MBMG Open-File Report 610

Hydrogeologic Investigation of the North Hills Study Area
Lewis and Clark County, Montana
Interpretive Report

January, 2012

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Ground Water Investigation Program

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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 this program is to investigate specific areas where factors such as current and anticipated growth of agriculture, industry, housing, commercial activity, or other criteria have created an elevated level of concern over groundwater issues. The areas to be studied are prioritized by the Ground Water Assessment Steering Committee. Additional information on the program and the ranking process can be accessed at: http://www.mbmg.mtech.edu/gwip/gwip.asp. Project goals are accomplished by collecting and compiling groundwater and surface-water data for each study area and analyzing those data through mapping and modeling to understand changes that are happening and to project future changes.

The final products for this study include an Interpretive Report, a Groundwater Modeling Report, a Technical Data Report, and a comprehensive set of data. Collected data are permanently stored on MBMG's Groundwater Information Center (GWIC) online database (http://mbmggwic.mtech.edu/) whenever possible. The purpose of each report is as follows:

Interpretive Report: This report summarizes the project and presents interpretations of the data, evaluating them in the context of the overall area and activities within the study area. The Interpretive Report includes the results of all aspects of the project. This report is intended for use by the general public, interest groups, decision-makers, and hydrogeologists.

Groundwater Modeling Report: This report provides detailed documentation of the procedures and assumptions inherent in the models and communicates the findings of the models. This report is intended to allow the models to be evaluated and used by others. All files needed to operate the groundwater models are posted to the project website (www.mbmg.mtech.edu/gwip/). These files are intended to enable qualified individuals to use the overall models developed by GWIP to test specific scenarios of interest, or to provide a starting point for site-specific analysis.

Technical Data Report: This report is a collection of relatively short technical reports that address specific aspects of the study. For example, details of aquifer testing and analysis are included. This report is intended to provide the technical data that will enable users of the Interpretive Report and the Modeling Report to perform their own evaluations.

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ABSTRACT

The purpose of the North Hills Groundwater Investigation was to scientifically address concerns relating to the sustainability of groundwater withdrawals, the potential for impacts to senior water-rights holders from groundwater withdrawals, and the potential for impacts to groundwater quality from septic effluent.

The North Hills study area is located approximately 8 miles north of Helena, Montana, on the northern edge of the Helena Valley. The core of the study area is composed of a south-facing, gently sloping pediment. It is bounded on the west, north, and east by hills. To the south, the Helena Valley is a relatively flat alluvial plain. This area drains to the Missouri River by way of Lake Helena. Precipitation ranges from less than 10 in. in the valley to over 16 in at higher elevations.

This area was historically used for grazing and irrigated agriculture. In recent years, substantial residential development has replaced the previous uses. The number of dwellings increased from 1,077 in 1995 to 2,150 in 2009. Most, if not all, of these homes obtain their water from wells. Many homes use individual water wells (exempt wells) and individual septic systems. The increasing development has raised concerns regarding the long-term capacity of aquifers to supply water and the potential for contamination of groundwater by septic effluent.

In 2002, the Montana Department of Natural Resources Conservation established a temporary Controlled Groundwater Area in the North Hills. This Controlled Groundwater Area was terminated in 2006. The matter was re-evaluated in 2008, resulting in the establishment of a second, smaller Controlled Groundwater Area, which has since been allowed to expire. It is expected that development in this area will continue to be controversial.

This study demonstrates that a water-level decline is occurring in the subdivisions west of the interstate and north of the Helena Valley Irrigation District canal. Modeling indicates that if pumping rates remain constant, and other factors remain stable, groundwater levels in this area should stabilize in approximately 6 years. Average annual water levels are projected to be about 3 ft below current levels in the area of maximum drawdown. Due to the low productivity of the bedrock aquifer, scattered wells show long-term declines, despite relatively modest pumping. In the area topographically below the canal irrigation recharge and canal leakage add excess water each year, and there are no long-term declines. Withdrawal of groundwater from anywhere in the North Hills has the eventual effect of decreasing groundwater discharge to Lake Helena, and thus to the Missouri River. The timing of the change in groundwater discharge is buffered by distance, so cyclic pumping in most of the North Hills results in a year round reduction in base flow.

Seventy-nine groundwater samples were collected and analyzed for major ions and trace elements. One sample exceeded the primary drinking water standard for nitrate, and one sample exceeded the secondary standard for iron. No other drinking water standards were exceeded. The source of elevated nitrate is likely septic effluent. The thin soils and fractured bedrock present in much of the North Hills study area provide limited opportunity for nitrate to be broken down by biological activity.

INTRODUCTION

The North Hills study area is approximately 8 miles north of Helena, Montana, and positioned on the northern edge of the Helena Valley (figs. 1 and 2). This study area is approximately 55 square miles in size. The study area boundary follows surface-water divides on the west, north, and east, and a groundwater flow line (Briar and Madison, 1992) on the south. Silver Creek enters in the southwest corner, and Lake Helena is in the southeast corner (fig. 1).

In recent years there has been substantial housing development in this area. Cadastral data (NRIS, 2009) show that for the 2,891 lots that are partly or completely located in the study area, 75 percent are less than 10 acres (figs. 3 and 4). Lots less than 10 acres constitute 10.4 percent of the total area. The number of dwellings within the study area has increased from 1,077 in 1995 to 2,150 in 2009. These homes obtain their water from either public water supply (PWS) wells or individual exempt wells (exempt from permitting requirements). These homes also typically use individual septic systems. The increasing development raises concerns regarding the long-term capacity of aquifers to supply water and the potential for contamination of these aquifers by septic effluent.

In this report, the areas of densest housing in the North Hills are referred to as Pumping Centers A (includes Cedar Hills, Townview, Sky View, Northern Lights, and North Star subdivisions), B (includes Ranchview, Bridge Creek, and Spring Creek subdivisions) and C (south of Lincoln Road; fig. 3).

In 2002, the Montana Department of Natural Resources and Conservation (DNRC) established a temporary Controlled Groundwater Area (CGWA) in the North Hills due to increasing development and observed declines in groundwater levels. Following the completion of a groundwater study by the Montana Bureau of Mines and Geology (MBMG; Madison, 2006) showing that the declines in some wells were related to drought rather than anthropogenic factors, the temporary CGWA was terminated in 2006.

The matter was re-evaluated in 2008, resulting in the establishment of a second, smaller, CGWA (fig. 1). This CGWA was allowed to expire in 2010. In the notice of expiration, the DNRC noted that it intended to use the information provided by this study to determine if a new CGWA should be designated. A CGWA may be proposed by the DNRC on its own motion, by petition of a state or local public health agency, or through a petition signed by at least 20 or one-fourth (whichever is less) of the groundwater users in an area.

Project Purpose and Scope

The North Hills groundwater investigation was conducted to use the best available science to address concerns relating to groundwater sustainability, the potential impacts of groundwater withdrawals to senior water rights holders, and to evaluate potential impacts to groundwater quality from septic effluent. This information can provide a basis for regulatory decisions regarding groundwater resources in this area.

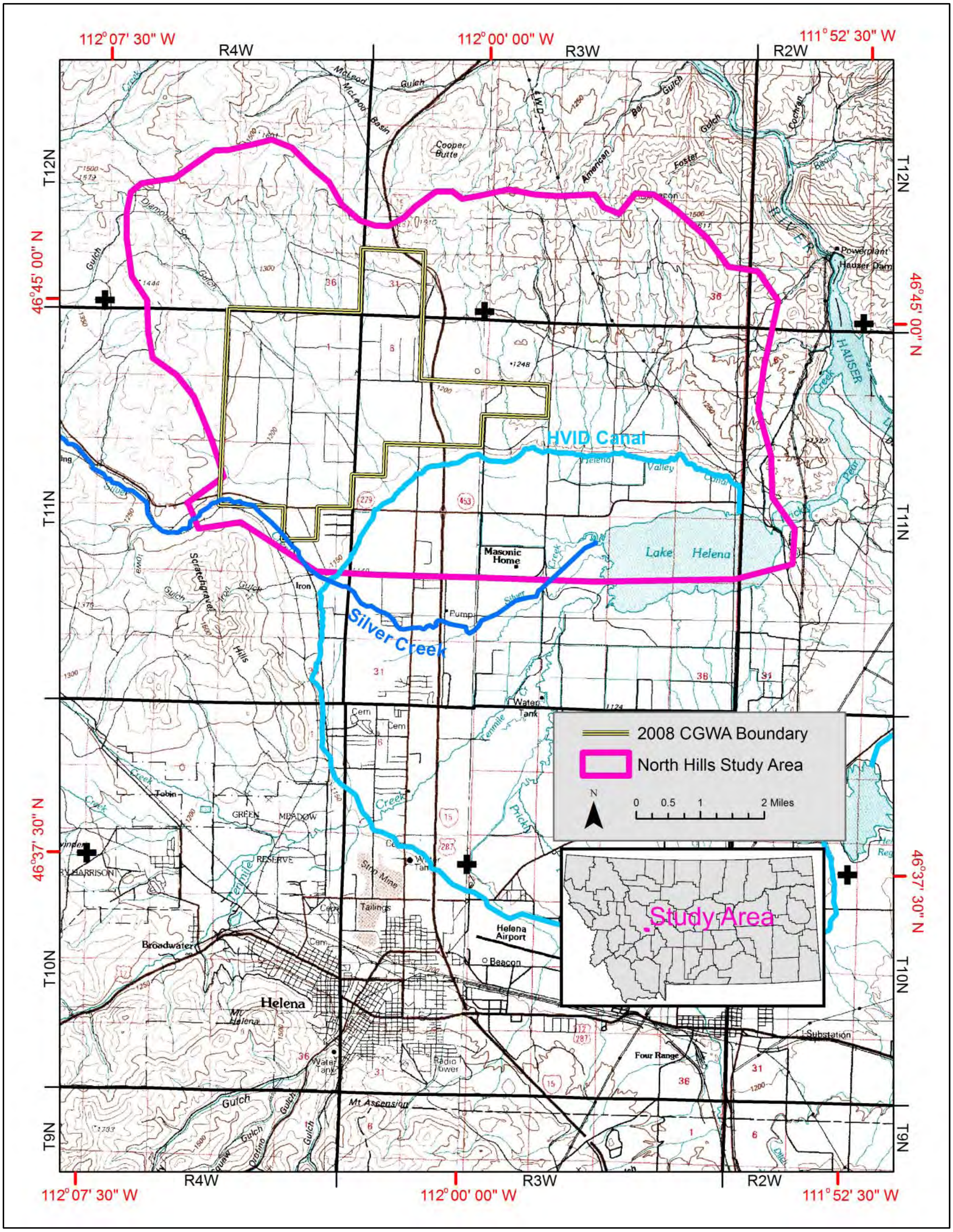


Figure 1. The North Hills Study Area is about 8 miles north of Helena, on the northern edge of the Helena Valley.

