2013 Montana Bureau of Mines and Geology Open-File Report 636

HYDROGEOLOGIC INVESTIGATION OF THE SCRATCHGRAVEL HILLS STUDY AREA LEWIS AND CLARK COUNTY, MONTANA INTERPRETIVE REPORT

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Montana Bureau of Mines and Geology
Ground Water Investigations Program

[1]Lewis and Clark County Water Quality Protection District, Helena, Montana

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PREFACE

This report has been prepared by the Montana Bureau of Mines and Geology (MBMG) Ground Water Investigations Program (GWIP). The purpose of GWIP is to investigate specific areas, as prioritized by the Ground Water Assessment Steering Committee (2-15-1523 MCA), where factors such as current and anticipated growth of industry, housing, and commercial activity or changing irrigation practices have created elevated concern about groundwater issues. Additional program information and project ranking detail can be accessed at http://www.mbmg.mtech.edu/gwip/gwip.asp. GWIP collects and compiles groundwater and surface-water data for each study area and uses various tools to interpret how the groundwater resource has responded to past stresses and to project future responses.

The final products of the Scratchgravel Hills study include:

- An Interpretive Report that presents interpretations of the data and summarizes the project results within the context of the study area and the issues to be addressed. The Interpretive Report includes all results and is intended for use by the general public, special interest groups, decision-makers, and hydrogeologists.

- A Groundwater Modeling Report that documents in detail the procedures, assumptions, and results for the numeric groundwater flow models. This report is designed so that qualified individuals can evaluate and use the groundwater flow models to test specific scenarios of interest, or to provide a starting point for a site-specific analysis. The files needed to run the models are posted to the GWIP website (http://www.mbmg.mtech.edu/gwip/gwip.asp).

- A collection of stand-alone chapters are presented as a Technical Data Report that provides detailed data and information about study components, such as aquifer tests and analyses. This report provides the technical foundation for the Interpretive and Modeling reports.

- A comprehensive data set is permanently stored on MBMG's Groundwater Information Center (GWIC) online database (http://mbmggwic.mtech.edu/).

ABSTRACT

The purpose of the Scratchgravel Hills Groundwater Investigation was to assess the sustainability of current and potentially increased groundwater withdrawals, and potential impacts from septic effluent to groundwater quality.

The Scratchgravel Hills study area is located approximately 3 miles northwest of Helena, Montana, on the western edge of the Helena Valley. Most of the study area is hilly upland underlain by fractured bedrock, but where the study area extends eastward into the relatively flat Helena Valley, it is underlain by alluvial deposits. Ephemeral streams within the Scratchgravel Hills are tributaries of Silver, Sevenmile, and Tenmile Creeks, which themselves are tributaries to the Missouri River via Lake Helena. Annual precipitation is less than 10 in at lower elevations along the study area's eastern edge, but more than 16 in at the highest elevations.

Development in the Scratchgravel Hills has been controversial since the subdivision of the Green Meadow Ranch in August, 1972. In 1977 a minimum lot size of 2 acres was recommended for this area, partly due to concerns over water availability and septic system density. In 2005 the Cornerstone Estates subdivision was proposed (0.4 acres per dwelling) for an area southeast of the junction of Head Lane and Franklin Mine Road. Because of ongoing development and in particular the proposal for the Cornerstone Estates subdivision, people living near and within the Scratchgravel Hills became concerned about the long-term capacity of area aquifers to supply water and the potential for septic effluent to contaminate these aquifers. The Montana Department of Natural Resources Conservation responded to citizen concerns by establishing the Green Meadow Temporary Controlled Groundwater Area in April 2008. Recent zoning decisions in the Green Meadow area now require a 10-acre minimum lot size.

Groundwater availability varies within the Scratchgravel Hills. Unconsolidated materials can produce significant volumes of water, but fractured bedrock units do not always have the ability to supply sufficient water. Monitoring does not indicate that there is area-wide groundwater depletion. Particular wells are being used at rates that exceed the aquifer's capacity, which is causing water levels to decline in those wells over time. Groundwater modeling indicates that if bedrock aquifers were used to supply water to high density subdivisions, noticeable groundwater-level declines would likely occur.

For this study groundwater samples were collected from 25 wells. Drinking water standards were exceeded for nitrate (3 sites), arsenic (1 site), and uranium (1 site). Septic effluent appears to be the cause of increased nitrate concentrations. Elevated arsenic and uranium concentrations are associated with alteration zones near the Bald Butte Fault and adjacent to igneous intrusions.

Results of this study suggest that if development at a density greater than one home per 10 acres is proposed, adaptive management should be used to ensure that excessive groundwater level declines do not occur. Also, due to the limited ability for nitrate to be broken down where there are thin soils and granitic bedrock, modifications to septic system requirements should be considered.

INTRODUCTION

Background

The Scratchgravel Hills study area covers 20 mi^2, and is located approximately 3 miles northwest of Helena, Montana, on the west side of the Helena Valley. The study area boundaries follow Tenmile Creek, Sevenmile Creek, and Park Creek on the south; Silver Creek and Threemile Creek on the north; Birdseye Road on the West, and Montana Avenue on the east (fig. 1).

Based on data obtained from NRIS (2009), there were 1,910 lots within or partially within the Scratchgravel Hills study area; 79.3 percent are less than 10 acres (fig. 2), but because they are small, these lots cover only 17.7 percent of the total area. Counts of buildings observable on aerial photographs indicate that between 1995 and 2009, the number of dwellings increased from 1,285 to 1,608. Many of these homes use individual wells and septic systems.

Development in the Scratchgravel Hills area has been controversial since subdivision of the Green Meadow Ranch in August 1972 (2,900 acres into 10-acre tracts). This subdivision precipitated the "Green Meadow Study" (Lewis and Clark County, 1977), which recommended lot sizes of not less than 10 acres per dwelling unless specific criteria for septic systems, building sites, and water availability were met. The recommended minimum allowable lot size was 2 acres per dwelling. The study also recommended community sewage and water systems.

The Cornerstone Estates subdivision (up to 800 homes on 320 acres; 0.4 acres per dwelling) was proposed in 2005 for an area southeast of the intersection of Head Lane and Franklin Mine Road (the former Franklin Mine area). As proposed, Cornerstone was to have community water and sewage services; however, the original application has since been withdrawn and re-proposed to have 10-acre lots. This revision is in line with recent zoning changes that now require a 10-acre minimum lot size. As currently proposed, individual wells and septic systems would likely be used. There have also been discussions regarding re-opening the Franklin Mine, which historically produced gold and silver.

Because of ongoing development, and in particular the proposal for the Cornerstone Estates subdivision, people living in or near the study area became concerned about the long-term capability of aquifers to supply water, and the potential for aquifer contamination by septic effluent. The Montana Department of Natural Resources Conservation (DNRC) responded to citizen concerns by establishing the Green Meadow Temporary Controlled Groundwater Area (CGWA) in April 2008. The main focus of the CGWA is the Scratchgravel Hills Stock, a fractured granite that forms the core of the Scratchgravel Hills (figs. 1, 3).

Mining has occurred in the Scratchgravel Hills since 1864 (Pardee and Schrader, 1933). The Montana Bureau of Mines and Geology (MBMG) abandoned mine database [available from the Groundwater Information Center (GWIC) website, http://mbmggwic.mtech.edu/], shows that there are 45 abandoned mines within the study area (fig. 3). These mines are primarily located in or near the Scratchgravel Hills Stock, and the metagabbro sills. The mines extracted minerals from veins, contact-metamorphic rocks, and placers (McCleman, 1983). Of these mines, 2 were placer deposits and the rest were lode deposits. Gold, silver, copper, lead, arsenic, zinc, manganese, rare earth elements, iron, and silicon are reported to have been produced from these mines (Metesh and others, 1998). Gold was the most important economically (McCleman, 1983). Mine portals observed during this study were not discharging water, and the Montana Department of Environmental Quality database for hardrock mine water samples does not include any samples from this area (DEQ, 1997).

Purpose and Scope

The Scratchgravel Hills groundwater investigation addresses concerns about the sustainability of current and future groundwater supply and the potential for septic effluent to impact groundwater quality. The main focus of the study is the Green Meadow CGWA. The study results are intended to provide a basis for future groundwater management by focusing on the large-scale behavior of the hydrogeologic system and provide a hydrogeologic framework within which site-specific hydrogeologic issues can be considered.

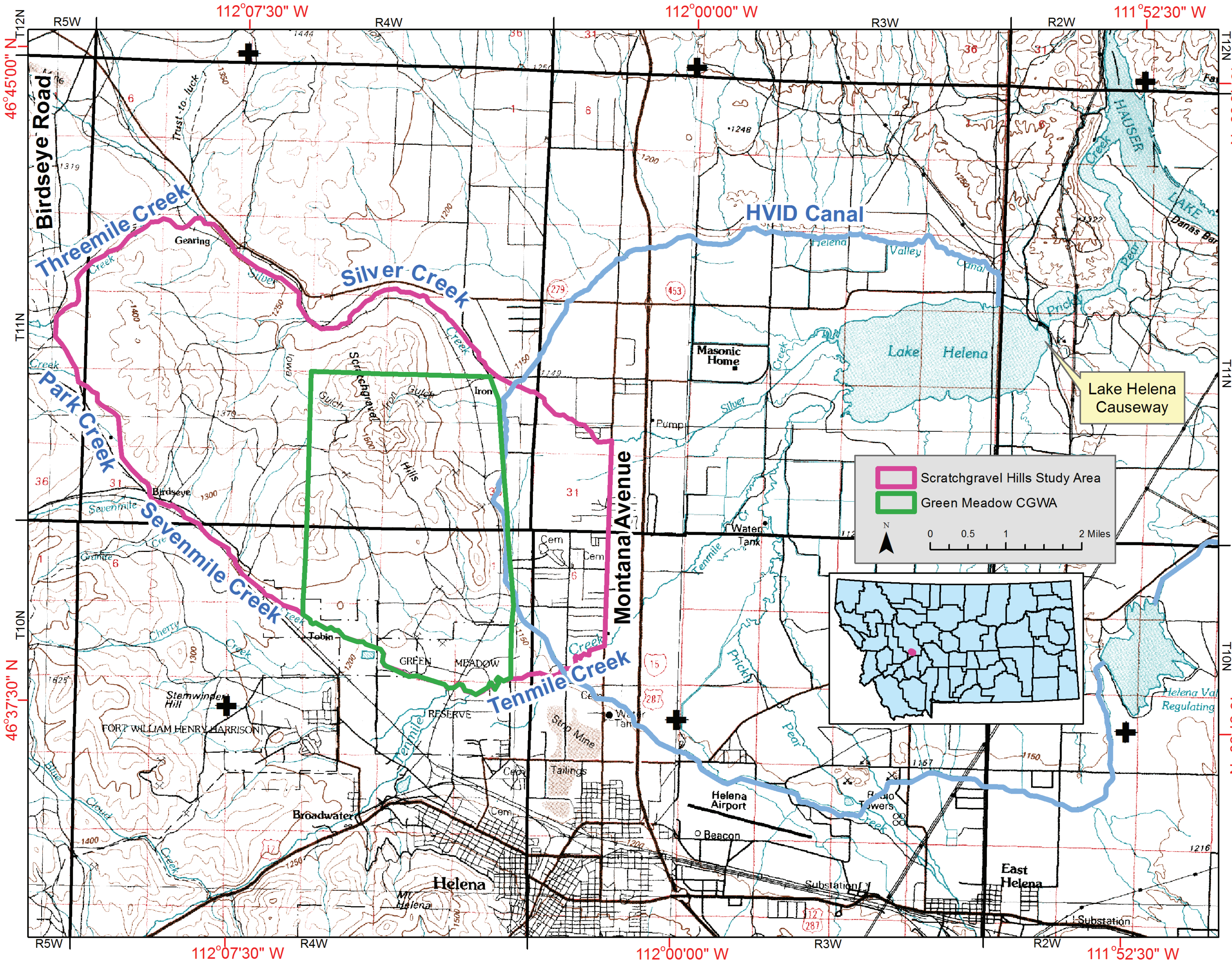


Figure 1. The Scratchgravel Hills study area is located north and west of Helena, Montana, on the western edge of the Helena Valley. The Green Meadow Controlled Groundwater Area is located in the central portion of the study area.

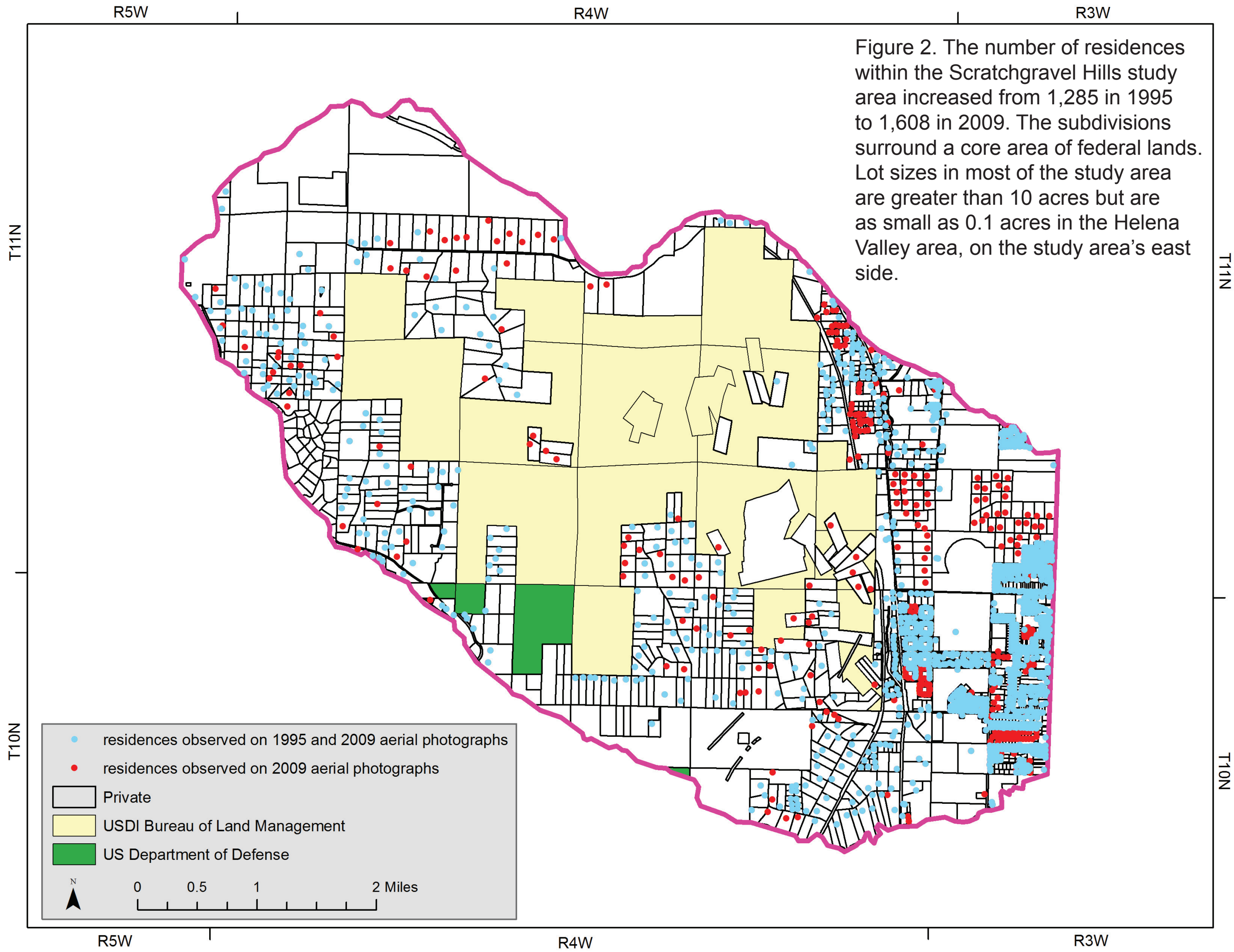


Figure 2. The number of residences within the Scratchgravel Hills study area increased from 1,285 in 1995 to 1,608 in 2009. The subdivisions surround a core area of federal lands. Lot sizes in most of the study area are greater than 10 acres but are as small as 0.1 acres in the Helena Valley area, on the study area's east side.

Previous Investigations

Reviews of previous work covering the Scratchgravel Hills have been provided by Noble and others (1982), Briar and Madison (1992), Kendy and Tresch (1996), and Thamke (2000). The following discussion focuses on studies most directly relevant to the current work, and the reader is referred to the publications listed above for additional background information.

Lorenz and Swenson (1951) described the geology and groundwater resources of the Helena Valley relative to existing and proposed irrigation. Their investigation provided information on the occurrence of productive aquifers, a potentiometric surface map depicting conditions in 1948, and an evaluation of groundwater quality.

Briar and Madison (1992) developed a groundwater budget and numerical groundwater model for unconsolidated alluvial materials within the Helena Valley (fig. 4). Their study showed that bedrock adjacent to the alluvial valley-fill contributes a significant volume of water to the flow system. They also determined that within about 4 miles of Lake Helena the vertical gradient is upward. This report also included a 1991 potentiometric surface map.

Thamke (2000) assessed the bedrock aquifer units surrounding the Helena Valley. This study provided baseline information on water levels and water chemistry, included a generalized geologic map (Reynolds, 2000), and provided groundwater-age estimates of between 10 and 38 years based on chlorofluorocarbons.

Madison (2006) evaluated the hydrogeology of the "North Hills" area, located adjacent to and northeast of the Scratchgravel Hills. The North Hills study provided general hydrogeologic information applicable to the Scratchgravel Hills.

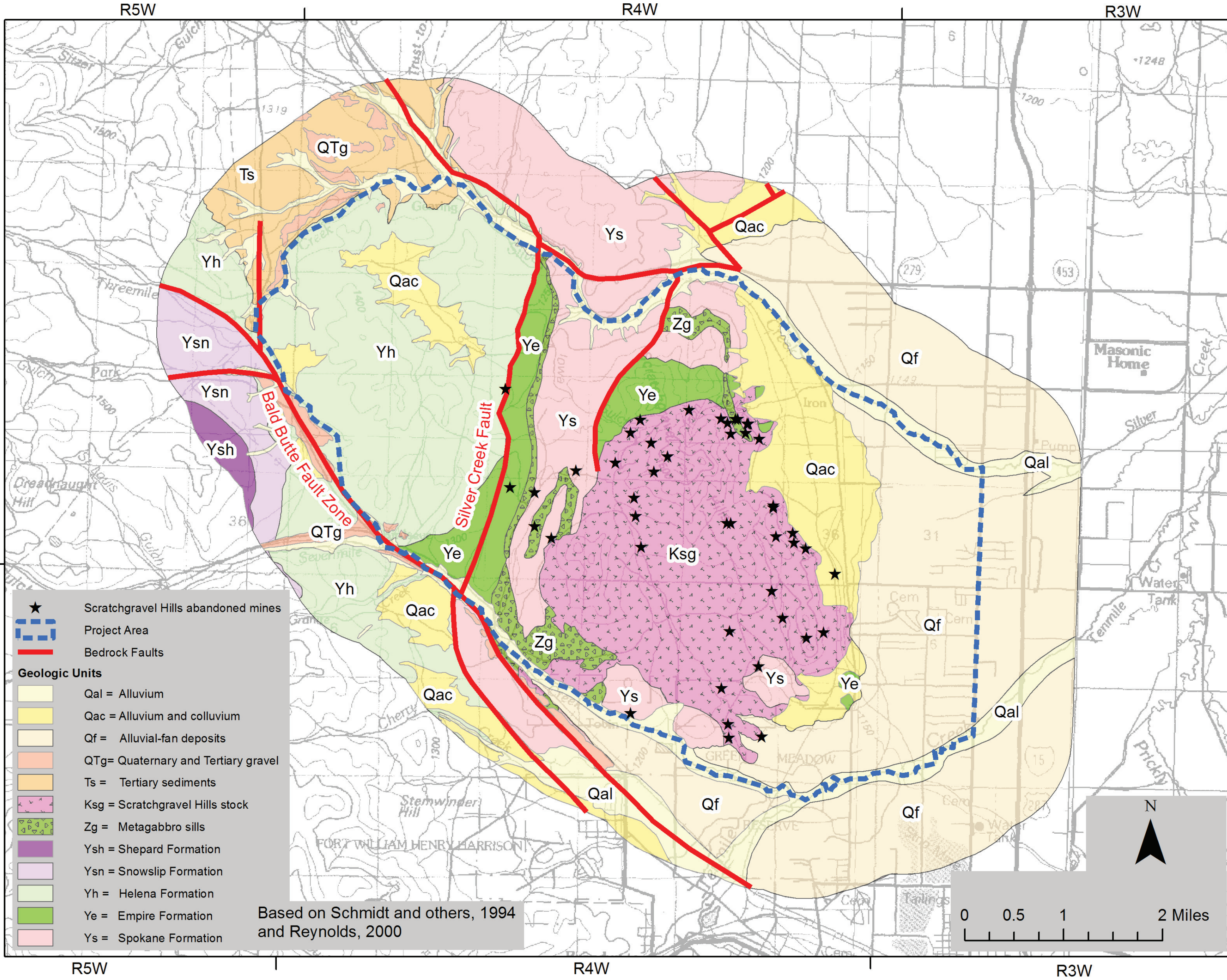


Figure 3. The core of the Scratchgravel Hills study area is an intrusive stock (Ksg) of mostly quartz monzonite and monzonite. Spokane and Empire Formation metamorphic argillite units (Ys and Ye) outcrop as north–northeast bands along the stock's west perimeter. The Helena Formation (Yh) carbonate units overlie the Spokane Formation to form the land surface in the study area's western third. Metagabbro sills, small bodies of granodiorite, and other intrusive rocks occur in bands and as small intrusive bodies within the Spokane, Empire, and Helena Formations. The west edge of the Helena Valley aquifer is east and south of the Scratchgravel stock. Alluvial sand and gravel deposits line modern stream channels and overlie bedrock. Several faults cut the bedrock units (geologic map based on Schmidt and others, 1994 and Reynolds, 2000). Historical mining occurred within and near the Scratchgravel Hills stock and the metagabbro sills.

Physiography

The Scratchgravel Hills study area is located on the west edge of an intermontane basin within the Northern Rocky Mountains physiographic province. Most of the study area is hilly upland underlain by fractured bedrock, but the study area extends eastward onto the relatively flat Helena Valley floor, where it is underlain by alluvial deposits (fig. 4). The highest altitude in the study area is the peak of the Scratchgravel Hills, at 5,252 ft above mean sea level (amsl). The lowest point is along Silver Creek at Montana Avenue, at 3,700 ft amsl. Surface water drains to the Missouri River via Silver Creek, Sevenmile Creek, and Tenmile Creek. The Missouri River (in the form of Hauser Lake) is located approximately 10 miles to the east.

Climate

The Scratchgravel Hills study area has a semiarid climate, typical for areas east of the Continental Divide in Montana, and is generally characterized by cold winters, mild summers, and low precipitation (Kendy and Tresch, 1996).

The National Oceanic and Atmospheric Ad-

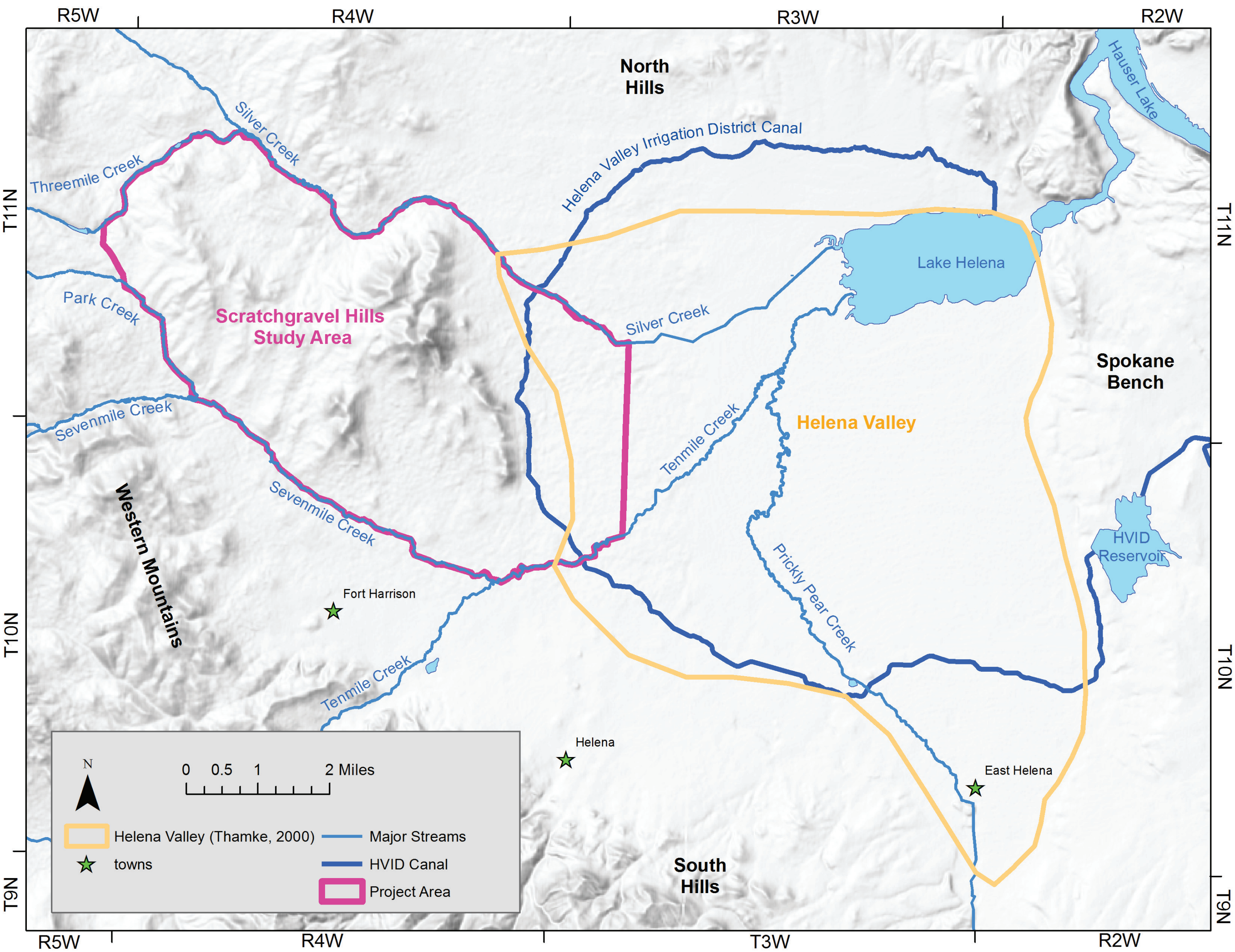


Figure 4. The Scratchgravel Hills study area is part of the Upper Missouri River drainage basin. Tenmile, Sevenmile, and Silver Creeks deliver surface water to the Missouri River via Lake Helena. The Scratchgravel Hills area has relatively high relief compared to the immediately adjacent Helena Valley to the east, which is a gently concave basin.

ministration (NOAA) has recorded climate data at the Helena airport (altitude 3,830 ft) since 1893 (NOAA, 2011). Between 1893 and 2010 the mean annual temperature was 43.9°F; the coldest temperature recorded was -42°F, and the warmest was 105°F. January is the coldest month, with an average temperature of 20.6°F; July is the warmest month, with an average temperature of 68.3°F. During the same period of record, average annual precipitation was 11.87 in. On average, the wettest month is June (2.12 in), and the driest is February (0.46 in). Between 1990 and 2010, precipitation was cumulatively 18.37 in. below average. Since 1990, the wettest year was 1993, when total precipitation was 6.94 in. above average. The driest year was 1994, when precipitation was 4.4 in. below average (fig. 5).

Generally precipitation increases with altitude (Thamke, 2000). This precipitation gradient also causes a change in vegetation. Non-irrigated lower areas, which receive less than about 12 in. of precipitation in an average year, are typically covered with grass and sage brush. At higher altitudes Ponderosa pine forests dominate.

