/2010	1.74
9/14/2009	1.71
4/14/2008	1.96
10/12/2007	1.69

PWSID: MT0004499
GWIC_ID: Unknown
Report_ID: Corvallis Community Ch.
Name_ID: Well 1
Latitude: 46.31458
Longitude: -114.11279

Sample Date	Nitrate (mg/L)
11/14/2016	1.92
9/22/2015	1.90
6/4/2014	0.80
3/18/2013	0.65
3/7/2012	1.77
2/8/2011	1.72
3/16/2010	1.69
2/11/2009	1.39
2/13/2008	1.50
3/14/2007	1.46
8/24/2006	1.46

PWSID: MT0004533
GWIC_ID: 203550; 203536
Report_ID: The Wildflower
Name_ID: Common Header 1 & 2
Latitude: 46.216818
Longitude: -114.14738

Sample Date	Nitrate (mg/L)
12/19/2016	0.64
8/11/2015	0.40
2/25/2014	0.80
8/7/2013	0.45
8/22/2012	0.11
9/21/2011	0.46
10/20/2010	0.51
9/23/2009	0.48
9/9/2008	0.51

PWSID: MT0004647
GWIC_ID: 209956
Report_ID: Corvallis United Methodist Ch.
Name_ID: Treatment Plant
Latitude: 46.299044
Longitude: -114.112766

Sample Date	Nitrate (mg/L)
10/3/2016	2.34
11/2/2015	2.51
4/23/2014	1.64
11/5/2013	2.45
12/10/2012	1.97
12/7/2011	2.05
2/24/2010	1.53
2/24/2009	1.65

Table D4—Continued.

PWSID: MT0004650
GWIC_ID: 258017
Report_ID: 7th Day Adventist
Name_ID: 2010 Well #2
Latitude: 46.2461
Longitude: -114.1834

Sample Date	Nitrate (mg/L)
2/24/2017	5.34
2/18/2016	5.40
10/30/2015	6.06
2/26/2014	4.18
7/26/2013	4.46
12/12/2012	4.01
12/27/2011	3.12
12/23/2010	2.40
5/22/2009	1.96

PWSID: MT0004651
GWIC_ID: 262111
Report_ID: Sfe
Name_ID: Treatment Plant
Latitude: 46.29870436
Longitude: -114.1584527

Sample Date	Nitrate (mg/L)
3/9/2017	0.57
2/10/2016	0.51
4/20/2015	0.43
4/21/2014	0.38
11/1/2013	0.39
3/15/2012	0.39
10/11/2011	0.43
3/23/2010	0.37
12/15/2009	0.61

PWSID: MT0004710
GWIC_ID: 131161
Report_ID: Artistic Impressions
Name_ID: Well 1
Latitude: 46.23309937
Longitude: -114.1449845

Sample Date	Nitrate (mg/L)
6/13/2016	0.78
4/22/2015	2.11
8/19/2014	0.64
8/14/2013	0.60
6/1/2011	1.24
7/26/2010	0.76

PWSID: MT0004725
GWIC_ID: Unknown
Report_ID: Town Pump
Name_ID: Treatment Plant
Latitude: 46.30965
Longitude: -114.158

Sample Date	Nitrate (mg/L)
7/13/2016	0.09
11/11/2015	0.08
12/10/2014	0.09
11/24/2014	0.09
11/18/2013	0.08
10/17/2012	0.07
12/21/2011	0.06
10/13/2010	0.06

PWSID: MT0004751
GWIC_ID: 265595
Report_ID: Nelson
Name_ID: 2011 Well
Latitude: 46.27836316
Longitude: -114.1627065

Sample Date	Nitrate (mg/L)
6/5/2017	0.23
5/17/2016	0.24
4/8/2015	0.26
4/28/2014	0.22
4/22/2013	0.26
4/18/2012	0.28

Table D5. Complete results of the Mann–Kendall trend test on PWS nitrates for the POR and for a 10-year period from 2007 to 2016, including wells that showed statistically insignificant trends that were excluded from table 7.