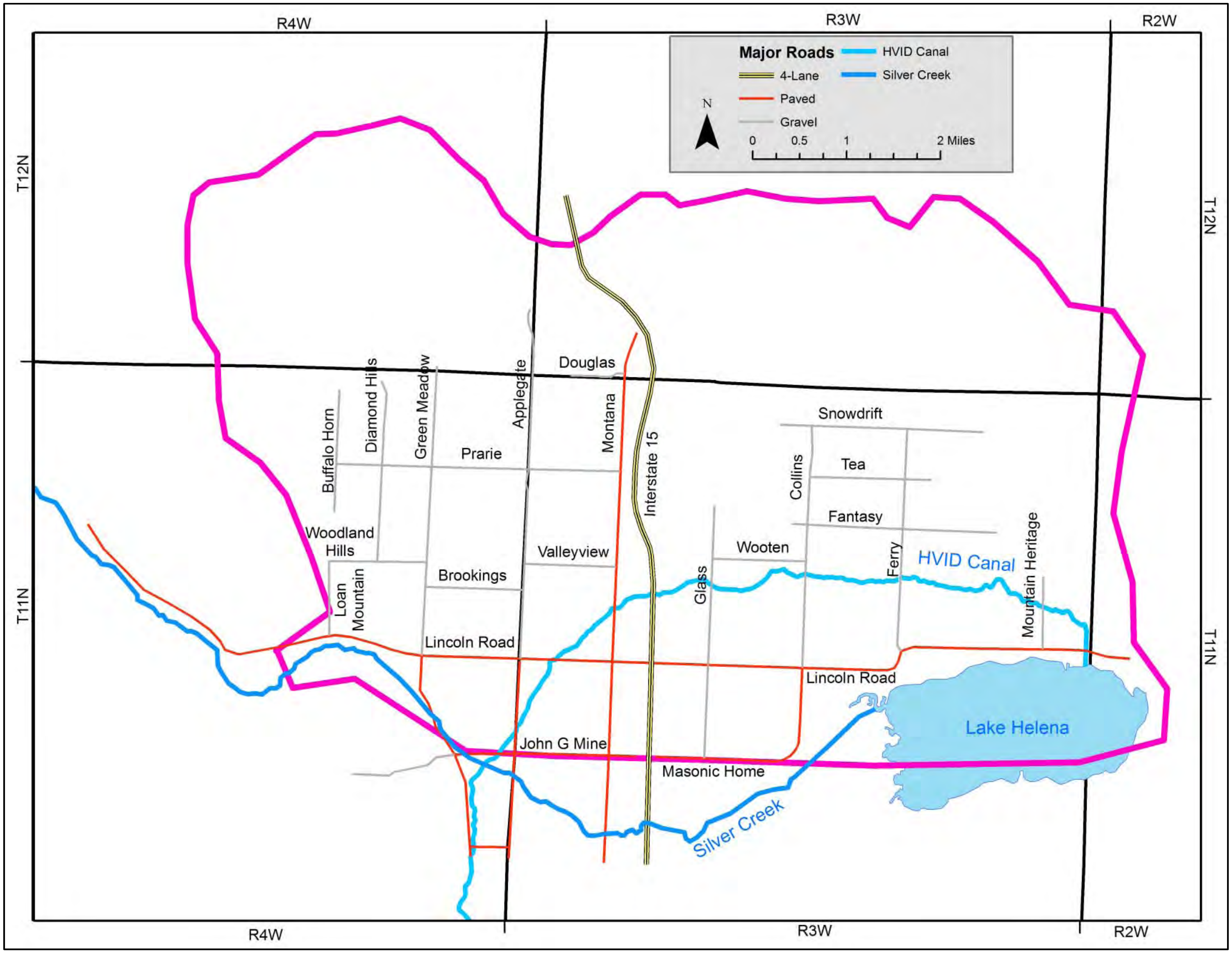


Figure 2. Major roads in and near the North Hills Study Area. Road names are sometimes used to identify locations.

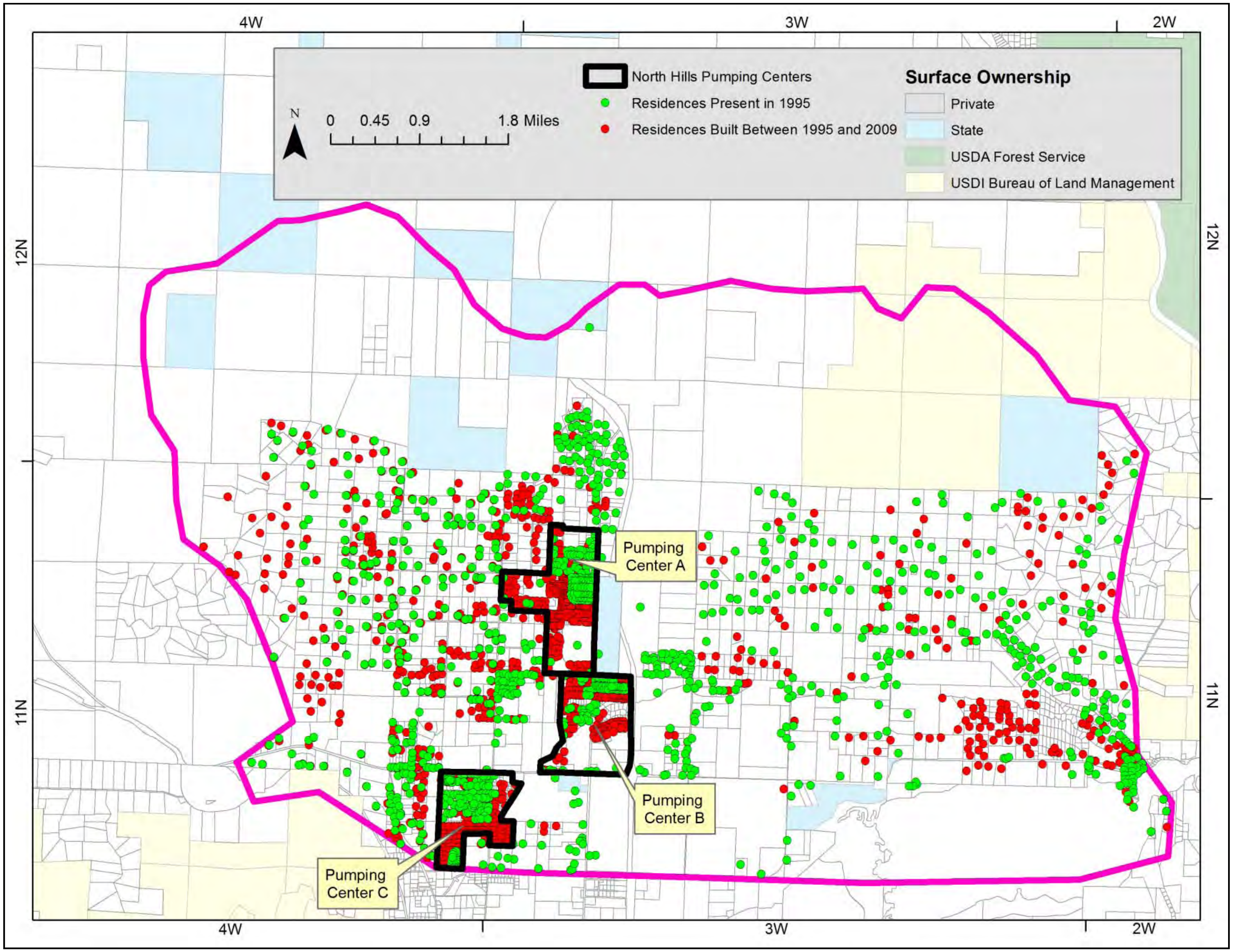
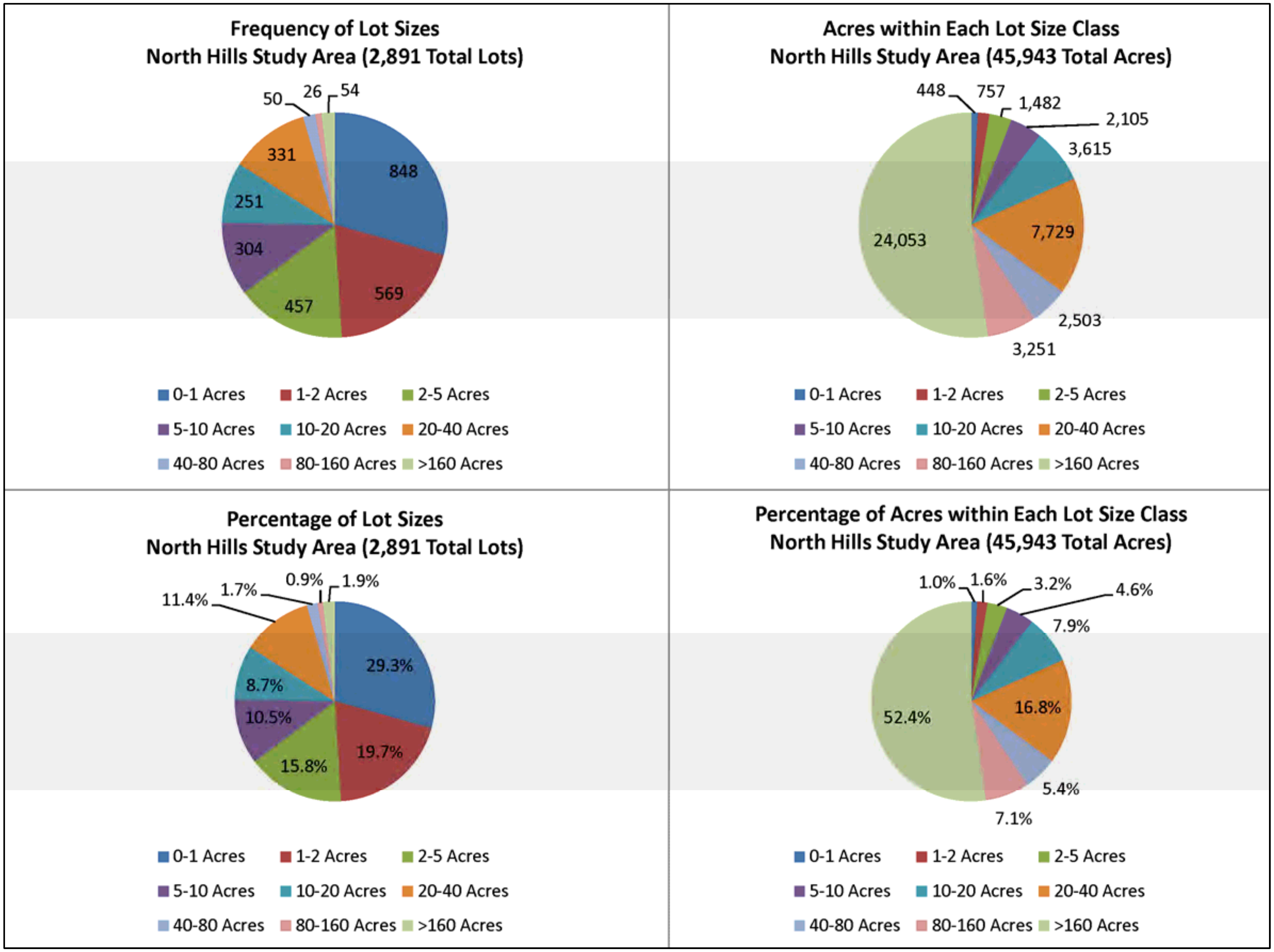


Figure 3. The number of homes in the North Hills Study Area increased from 1,077 to 2,150 between 1995 and 2009. Pumping Centers are designated for the densest residential areas.



Frequency of Lot Sizes North Hills Study Area (2,891 Total Lots)

Acres within Each Lot Size Class North Hills Study Area (45,943 Total Acres)

Percentage of Lot Sizes North Hills Study Area (2,891 Total Lots)

Percentage of Acres within Each Lot Size Class North Hills Study Area (45,943 Total Acres)

Figure 4. Within the North Hills Study Area cadastral data (NRIS, 2009; http://nris.mt.gov/gis) indicates that lots less than 10-acres make up 75percent of the lots, and 10.4 percent of the study area.

This study focuses primarily on the large-scale hydrogeologic behavior of the groundwater system. It is not intended to address site-specific issues, but rather to provide a conceptual framework within which site-specific issues can be considered.

The major goals of the North Hills study were to:

- evaluate long-term water-level trends;
- use groundwater chemistry to evaluate potential impacts from septic effluent;
- determine aquifer properties;
- evaluate the effect of bedrock faults;
- define the potentiometric surface;
- evaluate groundwater–surface-water interactions;
- develop a groundwater budget; and
- develop numerical models of groundwater flow.

Particular attention was given to the first two goals: groundwater-level declines and impacts to groundwater quality by septic effluent.

Previous Investigations

Reviews of previous work in this area have been provided by Nobel and others (1982), Briar and Madison (1992), Kendy and Tresch (1996), Thamke (2000), and Madison (2006). Our discussion focuses on those studies most directly relevant to the current work, and the reader is referred to these other sources for additional information.

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

Briar and Madison (1992) developed a groundwater budget and numerical groundwater model for the unconsolidated Helena Valley aquifer. Their study showed that the bedrock units contribute a significant volume of water to the flow system. Their report also included a 1991 potentiometric surface map and a study of nested wells that showed that within about 4 miles of Lake Helena the vertical gradient is upward, and in the rest of the area it is downward.