Water-Development Infrastructure

Hydrogeologically significant water-development infrastructure within the Scratchgravel Hills study area and the Helena Valley includes irrigation canals and ditches, irrigated fields, agricultural drains, wells, and septic systems. The main source of irrigation water in the Helena Valley is the Missouri River by way of the Helena Valley Irrigation

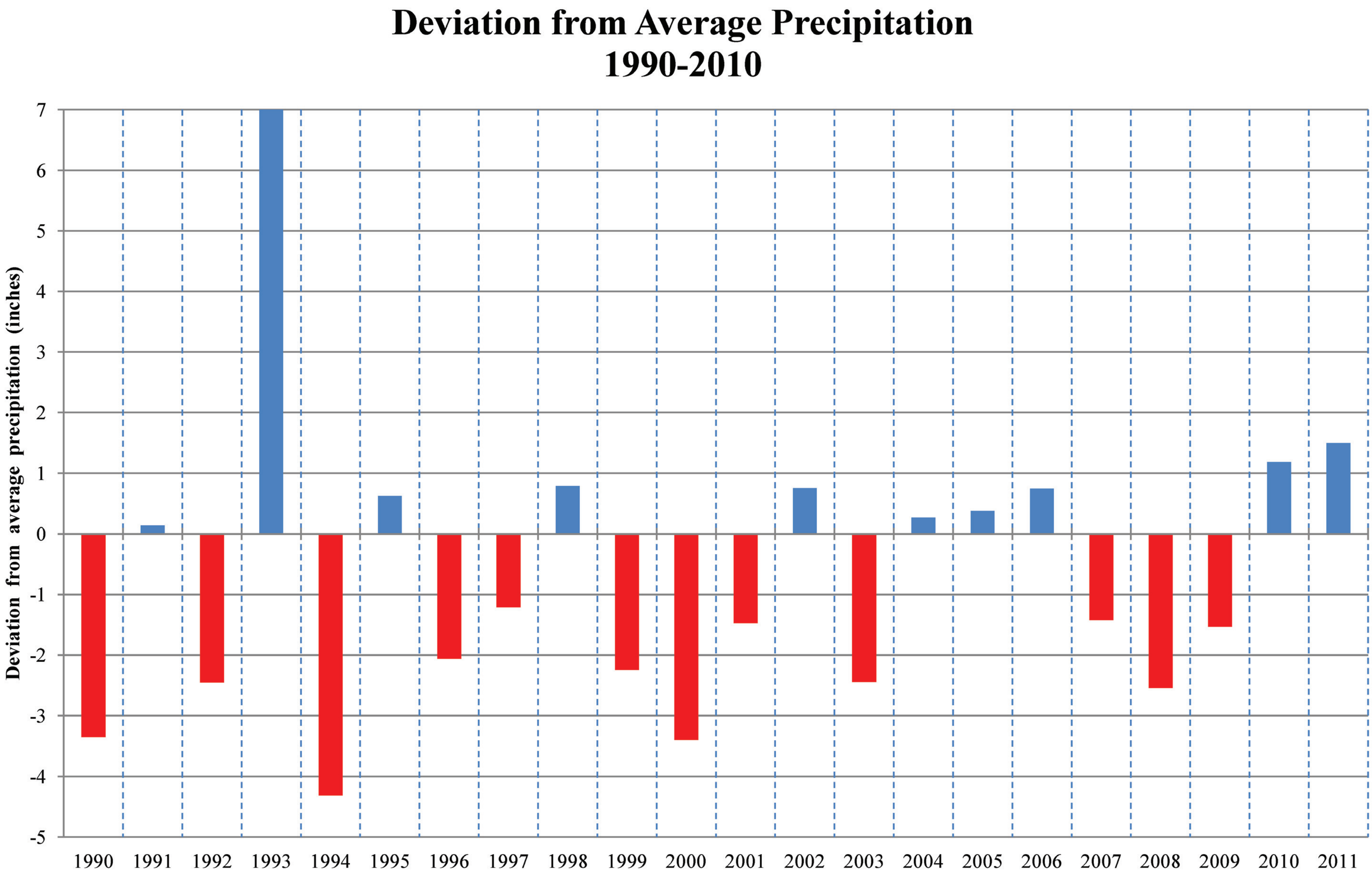


Figure 5. Annual records from the Helena Airport Weather Service Office (HLN – 244055; Helena WSO), gathered between 1990 and 2010, show that precipitation has been generally less than the period of record's 11.78-in average. 1993 stands out as an anomalously wet year (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt4055, accessed 6/27/2011).

District (HVID) infrastructure (fig. 6). Silver Creek, Sevenmile Creek, Tenmile Creek, and Threemile Creek provide minor amounts of irrigation water primarily to fields on the west side of the Helena Valley, or near the HVID canal (fig. 6). The primary irrigated crop is alfalfa (Briar and Madison, 1992; HVID, oral commun., 2012).

An effect of the canals and ditches is to recharge underlying aquifers through leakage; irrigated fields provide infiltration recharge when water is applied in excess of crop demand. Agricultural drains serve to limit the altitude to which Helena Valley groundwater levels may rise and prevent waterlogged land. Wells and septic systems are located adjacent to homes (fig. 2). Wells extract water and septic systems return a portion of that water to the groundwater system.

Geologic Setting

Schmidt and others (1994) provided detailed descriptions of the geology in the Scratchgravel Hills. Additional descriptions of the geologic units are provided by Reynolds (2000) and Reynolds and Brandt (2005).

Geologic Units

In the study area there are five significant bedrock units and unconsolidated deposits (fig. 3).

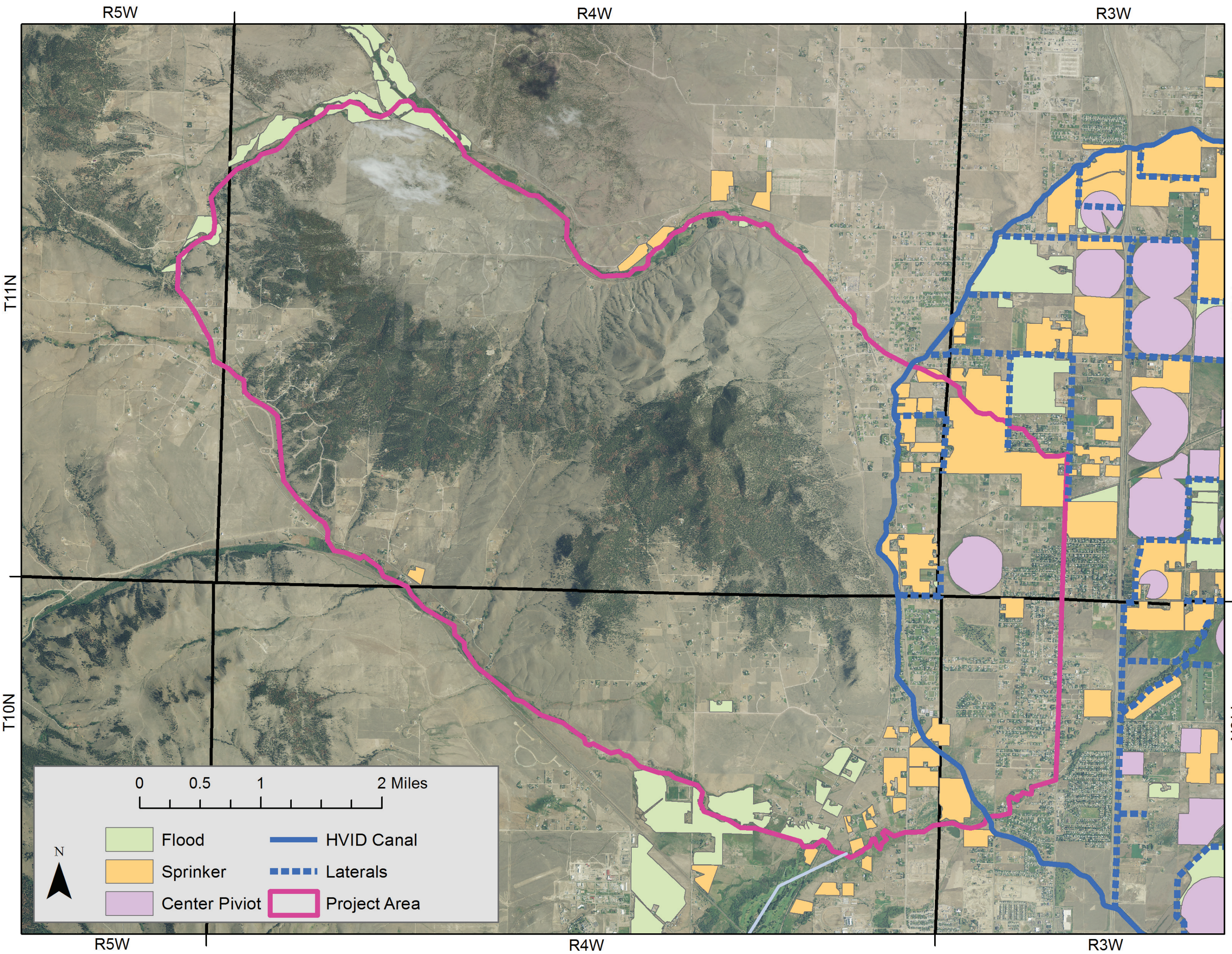


Figure 6. Leaky canals, laterals, and irrigated fields adjacent to the east side of the Scratchgravel Hills Study Area provide recharge to the Helena Valley Aquifer. The irrigation water is diverted from the Missouri River, Tenmile, Sevenmile, and Silver Creeks (irrigated fields from the Montana Department of Revenue, 2010; Canal and lateral traces from HVID, written commun., 2009).

Spokane Formation (Ys, fig. 3): The Middle Proterozoic Spokane Formation (~1,470 to 1,460 Ma; Evans and others, 2000), which is part of the Ravalli Group within the Belt Supergroup, is the study area's oldest unit. It is exposed at the surface immediately to the west of and has small exposures along the southern edge of the Scratchgravel Hills Stock. This bedrock unit essentially surrounds the Scratchgravel Hills Stock in the subsurface (i.e., beneath the unconsolidated deposits; Reynolds, 2000). This unit is primarily composed of argillite and siltite, and is often described as "shale" in driller's logs. It is typically grayish-red, dark-grayish-red, and purplish-red (Schmidt and others, 1994).

Empire Formation (Ye, fig. 3): The Middle Proterozoic Empire Formation (~1,460 to ~1,450 Ma; Evans and others, 2000), is also part of the Ravalli Group within the Belt Supergroup. This unit stratigraphically overlies the Spokane Formation. It occurs near the Silver Creek Fault, and to the northwest and southeast of the Scratchgravel Hills Stock (fig. 3). This unit is composed of argillite and siltite, and to a lesser extent limestone and quartzite. This unit is also commonly described as "shale" in driller's logs. It is typically calcareous and dolomitic, and is grayish-green, medium-green, and light-green (Schmidt and others, 1994).

Helena Formation (Yh, fig. 3): The Middle Proterozoic Helena Formation (~1,450 Ma; Evans and others, 2000) stratigraphically overlies the argillite bedrock units and is located in the western portion of the study area. The Helena Formation is also included in the Belt Supergroup and consists of cyclic beds of limestone, dolomite, quartzite, siltite and argillite (Schmidt and others, 1994).

Metagabbro (Zg, fig. 3): In the Late Proterozoic the Middle Proterozoic bedrock units were intruded by gabbro sills (~900 to ~570 Ma; Thamke, 2000). Metamorphism altered these sills to metagabbro. The metagabbro sills are discrete but infrequently occurring "layers" of crystalline rock within the Middle Proterozoic bedrock. This unit is also referred to as gabbro in some publications (e.g., Reynolds, 2000).

Scratchgravel Hills Stock (Ksg, fig. 3): In the Early Cretaceous (~97 Ma; Schmidt and others, 1994) the Scratchgravel Hills Stock intruded into the Proterozoic formations in the east-central part of the study area. The stock is primarily quartz monzonite, a rock with composition similar to granite but that contains less quartz. The monzonite is commonly described by drillers and others as "granite," and will be referred to as granite in this report. The Scratchgravel Hills Stock is somewhat older than many of the other plutonic rocks in the area, which are associated with the Boulder Batholith (80–72 Ma; Schmidt and others, 1994).

Unconsolidated Sediments (Qal, Qf, Qac, and QTg, fig. 3): Unconsolidated Quaternary (1.6 Ma to present) colluvium and alluvium cover the bedrock units within the Silver and Sevenmile Creek valleys and at some other upland locations. Unconsolidated near-surface Quaternary alluvial deposits, together with the underlying unconsolidated Tertiary (66 ma to 1.6 Ma) sediments, constitute the basin-fill deposits known as the Helena Valley aquifer. Briar and Madison (1992) report that the boundary between Quaternary and Tertiary sediments within the Helena Valley aquifer is generally indistinguishable on well logs. The unconsolidated materials in the Helena Valley are up to 6,000 ft thick (Noble and others, 1982). These unconsolidated sediments include sand, gravel, silt, and clay.

The Snowslip and Shepherd formations occur immediately southwest of the study area (fig. 3), but were not observed within the study area. Both formations are predominantly composed of quartzite, argillite and siltite. The Shepherd formation also contains some calcareous argillite and limestone.

Geologic Structure

Within the Scratchgravel Hills study area there are at least two major faults, and likely other lesser faults that have not been identified (Schmidt and others, 1994; Reynolds, 2000). The Silver Creek Fault runs roughly north–south and is located on the eastern edge of the Helena Formation outcrop (fig. 3). An unnamed fault runs east of and subparallel to the Silver Creek Fault, and is truncated where it has been cut by the Scratchgravel Hills Stock. The Bald Butte Fault Zone passes along the southwestern boundary of the study area, roughly parallel to Sevenmile and Park Creeks (fig. 3). Some geologic maps have shown the "Iron Gulch Fault" or

"Scratchgravel Hills Fault" (Stickney, 1987), along the eastern edge of the Scratchgravel Hills; however, more recent work (Stickney, 2007) shows that this scarp-like landform was formed by erosional rather than tectonic processes.

Hydrogeologic Setting

The six geologic units in the Scratchgravel Hills can be grouped as five hydrogeologic units: argillite bedrock (Spokane and Empire Formations), Helena Formation, metagabbro, Scratchgravel Hills Stock, and unconsolidated sediments. The bedrock units have little primary permeability and groundwater moves through and is extracted from the secondary permeability of fractures (Thamke, 2000).

The five hydrogeologic units within the study area each have different aquifer properties but readily exchange water with each other. For the purposes of the Scratchgravel Hills study, these are viewed as one aquifer system. Within the study area, fractures in the bedrock units are extensive enough so that when viewed at the study area scale these units can be treated as equivalent porous media. At local scales, the geometry of fractures may strongly affect groundwater flow and aquifer properties. The productivity of any individual well completed in bedrock is closely tied to the number of saturated fractures the borehole encountered, the aperture of those fractures, and how well those fractures are connected to the larger system. Unlike bedrock, the unconsolidated deposits have significant intergranular primary permeability, resulting in these units being typically more productive than the bedrock aquifers.

The Helena Formation differs somewhat from the rest of the bedrock in that it contains more carbonate rocks (Thamke, 2000). Carbonate rocks are susceptible to chemical weathering, which may increase or decrease the unit's secondary permeability due to local dissolution and/or re-precipitation of carbonate minerals (e.g., calcite). Where dissolution occurs fracture apertures widen, improving secondary permeability. Where re-precipitation occurs permeability is decreased.

The granite and metagabbro were intruded into the surrounding rocks. The intrusion of these rocks likely altered the surrounding country rock and the intrusions themselves are typically more finely crystalline near their edges. These factors may cause low permeability zones near the contacts (Thamke, 2000).

Near faults, highly fractured rocks can produce zones of high secondary permeability due to the shear produced by fault movement; however, at the fault plane where the formations actually slip past each other, fault gouge can act as a groundwater-flow barrier. Freeze and Cherry (1979) note that "faults that have developed thick zones of sheared and broken rock with little fault gouge may be highly permeable, while those that possess a thin (but continuous) layer of gouge may form almost impermeable barriers."

The shape of the potentiomentric surface is generally a subdued reflection of the land surface (Heath, 1983). As such, groundwater enters the study area from the mountains to the west. Local recharge also contributes water, particularly in the higher altitude areas which receive more precipitation. Groundwater flow is towards the Helena Valley aquifer and to the alluvium adjacent to streams.

METHODS

The hydrogeologic setting discussed above provided a framework for field activities and modeling efforts. Sixteen monitoring wells and 18 stream gages were installed (figs. 7, 8). Six aquifer tests were conducted (fig. 7).

Monitoring & Sampling

Groundwater

A monitoring well network of 67 wells was established to obtain water-level and water-quality information (fig. 8). These sites are listed in the Scratchgravel Hills Technical Report (Bobst and others, in preparation a), and full descriptions are available from GWIC. Monitoring sites were selected based on hydrogeologic setting, geographic location, historical record, and well owner permission. Surveyed elevations were obtained for measuring points at each site. These wells were monitored monthly, generally from February 2010 to June 2011. Twenty-seven wells were also equipped with pressure transducers that recorded water levels hourly. The monitoring wells were used to determine groundwater elevations throughout the study area and water-level change over time.

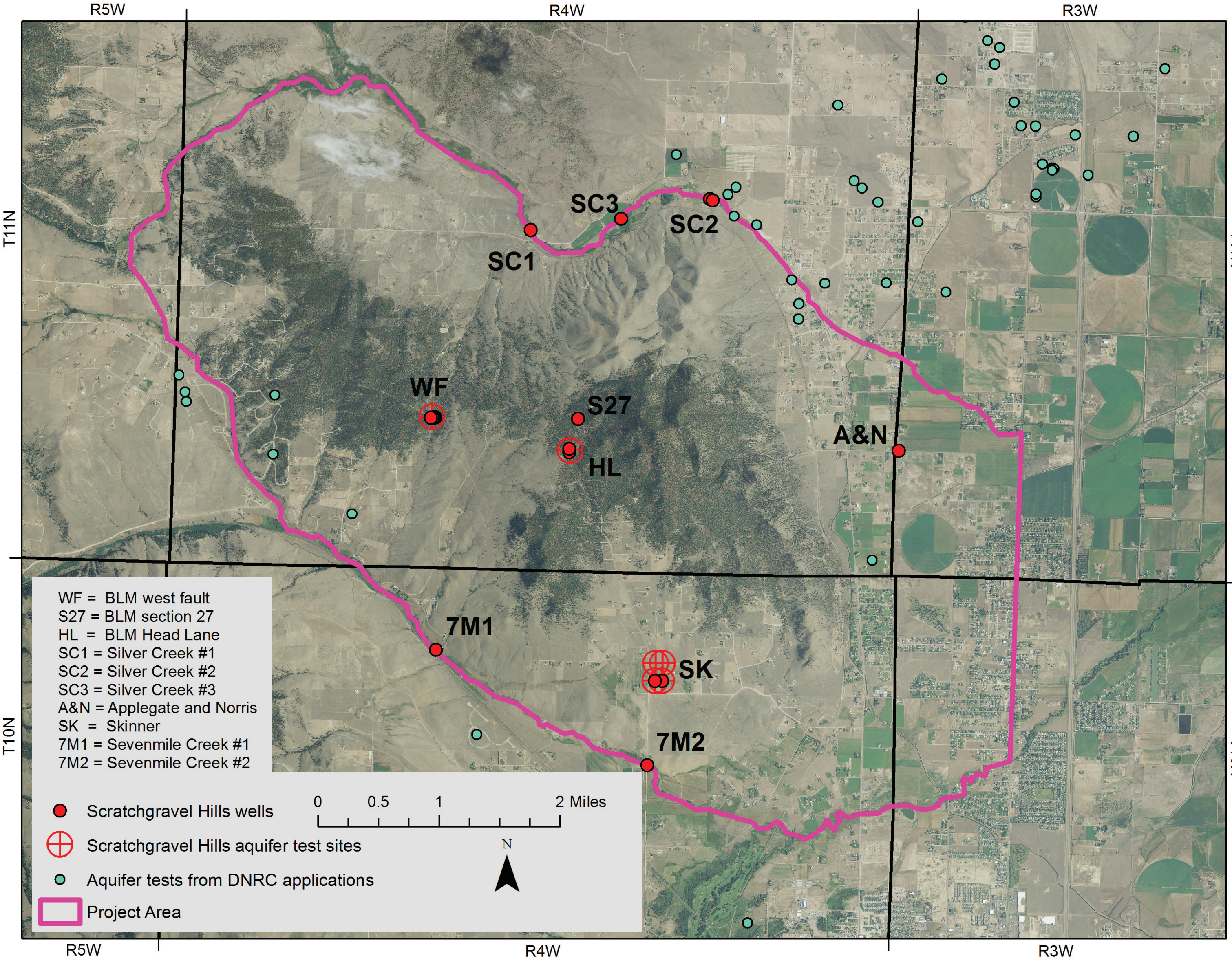


Figure 7. Wells were installed at 10 locations within the Scratchgravel Hills study area to acquire water-level information and to evaluate aquifer properties. Six aquifer tests were conducted. Aquifer test data from numerous DNRC water-rights applications also provided information on aquifer properties.

Water samples were collected from 25 of the wells (fig. 9) and analyzed for the parameters listed in table 1. Most sites were sampled for three synoptic events (April, August, and October 2010). Selected samples were also analyzed for hydrogen and oxygen isotopes of water ($\delta D\ H_2O$ and $\delta^{18}O\ H_2O$), sulfate isotopes ($\delta^{34}S\ SO_4$), nitrogen and oxygen isotopes of nitrate ($\delta^{15}NNO_3$ and $\delta^{18}O\ NO_3$), radon (^{222}Rn), and organic waste-water chemicals (OWCs). The sites, their uses, and the parameters analyzed at each are listed in the Scratchgravel Hills Technical Report (Bobst and others, in preparation a).

Surface Water

Surface-water discharge and stage were measured at 18 locations (fig. 8). Twelve of these sites (fig. 10) were also sampled for the analytes in table 1, $\delta D\ H_2O$, $\delta^{18}O\ H_2O$, and $\delta^{34}S\ SO_4$.

Springs

Discharge, specific conductance (SC), pH, and temperature were measured monthly at seven springs when they were accessible and flowing (fig. 8).

Data Management

Most data collected during the Scratchgravel Hills study are stored in the MBMG's GWIC database. This database stores statewide data for more than 220,000 water wells and makes those data publicly accessible. GWIC is accessible via the internet at http://mbmggwic.mtech.edu/. In addition to

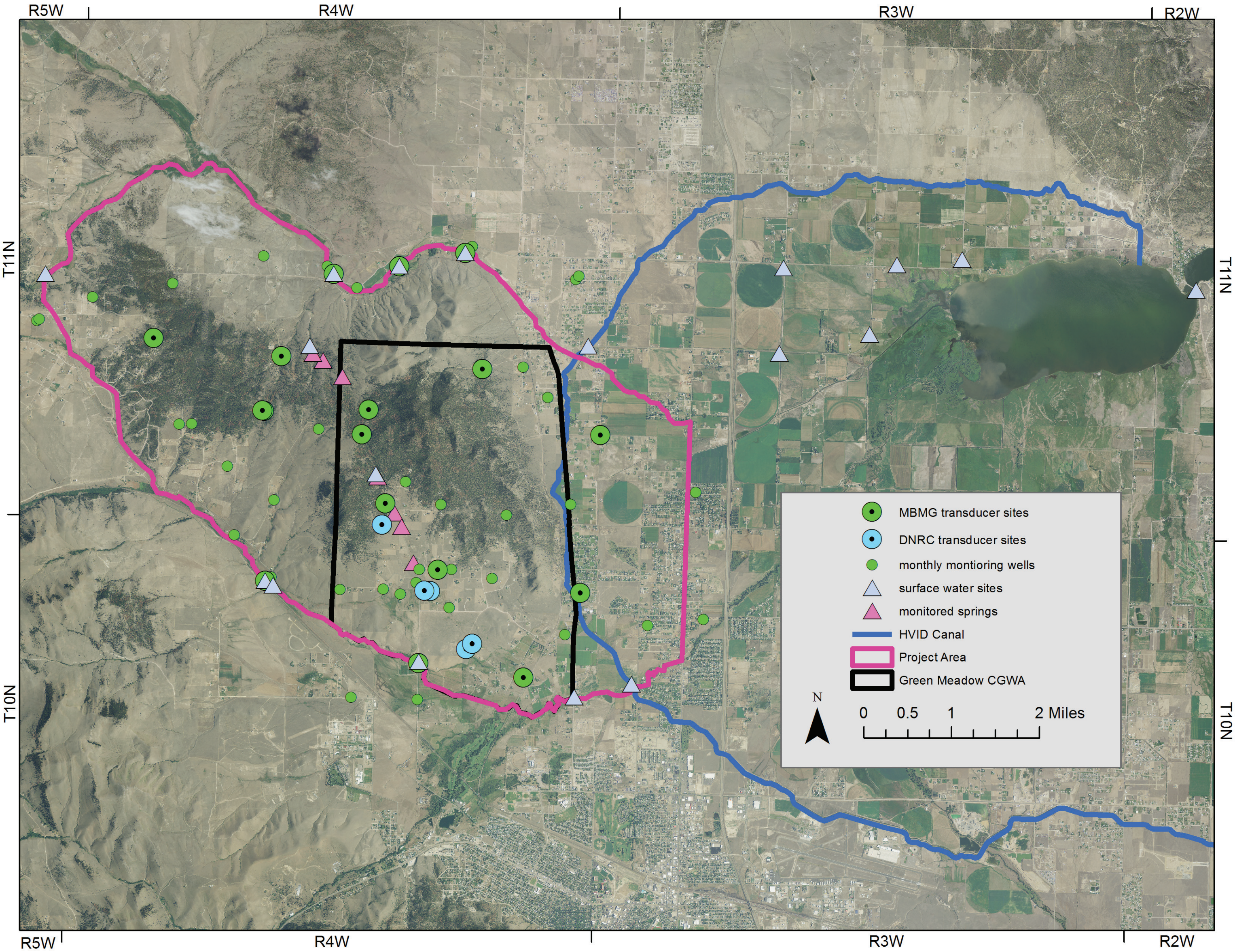


Figure 8. A monitoring network of 67 wells, 7 springs, and 18 surface-water sites provided the Scratchgravel Hills Groundwater Investigation's observational basis. Note that the symbols for some sites are stacked.

well-log data, GWIC contains information on water levels, water chemistry, and aquifer tests.

Numerical Modeling

Based on available hydrogeologic data, observed groundwater elevations, and the calculated groundwater budget, the MBMG developed and calibrated a numerical groundwater model for the Scratchgravel Hills flow system (Butler and others, in preparation). Groundwater Modeling Systems (GMS; Aquaveo, Provo, UT) software was used to develop a MODFLOW 2000 groundwater flow model (Harbaugh and others, 2000). The active model grid covered an area of approximately 20 square miles (fig. 11). Grid cells measured 200 ft by 200 ft horizontally. The model contained two layers; top layer cells were between 200 and 1,260 ft thick (100 to 600 ft of saturated thickness), and bottom layer cells were uniformly 200 ft thick.

Initially, a steady-state assumption was made for the Scratchgravel Hills numeric model to simulate average-annual conditions for all elements of recharge and discharge, and represent the system in equilibrium under a specified set of stresses. This steady-state model was calibrated to observed water levels in 53 wells and the results provided a basis from which to assess the ultimate impact of a new stress, such as a pumping well, and for evaluating the overall groundwater budget.