			Period of Record (POR)		2007–2016	
PWS ID	GWIC ID	POR	*p*-value	Sen Slope (mg/L)/yr	*p*-value	Sen Slope (mg/L)/yr
MT0000234	136335	1993–2016	0.215	NA	0.928	NA
MT0000234	54276	1996–2016	0.607	NA	0.653	NA
MT0000234	55295	1993–2004	0.858	NA	insufficient data	
MT0000234	54443	1993–2016	0.298	NA	0.093	NA
MT0000234	55251	1993–2016	0.928	NA	0.592	NA
MT0000234	173150	2005–2016	0.304	NA	0.283	NA
MT0000504	52638	1982–2017	0.580	NA	0.788	NA
MT0000506	NR	1994–2017	0.357	NA	0.788	NA
MT0000634	52557, 52555	1995–2017	0.105	NA	0.410	NA
MT0001046	NR	1995–2016	0.409	NA	0.046	0.03
MT0001059	52679	1994–2016	0.034	-0.01	1.000	NA
MT0001067	NR	1995–2016	0.337	NA	0.005	-0.05
MT0001071	55686	1994–2017	0.004	0.02	0.419	NA
MT0001074	276838	1993–2016	0.001	-0.02	0.035	-0.04
MT0001079	127283	1993–2017	0.751	NA	1.000	NA
MT0001080	NR	1993–2017	0.901	NA	0.675	NA
MT0001083	54495	1993–2016	0.799	NA	0.748	NA
MT0002131	53705, 228768	1993–2017	0.070	NA	0.592	NA
MT0002799	56636, 56575	1993–2016	0.014	-0.02	0.371	NA
MT0002926	56980	1995–2015	0.245	NA	0.759	NA
MT0003003	54701	1994–2016	<0.001	0.01	0.032	0.01
MT0003003	54709	1994–2016	0.294	NA	0.454	NA
MT0003003	54726	1994–2016	0.002	0.01	0.279	NA
MT0003186	54927	2003–2009	0.452	NA	insufficient data	
MT0003257	56586	1993–2017	0.013	-0.03	0.592	NA
MT0003277	53283	1994–2017	0.309	NA	0.178	NA
MT0003284	52662	1994–2017	0.309	NA	0.788	NA
MT0003284	52663	1994–2017	0.124	NA	0.653	NA
MT0003333	NR	1994–2017	0.034	-0.02	0.059	NA
MT0003422	55258	1994–2017	0.398	NA	0.592	NA
MT0003460	51448	1993–2016	0.017	-0.03	1.000	NA
MT0003610	53891	1994–2017	<0.001	-0.02	0.009	-0.02
MT0003646	NR	1994–2017	<0.001	0.05	0.174	NA

Table D5—*Continued*.

PWS ID	GWIC ID	POR	Period of Record (POR)		2007–2016	
			p-value	Sen Slope (mg/L)/yr	*p*-value	Sen Slope (mg/L)/yr
MT0003773	51575, 51576	2003–2013	0.517	NA	0.751	NA
MT0003861	151177	1996–2016	0.001	-0.01	0.035	-0.02
MT0003898	156242	1996–2016	0.070	NA	0.032	-0.04
MT0003982	NR	1999–2016	0.008	-0.03	0.003	-0.06
MT0004041	179092	1998–2017	0.036	0.01	0.127	NA
MT0004043	53123	1999–2016	0.161	NA	0.788	NA
MT0004044	167441	1999–2016	0.069	NA	0.928	NA
MT0004091	NR	2000–2016	0.001	-0.05	0.283	NA
MT0004145	NR	2002–2018	0.030	-0.05	0.419	NA
MT0004184	185861	2001–2017	0.837	NA	0.059	NA
MT0004325	221886	2004–2016	1.000	NA	1.000	NA
MT0004344	239537	2009–2016	0.059	NA	0.059	NA
MT0004369	163430	2003–2017	0.002	0.04	<0.001	0.05
MT0004381	54272	2004–2017	0.451	NA	0.917	NA
MT0004412	219224	2006–2016	0.347	NA	0.367	NA
MT0004425	214124	2005–2017	0.392	NA	0.025	-0.08
MT0004447	NR	2007–2016	0.149	NA	0.149	NA
MT0004499	NR	2006–2016	0.138	NA	0.152	NA
MT0004533	203550, 203536	2008–2016	0.834	NA	0.834	NA
MT0004647	209956	2009–2016	0.174	NA	0.174	NA
MT0004650	258017	2009–2017	0.005	0.53	0.004	0.59
MT0004651	262111	2009–2017	0.461	NA	0.900	NA
MT0004710	131161	2010–2016	0.707	NA	0.707	NA
MT0004725	NR	2010–2016	0.020	0.01	0.020	0.01
MT0004751	265595	2012–2017	0.181	NA	insufficient data	