In 2000, Thamke assessed the bedrock units that surround the Helena Valley. Her study provided baseline information on water levels and water chemistry for the bedrock aquifers and gave estimates of groundwater age based on chlorofluorocarbon data; groundwater age dates ranged from 20 to 37 years in the North Hills. That report also included a generalized bedrock geologic map of the area (Reynolds, 2000).

In 2006, Madison evaluated the hydrogeology of the North Hills area. That study provided additional baseline data and an initial conceptual model for the study area. His study also defined areas where water levels respond to Silver Creek leakage, to irrigation canal leakage and irrigation recharge, and only to infiltration of precipitation.

Climate

The North Hills study area has a semi-arid 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).

Weather data have been recorded at the Helena Weather Service Office station (altitude 3,830 ft) since 1893, the longest record in the area (NWS, 2011). From 1893 through 2010 the mean annual temperature at this station was 43.9^{o}F. The coldest temperature recorded at this station was -42^{o}F, and the warmest was 105^{o}F. January had the coldest average temperature (20.6^{o}F) and July had the warmest average temperature (68.3^{o}F). Over the same period of record the average annual precipitation at this station was 11.87 in. On average, the greatest monthly precipitation was received in June (2.12 in), and the least precipitation in February (0.46 in). During the period 1990 through 2010, precipitation was cumulatively 18.37 in below average. This period includes 1993, which was particularly wet (6.94 in above average, while the standard deviation of the entire record is 3.0 in; fig. 5).

Physiography

The North Hills study area is in the Northern Rocky Mountains physiographic province, on the boundary between the Helena Valley and the surrounding hills. Hills are present on the west, north, and east margins of the study area. The relatively flat alluvial plain of the Helena Valley is to the south. A broad, gently sloping pediment extends from the base of the hills to the Helena Valley. The highest altitude in the study area is the ridge in the northeast, at 5,287 ft above mean sea level (ft-amsl). The lowest point is Lake Helena, in the southeast, at 3,650 ft-amsl. Surface water in this area drains to the Missouri River, approximately 1.5 miles east of the study area, via Lake Helena (fig. 6).

Man-Made Features

Hydrogeologically significant man-made features within the North Hills include irrigation canals, irrigated fields, 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 District (HVID) canal (fig. 7). The effect of canals and irrigated fields is to recharge groundwater by canal leakage and infiltration of water that is applied in excess of crop demand (irrigation recharge). Agricultural drains serve to limit the altitude to which groundwater may rise. Drains were installed in the Helena Valley during the installation of the HVID canal and the associated expansion in irrigation, in order to prevent waterlogging land (fig. 7). Wells and septic systems are located adjacent to homes (fig. 3). Wells extract groundwater and septic systems return a portion of the extracted water.

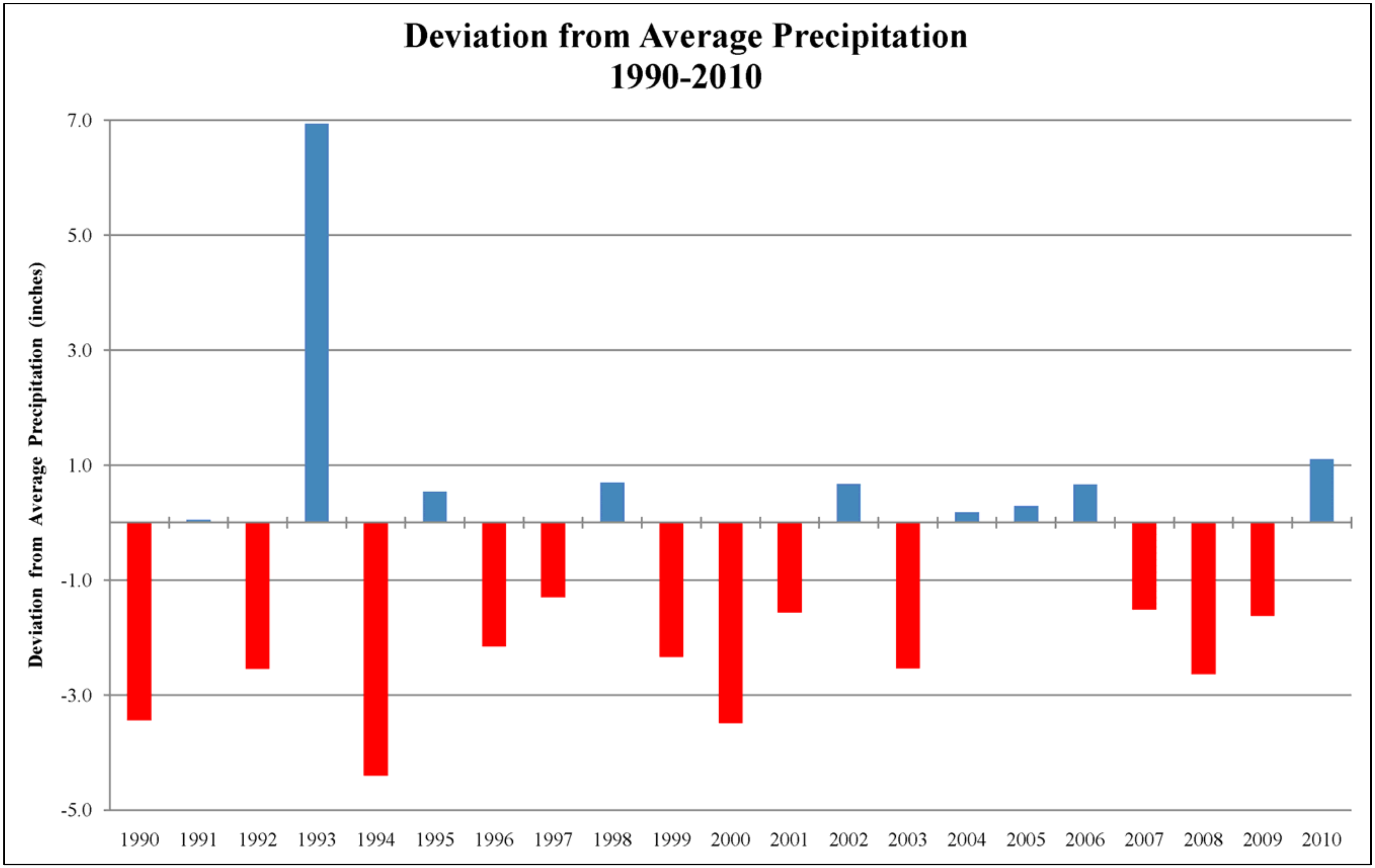


Figure 5. Annual precipitation at Helena Airport Weather Service Office (HLN – 244055; Helena WSO) from 1990 to 2010 shows a cumulative departure from average annual precipitation (11.87-inches) of 18.37 inches; 1993 was a particularly wet year (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt4055, accessed 6/27/11).

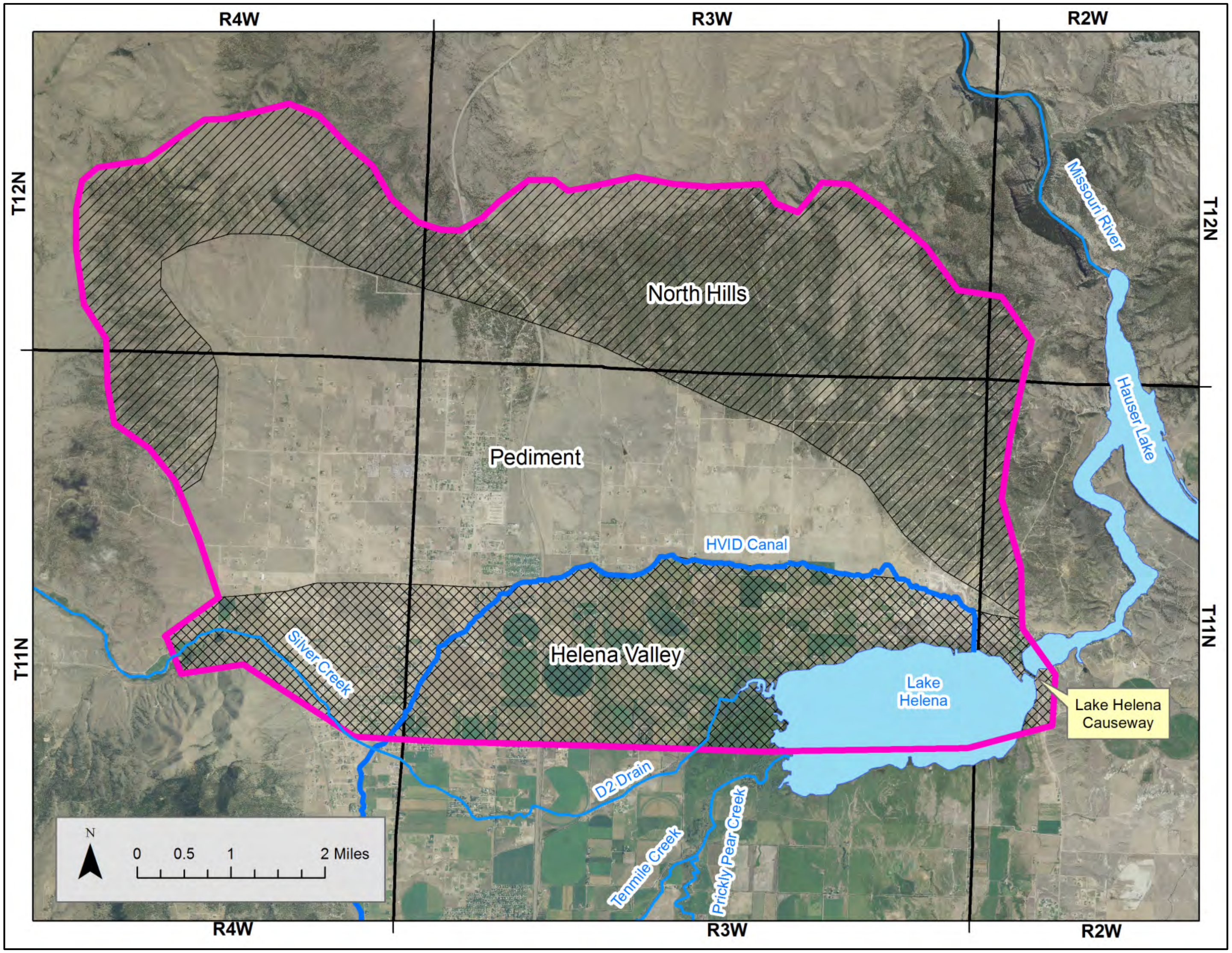


Figure 6. The North Hills Study Area drains to the Missouri River via Lake Helena. The Continental Divide is located approximately 10 miles west of the study area. The study area is split between hills to the west, north and east, a gently sloping pediment in the middle and the relatively flat Helena Valley in the south.