The transient Scratchgravel Hills numeric model used the aquifer properties derived from the steady-state model but allowed for changes over time. The transient model was used to simulate time-dependent stressors, such as seasonal irri-

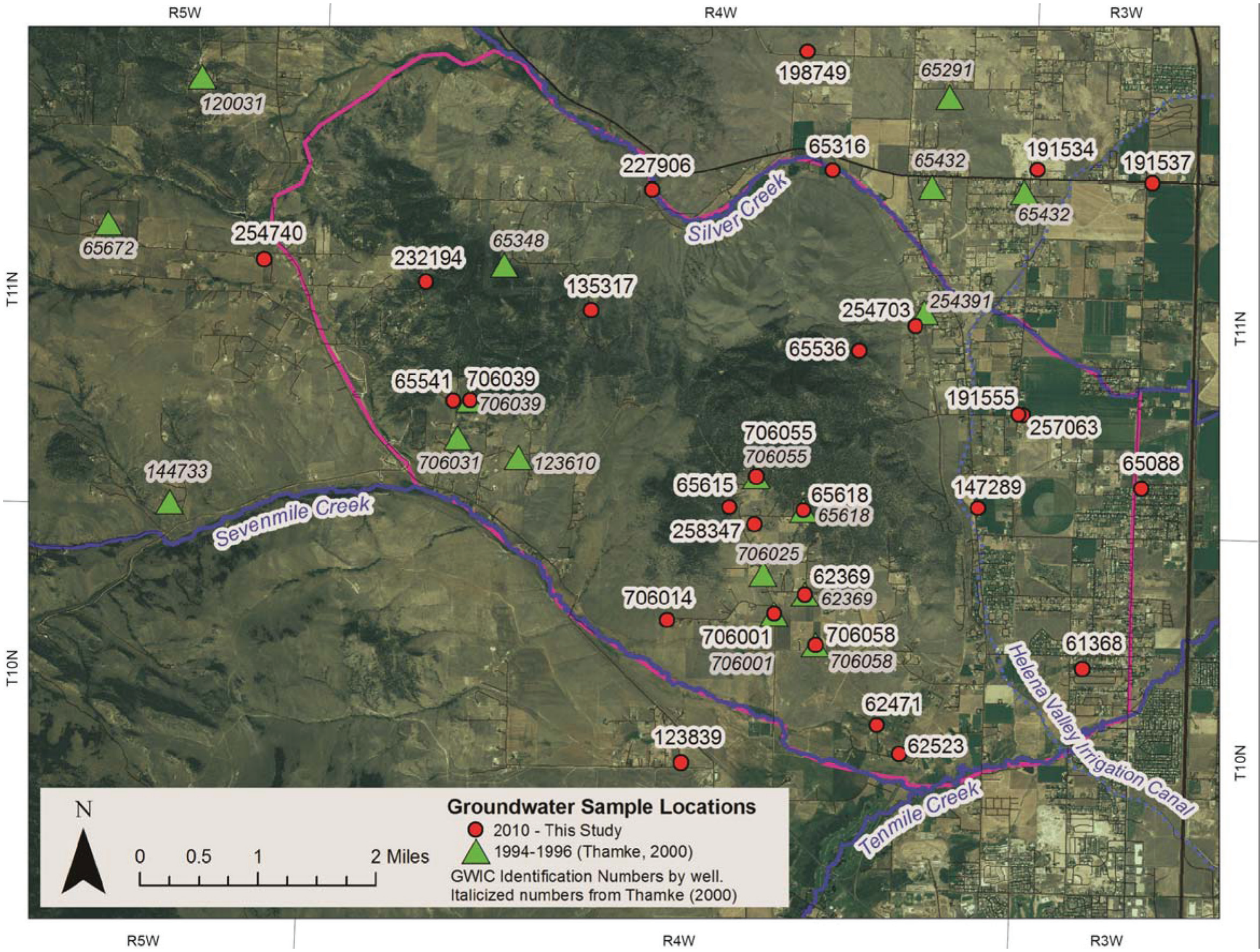


Figure 9. The Ground Water Investigations Program collected 75 groundwater samples from 24 sites. These data, along with data collected during a recently completed MBMG study in the North Hills (Waren and others, 2012) and a bedrock study done by the U.S. Geological Survey (Thamke, 2000), constitute the Scratchgravel Hills study area water-quality data set. Note that the symbols for some sites are stacked.

gation and pumping activities, and to predict the timing and magnitude of impacts resulting from potential future scenarios. A baseline transient model was developed using current stresses and data collected between February 2010 and February 2011.

The hydrologic effects of four subdivision-development scenarios were evaluated by comparing stresses for each scenario to the baseline transient model results. These scenarios were:

- Scenario 1—33 homes with a public water supply (PWS) well
- Scenario 2—33 homes using individual wells
- Scenario 3—267 homes with a PWS well
- Scenario 4—267 homes using individual wells

OBSERVATIONS

Hydrogeologic Framework

Logs for wells drilled within the Scratchgravel Hills area show that bedrock is generally near or at land surface, which is consistent with geologic mapping and field observations. Lithologies reported on well logs generally agree with formations described on geologic maps (fig. 3).

On the eastern edge of the Scratchgravel Hills study area, well logs show that bedrock underlies Helena Valley Aquifer sediments at increasing depth from west to east. At the study area's eastern border, bedrock is reported at depths as shallow as 90 ft but is not mentioned in some well logs for wells that are more than 200 ft deep. Within the study area's interior, colluvium mantles the bed-

Table 1. Analytical parameters and units used for reporting water samples collected in the Scratchgravel Hills study area.

Major Ions (mg/L)		
Calcium	Ca	
Magnesium	Mg	
Sodium	Na	
Potassium	K	
Iron	Fe	
Manganese	Mn	
Silica	SiO_2	
Bicarbonate	HCO_3	
Carbonate	CO_3	
Chlorine	Cl	
Sulfate	SO_4	
Nitrate	as N	
Fluoride	F	
Orthophosphate	as P	

Field Parameters		
Field Conductivity	Field SC	μmhos
Field pH	Field pH	---
Water Temperature	T	^{o}C

Other Parameters		
Total Dissolved Solids	TDS	mg/L
Sum of Dissolved Constituents	---	mg/L
Lab Conductivity	Lab SC	μmhos
Lab pH	Lab pH	---
Nitrite	as N	mg/L
Nitrate + Nitrite	as N	mg/L
Total Nitrogen	as N	mg/L
Hardness	as $CaCO_3$	mg/L
Alkalinity	as $CaCO_3$	mg/L
Ryznar Stability Index	---	---
Sodium Adsorption Ratio	SAR	---
Langlier Saturation Index	---	---
Phosphate (TD)	as P	mg/L

Trace Elements (μg/L)	
Aluminum	Al
Antimony	Sb
Arsenic	As
Barium	Ba
Beryllium	Be
Boron	B
Bromide	Br
Cadmium	Cd
Cerium	Ce
Cesium	Cs
Chromium	Cr
Cobalt	Co
Copper	Cu
Gallium	Ga
Lanthanum	La
Lead	Pb
Lithium	Li
Molybdenum	Mo
Nickel	Ni
Niobium	Nb
Neodymium	Nd
Palladium	Pd
Praseodymium	Pr
Rubidium	Rb
Silver	Ag
Selenium	Se
Strontium	Sr
Thallium	Tl
Thorium	Th
Tin	Sn
Titanium	Ti
Tungsten	W
Uranium	U
Vanadium	V
Zinc	Zn
Zirconium	Zr

Note. mg/L, milligrams per liter; μg/L, micrograms per liter;μmhos = micromhos per centimeter at 25^{o}C.

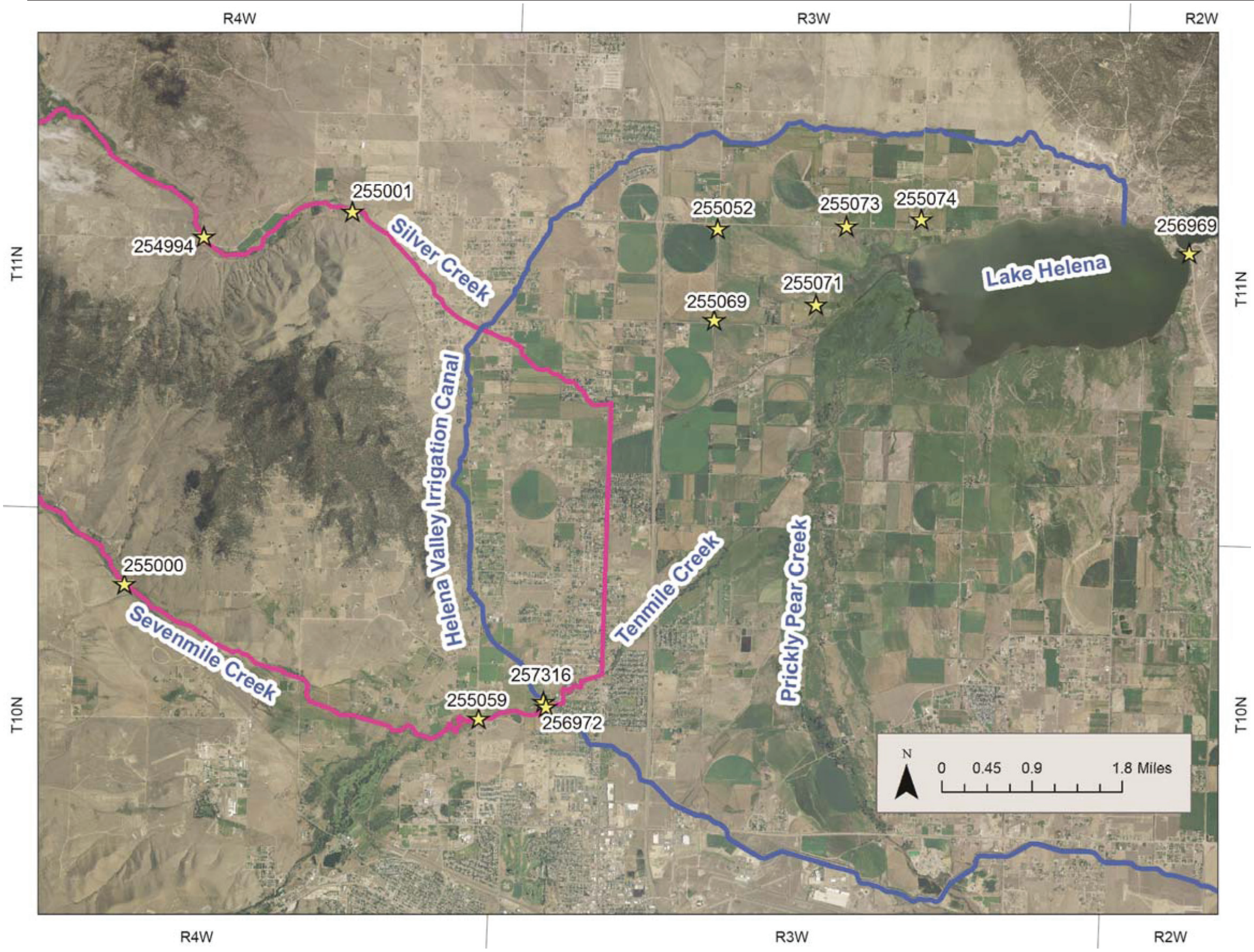


Figure 10. Thirty surface water-quality samples were obtained from 12 sites in and near the Scratchgravel Hills. Numbers are GWIC IDs.

rock; the bedrock–colluvium interface is between 3 and 50 ft below land surface. Reported depths to bedrock and thicknesses of alluvium and colluvium helped refine the distribution of the hydrogeologic units and evaluate modeled aquifer properties.

Water well logs also describe the relative productivity of different units. The median reported yield for wells completed in alluvium and the Helena Valley Aquifer is 20 gpm. Wells completed in bedrock have a median reported yield of 13 gpm and median reported yields from argillite bedrock (Spokane and Empire), Helena Formation, and the granite are 15, 12.5, and 12 gpm, respectively. In the alluvium, 29 percent of wells reportedly yield more than 25 gpm; in the argillite bedrock, Helena Formation, and granite, 25 percent, 12 percent, and 17 percent of the wells, respectively, reportedly yield more than 25 gpm.

Six aquifer tests were conducted for this study (Bobst and others, in preparation a). Additional data were obtained from DNRC records (P. Faber, written commun., 2010). Aquifer test data are summarized in table 2. These aquifer test results tend to be biased towards relatively high values of transmissivity and large storativities because aquifer tests for the DNRC are generally not conducted on wells that produce little water.

Faults may provide conduits for flow or may form a barrier. A solid understanding of how faults function in this area was needed to allow for accurate simulation of groundwater flow. Two wells were installed on each side of the Silver Creek Fault. Groundwater-level monitoring showed marked water-level differences east and west of the fault. During a 24-hour constant rate aquifer test water levels were drawn down 228 ft in the pumping well (WF2; east side of fault) and 63 ft in WF1 (east side of fault); no water-level change was observed in wells WF3 and WF4 west of the fault (fig. 12).

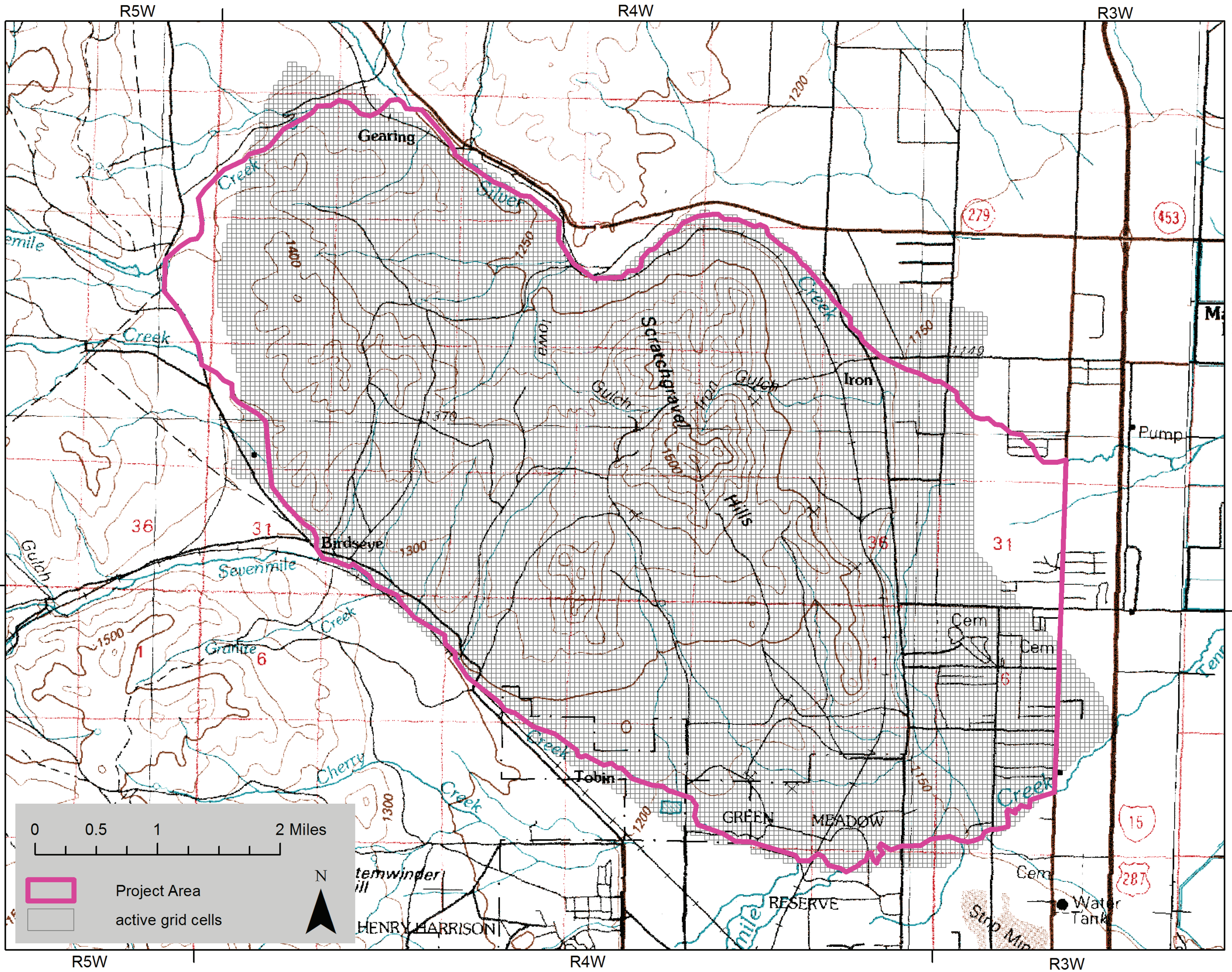


Figure 11. Two layers of 200-ft by 200-ft grid cells cover the aquifers modeled for the Scratchgravel Hills study area. The top layer is from 200 to 1,260 ft thick, and the bottom layer has a uniform 200 ft thickness.

Table 2. Aquifer properties determined from aquifer tests and numerical modeling.

Hydrogeologic Unit	Aquifer Tests						Numerical Modeling			
		K (ft/day)			S		K (ft/day)		S	
	n	Min	Max	Geometric Mean	Min	Max	Min	Max	Min	Max
Spokane/Empire Formations	30	0.9	163	3.9	0.00006	0.03	0.001	1.53	0.01	
Helena Formation	5	0.025	20	1.1	—	—	0.005	1.2	0.01	
Metagabbro Sills	3	1.9	2.7	2.2	0.00067	0.0011	0.001	0.3	0.01	
Scratchgravel Hills Stock	18	0.0009	14	0.18	—	—	0.001	1.25	0.01	
Quaternary Sediments	23	1	916	75	0.0008	0.05	0.15	46.9	0.05	0.08
Silver Creek Fault Zone	—	—	—	—	—	—	0.0002		0.01	

Note. K, hydrologic conductivity; S, storativity.

Precipitation, Evapotranspiration, and Groundwater Recharge

Climatic data show that average annual precipitation in the Scratchgravel Hills varies from less than 10 in. at low altitudes to more than 16 in. near the peaks (fig. 13; P. Farnes, written commun., 2010). From this it is calculated that precipitation totals an average of about 18,200 acre-ft/yr in the study area.

Because there is little observed runoff, precipitation less evapotranspiration (ET) on an average annual basis is approximately equal to diffuse groundwater recharge. In the Helena Valley it has been estimated that irrigated areas have ET rates of approximately 27 in/yr, and on native range ET is essentially equal to precipitation (Briar and Madison, 1992; Madison, 2006). Ponderosa Pine is the dominate forest type in the hills. Based on work by Anthoni and others (1999), actual ET is approximately 11 in/yr for Ponderosa Pine stands in a semi-arid setting. Precipitation in the forested hills ranges from 12 to 16 in, so this leaves 1 to 5 in/yr to recharge groundwater.

Surface Water

Approximately 980 acre-ft/yr [~1.3 cubic feet per second (cfs) on average] enters the study area via flow in Silver Creek, and approximately 4,150 acre-ft/yr (~5.7 cfs on average) enters through flow in Sevenmile Creek. Silver Creek is intermittent, particularly after it enters the Helena Valley. Field observations and anecdotal information indicate that most of the time Silver Creek is dry before it reaches Green Meadow Drive. Sevenmile Creek is perennial. These streams define the northern and southern boundaries of the study area.

In the Helena Valley surface-water and groundwater flow is towards Lake Helena. All outflow is through the Lake Helena Causeway (Briar and Madison, 1992). MBMG monitoring and previous USGS monitoring (J.P. Madison, written commun., 2010) at the causeway show that average annual outflow is about 79,700 acre-ft/yr (110 cfs).

Runoff from the uplands was monitored on ephemeral draws. Lack of measurable flow, and anecdotal evidence, shows that runoff in the Scratchgravel Hills is rare. This is likely due to soils being generally under saturated, and the fact that most

Figure 12. The West Fault Aquifer Test site in T. 11 N., R. 4 W., sec. 28 SWSW, transects the Silver Creek Fault. Static groundwater-level altitudes from November 9, 2010 (ft-amsl, in yellow) show an abrupt water-level difference of about 20 ft from east to west across the fault. A 24-hour pumping test at Well WF2 produced the maximum drawdowns (ft) shown in green.

drainages are cut directly into fractured bedrock, which allows runoff to rapidly infiltrate.

Springs

The MBMG monitored seven springs during this study (fig. 8). All spring flow measurements can be found in GWIC. Spring flow, water quality, and temperature fluctuate seasonally and in response to precipitation.

Groundwater Levels

Potentiometric Surface

Synoptic groundwater-altitude data were used to develop composite potentiometric surface maps for selected months during the study period. These maps are included in the Scratchgravel Hills Technical Report (Bobst and others, in preparation a). While there is some slight variation in the hydrologic gradient at the different mapped times, the overall shape of the potentiometric surface changes little throughout the year, which is consistent with earlier observations (Kendy and Tresch, 1996).

The potentiometric surface in the Helena Area (fig. 14; October 2010) is generally a subdued reflection of the topography. In areas where there is overlap, the surface developed for this study is similar to those drawn by Briar and Madison (1992) and Lorenz and Swenson (1951). The potentiomentric surface is generally a subdued reflection of surface topography (figs. 1, 14). The upland core of the Scratchgravel Hills is underlain by low permeability

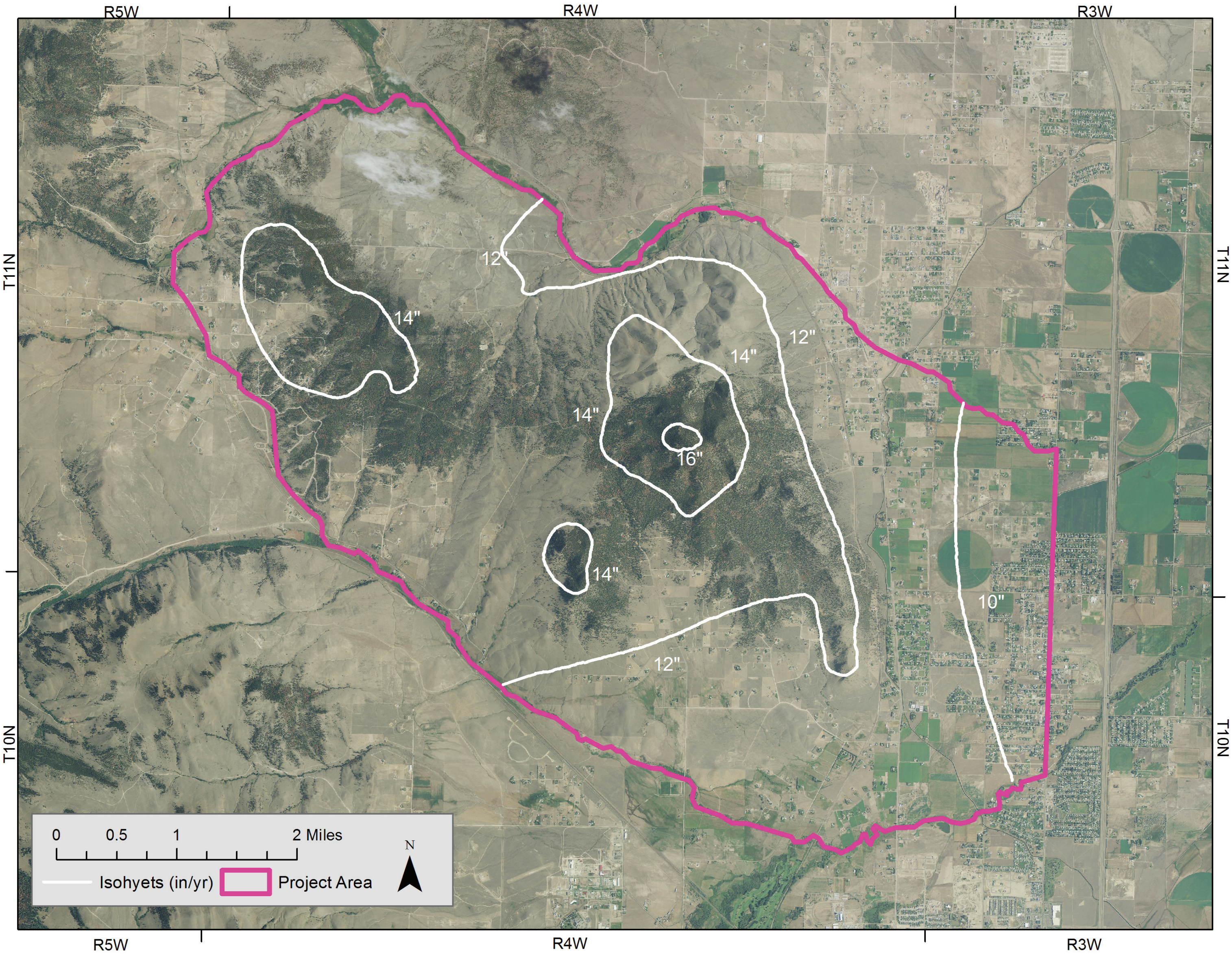


Figure 13. Average annual precipitation isohyets (1970–2000) for the Scratchgravel Hills study area show that precipitation ranges from less than 10 in. in the Helena Valley to more than 16 in. at the highest elevations (P. Farnes, written commun., 2010).

granite, which limits the flow of groundwater (fig. 3). A groundwater mound forms beneath the top of the Scratchgravel Hills, resulting in radial flow from this area. Regional groundwater flow is from the western mountains through the study area to Lake Helena. The Scratchgravel groundwater mound is superimposed on this regional pattern, causing the eastward regional groundwater flow, and the westward flow from the mound, to split north and south and discharge into the alluvial materials underlying Silver and Sevenmile Creeks. Northward and southward flow from the mound also discharges to alluvium. This alluvial groundwater as well as eastward flow from the mound flows into the Helena Valley Aquifer. All groundwater in the Helena Valley Aquifer flows toward Lake Helena.

Hydrograph Analysis

Groundwater-level data collected during 1995, 1996, and 2010 were evaluated to determine the overall magnitude and direction of groundwater-level change. Water-level records for 21 wells were evaluated. The water-level trend was determined by the slope of a linear regression between the measurements at wells made in 1995, 1996, and 2010. Some wells had additional measurements at times between 1996 and 2010, but for consistency those data were excluded from all linear regressions.

Two wells had downward trends of more than 0.5 ft/yr and two had upward trends of more than 0.5 ft/yr; the remaining 17 had upward or downward trends of less than 0.5 ft/yr. The group as a

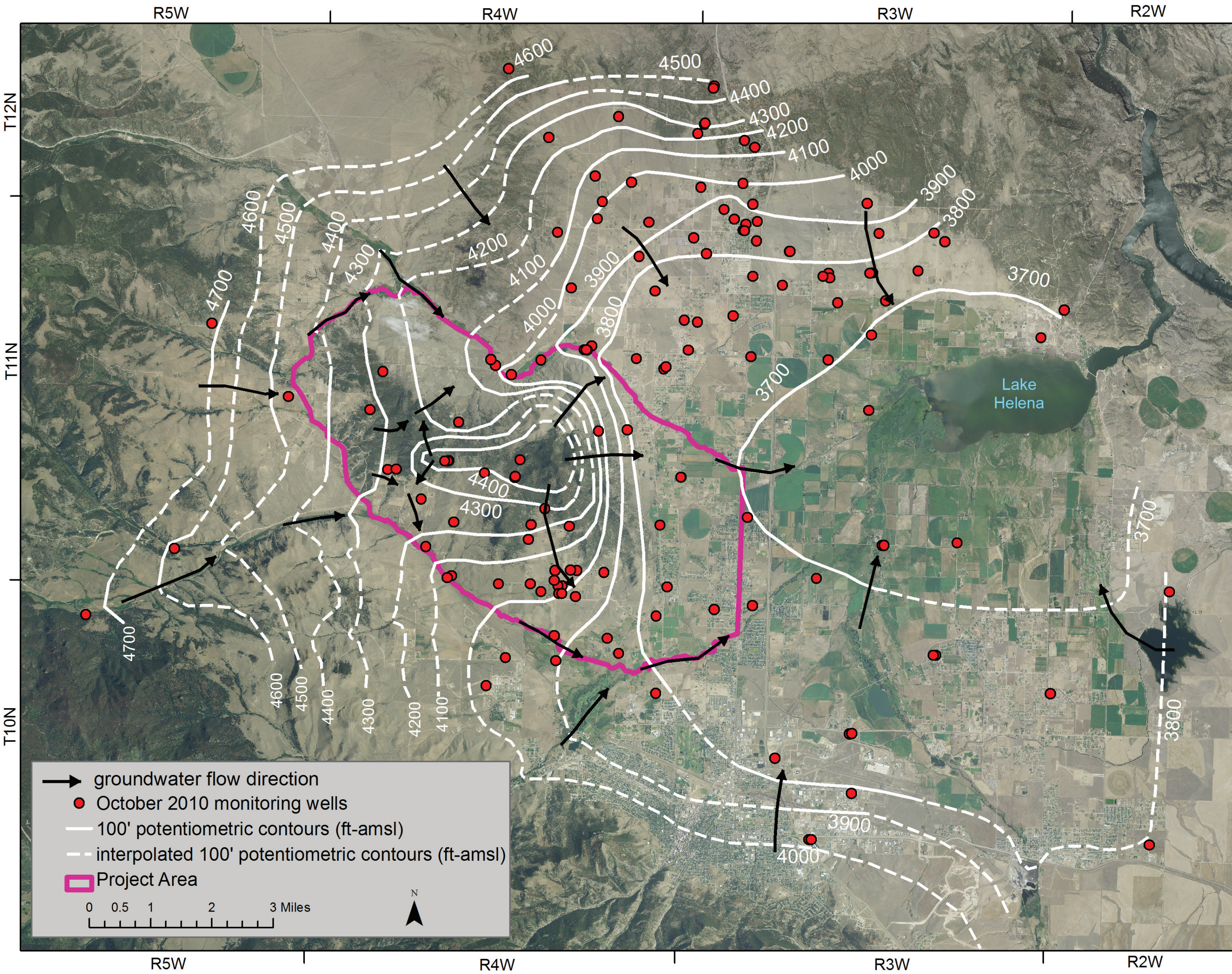


Figure 14. This potentiometric surface map of the area surrounding the Helena Valley is from October 2010 (based on water levels from the MBMG's North Hills study (Waren and others, 2012), Lewis and Clark County's monitoring, and this study). This map shows that groundwater flow is generally from the basin margins towards Lake Helena. The alluvial sediments along stream valleys act as drains for the less permeable bedrock. Local recharge and low-permeability bedrock within the Scratchgravel Hills study area uplands causes a 400 ft 'high' in the potentiometric surface.

whole had an overall downward average trend of -0.06 ft/yr, but if the well with the largest downward trend were removed from the data set as a possible outlier, the average group trend would be upward at 0.01 ft/yr. The hydrographs are included in the Scratchgravel Hills Technical Report (Bobst and others, in preparation a). Selected hydrographs are included in this report (figs. 15–17).

Monitored wells with strong upward or downward trends are isolated from each other (fig. 18), and are surrounded by wells that show less than 0.5 ft/yr of upward or downward change. This isolation indicates a lack of area-wide change.

The two wells with declining trends of more than 0.5 ft/yr indicate local aquifer conditions that cannot sustain local groundwater use. These wells are completed in the Helena Formation and the Scratchgravel Hills Stock, both of which are known to have areas with relatively low K values (table 2), comparable to the expected range for clay to silty sand (Fetter, 1994). When completed, wells 65618 (G3 in fig. 16) and 706039 (H1 in fig. 17) reported yields of 3 and 8 gpm, respectively.

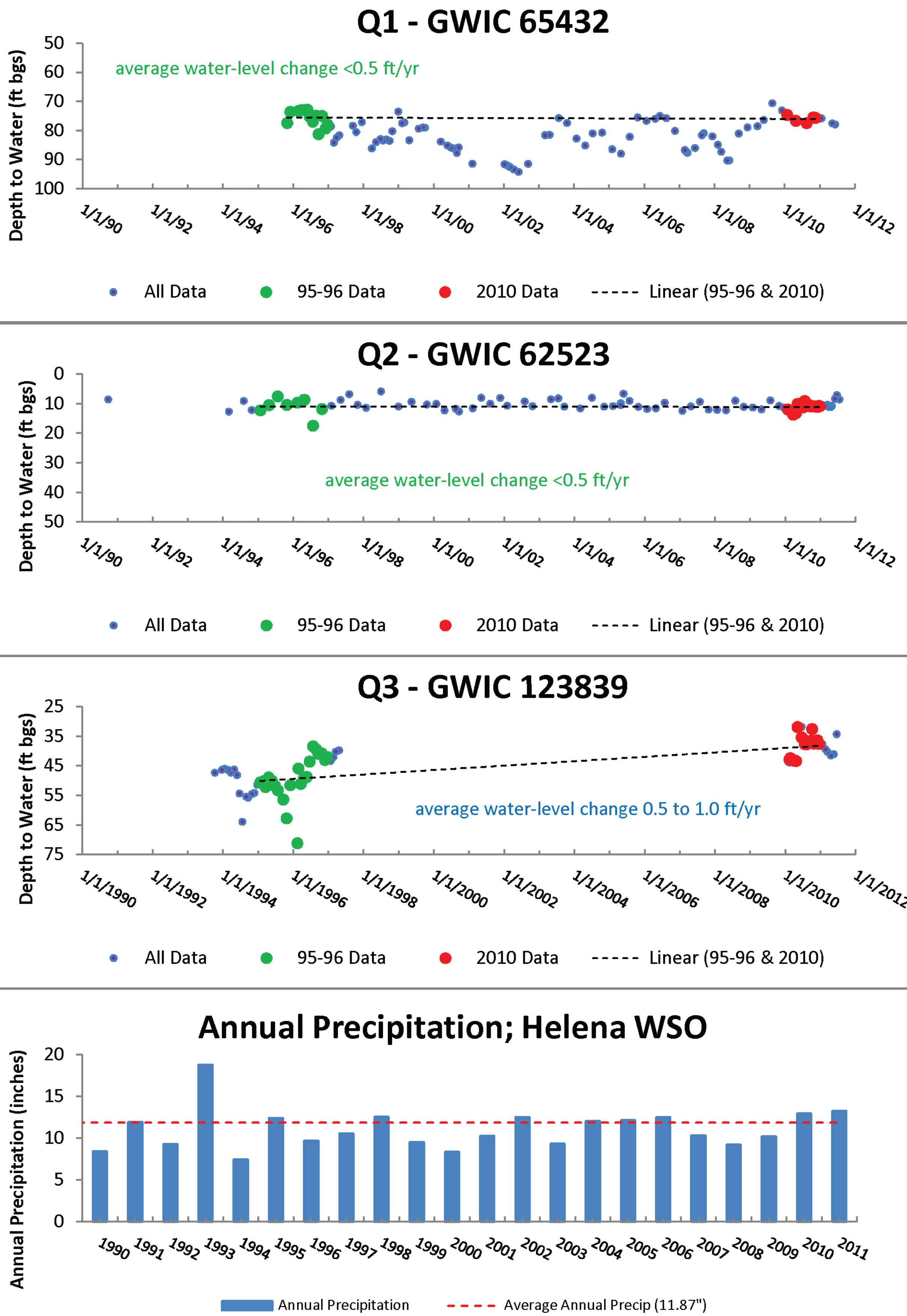


Figure 15. Water levels in most wells completed in or below the Quaternary alluvium changed very little between 1995–1996 and 2010 (Q1 and Q2). Some wells display cyclical changes due to recharge (Q1) and others respond to changes in local pumpage (Q3). Well locations are shown in fig. 18. In all hydrographs, the dashed line represents a rate of change between data collected during the years 1995, 1996, and 2010. Because data sets for some wells are incomplete, intermediate data are excluded from the regression for all wells.

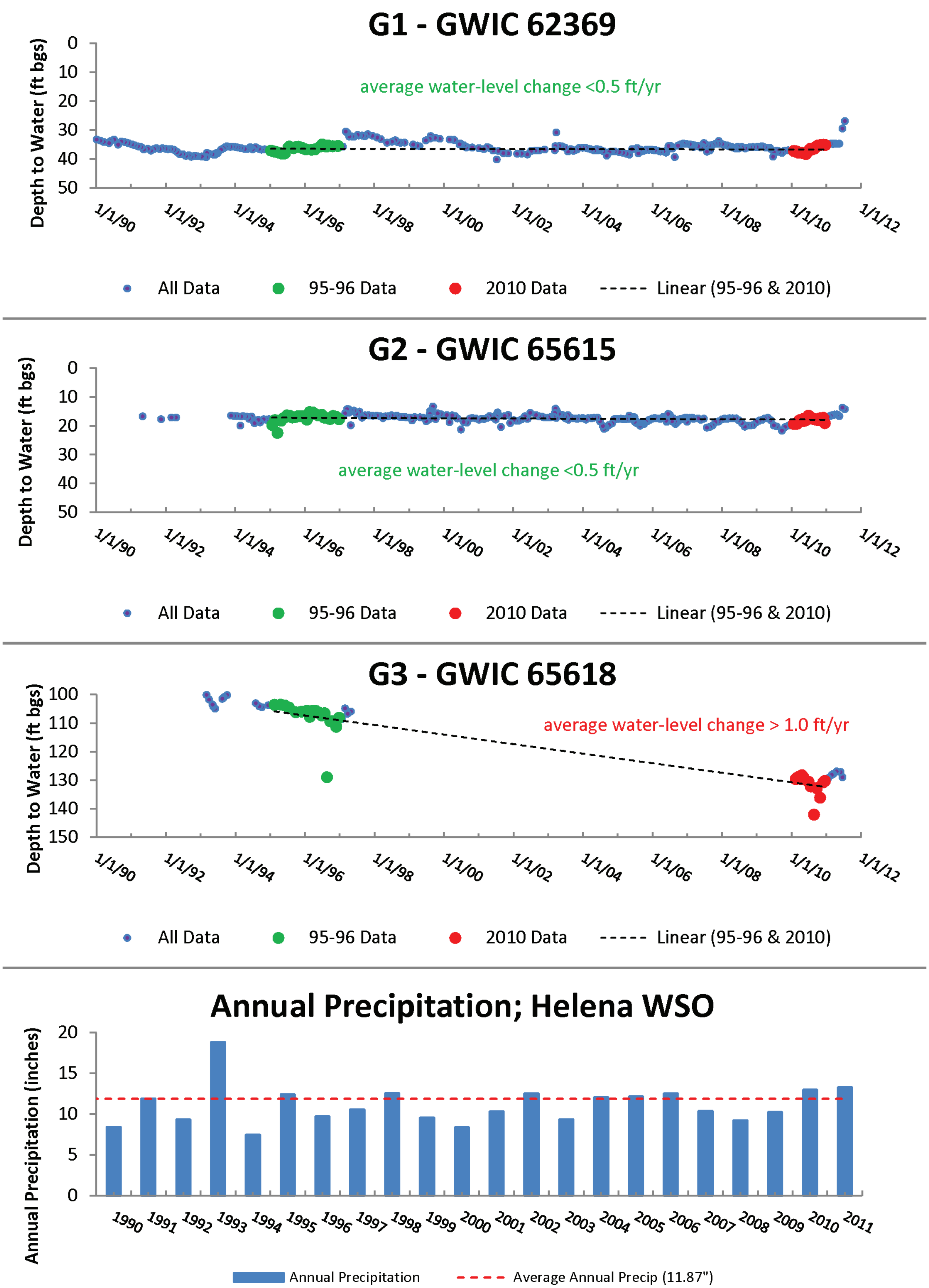


Figure 16. Water levels in most wells completed in the granite changed very little between 1995–1996 and 2010 (G1 and G2); however, at some locations the granite aquifer has low productivity, causing water-level decline even with modest use (G3). Well locations are shown in fig. 18. In all hydrographs, the dashed line represents a rate of change between data collected during the years 1995, 1996, and 2010. Because data sets for some wells are incomplete, intermediate data are excluded from the regression for all wells.

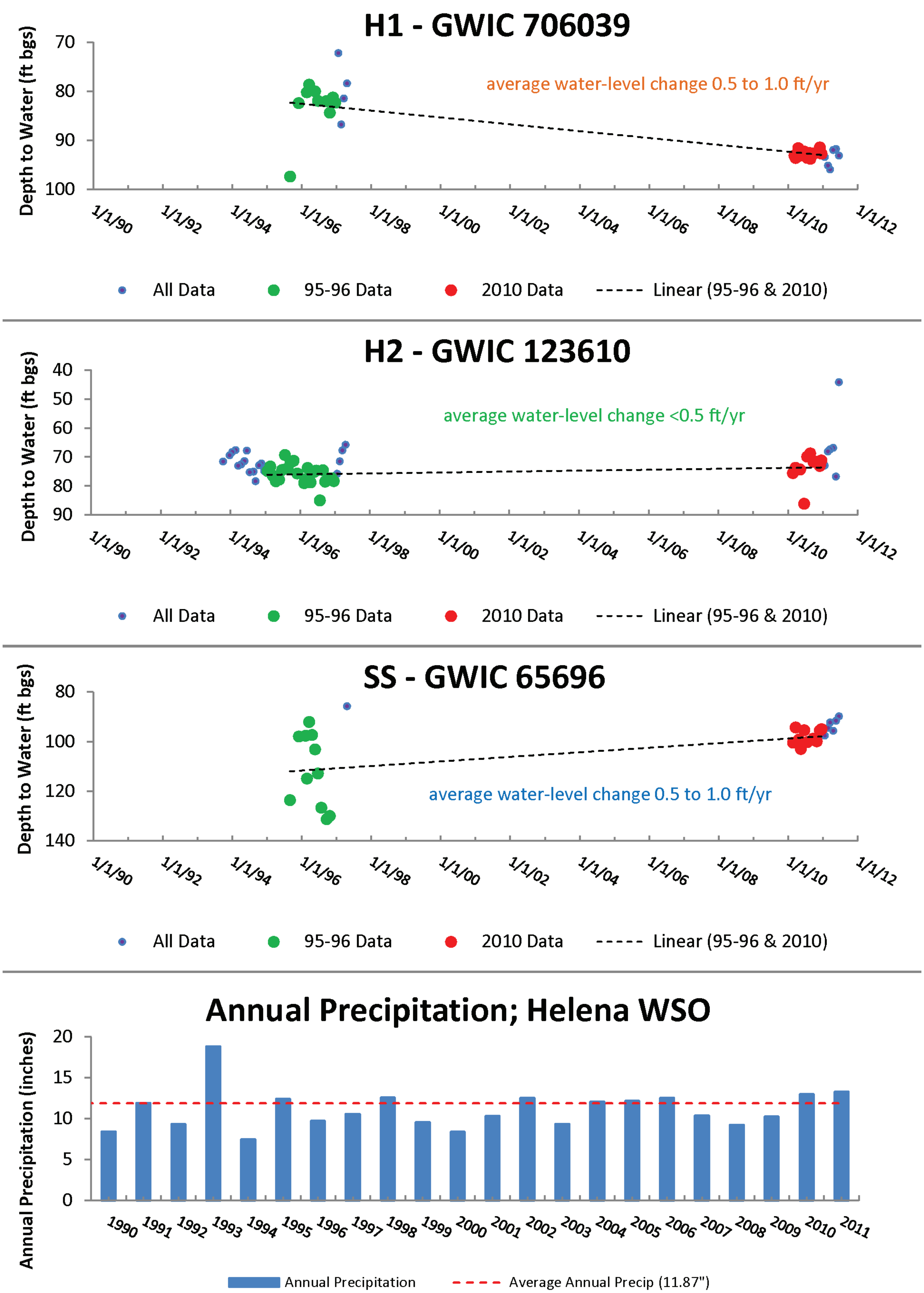


Figure 17. Water levels in most wells completed in the Helena and Snowslip Formations changed very little between 1995–1996 and 2010 (H2); however, at some locations these bedrock aquifers have low productivity, causing water-level decline even with modest use (H1). In other areas water levels respond to changes in local pumpage (SS). Well locations are shown in fig.18. In all hydrographs, the dashed line represents a rate of change between data collected during the years 1995, 1996, and 2010. Because data sets for some wells are incomplete, intermediate data are excluded from the regression for all wells.

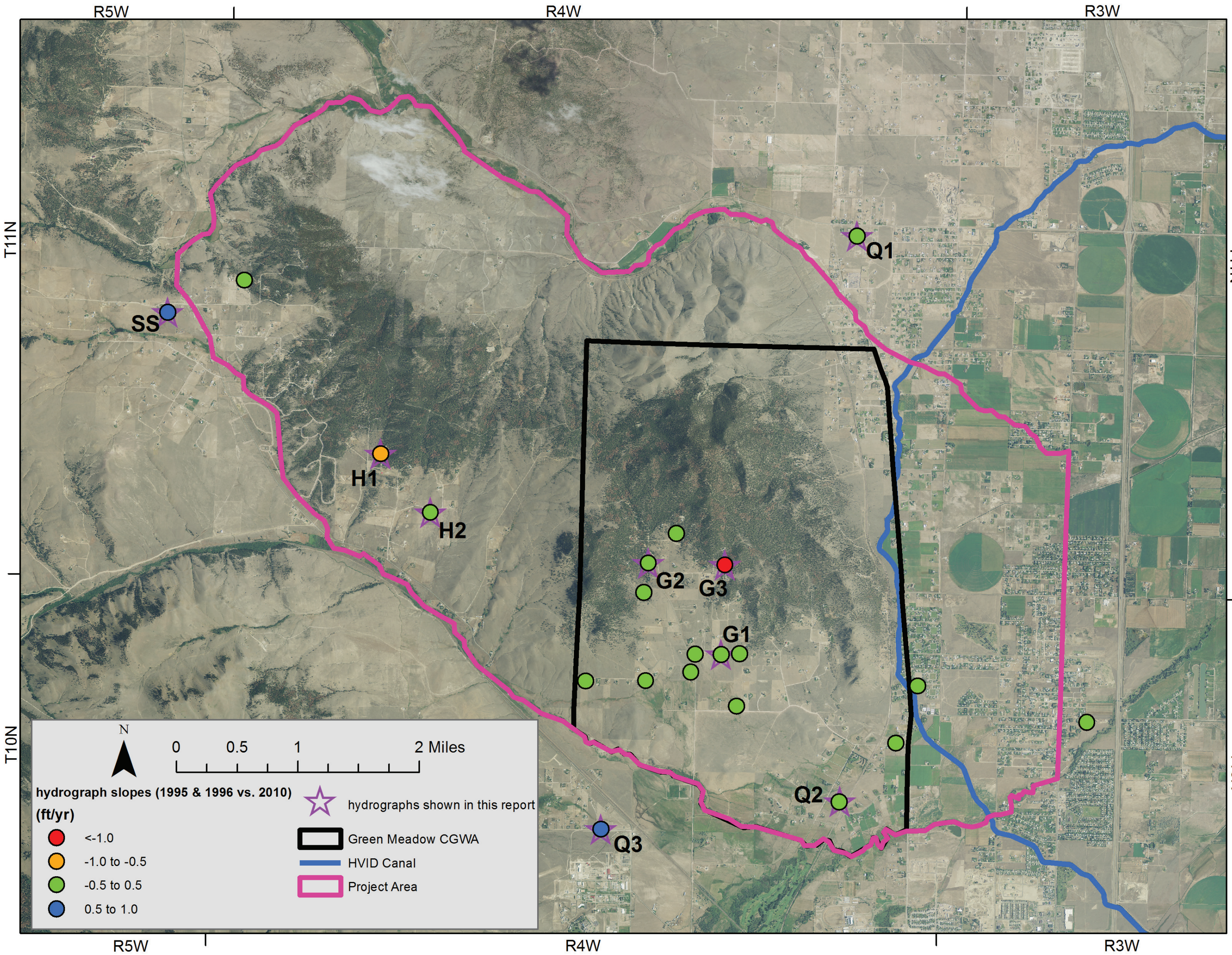


Figure 18. Hydrograph slopes in the Scratchgravel Hills study area show the general distribution of rising or falling groundwater levels. Negative slopes (red and orange markers) indicate declining water levels; positive slopes (blue markers) indicate rising water levels. Green markers indicate little change. Water-level trends are typically flat; however, some active wells show local long-term declines due to usage at rates greater than what the aquifer can sustain. There is no indication of regional drawdown. Example hydrographs for sites labeled Q, G, H, and SS are included in figs. 15, 16, and 17.

The two wells with upward water-level trends of more than 0.5 ft/yr may be explained by local changes in water management. Well Q3 (fig. 15) is adjacent to Fort Harrison. The well owner reports that Fort Harrison does not pump as much from nearby wells as previously. At well SS (fig. 17), the well owner reports that the installation of a new well has allowed decreased pumpage in the monitored well.

Precipitation data from the Helena Weather Service station (KHLN) indicate that in 1995–1996 average monthly precipitation was 0.92 in; in 2009–2010 it was 0.97 in. There is little difference in these averages, and barring other stresses, water-level altitudes would be expected to be similar. Most wells show essentially flat hydrographs, indicating that, overall, climate is not a driving factor during this time period. Many hydrographs have low relief, indicating that short-term precipitation events have little effect on water levels. The frequency and intensity of precipitation do drive 1- to 3-yr water-level cycles in some locations (e.g., wells 65432 (Q1) in fig. 15 and 62369 (G1) in fig. 16). Although these cycles may have caused intervening water levels to fall as much as 20 ft (Q1 in fig. 15), they have not resulted in overall water-level rises or declines.

Two wells in the study area (wells 62369 and 65615) have had water levels collected since the mid 1970s (fig. 19). Both of these wells are completed in the Scratchgravel Hills Stock. Evaluation of these hydrographs shows that water levels are generally lower than when measurements began; however, water levels increased substantially in the spring of 2011. Some portion of this overall decline is likely due to pumping of the wells themselves. Precipitation records show that it was particularly wet from the mid-1970s to the early 1980s. There was particularly high precipitation in May 1981 (6.09 in). The spring of 2011 was also particularly wet (8.54 in from May to June). The overall cumulative departure from average precipitation over this period also shows a general decline. As such, it appears that the decadal scale variations observed in these hydrographs are driven by a combination of short, wet periods (recharge), precipitation trends, and local pumping.

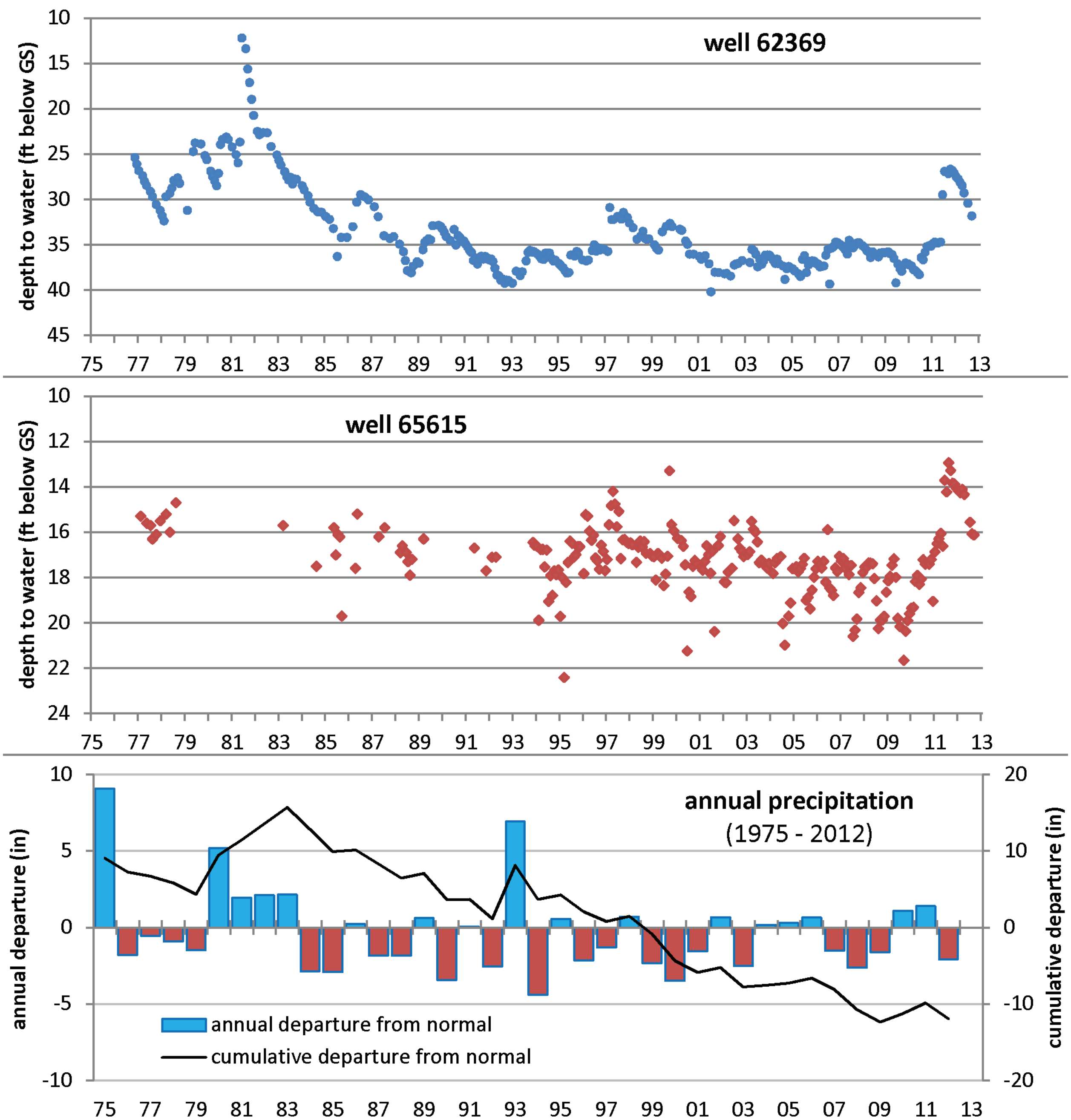


Figure 19. Long-term hydrographs show groundwater levels were lower than those seen in the mid 1970s to the early 1980s through 2010. In 2011 water levels higher than had been seen since 1983 (well 62369) or ever (well 65615) occurred. Precipitation in 1975 was particularly high, and the overall shape of the hydrographs is similar to cumulative departure from average precipitation. The particularly high water levels seen in 1981 and 2011 relate to periods of particularly intense and sustained rainfall, where substantial runoff was available to recharge the bedrock aquifer by infiltration through fractures on the bottoms of drainages.

Hydrographs show that seasonal water-level variations and long-term trends depend on a well's hydrogeologic setting. In upland areas recharge is from direct infiltration of precipitation or infiltration from ephemeral streams. Water levels are generally stable but do respond to recharge events, local pumping, and decadal-scale precipitation departures (e.g., well 65615). In some cases bedrock wells are pumped at rates greater than what these aquifers can locally sustain, particularly during summer months when land owners are irrigating their properties (e.g., well 65618). For wells recharged by canal leakage or irrigation recharge, peak water levels are seen in late summer and minimum levels occur in the spring before irrigation begins (e.g., well 254309; Briar and Madison, 1992). Near where Silver Creek enters the Helena Valley, groundwater levels are sensitive to its flows, which are determined by weather and irrigation practices (e.g., well 65432; Madison, 2006; Waren and others, 2012). Because Silver Creek is intermittent, it may not, in any given year, deliver water to the northwest edge of the Helena Valley Aquifer, which causes a significant decrease in recharge and groundwater level (storage) declines.

Groundwater/Surface-Water Interactions

Data from the three Silver Creek monitoring sites (fig. 8) show that surface-water levels are above groundwater levels during the entire monitoring period, and that groundwater levels quickly reflect changes in stream stage (fig. 20). The amount of surface flow is also observed to consistently decline downstream during both the irrigation and non-irrigation seasons (fig. 21). Irrigation diversions cause a few exceptions. These downstream declines are consistent with Silver Creek being a losing stream (Winter and others, 1998). Local residents confirm these observations, and report that in most years flow in Silver Creek ceases west of Green Meadow Drive. The creek water infiltrates to groundwater, and approximately half flows into the study area because Silver Creek is on the study area's northern boundary.

At the two monitoring sites on Sevenmile Creek (fig. 8), groundwater and surface-water elevations are nearly the same. Changes in surface-water and groundwater levels occur at the same time at both sites. At upstream site 7M1 alluvial-groundwater elevations are about 0.3 ft above stream elevations (fig. 22), indicating that Sevenmile Creek is a gaining stream at this site (Winter and others, 1998). At downstream site 7M2 alluvial groundwater elevations are about 0.3 ft below surface-water elevations when irrigation is not occurring; however, when irrigation is active stream-level elevations drop to groundwater elevations. This is consistent with a stream that transitions from losing to gaining (Winter and others, 1998), where the shifts are driven by the amount of irrigation water being removed from the stream. As irrigation water is removed the stream becomes as low as the groundwater, and is then replenished by it. When irrigation ends the stream rises slightly above groundwater levels and recharges the groundwater. Thus there is little net flow between Sevenmile Creek and groundwater on an annual basis. Briar and Madison (1992, p. 16) also concluded that "Sevenmile Creek does not lose or gain a significant quantity of flow".

Tenmile Creek flows for about 2.8 miles along the southeastern edge of the study area. Synoptic stream flow measurements conducted by the USGS (Briar and Madison, 1992) indicate that Tenmile Creek loses about 1.9 cfs per mile. Half of this water would flow into the study area because Tenmile Creek is on the study area's southern boundary.

Irrigation canals function similarly to the creeks, and monitoring shows that canal water levels are well above groundwater levels. As such, water in the canals leaks to the underlying groundwater. Canals in the study area obtain their water from the Missouri River, Silver Creek, and Sevenmile Creek. Briar and Madison (1992) evaluated leakage from irrigation canals, and determined that the HVID canal lost about 0.63 cfs per mile, while smaller canals lost about 0.21 cfs per mile.

While interaction between surface water and groundwater are quantitatively important to the overall groundwater budget, the infiltration of surface water has little impact in the area of most concern (Green Meadow CGWA). Except for a limited area affected by Sunny Vista Canal, infiltrated creek and canal water is only available to wells completed in the alluvium or in the Helena Valley Aquifer.