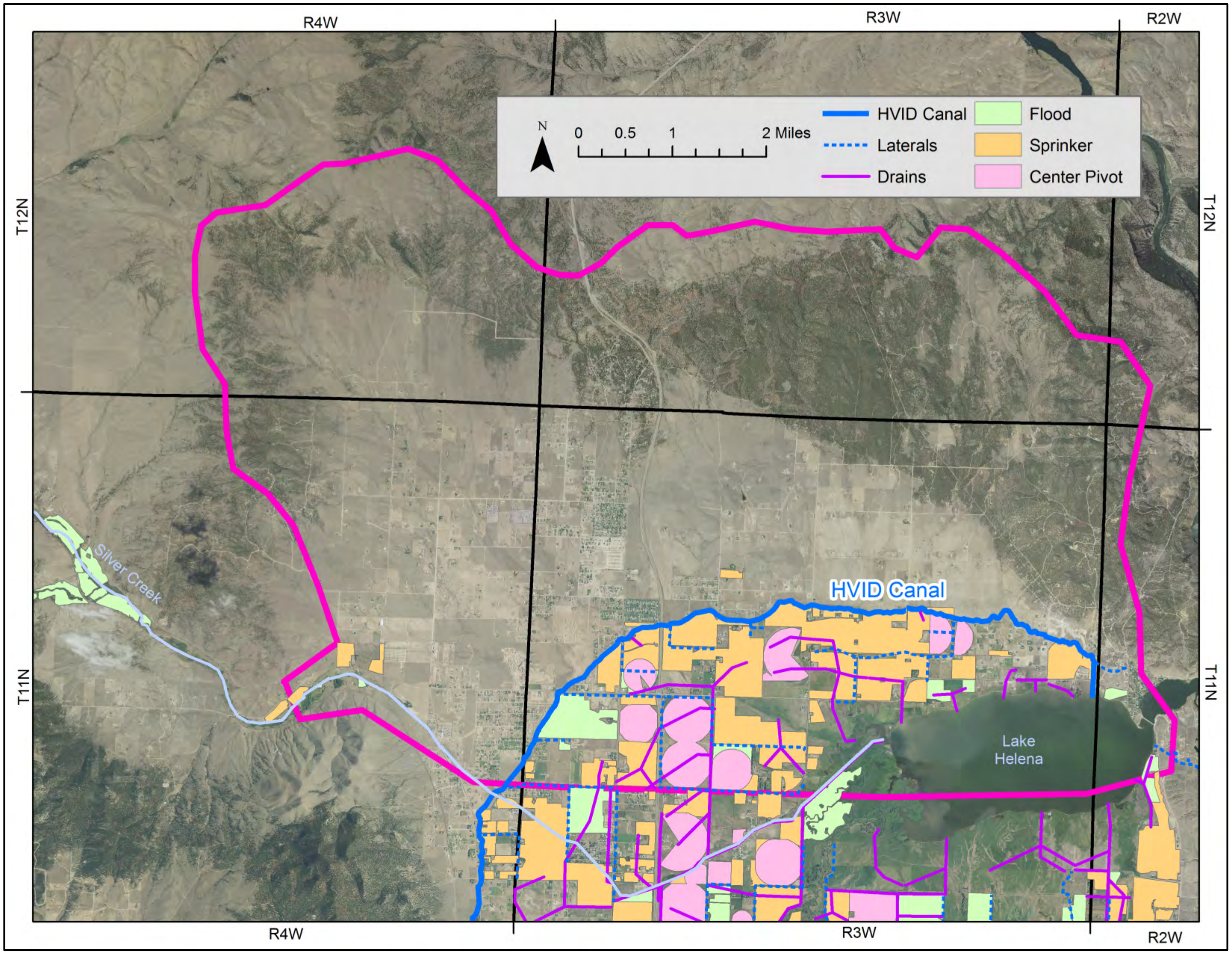


Figure 7. Irrigation canals and irrigated fields in the North Hills recharge groundwater with water diverted from the Missouri River (fields from MT DOR, 2010; canals and laterals from Helena Valley Irrigation District, written commun., 2009). The addition of this water required drains to be installed to prevent waterlogging.

Geologic Setting

Because different rock types transmit and store water differently, a sound understanding of the rock types present and their distribution in three dimensions is critical to a proper understanding of groundwater flow. For example, a well completed in a gravel layer will typically produce more water than a well finished in bedrock or clay.

Reynolds provided a detailed discussion of the geologic setting and a geologic map of the bedrock (fig. 8; from Reynolds, 2000). Reynolds and Brandt (2005) provided detailed descriptions of rock formations in the east part of the study area. Schmidt and others (1994) provided detailed descriptions of rock formations in southwest part of the study area.

Previous workers (Nobel and others, 1982; Briar and Madison, 1992, Madison, 2006) recognized three principal aquifers in the North Hills study area (figs. 9 and 10):

- <u>Bedrock Aquifer</u>: The bedrock aquifer forms the hills in the study area, and is also at or near the surface in the upper portion of the pediment. The bedrock aquifer is composed predominantly of Precambrian siltite and argillite of the Greyson and Spokane Formations of the Belt Supergroup. Other bedrock formations of lesser areal extent include the Precambrian Helena Formation and several Paleozoic and Mesozoic formations in the northeast corner of the study area. At several locations within the study area, granite sills have been reported from drill cuttings within argillite bedrock. Granite is also present in the southwest part of the study area, near the Scratchgravel Hills.

- <u>Tertiary Aquifer</u>: This unit is unconsolidated and is dominated by fine-grained sediment; however, thin, discontinuous sand and gravel lenses are also present. This unit overlies bedrock and thickens southward on the pediment toward the Helena Valley. In many areas, coarser gravel deposits are reported in the lower portion of the Tertiary aquifer. The gravels are typically thicker in the western part of the pediment, west of Interstate 15. Conversely, the clay-rich layer thickens to the east and may be absent in some areas to the west. The Tertiary sedimnets are typically covered by younger colluvium and alluvium; however, they are exposed at the surface at a few isolated locations within the study area.

- <u>Helena Valley Aquifer</u>: The Helena Valley aquifer is a combination of unconsolidated Tertiary and Quaternary clastic sediments that are generally coarser in the western part of the study area and finer toward Lake Helena. This unit is dominated by sand and gravel, and is the most productive aquifer in the study area.

In the bedrock, groundwater moves through and is extracted from fractures. These units have little primary porosity, but they are variably fractured and may have significant secondary porosity and secondary permeability (Thamke, 2000). Within the North Hills study area there are several mapped bedrock faults (Schmidt, 1994; Reynolds, 2000; Reynolds and Brandt, 2005). The most significant of these is the Helena Valley Fault, which runs from the northwest corner to the southeast corner of the study area (fig. 8). Several faults have been mapped sub-parallel to

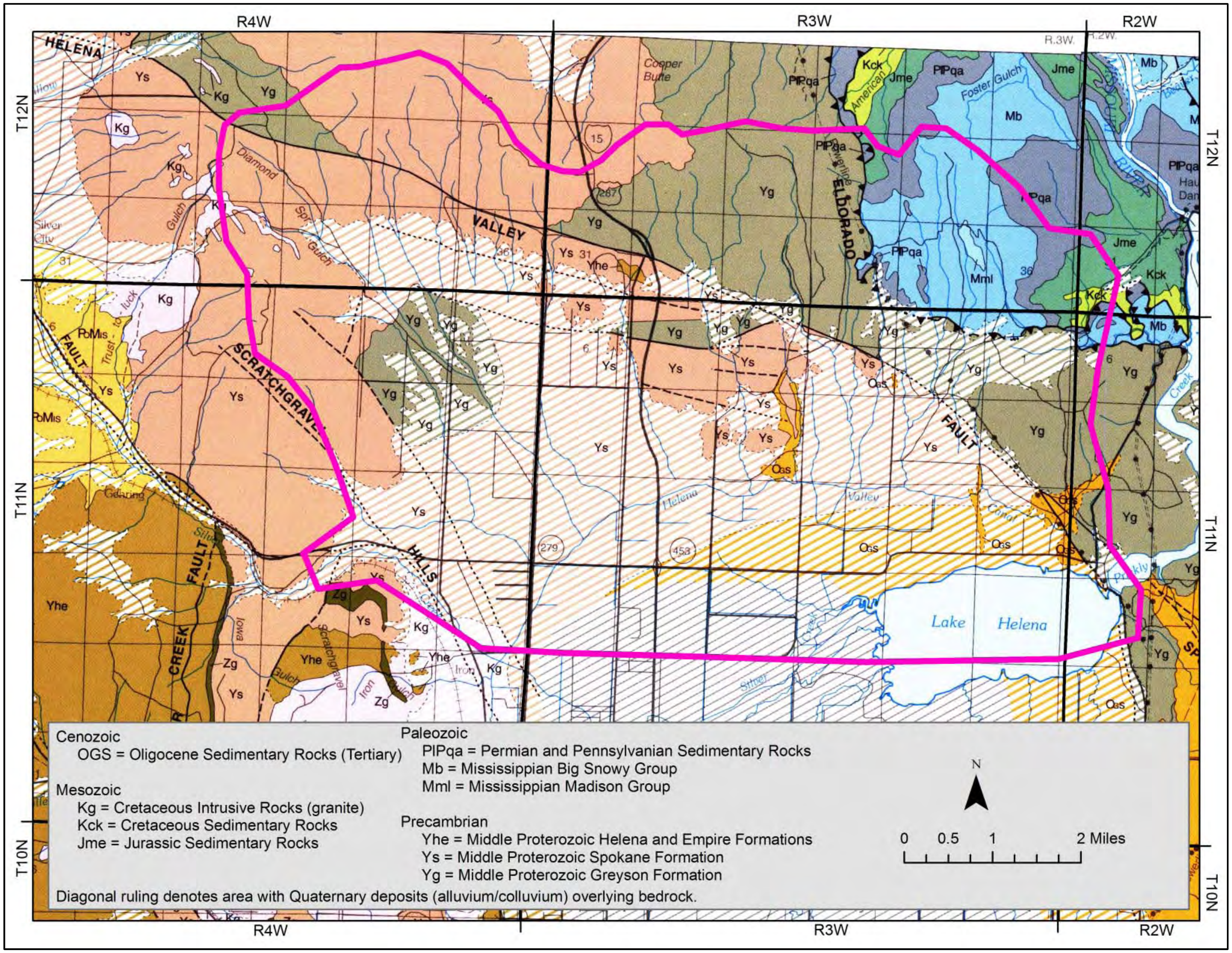


Figure 8. As shown by this bedrock geologic map (from Reynolds, 2000) the upper portion of the study area has argillite bedrock at the surface. This bedrock underlies unconsolidated Tertiary materials and the more coarse-grained Helena Valley aquifer towards the center of the Helena Valley. Several bedrock faults are also present in the area.

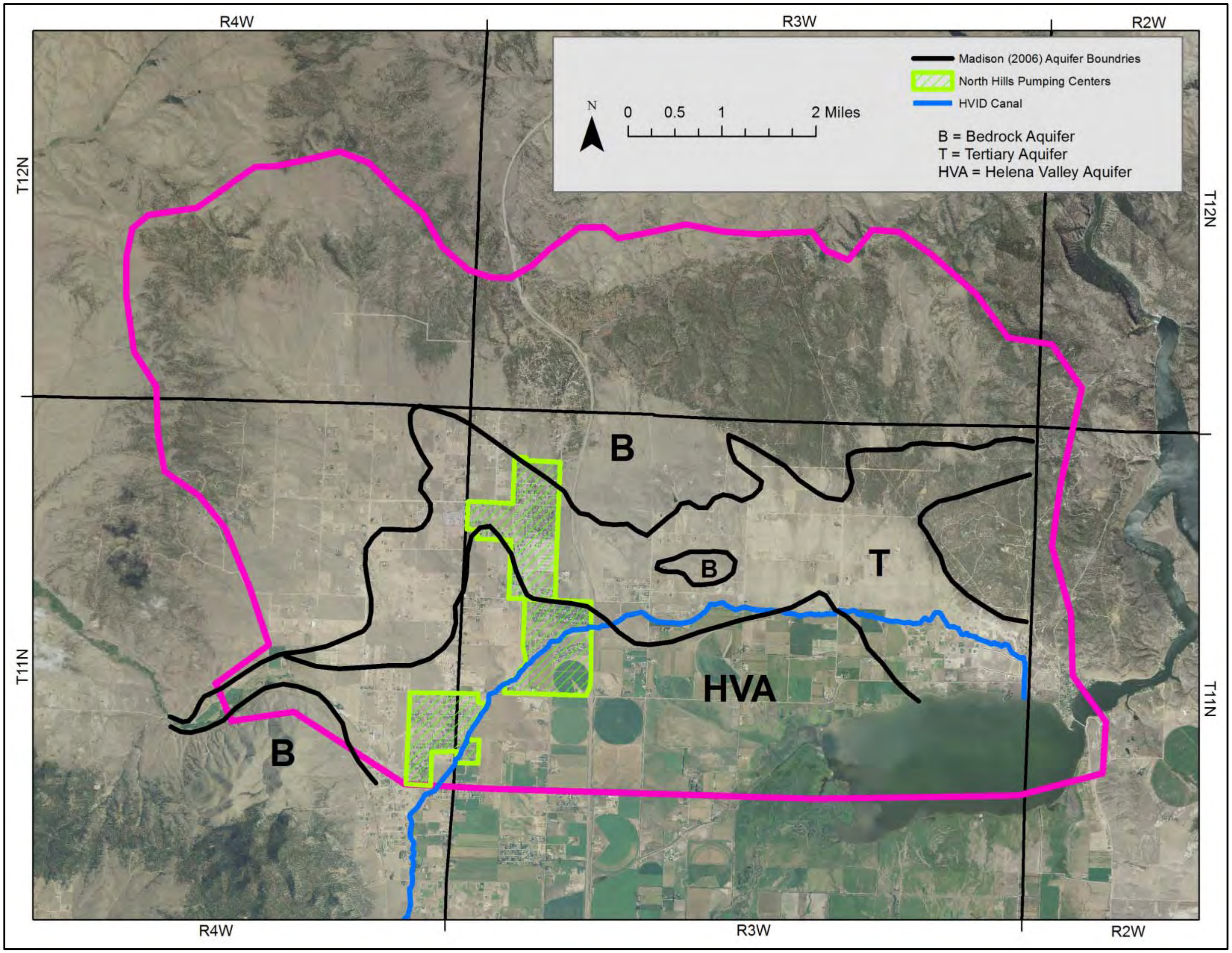


Figure 9. In the northern part of the study area wells depend on the bedrock aquifer. In the central part of the study area wells are completed in sand or gravel lenses within clay-rich Tertiary deposits. In the valley wells are completed in the sand and gravel deposits of the Helena Valley Aquifer (after Madison, 2006).

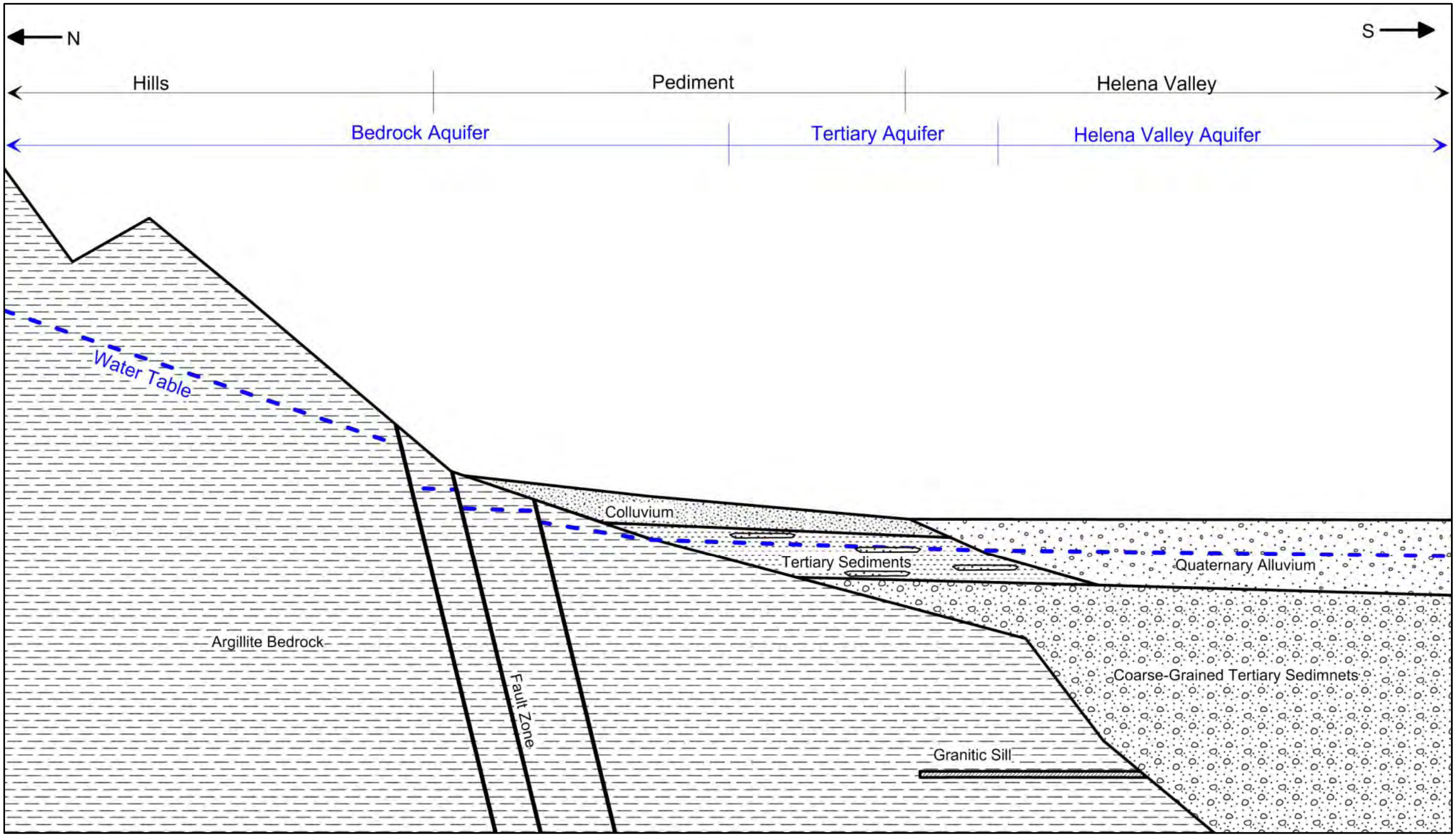


Figure 10. This schematic north-south geologic cross section in the vicinity of Interstate 15 illustrates the basic conceptual model for the North Hills Study Area. Physiographic areas are delineated in black, and principal aquifers are delineated in blue. Note that the clay-rich Tertiary materials include discontinuous sand and gravel lenses.

the Helena Valley Fault, and conjugate faults splay off these. It is likely that additional unmapped faults are present in the area, but are covered by younger sediments.

Madison (2006) noted that the bedrock, Tertiary, and Helena Valley aquifers are connected and that groundwater flows from one aquifer to the other. They are named and described because of differences in the rock materials, but together form the variable medium through which groundwater flows.

Regional Bouguer gravity anomalies (Kucks, 1999) indicate the presence of a major low-gravity area in the central part of the Helena valley south of Lake Helena. Noble and others (1982) estimated that this gravity anomaly represents about 6000 ft of unconsolidated Tertiary and Quaternary sediments.

Acknowledgments

We thank the many landowners and residents of the North Hills study area for their interest in the study, and for their permission to conduct various aspects of the investigation on their properties. Lewis and Clark County Local Water Quality Protection District provided significant assistance by allowing us to contract the services of Gary Burton for monthly measuring of water levels in about 50 wells, and for hydrogeologist James Swierc to work on and contribute to this project. Joe Michaletz of GeoLux, Inc. kindly provided some shallow magnetic geophysical results from a property in the northwest part of the study area. Russell Levens and James Beck of the Montana DNRC contributed substantially to this project by providing us with comments and direction regarding water-rights issues, groundwater-modeling efforts, and surface-water monitoring.

Richard Berg, Jeff Lonn, Tom Patton, James Madison, and Gary Icopini from the MBMG provided technical assistance for various aspects of this study. Allison Brown, a Montana Tech student, provided assistance in both field and office aspects of this project. The Montana Tech Geophysics Department conducted a number of geophysical projects that provided students an opportunity to test geophysical techniques and provided us with information on subsurface conditions at the sites.

The Tenmile Creek and Lake Helena watershed groups provided opportunities for us to discuss the study, increasing our public presence in the Helena area and allowing us to better understand the issues. The Montana Watershed Coordinating Council Groundwater Work Group provided a format to share our plans and activities with hydrologists and geologists from other agencies and vice versa. The Lewis and Clark County Conservation District provided permission for stream access for instrumentation used in the study. The Helena Valley Irrigation District (HVID) provided permission for access to the HVID canal and agricultural drains to measure flows and to instrument drains as needed.

METHODS

A review of the previous studies and field reconnaissance allowed development of an initial conceptual model of groundwater flow. This conceptual model guided field activities and modeling efforts.

Well Installation

Twenty-two wells were installed during this study (fig. 11). These were located in areas where there were no available existing wells, where additional wells were needed for aquifer tests, where additional wells were needed to evaluate vertical gradients, and adjacent to streams to evaluate surface-water–groundwater interactions. A listing of the wells installed for this study is included in the North Hills Technical Report (Bobst and others, in preparation a). All well logs, including completion details, are available on GWIC by using the GWIC ID number.

Well Log and Cuttings Analysis

In order to further refine the distribution of hydrogeologic units in the North Hills study area, well logs were analyzed. Well logs are required to be submitted by well drillers upon completion of each well (MCA 85-2-516), and include well location, lithologic descriptions, and well-completion details. Under the North Hills CGWA designation, drillers were also required to collect cuttings for new wells installed in the area, at the discretion of the DNRC. Cuttings were also collected for the wells installed as a part of this study. These cuttings were examined to aid in well log analysis.

Well logs for wells drilled to at least 200 ft were extracted from the GWIC database. The locations and elevations for these well logs were checked and corrected as needed. Additional well logs for shallower wells were later added in selected areas where there were conflicting well logs or where no well logs met the initial criteria. Over 250 well logs were entered into the Groundwater Modeling System (GMS) software used to develop the groundwater models for this project.

Well drillers' reported lithologies were categorized to allow the creation of cross sections and computer-generated three-dimensional representations of subsurface materials. The process used to evaluate the well logs and cuttings is discussed in greater detail in the North Hills Modeling Report (Waren and others, in preparation).

Aquifer Tests

Aquifer tests were conducted to estimate aquifer physical properties by pumping one well at a known rate and observing the drawdown and recovery of water levels in the pumping well and in observation wells (if possible). Aquifer properties typically estimated from aquifer tests are transmissivity (*T*), and storage coefficient (*S*). Hydraulic conductivity (*K*) is calculated based on

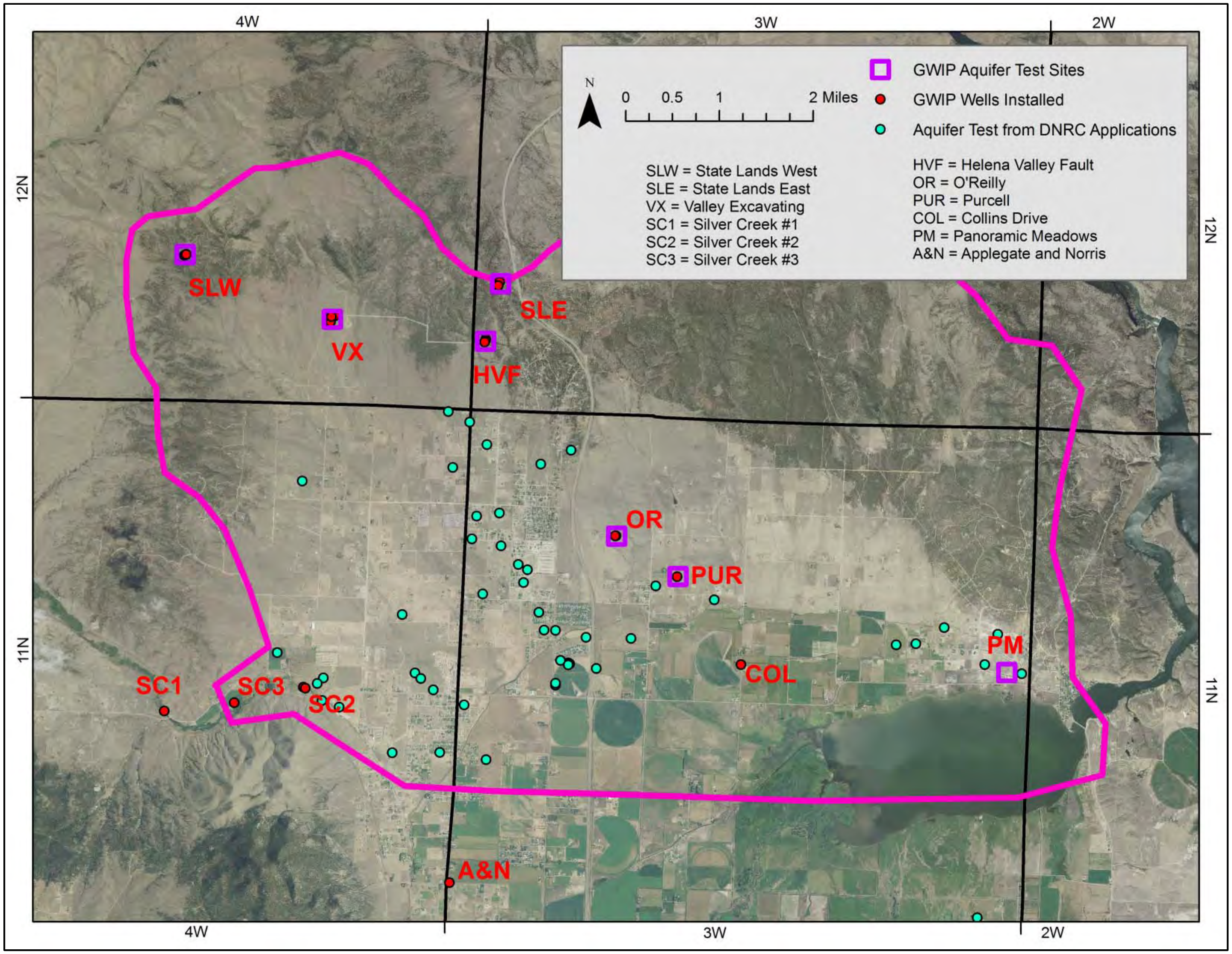


Figure 11. Wells were installed and aquifer tests were conducted at various locations within the North Hills Study Area to acquire water-level information and to evaluate aquifer properties. Aquifer test data from DNRC applications (P. Faber, written commun., 2010) also provided significant additional information on aquifer properties.