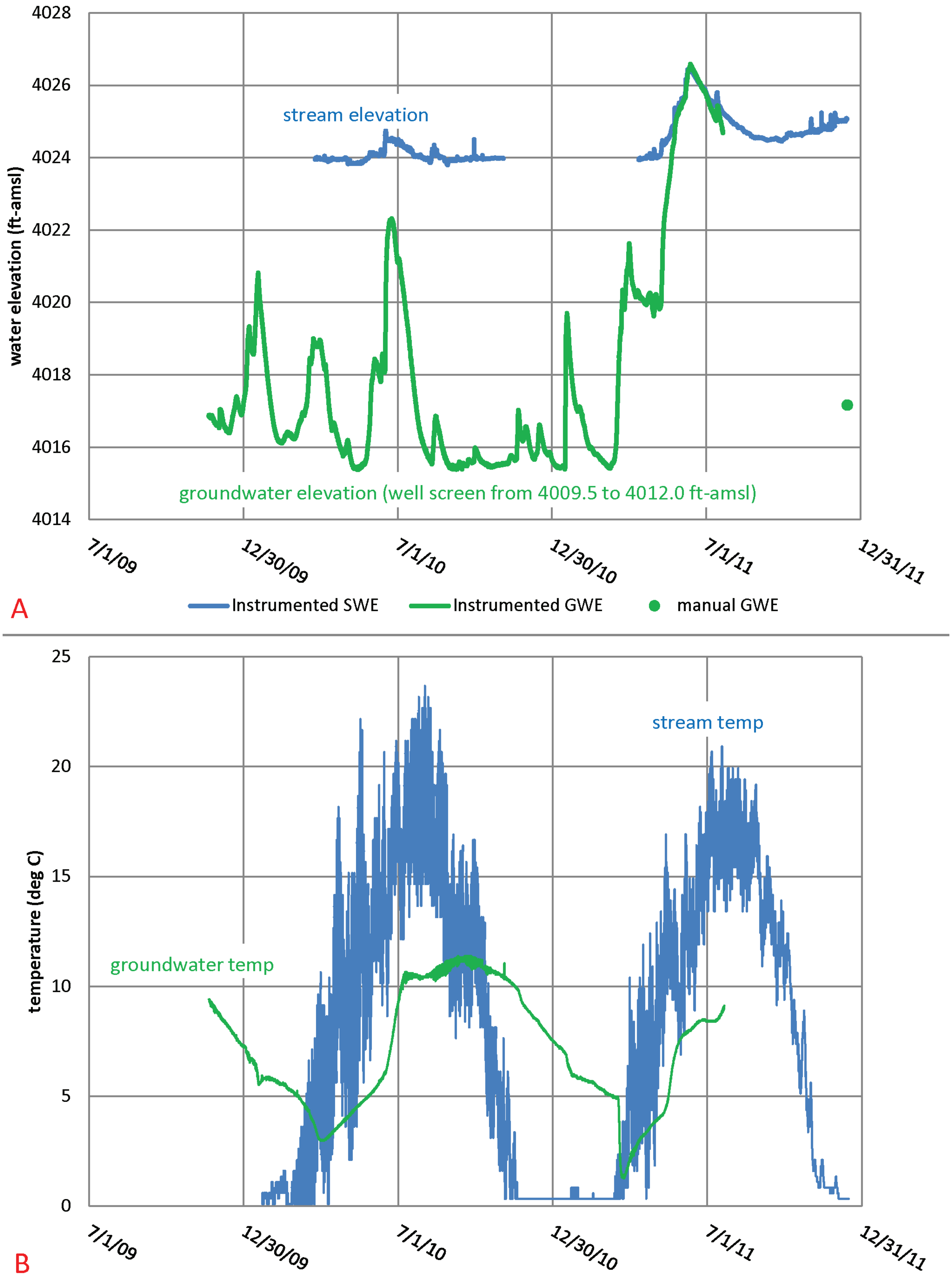


Figure 20. Measured groundwater and surface-water elevations at the Upper Silver Creek Site (SC1; well 254216 and stilling well 254994) show that the stream surface is consistently higher than groundwater (A). The only time that this was not the case was during the extended flooding during the spring of 2011, when elevations were equal. Surface-water temperatures show strong diurnal variations; however, groundwater temperatures have no diurnal response but do change seasonally (B). Even though groundwater elevation changes correspond with changes in stream stage, the lack of a diurnal temperature signal in the groundwater may indicate the volume of water flowing from surface water to groundwater is relatively small. This lack of diurnal temperature response in the groundwater may also be due to the top of the well screen being more than 3 ft below the water table.

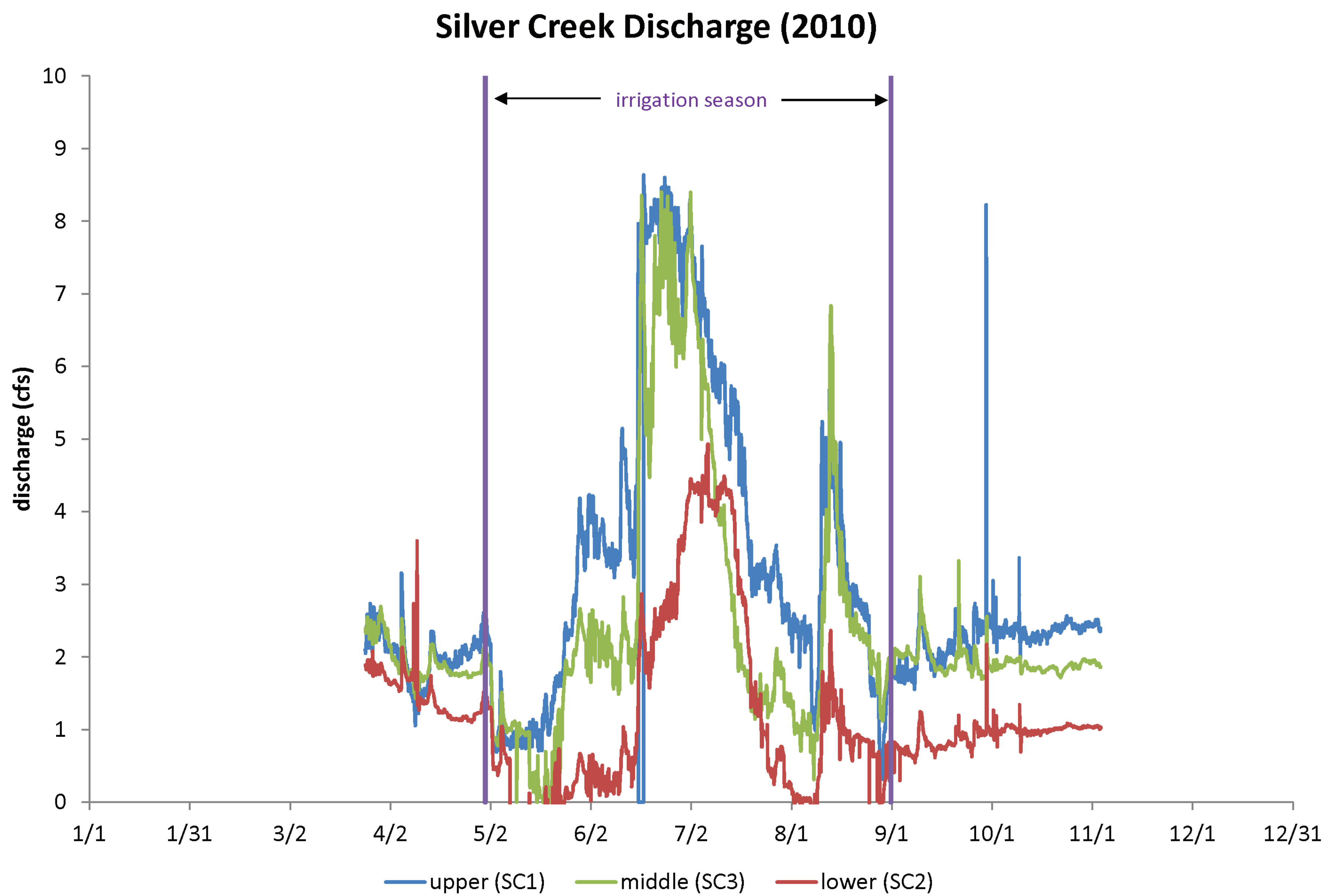


Figure 21. Flow in Silver Creek generally decreases downstream at all times during the year. Short-term irrigation practices cause a few exceptions.

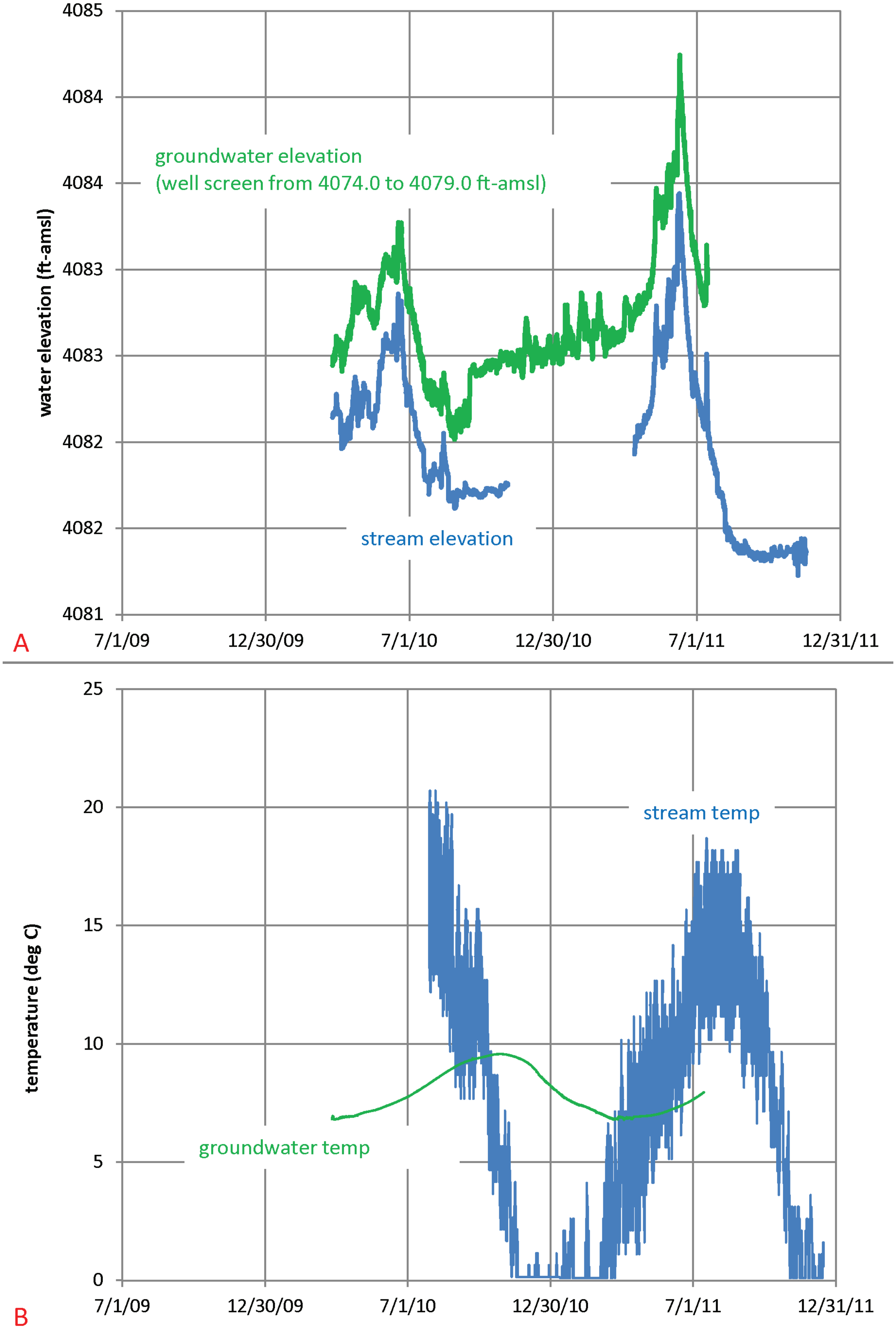


Figure 22. At the Upper Sevenmile Creek Site (7M1; well 255141 and stilling well 255000) groundwater elevation is consistently slightly above stream surface elevation (A). Groundwater elevation changes also correspond with changes in stream stage. Surface-water temperatures show strong diurnal variations; however, groundwater temperatures have no diurnal response but do change seasonally (B). The lack of diurnal temperature signal in the groundwater supports the idea that flow is from groundwater to the stream; however, it may also be due to the top of the well screen being more than 3 ft below the water table.

Groundwater Budget

A detailed report on the Scratchgravel Hills Groundwater budget is included in the Scratchgravel Hills Technical Report (Bobst and others, in preparation a). A brief summary of the major components is below. The general form of the groundwater budget equation is:

Water in = Water out ± Changes in groundwater storage.

For the Scratchgravel Hills study area this equation can be expanded to:

$$BR + DI + 10M + SC + CL + IR = WL + HVA \pm \Delta S,$$

$$[(BR=480)+(DI=2{,}190)+(10M=1{,}740)+(SC=490)+(CL=1{,}450)+(IR=1{,}620)] = 7{,}970 \text{ in},$$

$$[(WL=780)+(HVA=2{,}900+4{,}290)] = 7{,}970 \text{ out}$$

$$\Delta S = 0,$$

where values are in acre-ft/yr; BR, bedrock inflow; DI, diffuse infiltration; 10M, Tenmile Creek infiltration; SC, Silver Creek infiltration; CL, irrigation canal leakage; IR, irrigation recharge; WL, withdrawals from wells; HVA, discharge to the Helena Valley aquifer and the alluvium along creeks; and ΔS, changes in storage.

Groundwater inflow through bedrock (BR) from the western mountains occurs at the study area's western boundary. Local westward groundwater flow off the Scratchgravel Hills groundwater mound causes this inflow to be deflected to the north and south and show up as discharge to the alluvium along Silver and Sevenmile creeks, and eventually to the Helena Valley Aquifer (fig. 14). By Darcy's Law, total bedrock groundwater inflow (BR) is calculated to be approximately 480 acre-ft/yr [K (0.4 ft/day) * L (18,643 ft) * b (400 ft) * dh/dl (137.54/7,135) = Q (57,500 ft3/day = 480 acre-ft/yr)].

Diffuse infiltration (DI) occurs when precipitation exceeds runoff, evaporation, or plant use (Lerner and others, 1990; DeVries and Simmers, 2002; Ng and others, 2009). For the Scratchgravel Hills study area, diffuse infiltration includes only non-irrigated lands because irrigation recharge (IR; see below) accounts for the irrigated areas. Because runoff in the study area is minimal, diffuse infiltration is approximately equal to precipitation minus actual ET. Precipitation is equal to ET in non-forested areas that are not irrigated, so diffuse recharge only occurs in the forested hills where 1 to 5 in/yr of water infiltrates and results in a total diffuse infiltration of about 2,190 acre-ft/yr (10,795 acres with an average of 2.43 in. of recharge).

Leakage from streams to groundwater occurs along Silver Creek (SC) and Tenmile Creek (10M). Approximately 2.8 miles of Tenmile Creek borders the study area on the southeast. Leakage estimates from this reach (Briar and Madison, 1992) suggests that about 1,740 acre-ft/yr enter the study area from Tenmile Creek. Silver Creek contributes all of its flow to groundwater, and about half of this flows into the study area (about 490 acre-ft/yr).

Canal leakage (CL) occurs along 4.3 miles of the HVID canal and 7.8 miles of smaller canals within the study area. The HVID canal and its laterals obtain water from the Missouri River, while other canals obtain water from Silver, Threemile, Tenmile, and Sevenmile creeks. Groundwater under these canals is often more than 20 ft below ground surface each year before the canals are turned on. Several hydrographs clearly demonstrate impacts from canal leakage (e.g., wells 254309 and 239913). Briar and Madison (1992) estimated that the HVID canal loses about 0.63 cfs/mi, and other canals lose about 0.21 cfs/mi. Therefore the canal system loses a total of about 1,450 acre-ft each irrigation season to groundwater.

When water (irrigation water plus precipitation) is applied to a field in excess of crop demand and evaporation, the excess must either runoff or infiltrate to underlying groundwater. On irrigated fields the water that recharges groundwater is termed irrigation recharge (IR). Some irrigation recharge of groundwater is desirable because having some water flow through the root zone prevents the buildup of salts. Briar and Madison (1992) calculated that the average irrigation recharge in the Helena Valley using the amount of water applied by irrigation, the amount of precipitation, and crop demand was about 1.5 ft/yr. GIS analysis shows that there are approximately 1,078 acres irrigated in the Scratchgravel Hills Study Area, thus irrigation recharge to the study area accounts for about 1,620 acre-ft/yr. Because most of the irrigated areas are on or near alluvium, IR water is only available to wells completed along these streams, or in the Helena Valley Aquifer. The exception is that area supplied by the Sunny Vista Canal (~120 acres).

In the northern portion of the Helena Valley, 20 years of monthly metered water-use data from Townview Estates were assessed (Bobst and others, in preparation b). This analysis provided an estimate that the annual average consumption by a rural home with a septic system near Helena is about 435 gallons of water per day. Consumed water is that water that is not returned to the groundwater system (i.e., septic returns). Approximately 98 percent of this water is consumed by landscaping (lawns and gardens) during the growing season. This figure is in good agreement with estimates by Stahly Engineering (2008) for the proposed Cornerstone Estates subdivision (438 to 445 gallons per day per lot). Given that there were 1,608 homes in the Scratchgravel Hills study area in 2009, about 781 acre-ft/yr of water is consumptively used for homes and removed from the groundwater system.

Using Darcy's Law, the amount of groundwater flowing out to the Helena Valley Aquifer along the eastern edge of the study area was calculated to be about 3,270 acre-ft/yr to the alluvium along the creeks, and about 4,290 acre-ft/yr directly to the Helena Valley aquifer (fig. 14).

The groundwater budget indicates that overall inputs to the Scratchgravel Hills study area are between 7,300 and 9,400 acre-ft/yr. Outputs are estimated to be between 7,400 and 9,400 acre-ft/yr. Because there is no evidence for regional changes in groundwater levels, and thus no appreciable change in groundwater storage, the budget should be in balance (table 3 and fig. 23). The probable range of inflows and outflows shown in table 3 account for each calculation's estimated uncertainty.

Numerical Modeling Scenarios

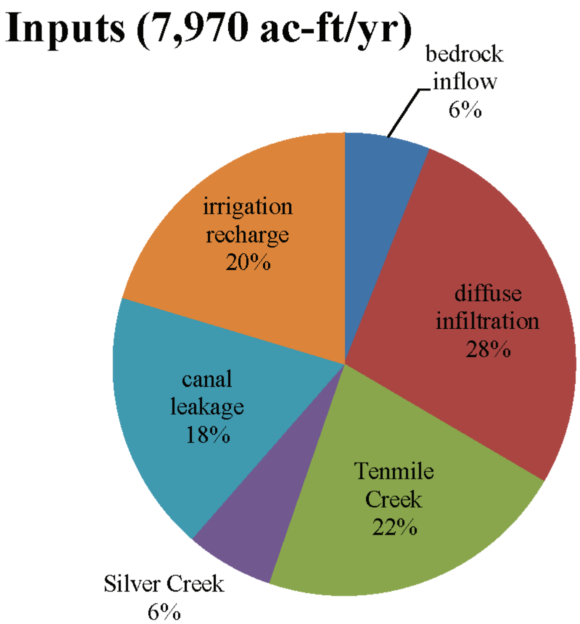
Details concerning the design, construction, calibration and limitations of the numerical groundwater models are included in the Scratchgravel Hills Modeling Report (Butler and others, in preparation), and model design is discussed in the Methods section of this report. The files needed to run the models are posted to the GWIP website (http://www.mbmg.mtech.edu/gwip/gwip.asp).

A calibrated transient model was used to assess four potential development scenarios for the Cornerstone Estates area within the Green Meadow CGWA. Each scenario included 10 years of pumping. Specific attention was given to the effects of varying well locations and pumping rates. The assigned pumping rates ranged from those necessary for a subdivision with the currently proposed 33 homes, to those needed for 267 homes. The question of using a single PWS well relative to individual wells was also tested. For modeling purposes, the PWS was placed in the alluvium in the extreme southeast corner of the property, while most individual wells were completed in granitic bedrock.

Model results indicated that the lateral extent of drawdown was considerably less in scenarios

Table 3. Scratchgravel Hills groundwater budget vs. model budget calculated as acre feet per year.

	Best Estimate	Probable Range		Modeled Values
		Min	Max	
INPUTS				
Bedrock Inflow	480	240	720	378
Diffuse Infiltration	2,190	1,970	2,400	1,330
Tenmile Creek Infiltration	1,740	1,570	1,910	N/A
Silver Creek Infiltration	490	440	535	N/A
Irrigation Canal Leakage	1,450	1,638	2,001	1,410
Irrigation Recharge	1,620	1,455	1,778	3,098
TOTAL INPUT	7,970	7,303	9,355	6,216
OUTPUTS				
Well Withdrawals	780	721	901	N/A
Outflow to Alluvial Drainages	2,900	2,767	3,759	3,117
Outflow to Helena Valley Aquifer	4,290	3,887	4,751	3,100
TOTAL OUTPUT	7,970	7,376	9,411	6,217



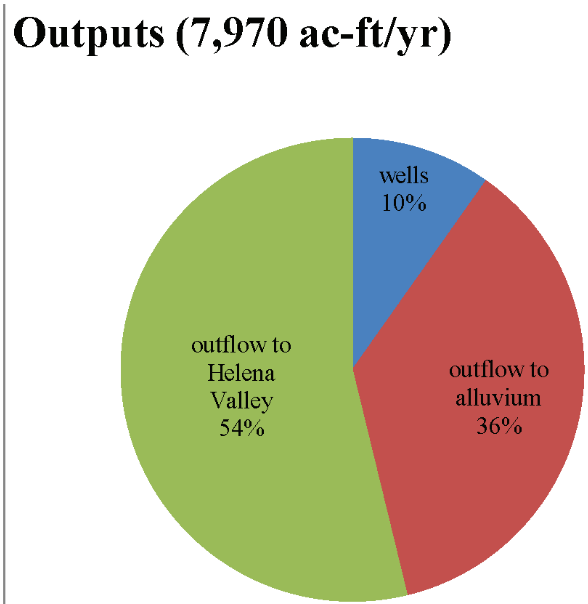


Figure 23. There are no observed large-scale changes in groundwater levels, so groundwater budget balances (no change in storage). Water inputs relate to irrigation activities (38%), stream infiltration (28%), diffuse infiltration (28%), and bedrock inflow (6%). The Green Meadow CGWA is supplied only by diffuse infiltration (fig. 14). Outflow is to wells (10%) and directly or indirectly to the Helena Valley Aquifer (90%). The Helena Valley Aquifer discharges to Lake Helena.

featuring a PWS well rather than individual wells (figs. 24 to 27, and table 4), which was strongly influenced by the selective placement of the PWS well in relatively productive alluvium. The lateral and vertical extent of drawdown also increased substantially with increased numbers of houses.

Water Chemistry

Seventy-four groundwater samples from 25 sites and 30 surface-water samples from 12 sites have been analyzed for this study. Groundwater samples were collected from domestic wells and monitoring wells. Data from the USGS's bedrock study (Thamke, 2000) and from the MBMG's North Hills Investigation (Waren and others, 2012) were also used in this analysis. The Scratchgravel Hills Technical Report (Bobst and others, in preparation a) includes a listing of the sampling locations, including GWIC IDs. All results are available on GWIC by using each site's GWIC IDs.

Groundwater

Water types are classified based on the relative abundance of major-ions (as milliequivalnts per liter). Because classification systems are typically developed for specific regions (Harvey and others, 2002), for this study the chemistry of the sampled groundwater in the Scratchgravel Hills study area has been grouped as six different water types following the approach developed for the Helena Valley by the Lewis and Clark Water Quality Protection District (Swierc, 2011, 2013). These results are also presented as Stiff diagrams (fig. 28; Stiff, 1951).

Calcium-magnesium bicarbonate (Na+K<20%; SO_4<25%) water with fairly low Total Dissolved

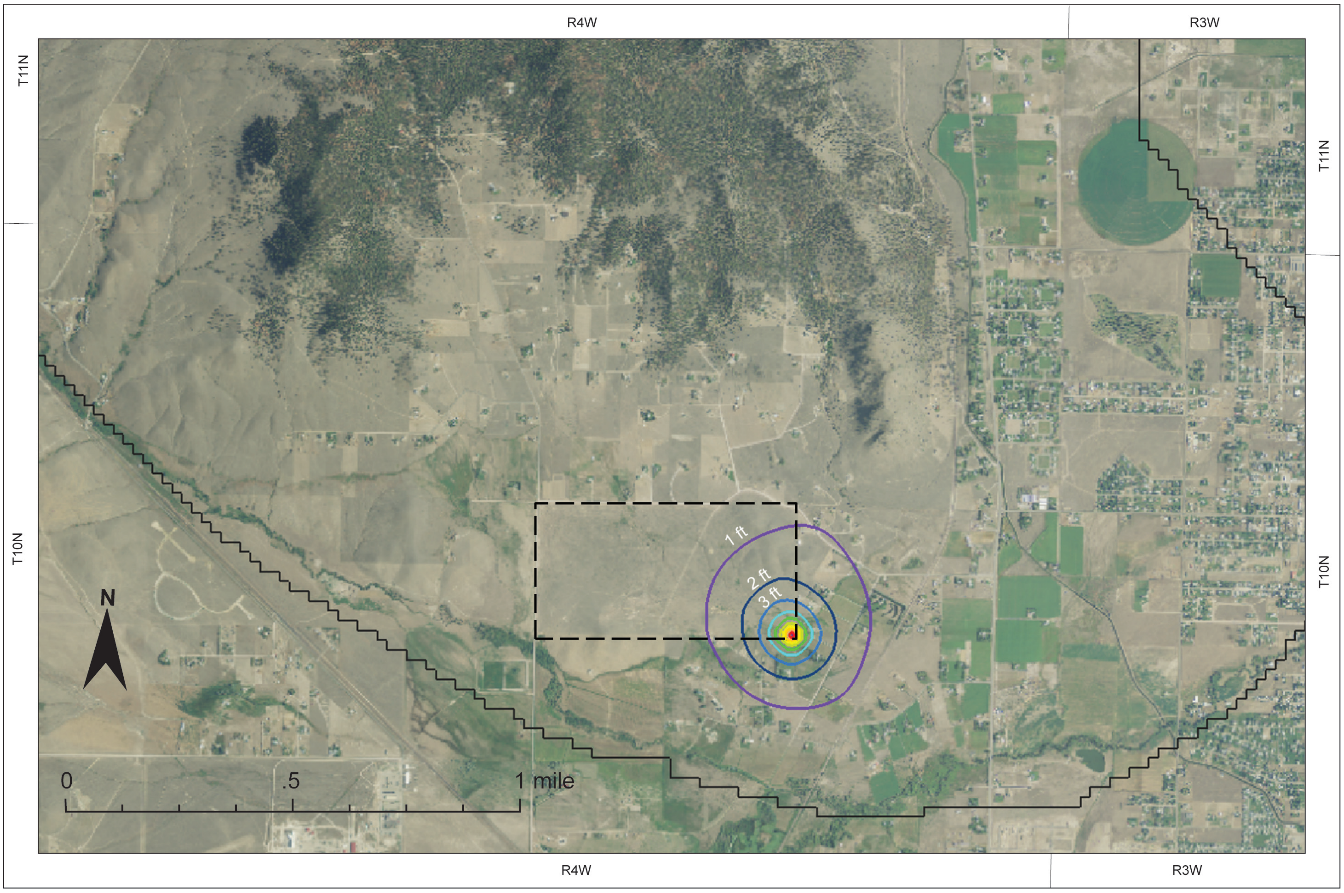
Table 4. Predictive Model Results for Scenarios 1–4.

Scenario	Scenario Description	Maximum Radius of 1 ft of Drawdown (miles) N	E	S	W	Maximum Drawdown (ft)	Time of Maximum Drawdown*[1]	Maximum Drawdown Location
1	10 acre lots—PWS well	0.47	0.33	0.31	0.36	11.2	August of Year 20	PWS well
2	10 acre lots—exempt wells	0.86	0.68	0.52	0.71	7.4	August of Year 20	500 ft N of well field center
3	1.2 acre lots—PWS well	1.33	0.79	0.54	0.87	112	August of Year 20	PWS well
4	1.2 acre lots—exempt wells	1.92	1.14	0.75	~2.0[2]	52.5	September of Year 20	500 ft NE of well field center

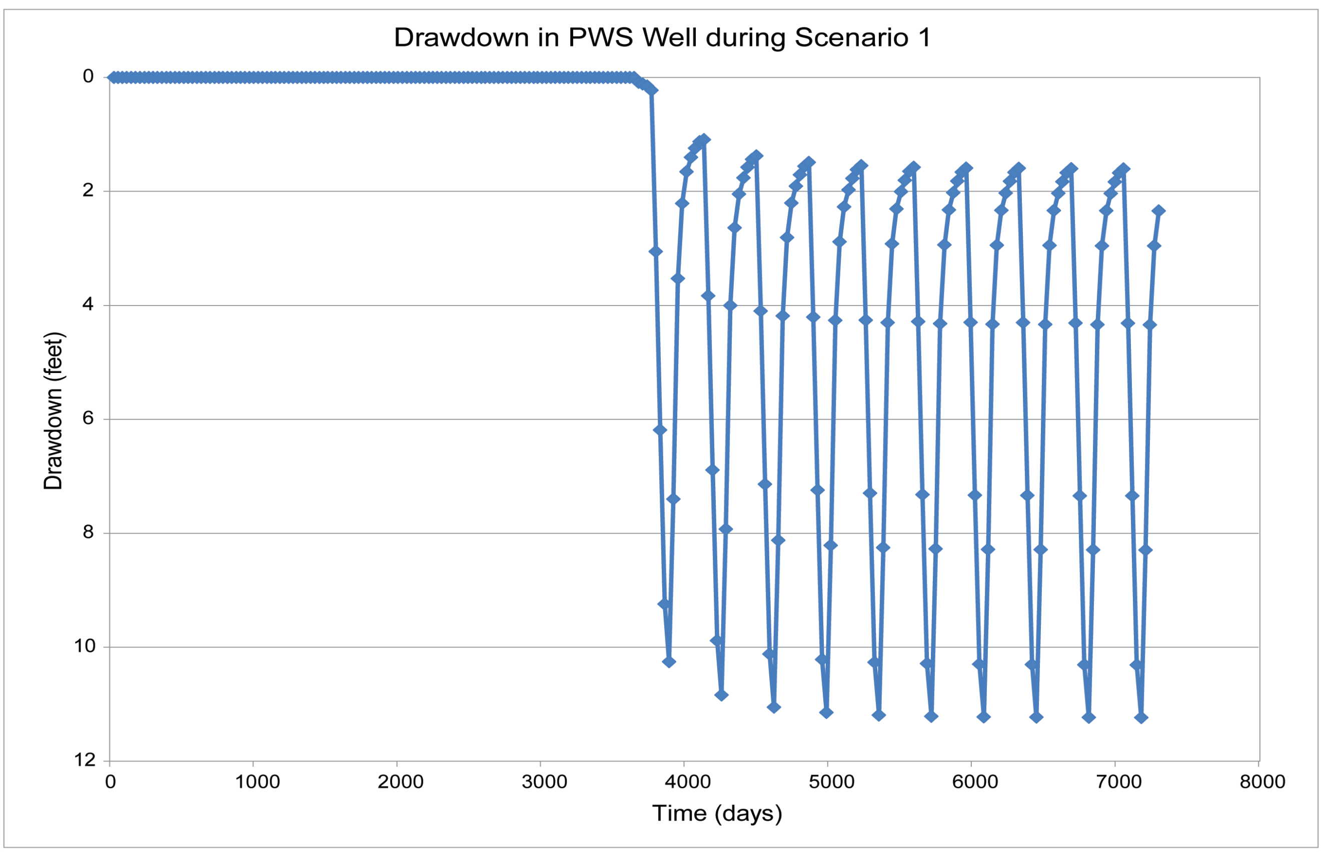
* The time of maximum drawdown did not coincide with the max radius of 1 ft of drawdown. The maximum extent of the 1 ft of drawdown occurred 1 to 4 months after the max drawdown.

[1] Pumping began in Year 11 of each simulation, and so Year 20 represents the tenth year of pumping.

[2] The western max radius of the 1 ft drawdown contour was approximated in Scenario 4 because it hit the grid boundary.

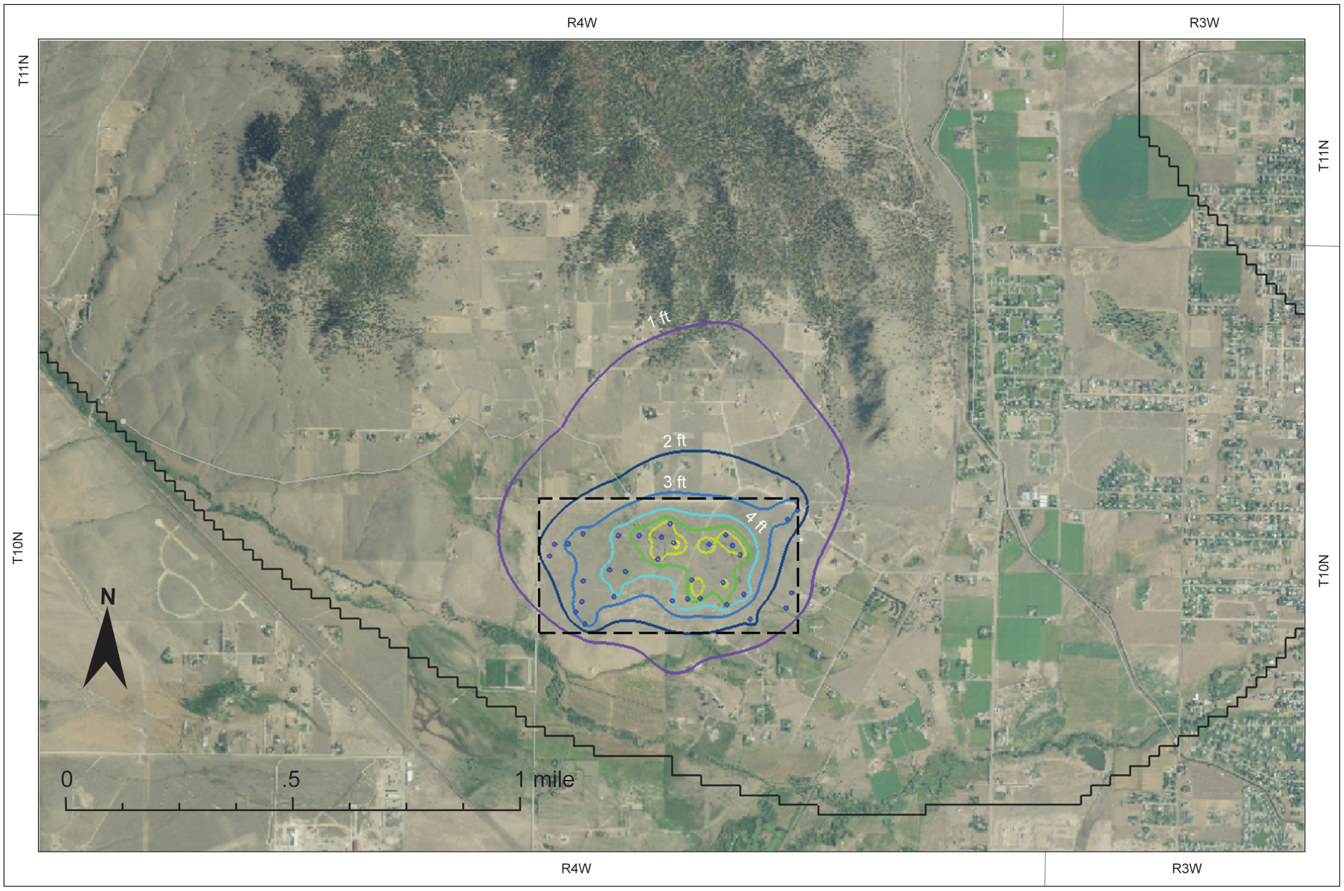


A



B

Figure 24. Scenario 1 illustrates modeled drawdown from a public water supply well located in the SE¼SE¼NE¼ sec. 11, T. 10 N., R. 4 W., designed to provide water to 33 homes on 10-acre lots. This well is completed in the alluvium. The well's maximum radius of influence extends about 0.5 mile (A), its maximum drawdown is approximately 11 ft, and water levels stabilize during the 10-yr model run (B).



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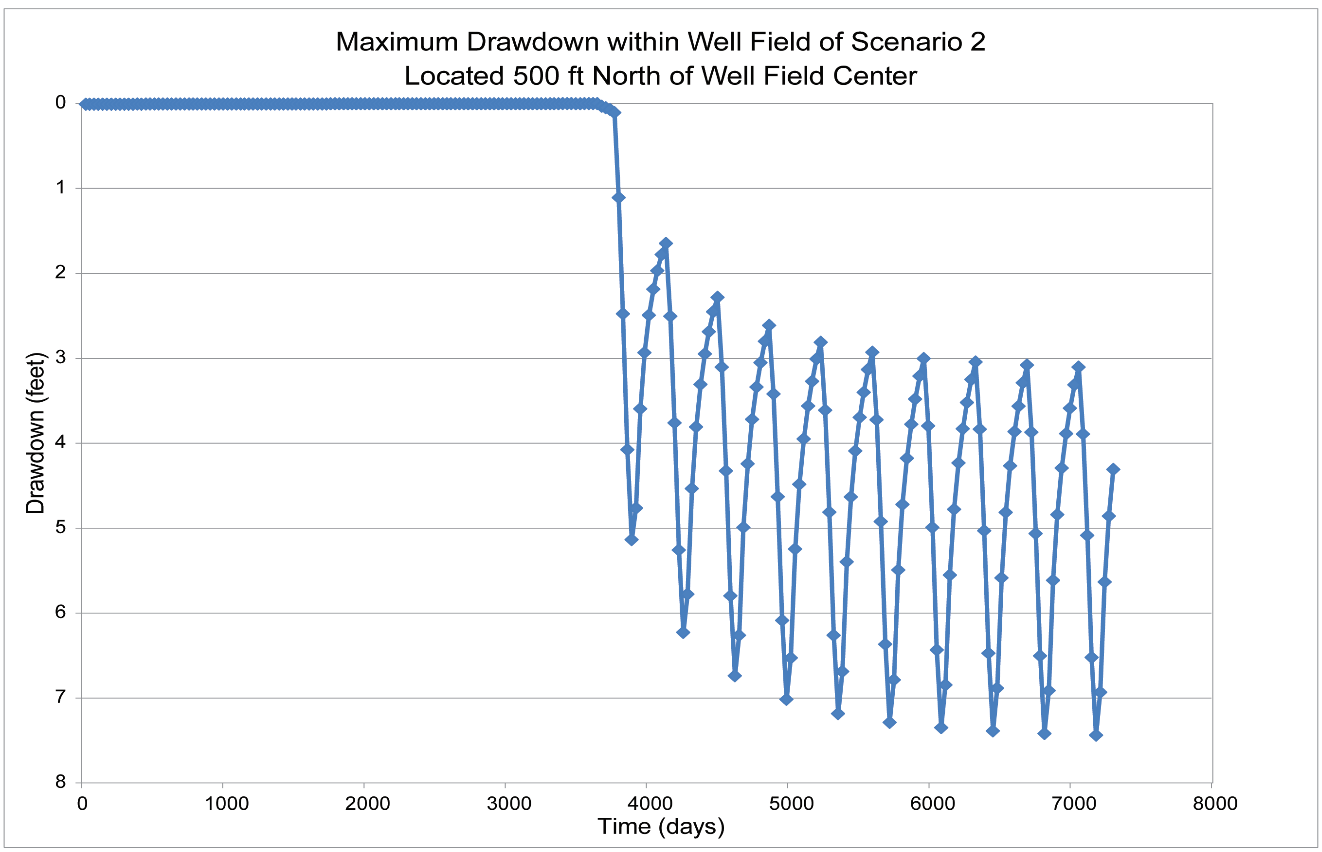


B

Figure 25. Scenario 2 illustrates modeled drawdown from individual wells used for 33 homes on 10-acre lots in the north half of sec. 11, T. 10 N., R. 4 W. Most of these wells are completed in the granite. The maximum radius of influence extends about 0.9 miles beyond the outermost well (A), maximum drawdown is approximately 7 ft, and water levels stabilize during the model run (B).

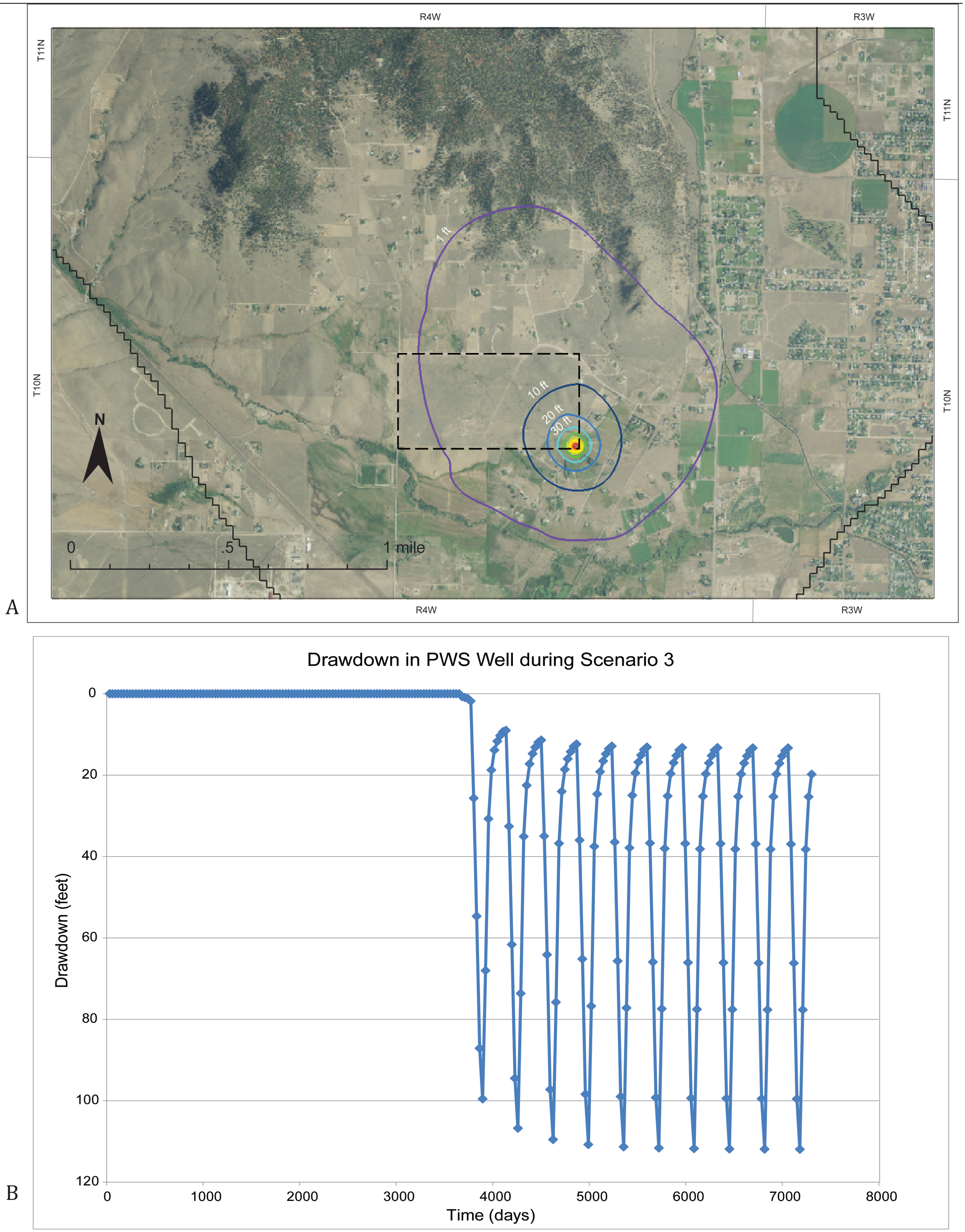
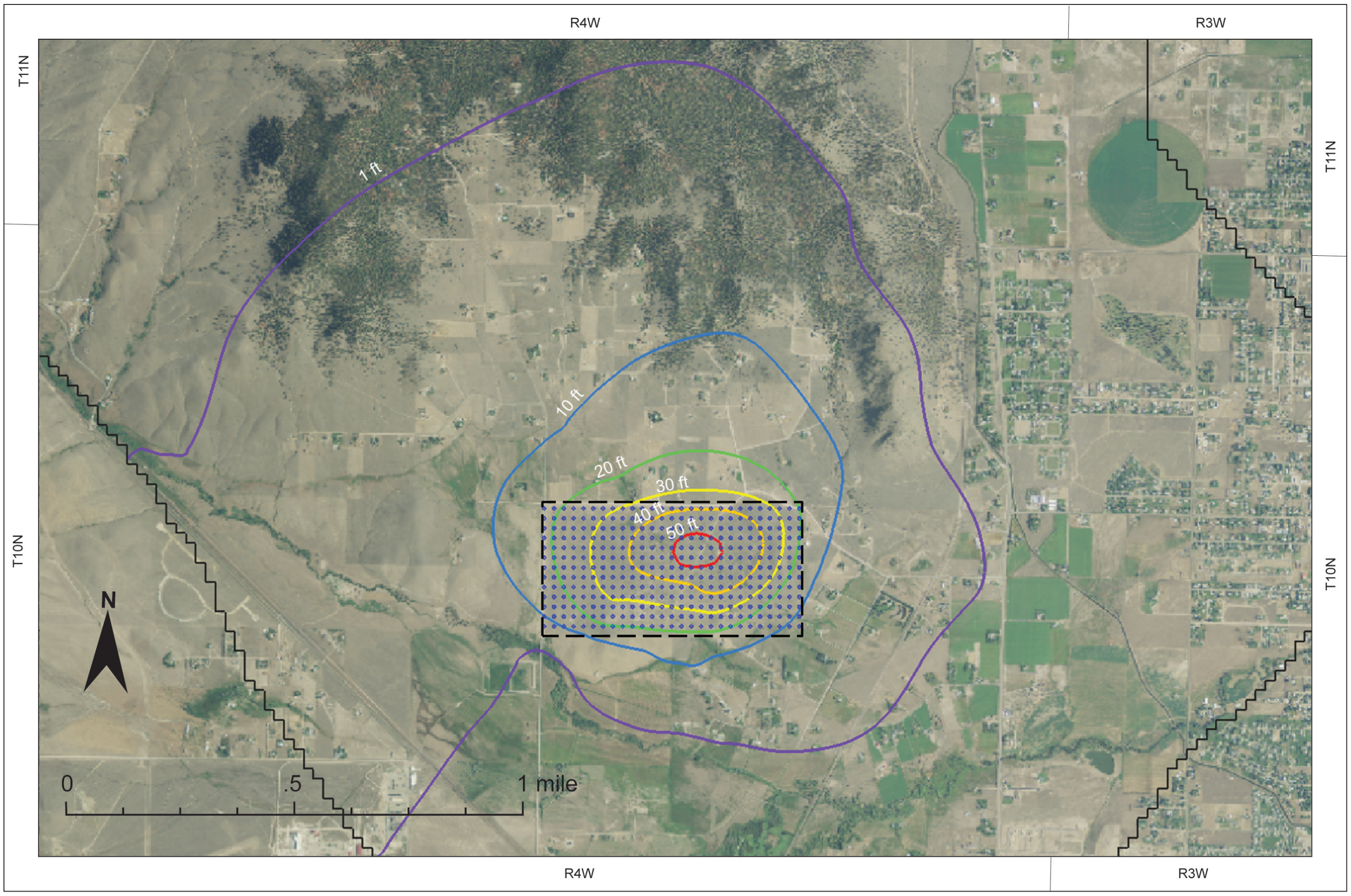


Figure 26. Scenario 3 illustrates modeled drawdown from a public water supply well located in the SE¼SE¼NE¼ sec. 11, T. 10 N., R. 4 W., designed to provide water to 267 homes on 1.2-acre lots. This well is completed in the alluvium. The well's maximum radius of influence extends about 1.3 miles (A), maximum drawdown is approximately 112 ft, and water levels stabilize during the model run (B).



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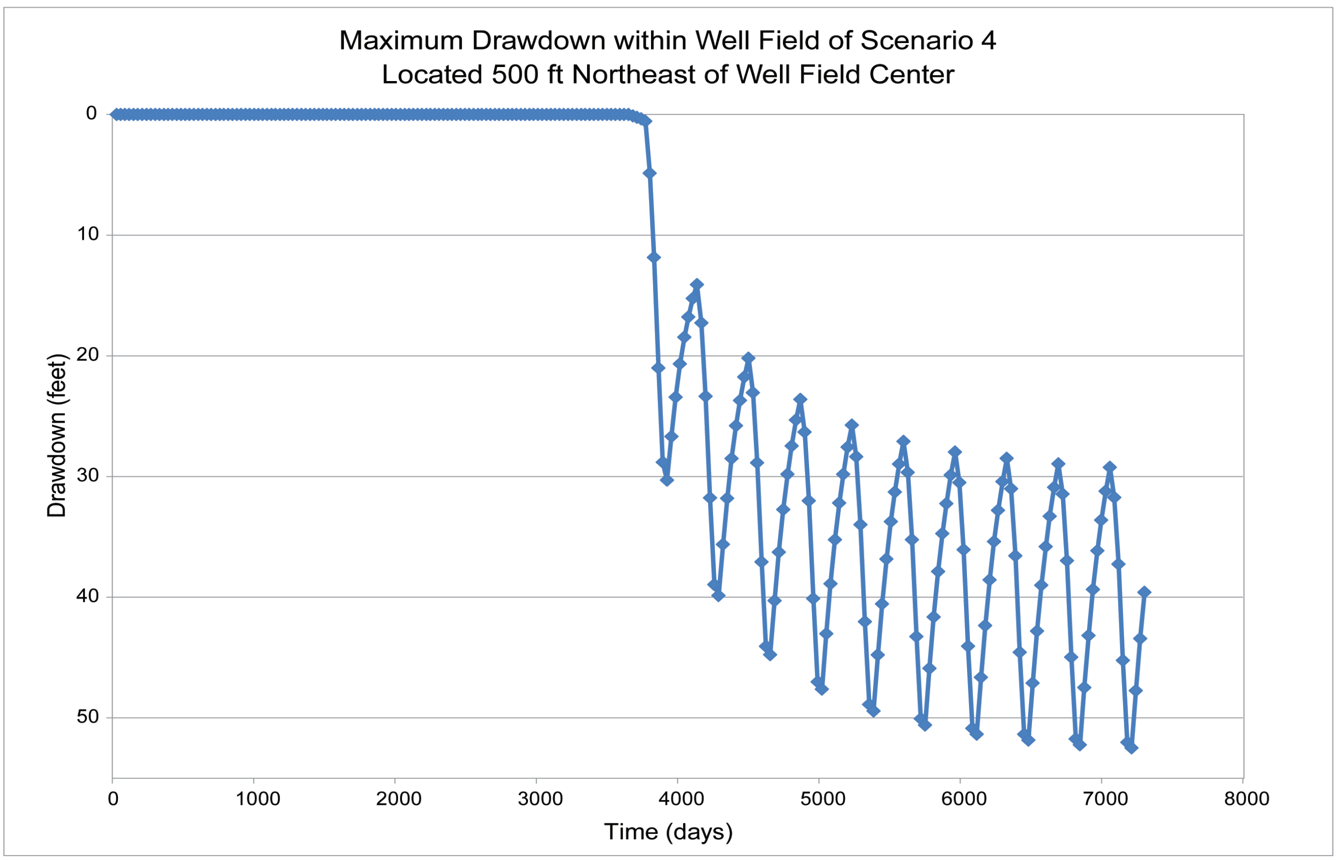

B

Figure 27. Scenario 4 illustrates modeled drawdown from individual wells used for 267 homes on 1.2-acre lots in the north half of sec. 11, T. 10 N., R. 4 W. Most of these wells are completed in the granite. The maximum radius of influence extends 2 miles beyond the outermost well (A), maximum drawdown is approximately 52 ft, and water levels do not fully stabilize during the model run (B). Well interference within the well field causes the maximum drawdown to occur in an area 500 ft northeast of the well field's center.

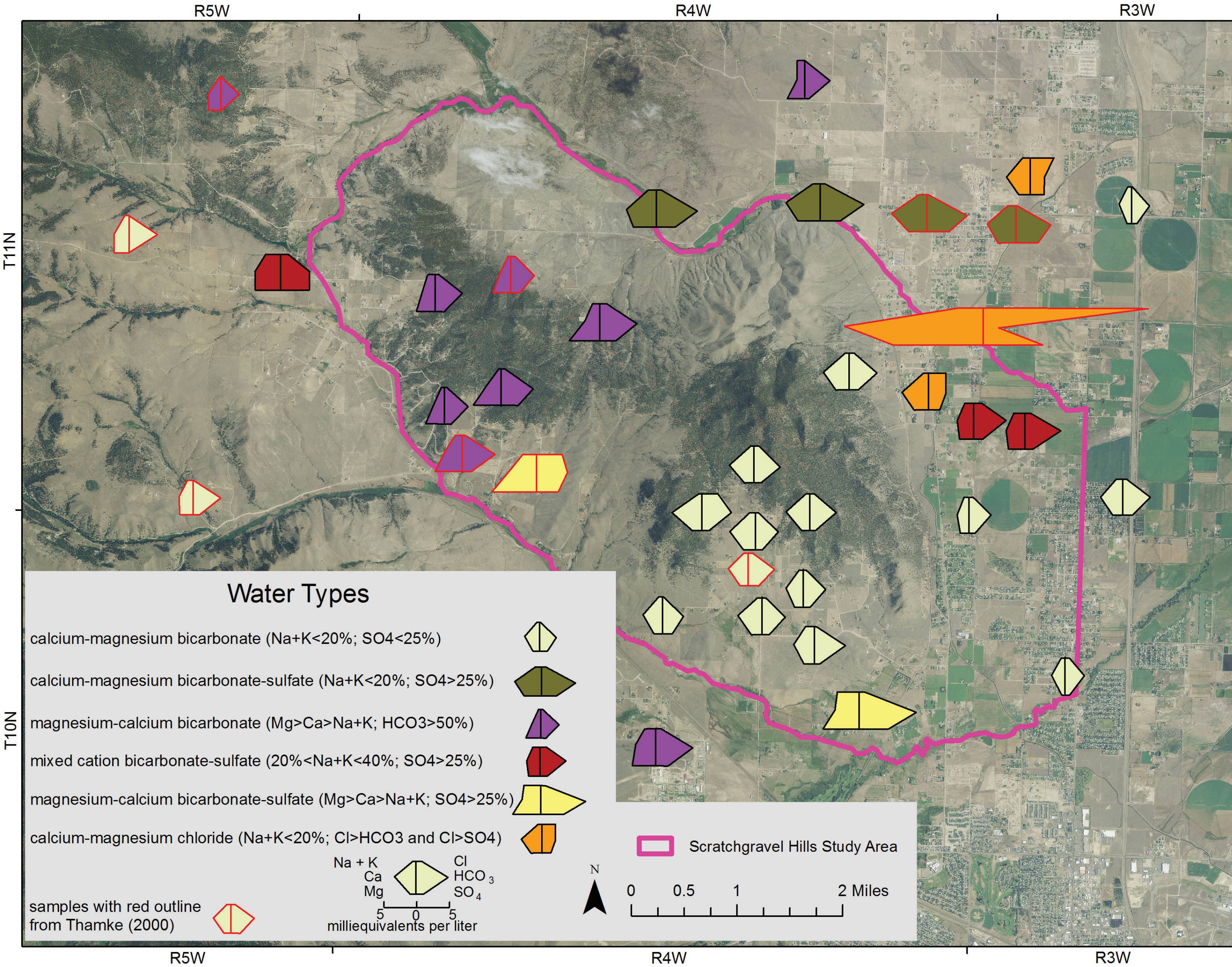

Figure 28. Stiff diagrams (Stiff, 1951) of groundwater chemistry show six general groundwater types within the Scratchgravel Hills Study Area. Diagrams developed using data from this study have black outlines. Diagrams with red outlines use data from Thamke (2000). Three rounds of sampling were conducted for this study; however results from each event were similar.

Solids (TDS) concentrations was the dominant water type in samples from the granitic core of the Scratchgravel Hills, wells completed in bedrock west of the study area, and wells completed in the Helena Valley Aquifer. This chemistry commonly results from water flowing through aquifers containing limestone and igneous rocks.

Calcium-magnesium bicarbonate-sulfate ($Na+K<20\%$; $SO_4>25\%$) water was observed in the alluvium near Silver Creek. This chemistry is similar to that seen in Silver Creek water.

Magnesium-calcium bicarbonate ($Mg>Ca>Na+K$; $HCO_3>50\%$) type water occurs in the dolomitic Helena formation, and the west part of the study area. Dolomite is similar to a limestone, except that it contains more magnesium.

Mixed cation bicarbonate-sulfate ($20\%<Na+K<40\%$; $SO_4>25\%$) water was present in several locations in the study area. Based on geology, this chemistry may be associated with areas of skarn. This chemistry is observed in a well completed in the Bald Butte Fault Zone, and in two wells downgradient from the former John G. Mine.

Magnesium-calcium bicarbonate-sulfate ($Mg>Ca>Na+K$; $SO_4>25\%$) water was present at a couple locations in the southern part of the study area. Based on geology, this chemistry may be associated with alteration of the Helena Formation near igneous bodies.