T and aquifer thickness. It has been noted that "[w]hereas laboratory tests provide point values of the hydrogeological parameters, and piezometer tests [slug tests] provide *in situ* values representative of a small volume of porous media in the immediate vicinity of a piezometer tip, pumping tests provide *in situ* measurements that are averaged over a large aquifer volume" (Freeze and Cherry, 1979, p. 343). Thus aquifer tests offer a powerful tool for estimating the hydrogeologic properties of an aquifer. It must be kept in mind, however, that those values still only represent a relatively small area. Due to heterogeneity of the aquifer, the results of an aquifer test only provide a first approximation of what the hydrogeologic properties will be over a larger area.

For this study, seven aquifer tests were conducted (fig. 11). These tests were conducted and analyzed in accordance with ASTM standards (ASTM, 2010). Three tests were conducted to determine the horizontal flow properties of the bedrock aquifer. Two tests were done to evaluate the nature of bedrock faults, one to evaluate vertical flow in the bedrock aquifer, and one to determine the horizontal flow properties of the Tertiary aquifer. Detailed discussion of these tests is included in the North Hills Technical Report (Bobst and others, in preparation a). Existing data on aquifer properties are also available from water-rights applications obtained from the Montana DNRC. These data were compiled by Aqua Bona Consulting (P. Faber, written commun., 2010) and are presented in the North Hills Technical Report (Bobst and others, in preparation a).

Precipitation Distribution

Lines of equal precipitation (isohyetal lines or isohyets) were developed for this study from weather station data in the area from 1970 to 2000 (P. Farnes, written commun., 2010). This was the most recently analyzed 30-year period available at the time of the analysis. This analysis used the correlation between average annual precipitation and elevation.

Groundwater Levels

Water levels were monitored at 74 wells (fig. 12) to determine groundwater altitudes throughout the North Hills study area, and how these levels changed with time. Sites were selected based on well availability, well owner permission, historical record, geographic location, and hydrogeologic setting. A listing of all monitored sites is included in the North Hills Technical Report (Bobst and others, in preparation a).

The network sites were periodically manually monitored; some also had pressure transducers installed. Monthly manual measurements were made by the Lewis and Clark Water Quality Protection District at 49 sites. At 25 additional sites, transducers were installed and monitoring was performed by MBMG staff as a part of this study.

Manual groundwater-level measurements were made using an electric sounder. At each site, a surveyed measuring point (MP) was designated to ensure that all measurements were taken from

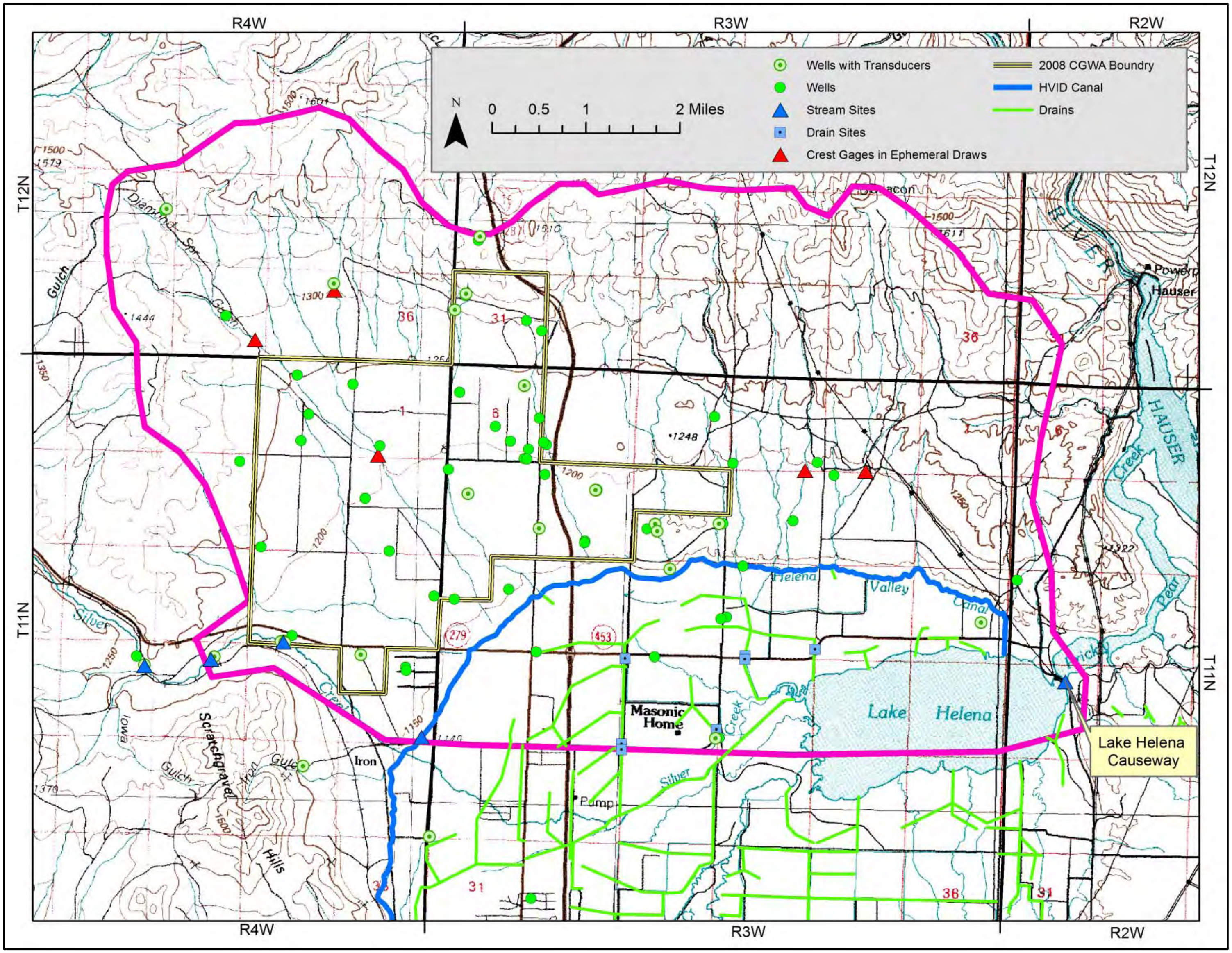


Figure 12. The North Hills monitoring network provides the observational basis for this study.

the same reference point. The MP was surveyed to ±0.01 ft by professional surveyors, so depth to water values could be converted to groundwater altitudes.

Pressure transducers are integrated sensing and recording devices that function by recording pressure and temperature at preset intervals. They were suspended using a wire. Manual depth to water readings were taken when the transducer was installed and each time the site was visited. These manual readings were used to convert the pressure readings of the transducer to groundwater altitudes and to ensure the transducer was functioning properly.

To test for trends in water levels, a best-fit linear relationship using data from 2005 and 2010 was applied to selected groundwater-level hydrographs. Regression relations were developed for hydrographs for wells with groundwater-level data from 2005 and 2010. Other data at a site were also used qualitatively to ensure that the resulting trend was in fact representative of water levels at the site (e.g., that the seasonality of data collection did not bias the result). The primary sources of data for this analysis were from data collected by Madison (2006) and this study. Historical data were from a variety of sources, including the U.S. Geological Survey (USGS) (Thamke, 2000), the Lewis and Clark Water Quality Protection District, and MBMG's Ground Water Assessment Monitoring Network.

Water-altitude data (water levels referenced to a common datum, typically mean sea level) collected over a short time period can be used to construct a potentiometric surface map. A potentiometric surface is "[a]n imaginary surface representing the total head of groundwater and defined by the level to which water will rise in a well" (Bates and Jackson, 1984, p. 400). Because groundwater will flow from areas of high head to low head, these maps are useful for defining the groundwater flow system.

Surface-Water Flow

Surface-water flow was measured at 17 sites during this study (fig. 12), including Silver Creek, Diamond Springs Gulch, other unnamed tributaries of Silver Creek, the HVID canal, the Lake Helena Causeway, and irrigation drains. Instantaneous discharge was measured using velocity meters. Stage was recorded with staff gauges, water-height probes (TruTrack), or transducers. Stage readings were used to estimate discharge based on rating curves developed for each site. Crest gauges were installed in ephemeral drainages.

Groundwater–Surface-Water Interactions

In order to understand the hydrogeologic effect of the streams in the North Hills study area, it was necessary to determine if the streams were gaining or losing, and if losing, if they were connected or perched relative to groundwater. In order to evaluate this, three monitoring sites were established on Silver Creek (fig. 12). At each site, water altitudes and temperature were recorded in a stilling well (the stream) using a water-height probe, and in a well completed next to the stream (the aquifer) using a transducer. Using this information, water-level altitudes were compared to determine if flow is to the stream from groundwater (gaining), or if water is leaking out of the stream and recharging groundwater (losing). Temperature measurements allowed the effects of diurnal temperature variations to be used to estimate the magnitude of water movement.

Estimation of Evapotranspiration

Some portion of precipitation evaporates, sublimates, is transpired by plants, or is trapped by under-saturated soil in the root zone. All of this water eventually leaves the study area as water vapor, and as such it is collectively termed evapotranspiration (ET).

The actual evapotranspiration for the North Hills was estimated for this study by researchers at the University of Idaho using METRIC remote sensing techniques (Trezza and others, 2011). This process uses 30–m resolution Landsat images. According to the project report "[t]he METRIC procedure utilizes the visible, near-infrared and thermal infrared energy spectrum bands from Landsat satellite images and weather data to calculate ET on a pixel by pixel basis. Energy is partitioned into net incoming radiation (both solar and thermal), ground heat flux, sensible heat flux to the air and latent heat flux. The latent heat flux is calculated as the residual of the energy balance and represents the energy consumed by ET" (Trezza and others, 2011). A more detailed description of METRIC is provided in Allen and others (2007a, b, and 2010).

Groundwater Budget

A groundwater budget helps to quantify the conceptual model of the area. While there is inherent uncertainty associated with the calculations, a groundwater budget is useful for determining the relative importance of different processes. A groundwater budget combines water entering and leaving the study area from boundaries, sources, and sinks. The idea of a water budget is the same as the more general law of a mass balance. That is, matter cannot disappear or be created spontaneously. Thus, the amount of water which enters over a period of time must be equal to the amount of water that leaves over that same time period, plus or minus any water that is removed from, or put into, storage. In a groundwater system changes in storage are directly related to changes in groundwater levels. The general form of the mass balance equation is:

$$\text{Inputs} = \text{Outputs} \pm \text{Changes in storage.}$$

The components of the water budget are discussed in greater detail in the Results section of this report.