Calcium-magnesium chloride (Na+K<20%; Cl>HCO_3 and Cl>SO_4) water was present in several locations. High chloride levels may be an indication of septic effluent, water softener effluent, or livestock waste (Thamke, 2000).

Results for the most common trace element contaminants of concern for the Helena Valley, as identified in the Lake Helena Watershed Planning Area Restoration Plan (EPA, 2006), and with the addition of manganese, uranium, nitrate and radon are summarized in tables 5 and 6. The maximum contaminant level (MCL) for each parameter are also included for context (DEQ, 2012). Full results are available from GWIC.

Arsenic (As) was detected in all groundwater samples, with a maximum concentration of 27 µg/L. The MCL for arsenic (10 µg/L) was exceeded at one site (well 254740). This site is a well completed within the Bald Butte Fault Zone. Arsenic is associated with skarn mineralization in this area (R. McCulloch, oral commun., 2011).

Cadmium (Cd) was not detected in any samples (MCL = 5 µg/L).

Copper (Cu) was detected at trace levels in 95% of the samples but all results were well below the drinking water standard. The maximum concentration was 16.7 µg/L (MCL = 1,300 µg/L).

Lead (Pb) was detected at trace levels in 50% of the samples but at concentrations below the drinking water standard. The maximum concentration was 2.76 µg/L (MCL = 15 µg/L).

Zinc (Zn) was detected in all samples at levels below drinking water standards. The maximum concentration was 244 µg/L (SMCL = 5,000 µg/L).

Uranium was detected in all groundwater samples, with a maximum concentration of 71.1 µg/L. The MCL for uranium (30 µg/L) was exceeded at one site (well 62471). This site is a well completed near the margin of the Scratchgravel Hills Stock. Uranium is known to occur at seemingly random locations in the valley, and in alteration zones proximal to igneous rocks in the region (Swierc, 2011).

Manganese was detected in 27% of the samples, with a maximum concentration of 85 µg/L. The SMCL for manganese (50 µg/L) was exceeded at three locations (wells 254740, 257063, and 706014).

Nitrate: A statistical summary of nitrate from the groundwater sampling program is presented in table 6. Exceedances of the MCL for nitrate (10 mg/L) were detected during all three sampling events, and the maximum concentration was 14.36 mg/L. Six samples from three sites (wells 65536, 254703, and 706001) had nitrate concentrations greater than the MCL. One site is located near Head Lane, and the other two are near John G Mine Road (fig. 29).

Isotopic ratios for all seven of the nitrate isotope samples from the Scratchgravel Hills plot in the manure and/or septic waste field (Kendall, 1998); however, ratios from three samples plot within the overlapping field, indicative of soil nitrate (fig. 30). All of the samples form a tight group, which suggests a single nitrate source.

Comparisons of nitrate to chloride and Cl/Br mass ratios (fig. 31) indicate that for some samples there are correlations between nitrate and chloride and the Cl/Br mass ratio, while for other samples there are not. If a septic system is working properly, chloride and the Cl/Br mass ratio would be elevated but nitrate would be near background. If the septic system is not fully breaking down nitrate, a correlation between elevated nitrate and chloride and the Cl/Br mass ratio would exist (Davis and others, 1998; Katz and others, 2011). Both situations are seen in the Scratchgravel Hills data, indicating that at some sites septic systems are breaking down nitrate as desired, but at other sites they are not.

Table 5. Statistical summary of selected trace elements in groundwater—Scratchgravel Hills Study Area (μg/L)

	As	Ba	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Se	Tl	U	Zn
Drinking Water Standards	10	2000	5	100	1300	300	50	NA	NA	15	6	50	2	30	5000
(s = secondary MCL)						s	s								s
April 2010 Sampling Event (*n* = 21 total samples)															
Detections	21	20	0	3	21	9	12	21	3	15	7	20	0	21	21
Maximum	25.0	112	0	0.3	13.3	244	56.0	105	0.3	2.8	1.2	43.9	0	16.3	213
Minimum	0.2	0.3	0	0.1	0.3	3.0	1.0	1.1	0.1	0.1	0.1	0.5	0	1.0	1.5
Average	4.1	41.6	N/A	0.2	3.1	36.0	5.7	10.1	0.2	0.7	0.5	3.3	N/A	6.7	37.7
Median	2.9	36.9	N/A	0.1	1.6	4.0	1.0	4.2	0.2	0.2	0.2	1.0	N/A	5.4	16.5
Standard Deviation	5.1	32.4	N/A	0.1	3.4	79.2	15.9	22.1	0.1	0.9	0.4	9.6	N/A	4.4	59.6
August 2010 Sampling Event (*n* = 24 total samples)															
Detections	24	24	0	1	23	8	4	24	1	15	3	23	0	24	24
Maximum	26.9	104	0	0.2	14.1	213	78.0	90.7	0.8	2.4	1.0	30.9	0	60.1	244
Minimum	0.2	0.3	0	0.2	0.7	3.0	1.0	0.9	0.8	0.2	0.4	0.3	0	1.1	1.5
Average	3.7	41.2	N/A	0.2	2.5	79.8	44.8	9.1	0.8	0.5	0.7	2.3	N/A	10.0	25.8
Median	2.6	35.5	N/A	0.2	2.0	26.0	50.0	3.4	0.8	0.3	0.6	0.9	N/A	5.7	10.2
Standard Deviation	5.2	30.1	N/A	N/A	2.7	94.2	35.9	18.2	N/A	0.6	0.3	6.3	N/A	12.0	51.6
October 2010 Sampling Event (*n* = 25 total samples)															
Detections	25	25	0	1	23	5	4	25	0	7	3	24	0	25	25
Maximum	27.0	110	0	0.3	16.7	225	85.0	102	0	2.6	1.0	37.4	0	71.1	231
Minimum	0.2	0.2	0	0.3	0.5	15.0	1.0	1.1	0	0.2	0.4	0.4	0	1.2	0.7
Average	3.9	43.8	N/A	0.3	3.2	120.6	35.5	9.3	N/A	0.9	0.7	2.6	N/A	11.8	30.7
Median	2.9	36.7	N/A	0.3	1.8	156.0	28.0	4.0	N/A	0.5	0.6	1.0	N/A	7.1	8.1
Standard Deviation	5.1	31.8	N/A	N/A	3.6	89.0	35.4	20.0	N/A	0.9	0.3	7.4	N/A	14.2	58.2
April 2011 Sampling Event (*n* = 4 total samples)															
Detections	4	4	0	0	3	0	0	4	0	0	0	4	0	4	4
Maximum	3.7	81	0	0	3.2	0	0	9.6	0	0	0	1.5	0	12.7	5.9
Minimum	0.4	17.4	0	0	1.7	0	0	1.6	0	0	0	0.6	0	4.6	0.6
Average	1.9	50.1	N/A	N/A	2.2	N/A	N/A	4.3	N/A	N/A	N/A	0.9	N/A	7.1	2.8
Median	1.7	50.8	N/A	N/A	1.9	N/A	N/A	2.9	N/A	N/A	N/A	0.8	N/A	5.5	2.4
Standard Deviation	1.5	35.2	N/A	N/A	0.8	N/A	N/A	3.6	N/A	N/A	N/A	0.4	N/A	3.8	2.4

Note. Statistics are based on samples for which the element was detected. Highlight indicates exceedance of a standard.

Table 6. Summary of groundwater nitrate data—Scratchgravel Hills (concentrations in mg/L)

	April 2010	August 2010	October 2010
Total Number of Samples	21	26	27
Number of Detections	18	22	25
Maximum	12.96	13.53	14.36
Minimum	0.52	0.15	0.06
Average	3.56	2.85	2.70
Median	1.70	1.41	1.13
Standard Deviation	3.59	3.82	3.66

Note. Highlight indicates exceedance of the drinking water standard (10 mg/L).

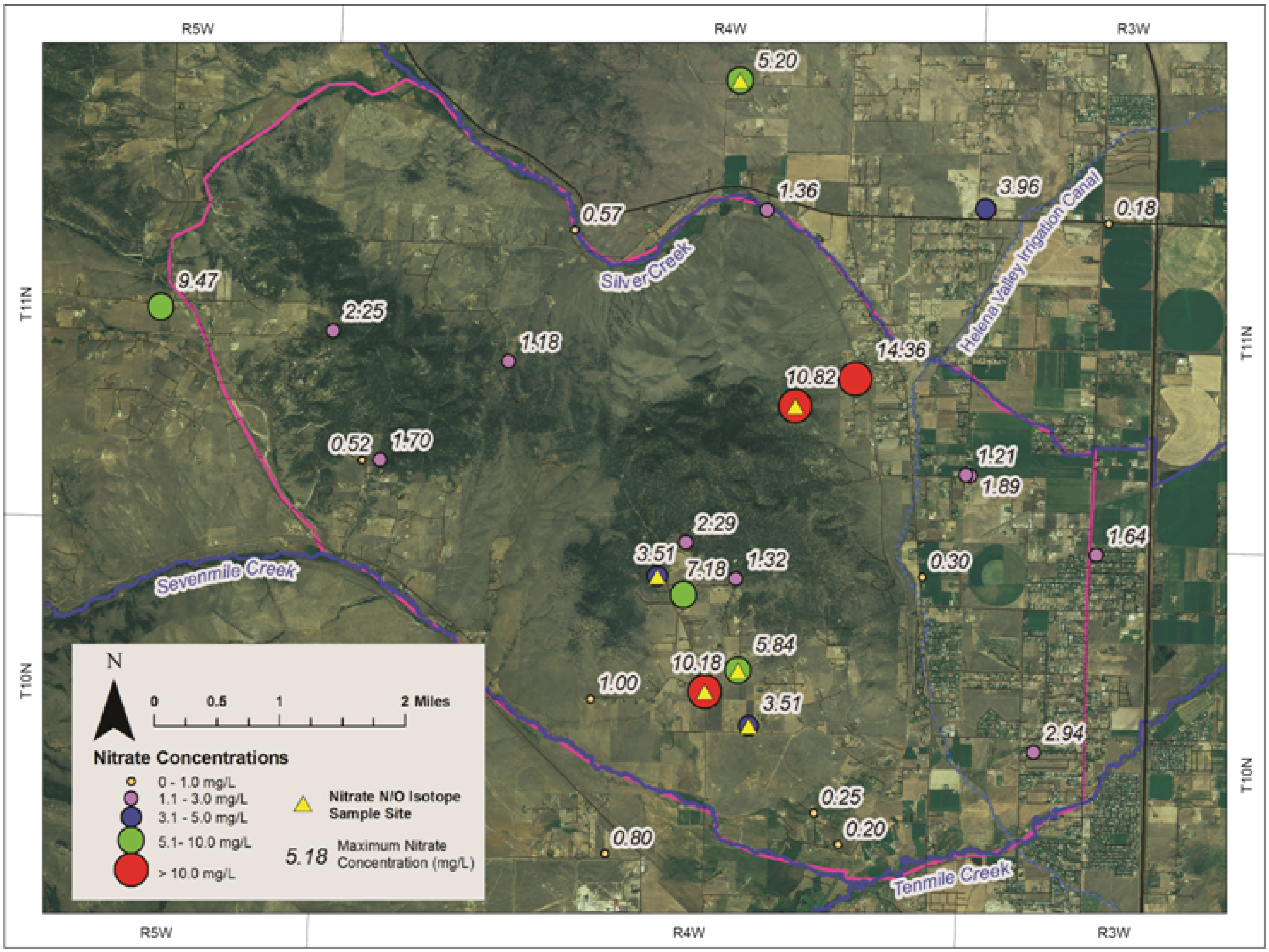

Figure 29. Groundwater samples from three sites had nitrate (NO_3 as N) concentrations that exceeded the primary drinking water standard of 10 mg/L. There is no apparent correlation between nitrate concentrations and housing density or upgradient or downgradient locations. All concentrations greater than 5 mg/L occur where bedrock is near land surface.

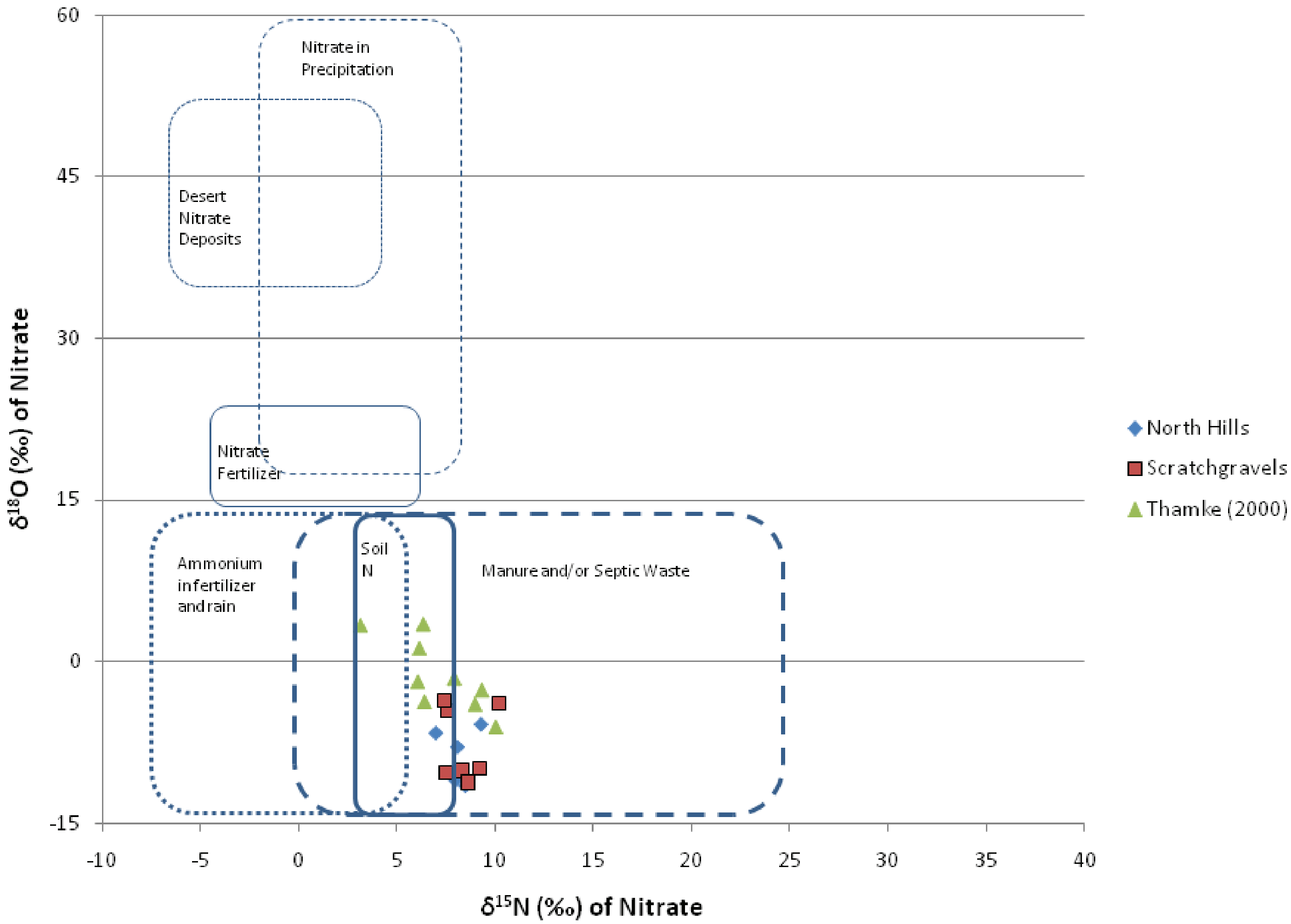

Figure 30. Nitrogen and oxygen isotopic analyses on groundwater samples from this study, a recently completed MBMG study in the North Hills (Warren and others, 2012), and a previous USGS study (Thamke, 2000) produced results that plot in the manure and/or septic waste region (Kendall, 1998). About 50 percent also plot within the overlapping soil nitrogen region, and one sample also falls within the overlapping ammonium field.

Isotope ratios identify three potential sources of nitrate (septic, livestock, and soils); however, nitrate concentrations and correlations with chloride and the Cl/Br mass ratio indicate that within the Scratchgravel Hills, septic systems are the primary sources. Because natural groundwater nitrate levels resulting from soil nitrogen are typically less than 2 mg/L (Mueller and Helsel, 1996), and the isotope samples were obtained from wells that had nitrate concentrations in excess of 3 mg/L, soil nitrate is an unlikely source. Nitrate levels from soil can become elevated due to ground disturbance (Wakida and Lerner, 2002); however, the distribution of maximum-nitrate values shows that the highest values are in areas where there has been little recent construction activity. Additionally, most samples have chloride and Cl/Br mass ratios that are elevated relative to natural background levels. Soil nitrate sources would not also change the background chloride values. The chloride to Cl/Br mass ratio plot also shows a trend between dilute groundwater and septic effluent, indicating that groundwater quality is affected by septic effluent (fig. 31). If the source were from cattle (Cl/Br mass ratio of 86; Hudak, 2003), the chloride to Cl/Br mass ratio plot would not slope upward.

While nitrate levels were generally low in sampled groundwater, these data should not necessarily be interpreted as representative of concentrations all locations within the study area. Nitrate plumes from septic systems are generally narrow and well defined when present in groundwater (DeBorde and others, 1998). Well location relative to the plume is critical when characterizing water-quality effects, particularly in fractured flow systems. As a result, closely spaced wells can have significantly different nitrate concentrations (fig. 29). The majority of wells sampled with this

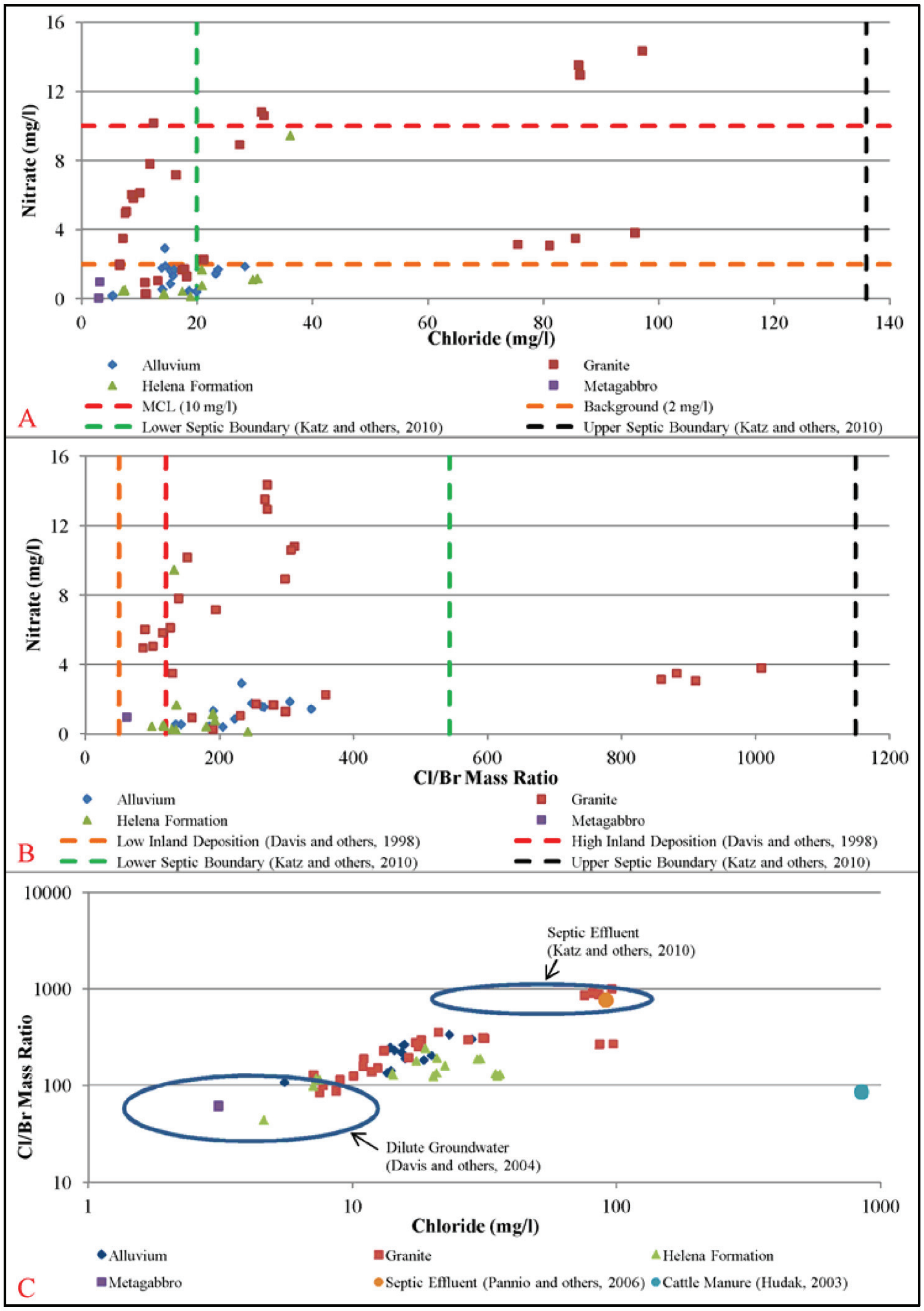

Figure 31. Elevated nitrate concentrations are related to elevated chloride concentrations (A) and high Cl/Br mass ratio values (B); however, there are some elevated chloride concentrations (A) and high Cl/Br mass ratio values (B) that do not correspond with elevated nitrate. The incongruity appears to be caused by sites where nitrate in septic effluent is being partially or completely degraded in the soil zone. Almost all samples containing elevated nitrate concentrations came from granitic aquifers. These elevated nitrate concentrations cannot be caused by soil or livestock sources because both chloride concentrations and Cl/Br mass ratios are high. That the high nitrate concentrations come from septic effluent sources is also supported by the trend between regions of dilute groundwater and septic effluent (shown by ovals) on the chloride to Cl/Br mass ratio plot (C).

study are domestic wells, located by design away from known septic systems. In addition, monitoring wells are located in areas away from specific potential contaminant sources to obtain samples representative of general groundwater conditions. Fractured bedrock tends to allow for rapid infiltration of effluent, and the fractures tend to focus contaminate plumes.

Radon: Granite and shale have been associated with high radon levels (Tanner, 1986); however, all groundwater radon values from the Scratchgravel Hills (maximum of 2,346 pCi/L) were below the proposed standard (4,000 pCi/L; EPA, 1999; fig. 32).

Organic Waste Chemicals: Four sites were sampled for organic waste-water chemicals (OWCs; e.g., pharmaceuticals) in the Scratchgravel Hills. The only compound detected was sulfamethoxazole, a bacteriostatic antibiotic that is sold under the brand names Bacterim, Septerin, or Septra. Sulfamethoxazole was found at three sites (wells 62369, 65088, and 65615). Concentrations ranged from 5.9 to 53 nanograms per liter (ppt). Sulfamethoxazole is commonly found in groundwater since it is typically not well attenuated (Avisar and others, 2009; Barber and others, 2009; and Underwood and others, 2011). The presence of sulfamethoxazole indicates that water quality has been influenced by septic discharges; however, because sulfamethoxazole is not easily broken down, and septic systems are supposed to discharge to groundwater, the indication is not unexpected. Because only four wells were sampled for OWCs, no significant conclusions can be drawn from these data.

A previous study in the area (Miller and Meeks, 2006) also found sulfamethoxazole in groundwater; however, in that study atrazine was also detected. The authors of that study note that advanced treatment of waste water may be needed to remove these contaminants.

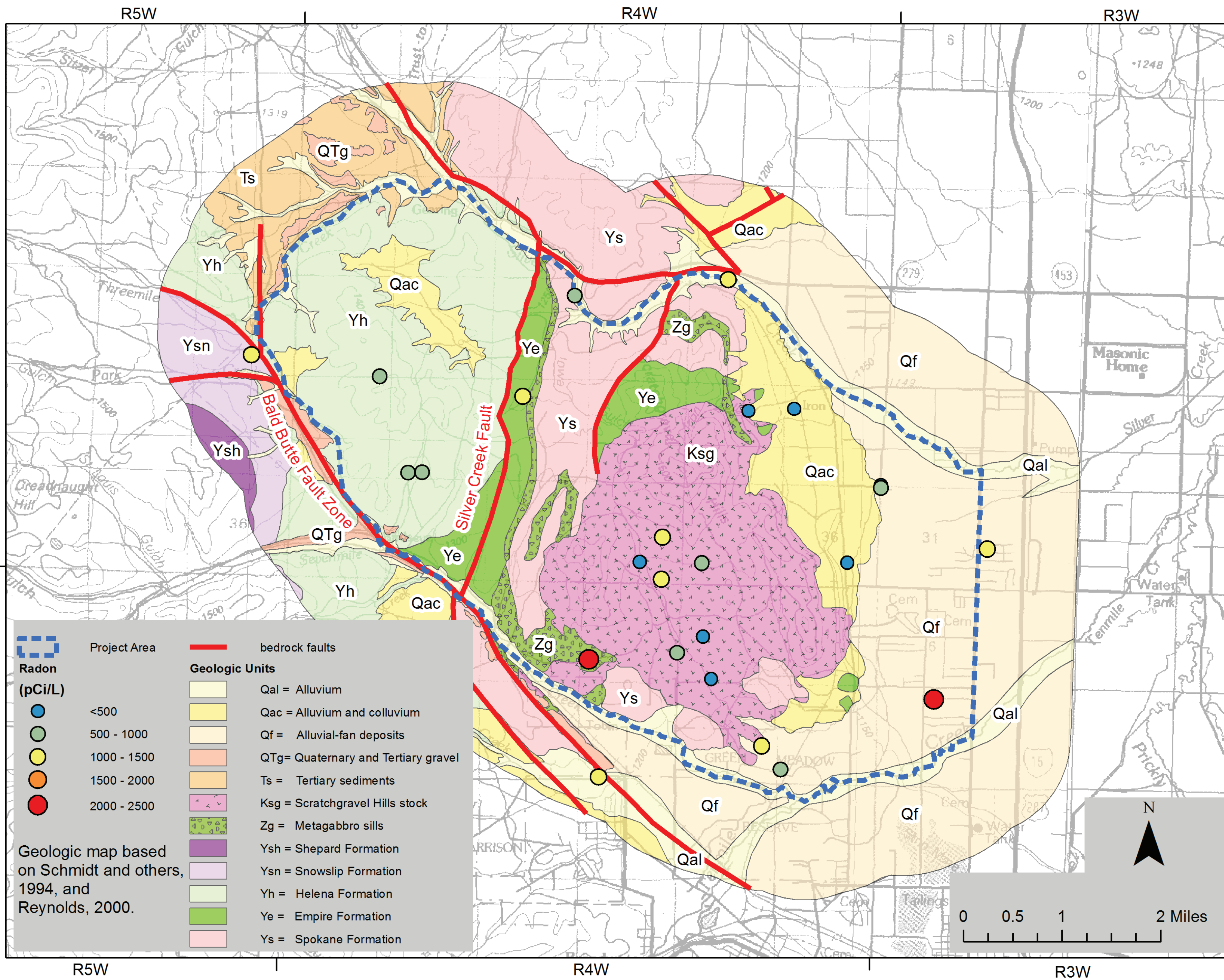

Figure 32. Analysis for radon in groundwater shows that all values are less than the proposed 4,000 pCi/L standard. The highest radon concentration was in a groundwater sample obtained from the metagabbro (Zg).

Surface Water

Surface-water chemistry was generally stable over time. Samples of Silver Creek water were a calcium-magnesium bicarbonate-sulfate type similar to that of local groundwater. Water collected from the agricultural drains west of Lake Helena is considered representative of shallow groundwater, because the drains were installed to remove excess groundwater in the central part of the valley. The drain water was generally a mixed-ion type. Water chemistry in the Lake Helena causeway was calcium-magnesium bicarbonate type, consistent with that observed in the Tenmile Creek and the HVID canal. These sources, along with Prickly Pear Creek, are the major contributors of surface water to Lake Helena (fig. 33).

The only drinking water standard exceeded in surface water was for arsenic (table 7). Arsenic was detected in samples from Silver Creek and Tenmile Creek at concentrations slightly above the drinking water standard, consistent with the TMDL designation of impairment for those streams (EPA, 2006). In addition, arsenic concentrations above the drinking water standard were detected in the HVID canal, consistent with a previous USGS study (Kendy and others, 1998). Arsenic typically exceeds the drinking water standard in the Missouri River. The major source of this arsenic is hydrothermal inputs from Yellowstone Park to the Madison River (Sonderegger and others, 1989a,b). The water in the HVID canal is obtained from the Missouri River.

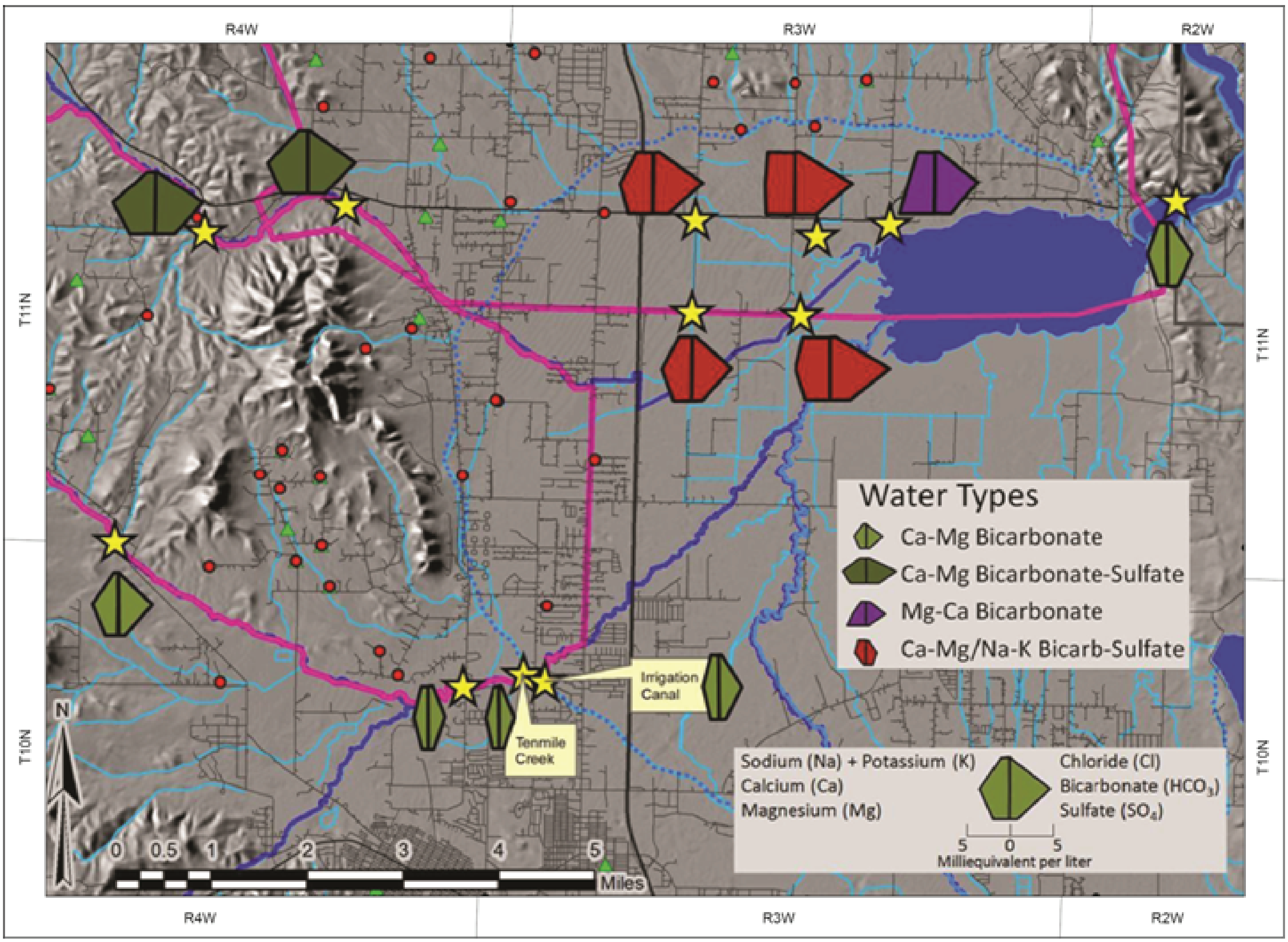

Figure 33. There are four general surface-water types in the area of the Scratchgravel Hills. These data also show that the water flowing out the Lake Helena Causeway is similar to water from Tenmile Creek, Sevenmile Creek, and the HVID Canal. Waters from Silver Creek have the highest TDS, while Tenmile Creek has the lowest TDS.

The chronic aquatic-life standards for cadmium were exceeded in two samples from Tenmile Creek (table 7). All surface-water samples for copper, lead, and zinc were below the acute and chronic standards.

Total nitrogen was detected above the target goal concentration (0.33 mg/L) from at least one event at most locations; however, the highest levels were detected in the drain samples during all sampling events (table 7). The MCLs for nitrate and total nitrogen were not exceeded in surface waters. All phosphorus samples were below the detection limit (0.1 mg/L).

Hydrogen and Oxygen Isotopes of Water

Hydrogen and oxygen isotope data from water sampled for this study are plotted with data from a recent MBMG study in the North Hills (Waren and others, 2012), from a previous USGS study (Thamke, 2000), and from Butte (Gammons and others, 2006; fig. 34). Snow samples were collected in early March 2010 from locations within the North Hills and from higher altitudes in the Silver Creek watershed north and west of the Scratchgravel Hills study area. Samples from drains, the HVID canal, springs, streams, and wells were collected between March and June 2010.

The snow samples plot near the meteoric water line (MWL) and are comparable to the lower end of Butte values (fig. 34), which is not unexpected since they are from winter precipitation. The remaining data plot parallel to but offset to the right of the MWL and the Butte data. The offset is consistent with the groundwater being from relatively recent precipitation that has undergone minor evaporation, little exchange of oxygen with calcite, or has slight hydrothermal inputs (Drever, 1997). Because groundwater ages have been reported as being relatively young (Thamke, 2000), and results from surface-water and groundwater samples are both and similarly offset, significant hydrothermal inputs are unlikely.

DISCUSSION OF THE HYDROGEOLOGIC SYSTEM

Groundwater Flow

There are five hydrogeologic units in the Scratchgravel Hills. These units form a single groundwater flow system within which water flows readily between units, generally under unconfined conditions.

Aquifer properties vary by unit, are geologically controlled, and have predictable distributions (fig. 3). Precambrian bedrock units have similar permeability, with the geometric mean hydraulic conductivities of the argillite, Helena Formation, and metagabbro being 3.9, 1.1, and 2.2 ft/day, respectively (table 2). The granitic core of the Scratchgravel Hills is about an order of magnitude less permeable, having a geometric mean hydraulic conductivity of 0.18 ft/day. Storativity values for the bedrock units indicate semi-confined to unconfined conditions (0.0001 to 0.03). The median reported well yield from the bedrock aquifers is 13 gpm, with production rates ranging from 1 to 200 gpm. Hydraulic conductivity, storage, and yield are all dependent on the degree to which the bedrock units are fractured.

Unconsolidated Quaternary units are generally more productive than the bedrock. They have a geometric mean hydraulic conductivity value of 75 ft/day. These aquifers are generally unconfined (storativity from 0.008 to 0.05). The median reported well yield from the unconsolidated aquifers is 20 gpm, with yields ranging from 4 to 890 gpm.

Investigations at sites along faults, in the Scratchgravel Hills and the North Hills study areas (Waren and others, 2012), indicate that faults are typically barriers to flow due to the formation of fine-grained fault gouge. Water does move through the faults, but at a much slower rate than through surrounding bedrock. Where faults are present, they will have a strong site-specific influence on groundwater flow.

The potentiometric surface in the Scratchgravel Hills is generally a subdued reflection of the ground surface. Regional flow is from the mountains to the west to the Helena Valley; however, this is modified by local patterns. Groundwater flow is radial

Table 7. Summary of surface-water parameters which exceed some standard.

Site Name	Sample Date	As (μg/l) MCL = 10 AA = 340, AC = 150	Cd (μg/l) MCL = 5 1.2<AA<7.8; 0.2<AC<0.7; hardness dependent	N (mg/l) - MCL = 10 MCL = 10; TMDL target = 0.33 NO_3–N	Total N
HVID D-2-2.3-1 (DA)	4/6/2010	2.4	<0.1	1.89	N/A
HVID D-2-2.3-1 (DA)	8/12/2010	3.6	<0.2	3.21	4.14
HVID D-2-2.3-1 (DA)	10/11/2010	2.8	<0.2	4.69	5.02
HVID D-2-2.3-2L (DC)	4/6/2010	3	<0.1	2.65	N/A
HVID D-2-2.3-2L (DC)	8/13/2010	15.9	<0.2	0.72	1.61
HVID D-2-2.3-2L (DC)	10/11/2010	3.2	<0.2	4.5	5.19
HVID D-2-0.7-1 (DD)	4/7/2010	4.9	<0.1	0.99	N/A
HVID D-2-0.7-1 (DD)	8/12/2010	9.2	<0.2	0.51	2.61
HVID D-2-0.7-1 (DD)	10/11/2010	4.4	<0.2	0.87	1.22
HVID D-1_UPPER (DE)	4/6/2010	3.7	<0.1	1.57	N/A
HVID D-1_UPPER (DE)	8/13/2010	3.8	<0.2	2.2	3.11
HVID D-1_UPPER (DE)	10/11/2010	3.6	<0.2	2.3	2.95
HVID D-0 ARMSTRONG (DG)	4/6/2010	8.1	<0.1	2.05	N/A
SILVER CREEK; SW-SC1	4/7/2010	5.2	<0.1	<0.5	N/A
SILVER CREEK; SW-SC1	8/12/2010	11.1	<0.2	<0.05	1.64
SILVER CREEK; SW-SC1	10/8/2010	8.1	<0.2	<0.05	<1.0
SEVENMILE CREEK * 7M-SW1	4/7/2010	5.7	<0.1	<0.5	N/A
SEVENMILE CREEK * 7M-SW1	8/13/2010	7.5	<0.2	0.13	<1.0
SEVENMILE CREEK * 7M-SW1	10/11/2010	6.9	<0.2	<0.05	2.54
SILVER CREEK; SC-2 * SC-SW2	4/6/2010	5.6	<0.1	0.26	N/A
SILVER CREEK; SC-2 * SC-SW2	8/12/2010	10.7	<0.2	<0.05	1.13
SILVER CREEK; SC-2 * SC-SW2	10/8/2010	8	<0.2	<0.05	<1.0
LAKE HELENA CAUSEWAY	4/7/2010	5.9	<0.1	<0.5	N/A
LAKE HELENA CAUSEWAY	8/13/2010	13.7	<0.2	<0.05	1.29
LAKE HELENA CAUSEWAY	10/11/2010	10.4	<0.2	0.08	<1.0
TENMILE AT GREEN MEADOW	4/6/2010	10.2	0.48	<0.5	N/A
TENMILE CREEK AT MCHUGH LANE	8/12/2010	9.7	0.2	0.07	1.31
TENMILE CREEK AT MCHUGH LANE	10/7/2010	12.4	<0.2	0.13	<1.0
HVID-1 (MCHUGH LN)	5/4/2010	24.7	<0.1	0.33	N/A
HVID-1 (MCHUGH LN)	8/12/2010	19.9	<0.2	<0.05	<1.0

Note. Highlight indicates exceedance of a standard. AA, Acute aquatic life standard; <0.2 = less than detection limit; TMDL, Total Maximum Daily Load; AC, chronic aquatic life standard; MCL, maximum contaminate level (drinking water standard).

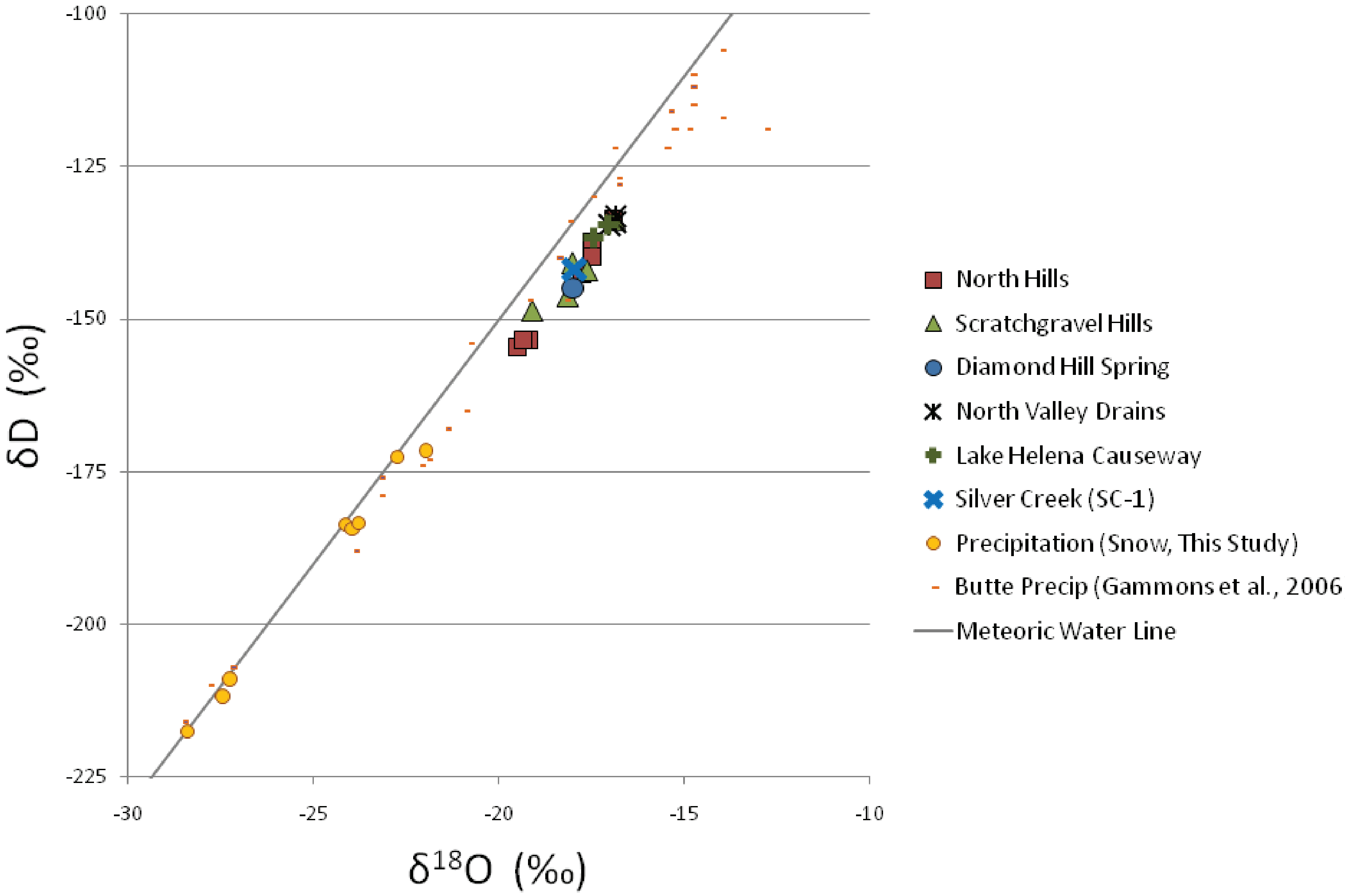

Figure 34. $\delta^{18}O$ and δD data from the Scratchgravel Hills study show that data from snow samples plot on the meteoric water line (MWL) while data from other sources plot parallel to the MWL, but with heavier $\delta^{18}O$. Samples identified as Scratchgravel Hills and North Hills are groundwater from wells. The North Hills samples were obtained during the recently completed MBMG study in the North Hills (Waren and others, 2012). The Diamond Hills sample is from a spring in the North Hills. Surface-water samples are from the North Valley drains near Lake Helena, the Lake Helena Causeway, and Silver Creek. The modestly heavier $\delta^{18}O$ values are consistent with water that has been slightly evaporated, has undergone oxygen exchange with calcite, or has been influenced by hydrothermal waters (Drever, 1997, p. 315).

from the high hills in the center of the study area. Regional flow enters from the west; however, it is deflected to the north and south into the alluvium along Silver Creek and Sevenmile Creek. Overall, flow is towards the Helena Valley Aquifer. Each year the Helena Valley Aquifer “fills up” until agricultural drains prevent further storage (Waren and others, 2012). Irrigation and canal leakage cause water levels below the HVID Canal and the Sunny Vista Canal to rise during the irrigation season, and to decline during the non-irrigation season. In the uplands, above the canals, where there is significant irrigation from groundwater (e.g., yards and gardens), water levels decline during the irrigation season and rise during the non-irrigation season. In the upland area, water levels typically peak in the spring following snowmelt.

Wells in the Green Meadow CGWA obtain groundwater from the local flow system originating in the Scratchgravel Hills. The local flow discharges to the alluvium along the creeks, and to the Helena Valley Aquifer. This alluvial water all flows toward Lake Helena.

The Scratchgravel Hills study area extends about 2 miles onto the western edge of the Helena Valley Aquifer. Briar and Madison (1992) measured water levels in 15 nested shallow-deep well pairs (30 wells) to evaluate vertical gradients. Their study showed that the Helena Valley Aquifer within about 4 miles of Lake Helena has an upward groundwater flow gradient; the aquifer’s perimeter, including that extending into the Scratchgravel Hills study area, has a downward gradient. Monitoring conducted during this study confirms the downward vertical groundwater flow relationships in the Scratchgravel Hills.

Silver Creek, Threemile Creek, Sevenmile Creek, and Tenmile Creek regularly have flow within the study area. Monitoring showed that Silver Creek is a losing stream, where water flows from the stream to the underlying alluvium. While bedrock groundwater flow is towards Silver Creek (fig. 14), Silver Creek does not receive this water because it flows into the alluvium, which is permeable enough to transmit it without discharging groundwater to the surface. Monitoring along Sevenmile Creek shows that the stream and alluvium are in direct communication, and the direction of flow between surface water and groundwater changes depending on conditions. Tenmile Creek is a losing stream. Irrigation canals also leak water to the underlying groundwater.

Surface-water runoff is insignificant on an average annual basis. Runoff was not observed at crest gauges during this study. Due to average annual potential ET being higher than average annual precipitation (Thamke, 2000), the soil is often undersaturated, and is able to absorb the moisture from moderate precipitation events. Fractured bedrock at the surface in many drainages also allows runoff to rapidly infiltrate. Runoff only occurs during relatively rare periods of extended and abundant rainfall or significant snowmelt (e.g., rain on snow events). Thus diffuse groundwater recharge can be approximated as precipitation minus actual ET.

The seasonal fluctuations in flow and water quality observed at springs in the Scratchgravel Hills indicate that their water is obtained from local recharge that travels along short flowpaths, a result of infiltrating water seeping through the colluvial mantel and then encountering the less permeable underlying bedrock, which forces the water to move laterally until it intersects the land surface.

Approximately 8,000 acre-ft/yr of groundwater flows through the Scratchgravel Hills study area. Of this, approximately 41 percent is from infiltration under irrigation canals or from irrigation recharge, 27 percent is from the infiltration of creeks, 26 percent is from diffuse infiltration in the hills, and 6 percent is groundwater inflow. Only the diffuse infiltration in the hills is available to most of the Green Meadow CGWA. Within the Helena Valley and downgradient from the Sunny Vista Canal, leakage of canal water and irrigation recharge are important contributors to the groundwater system. Changes in canal management, or land-use changes, could have significant impacts on groundwater levels in these areas. About 10 percent of the annual groundwater flow is removed by wells and consumed (not returned by septic systems). About 98 percent of the groundwater consumed from domestic wells is for irrigation of lawns and gardens. The rest of the water flows out to unconsolidated sediments, and eventually discharges to Lake Helena. Groundwater withdrawals anywhere in the study area could have the eventual impact of decreasing the total annual flow out the Lake Helena causeway. Due to the distance to Lake Helena, and the intervening influence of irrigation ditches and irrigated fields, any impacts to discharge at the causeway would be seen as steady year-round reductions. These reductions would likely be far smaller than variations caused by normal year-to-year changes in water management in the Helena Valley. Because lake levels are controlled by Hauser Dam, changes in groundwater discharge will cause little variation in lake levels.

Groundwater-Level Trends

Most sites in the Scratchgravel Hills show seasonal groundwater-level variation, but long-term trends not strongly increasing or decreasing. Water levels respond to wet periods when above average recharge occurs (e.g. 1981 and 2011), and to overall trends in precipitation. At two wells water levels show stronger downward trends where annual peak water levels decline at a rate greater than can be attributed to precipitation trends. Due to the scattered distribution of these sites and that landscaping at these sites is rather modest, it appears that this results from aquifers being particularly unproductive at these locations, rather than the result of area-wide drawdown, or excessive local groundwater usage.

Wells completed in the granitic core of the Scratchgravel Hills and in the Helena Formation generally have low yields, and are most susceptible to declines. This is due to these units being less permeable (table 2). These units have median yields around 12 gpm, compared to median reported yields of 15 and 20 gpm for the argillite bedrock and alluvium.

Groundwater Chemistry

Groundwater chemistry in the Scratchgravel Hills was generally good; however, some drinking water standards (MCLs) were exceeded. The major-ion chemistry of local groundwater in the Scratchgravel Hills generally reflects a combination of the chemistry of recharging waters and the geology of the source aquifer.

Six samples from three sites exceeded the drinking water standard for nitrate. Twenty-three samples had nitrate values above background (2 mg/L; Mueller and Helsel, 1996), and of these 21 were from wells completed in the granite. The bedrock aquifers of the Scratchgravel Hills are believed to be susceptible to contamination by nitrate since thin, well-drained soils low in organic carbon overlie fractured crystalline bedrock (Nolan and Hitt, 2006). If a source of nitrate is present, these conditions result in rapid direct infiltration to the groundwater with little potential for denitrification. Septic systems appear to be the source for elevated nitrate.

Three samples from one site exceeded the drinking water standard for arsenic. Two samples from one site exceeded the drinking water standard for uranium. It appears that these higher metals values are local conditions related to alteration zones near the Bald Butte Fault and along the margin of the Scratchgravel Hills stock (granite). It is also likely that other zones where hydrothermal alteration has occurred will have elevated trace element concentrations. Kendy and others (1998) have noted that arsenic levels are elevated in alluvial wells completed near the HVID canal, which obtains its water from the Missouri River. Water from other alluvial wells typically meet water quality standards.

CURRENT AND POTENTIAL IMPACTS FROM HOUSING DEVELOPMENTS

The primary purpose of this groundwater investigation was to determine if groundwater pumping in the Scratchgravel Hills is causing large-scale groundwater declines, or if such declines are likely to occur in the future. The potential for impacts to groundwater quality from the discharge of septic effluent was also a concern.

Domestic Wells

Pumping water from aquifers causes water levels to drop in the area around the wells. When wells are consistently pumping at rates higher than the water can be replenished by the aquifer, area-wide declines can occur (Waren and others, 2012). When water levels in wells drop, the yield will decrease, and in some cases wells will need to be deepened, or they may become unusable.

Analysis of groundwater-level trends in the Scratchgravel Hills shows that in most cases overall trends are not strongly upward or downward. Precipitation trends (e.g., cumulative departure from long-term average) and recharge events affect groundwater levels on decadal scales. A few wells show consistent downward trends; however, due to the isolated nature of these sites, it appears that these declines result from local over-pumping of marginal aquifers rather than the result of area-wide drawdown. As such, there is no indication of area-wide drawdown caused by current levels of development.

Groundwater models were used to evaluate the potential for future groundwater declines. The models indicate that low-density development (10-acre lots) with individual bedrock wells results in the 1 ft drawdown contour extending approximately 0.9 miles from the well field. Higher density development (1.2-acre lots) resulted in the 1 ft drawdown contour extending approximately 1.9 miles. Water-use restrictions could be used to reduce the consumptive use of water, and therefore reduce the area of drawdown.

Groundwater modeling was also used to differentiate potential impacts from individual wells relative to those from a PWS well. If aquifer properties are consistent (homogeneous) across a development area, and a PWS well is placed in the center of the development, the model simulations suggest that the drawdown at the edge of the development area and beyond will be virtually the same as would result from individual wells. However, PWS wells have the advantage that they can be preferentially located where aquifers are the most productive (e.g., alluvium), or otherwise located to minimize drawdown impacts on neighboring wells. Also, it may be easier to implement water conservation strategies with a metered water system. A PWS system would also be easier to monitor and protect from contamination.

Septic Systems

In areas where fractured bedrock is overlain by thin soils with low organic carbon, there is limited ability to break down septic effluent (nitrate) due to low biological activity and rapid recharge. Sampling has shown elevated nitrate (>2 mg/L) associated with septic effluent in many bedrock wells within the Scratchgravel Hills, particularly in the granitic Scratchgravel Hills Stock. As such, it appears that traditional septic systems are not consistently effective in removing nitrate in these settings. If similar systems are installed in the future, it can be anticipated that elevated groundwater nitrate levels will result.

RECOMMENDATIONS

This study shows that Scratchgravel Hills Stock and the Helena Formation are particularly limited in their ability to supply water to wells. Current lot sizes on these units are typically 10 acres or more, and no area-wide groundwater decline is seen at this time. Study results suggest that if development at a density greater than one home per 10 acres (64 homes per square mile) is proposed, target groundwater levels should be defined. Modeling can assist in setting these targets. The target groundwater levels would best be defined as groundwater elevations measured in dedicated monitoring wells. Once target groundwater levels are defined, groundwater modeling should be conducted to determine what (if any) control measures would be needed to prevent unacceptable groundwater declines. Use of models in this way should allow effective, but not overly restrictive, controls to be adopted. Monitoring would be needed to ensure that target groundwater levels are maintained. Modification of the controls may be needed if the target groundwater levels are not achieved.

Many approaches can be taken to attempt to achieve target groundwater levels. For example, if lawn and garden irrigation were not allowed in new housing developments, the consumptive use of water would be reduced by about 98 percent. It is also possible that water could be obtained from off-site, such as from PWS wells in alluvial aquifers, and pumped to new housing developments. The appropriateness of any control should be verified by monitoring after it has been adopted.

Groundwater samples collected during this study show that the drinking water standard for nitrate was exceeded in six samples, and 31 percent of the samples were above background nitrate levels (2 mg/L). Of the 23 samples that had nitrate values above background, 21 were from wells completed in the granite. This nitrate is likely derived from septic systems. In the granitic bedrock areas of the Scratchgravel Hills, thin soils with low organic carbon overlie fractured igneous bedrock. This setting provides little opportunity for nitrate to be broken down by natural microbes. Continued installation of conventional septic systems in these parts of the Scratchgravel Hills, particularly if dense development (greater than 1 home per 10 acres) is proposed, is likely to lead to more exceedances of the drinking water standard for nitrate. Study results suggest that within the granitic core of the Scratchgravel Hills modifications in septic system design should be considered.

Specific areas within the Scratchgravel Hills study area are particularly prone to water-quality issues from natural sources. Wells installed near the margin of the granite may have high uranium. Wells installed in the Bald Butte Fault Zone, or in other areas where hydrothermal mineral deposits are known to occur, may have high arsenic concentrations. These issues should be taken into account when new water sources are developed.

As a part of this study the area-wide monitoring network operated by the Lewis and Clark Local Water Quality Protection District was evaluated, and improvements were made. This network provides important information on groundwater levels and groundwater chemistry throughout the Helena

Valley, and should be continued. While this network provides a solid understanding of the overall system, it may need to be supplemented in some areas if the effectiveness of particular control measures are to be assessed. This network should also be reassessed regularly to ensure that the objectives of the network are being met, and to respond to changes in the area.

Near where Silver Creek enters the Helena Valley, groundwater levels are susceptible to significant changes as flows in Silver Creek change. These fluctuations are mainly linked to climatic patterns and irrigation practices. Wells completed in this area should be drilled deep enough to remain productive. Some wells have been observed to fluctuate more than 25 ft. If it is assumed that 20 ft of available drawdown are needed for a well to remain productive, wells should be drilled so that there is at least 45 ft of available drawdown at the time of installation.

The groundwater system in the area below the HVID Canal and Sunny Vista Canal are strongly dependent on the infiltration of irrigation water. Forty-one percent of the water entering the groundwater system is from irrigation activities. Impacts to the groundwater system should be considered when major changes in land use or ditch management are proposed (e.g., lining canals). Abandonment of canals, and the associated irrigated fields, would cause major groundwater-level declines within irrigated areas, and downgradient.

If the models from this project are to be used for site-specific decisions, more detailed data from that site need to be collected and incorporated. In particular, if geologic conditions different than assumed in the models are encountered (e.g., the presence of a fault), the models will need to be modified to incorporate these features. The models prepared for this study provide a method to consider the entire area; however, they should be considered a starting point for any site-specific decisions, rather than the final analysis. The models can be used for providing estimates of impacts from large-scale changes (e.g., a 100-acre subdivision); however, analysis at smaller scales will be prone to relatively large error. While it is considered valid to treat the fractured and faulted bedrock as porous media from an area-wide perspective, the geometry of fractures and faults at a specific site will strongly influence local groundwater conditions and response.

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