Numerical Modeling

A numerical groundwater flow model is a mathematical representation of a groundwater flow system based on the principles of groundwater flow and the geometry, hydraulic characteristics, and hydraulic stresses of a particular area.

Two groundwater models were developed for the North Hills project. The North Hills Area Model covers the whole study area. Its purpose is to provide a tool to analyze the water budget of the area, which approximates the key elements of groundwater recharge and discharge. It can also be used to evaluate how groundwater extractions or other activities impact Lake Helena and the Missouri River. The Pediment Focus Model is a smaller area model, which addresses the area of the North Hills pediment above the HVID canal, where available observation-well data are the densest, and where the concerns about groundwater withdrawals and observed drawdowns in the aquifer are the greatest. Because this area is upgradient of the HVID canal, the water budget is greatly simplified. The purpose of this model is to provide a tool that can best analyze and predict the impacts of various pumping schemes on groundwater above the HVID canal, particularly within the North Hills CGWA.

For this project, numerical groundwater models were developed using GMS software (Aquaveo; Provo, Utah) and operating MODFLOW 2000, a computer code developed by the U.S. Geological Survey to simulate groundwater flow through aquifers (Harbaugh and others, 2000). Details about the versions used are documented in the Modeling Report (Waren and others, in preparation).

The model grid is the same for both models, but the cells are activated within a smaller area for the Pediment Focus Model. Both models consist of a single layer and square cells 400 ft on each side (figs. 13 and 14). The saturated thickness of the model is approximately 400 to 600 ft. Multiple-layer model designs were considered, but the lack of well-defined shallow and deep aquifers did not justify a multi-layered model. The 400-ft grid spacing was deemed adequate to evaluate the aquifer system without a cumbersome number of rows and columns and yet provided enough detail to evaluate the groundwater budget and model groundwater levels associated with pumping and other hydrologic stresses.

The boundary conditions for the North Hills Area Model are mostly no-flow boundaries. No-flow boundaries were placed along the west, north, and east sides of the model, following surface water divides. Along most of the southern side a no-flow boundary was placed following a groundwater flow line determined from a 1991 potentiomentric surface map of the Helena Valley (Briar and Madison, 1992). The southeast corner of the model was set as a constant-head boundary to represent Lake Helena. A constant-flux boundary was used in the southwest portion of the model to represent bedrock inflow from the Scratchgravel Hills. These simple model boundaries allow the aquifer system to be modeled from its expected local source area (the North Hills on the Helena Valley side of the divides) to the discharge area (Lake Helena).

The boundary conditions for the Pediment Focus Model are no-flow boundaries along all sides except the southeast edge of the model. No-flow boundaries are placed at the location of the surface-water divides between the Helena Valley and the Silver City area to the west, and the Gates of the Mountains area to the north. The lateral edges of the model are placed along flow lines based on the potentiometric surface map, extending from the divide to the vicinity of the HVID canal and the 3,725-ft potentiometric contour. The southeast edge of the model is a specified head boundary along the approximate location of the 3,725-ft potentiometric contour. The specified head is constant during steady-state simulations and varies seasonally in transient

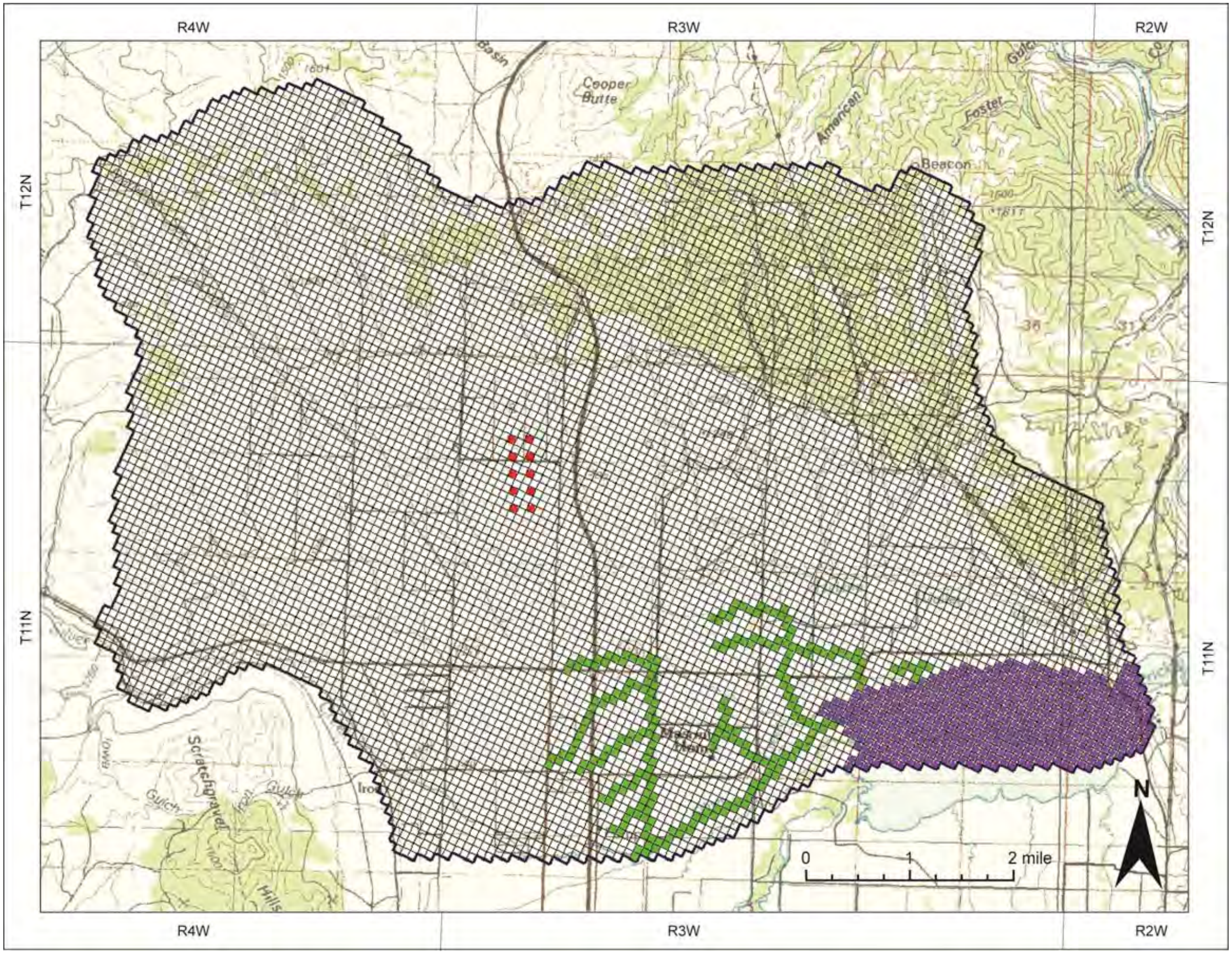


Figure 13. The active cells in the North Hills Area Model grid subdivide the study area into 400-foot by 400-foot blocks. Green cells are drain cells and purple symbols indicate constant-head cells. The red cells represent the modeled wells in Pumping Center A.

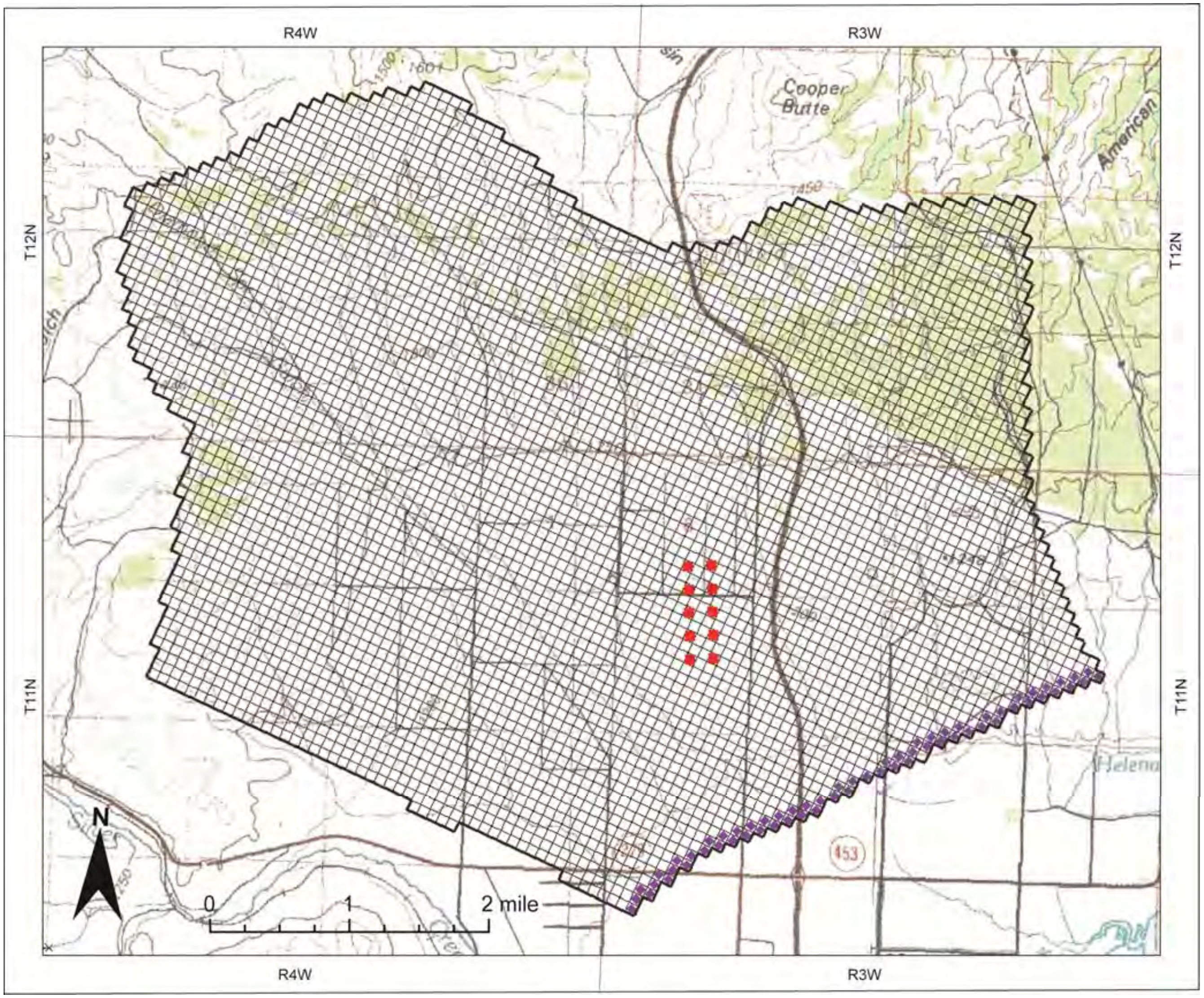


Figure 14. The active cells in the Pediment Focus Model grid subdivide the study area into 400-foot by 400-foot blocks. Constant-head cells for steady-state runs and variable-head cells for transient runs are shown in purple. Locations of modeled wells used to simulate Pumping Center A groundwater withdrawals are shown in red.

simulations based on groundwater-level observations. This boundary replicates the stable groundwater-level setting associated with the HVID canal.

The source of water for the simpler Pediment Focus Model is recharge, applied using the recharge package. Recharge is limited to the upgradient portion of the model representing the North Hills vicinity and, for the steady-state version, a small portion of the model near the southeast edge that extends below the HVID canal. Recharge is not applied to the pediment surface. Recharge from precipitation sources in the North Hills area is held constant at estimated values of 3 to 4 in/year during steady-state and transient calibrations. Exact locations are illustrated in the model report (Waren and others, in preparation).

The sinks in the Pediment Focus Model include the specified head cells at the southeast edge of the model (described above) and discharge from wells. The well package is used to simulate 10 wells extracting approximately 152 acre-ft/year. These wells simulate the pumping withdrawals estimated for Pumping Center A (figs. 2 and 3). Average annual rates are used in the steady-state model, while estimates of monthly pumping rates are applied in the transient model. The estimates are based on a detailed water budget analysis presented in the technical report (Bobst and others, in preparation a). The estimated values are also provided in more detail in the model report (Waren and other, in preparation).

The North Hills Area Model uses the same recharge and pumping rates as the Pediment Focus Model for recharge from precipitation in the hills and for pumping from Pumping Center A. Recharge from infiltration of water from Silver Creek and the HVID canal, and from irrigation water derived from these sources, is added to this larger area model. Constant-head cells at the location of Lake Helena form the dominant sink in the model. Agricultural drains, which also act as sinks, are modeled in the irrigated area between the HVID canal and Lake Helena.

For each of the models, there is a steady-state and a transient version. The steady-state versions simulate average annual conditions for all elements of recharge and discharge, and represent the system in equilibrium with a specified set of stresses. The steady-state models are used to generate optimal hydraulic conductivities for each cell by optimizing the root mean square error using automated parameter estimation (PEST), and to evaluate the overall water budget. The generated hydraulic conductivities and water budget were evaluated relative to the conceptual model, the results of aquifer tests, and the manually calculated water budget to ensure they were reasonable. The steady-state area model is also useful for predicting the ultimate impact to the groundwater system from a new stress. The transient models use the aquifer properties from the steady-state model, adding the element of time, and are able to simulate time-dependent stresses, such as seasonal irrigation and pumping activities. Transient models are used to simulate observed stresses and conditions, and to predict the timing and magnitude of impacts from different stresses.

For both steady-state models the PEST pilot point method was used to calibrate the model to observed values. A calibration criterion of ±10 ft was used. This value was selected based on the results of models of similar scale in Montana and Utah (Kauffman, 1999; Uthman and Beck, 1998; Waren, 1998; Brooks and others, 2003). The calibration criteria is about 1 percent of the range of observed groundwater elevations within the modeled area.

The transient models utilize monthly stress periods, each of which has 10 time steps. The modeled period was from September 2005 through February 2011. Transient model calibration was conducted by adjusting storativity properties until observed transient water-level changes caused by transient stresses (the modeled pumping center and the irrigation activities) were reasonably replicated by the model.

Predictive simulations can be made with the models. For the ultimate impact of a particular stress, steady-state simulation can be used to evaluate the average annual effects. Transient simulations can be used to estimate the timing and seasonal magnitudes of a particular stress, such as seasonal pumping, by extending the model stress periods into the future and specifying the stresses to be tested.

A variety of scenarios were analyzed to evaluate specific points of interest and to demonstrate the ability of the models to predict changes in groundwater elevations and in the groundwater budget. These included scenarios investigating the effects of various pumping rates in the vicinity of Pumping Center A, an evaluation of the effects of pumping groundwater from new wells in an undeveloped quarter section, an evaluation of the effect of a 5-year drought, and an evaluation of the effect of removing the HVID canal and irrigation from the Helena Valley. The baseline selected to evaluate impacts of various stresses was typically the modeled steady-state or transient condition for 2010, the latest full year modeled. Groundwater levels and budgets were calculated for future conditions without any changes to the system, and compared to similar information generated for the same model but with different stresses being applied.

Water Chemistry

Groundwater Chemistry

During this study 79 groundwater samples were collected from 28 sites (fig. 15) and analyzed for major ions, trace elements, and nutrients. Three synoptic groundwater sampling events were conducted in April, August, and October 2010.

The chemistry of local groundwater generally reflects a combination of the chemistry of recharging waters and the geology of the source aquifer. Recharge waters from rainfall and/or snowmelt infiltrating directly into the subsurface generally have low total dissolved solids (TDS). Runoff into streams will interact with materials as it flows to the surface-water body, increasing the TDS. Surface-water chemistry can be highly variable depending on stream length, local geology, and seasonal variations in recharge conditions. When stream loss recharges groundwater, the groundwater chemistry is typically similar to the surface-water chemistry. As water flows through the ground, the chemistry of the water is often affected by the minerals present in the geologic materials that make up the aquifer. For example, water from a limestone aquifer (calcium carbonate) will typically have a high concentration of dissolved calcium and bicarbonate. Discharges from anthropogenic activities such as mining, agriculture, and wastewater treatment may also alter groundwater chemistry.

Samples were collected after purging the wells and ensuring that field parameters were stable. All samples were analyzed for the parameters listed in table 1. Some samples were also analyzed for hydrogen and oxygen isotopes of the water ($\delta D\ H_2O$ and $\delta^{18}O\ H_2O$), sulfur isotopes of the

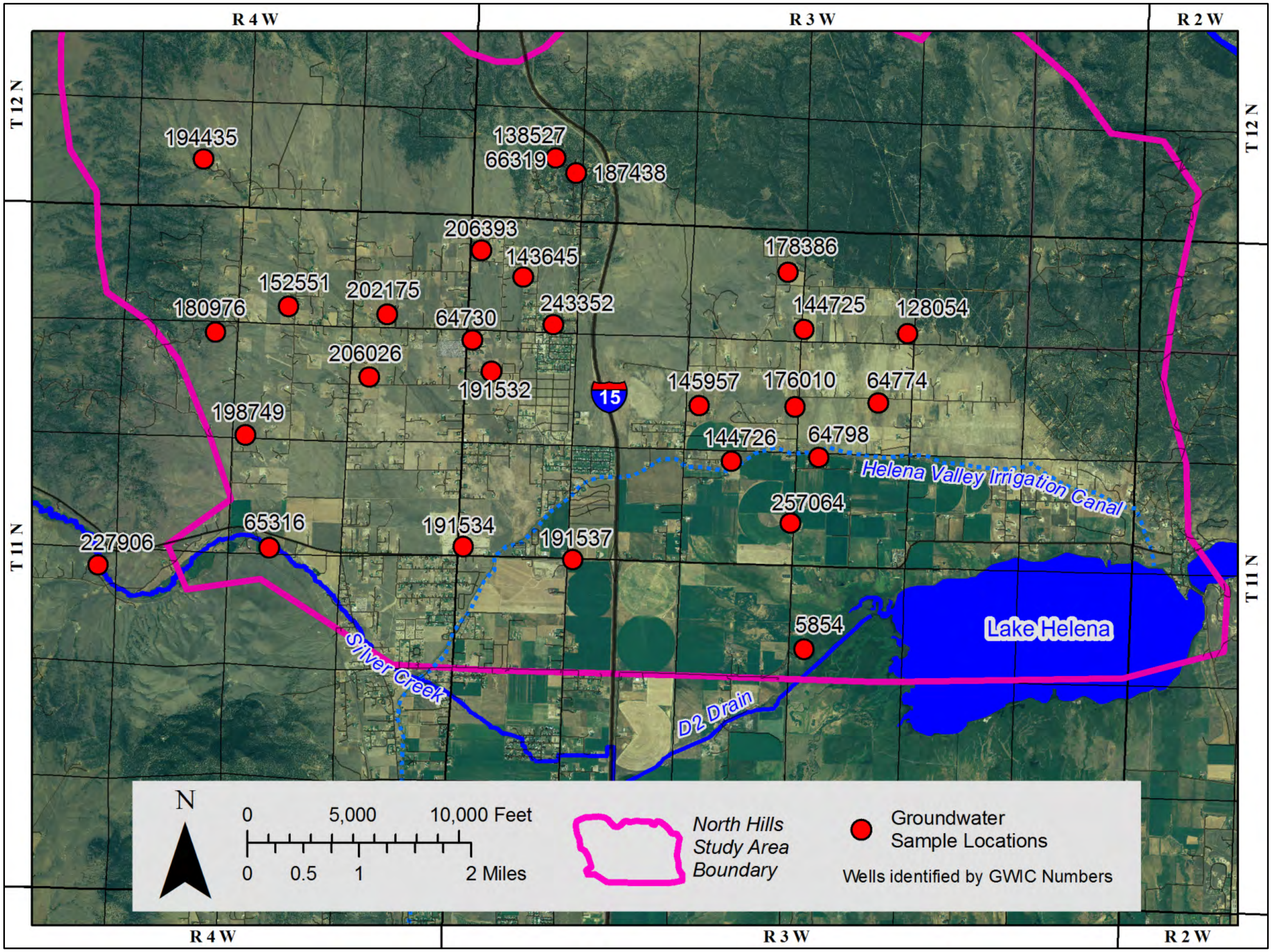


Figure 15: Eighty-seven groundwater samples were collected at 28 sites in the North Hills. Numbers designate the GWIC ID number for each site.

Table 1
Analytical Parameters and units used for reporting
North Hills Study Area

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

Field Parameters		
Field Conductivity	Field SC	μmhos
Field pH	Field pH	---
Water Temperature	T	°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		
Aluminum	Al	μg/L
Antimony	Sb	μg/L
Arsenic	As	μg/L
Barium	Ba	μg/L
Beryllium	Be	μg/L
Boron	B	μg/L
Bromide	Br	μg/L
Cadmium	Cd	μg/L
Cerium	Ce	μg/L
Cesium	Cs	μg/L
Chromium	Cr	μg/L
Cobalt	CO3	μg/L
Copper	Cu	μg/L
Gallium	Ga	μg/L
Lanthanum	La	μg/L
Lead	Pb	μg/L
Lithium	Li	μg/L
Molybdenum	Mo	μg/L
Nickel	Ni	μg/L
Niobium	Nb	μg/L
Neodymium	Nd	μg/L
Palladium	Pd	μg/L
Praseodymium	Pr	μg/L
Rubidium	Rb	μg/L
Silver	Ag	μg/L
Selenium	Se	μg/L
Strontium	Sr	μg/L
Thallium	Tl	μg/L
Thorium	Th	μg/L
Tin	Sn	μg/L
Titanium	Ti	μg/L
Tungsten	W	μg/L
Uranium	U	μg/L
Vanadium	V	μg/L
Zinc	Zn	μg/L
Zirconium	Zr	μg/L

mg/L = milligrams per Liter
μg/L = micrograms per Liter

sulfate ($\delta^{34}S\ SO_4$), nitrogen and oxygen isotopes of the nitrate ($\delta^{15}N\ NO_3$ and $\delta^{18}O\ NO_3$), and radon (^{222}Rn).

Sampling for organic waste-water chemicals (OWCs) was conducted for three wells in the study area as a separate event in April 2011. OWCs include pharmaceuticals, hormones, fire retardants, industrial chemicals, personal care products, and pesticides.

All samples were handled according to MBMG standard protocols. Most parameters were determined by the MBMG Analytical Lab in Butte, Montana. Isotope analyses were performed by Isotech Laboratories Inc. in Champaign, Illinois, and the OWCs were analyzed by Columbia Analytical Services in Kelso, Washington.

Surface-Water Chemistry

Thirty surface-water samples were collected from 12 sites (fig. 16). These were collected during the groundwater sampling events and were handled and analyzed in the same way as groundwater samples.

Data Management

The MBMG operates the Groundwater Information Center (GWIC), where data for more than 220,000 water wells are stored and are accessible to the public. This database is accessible via the internet at http://mbmggwic.mtech.edu/. In addition to well log data, this database also contains information on water levels, water chemistry, aquifer tests, and other information. Most data collected in this study are stored in the GWIC database.

Within GWIC, the data are grouped into projects when appropriate. This allows those interested in a particular project to easily obtain all pertinent data. The North Hills Project is found on GWIC's "Projects" page under "Groundwater Investigation Program." One umbrella project (BWIPNH) is used, as well as various other projects that divide out the pertinent records into appropriate sub-projects. For instance, the first sampling event for this project is separated out as BWIPNHWQ1.

A total of 193 sites were used for this study. These sites included wells, springs, piezometers, streams, crest gauges (gauges that record the maximum water level), precipitation gauges, drains, and irrigation canals. Data were collected at some of these sites during this study, while others provided historical data. The locations of these sites were confirmed by survey, navigational GPS, maps, or aerial photographs. The aquifer was designated for each well based upon lithologic descriptions, location, and depth. Water levels, hydrographs, water chemistry, flow rates, and other pertinent data were attributed to the sites. Sites referred to in this report are denoted by the site's GWIC identification number (e.g., well 211387).

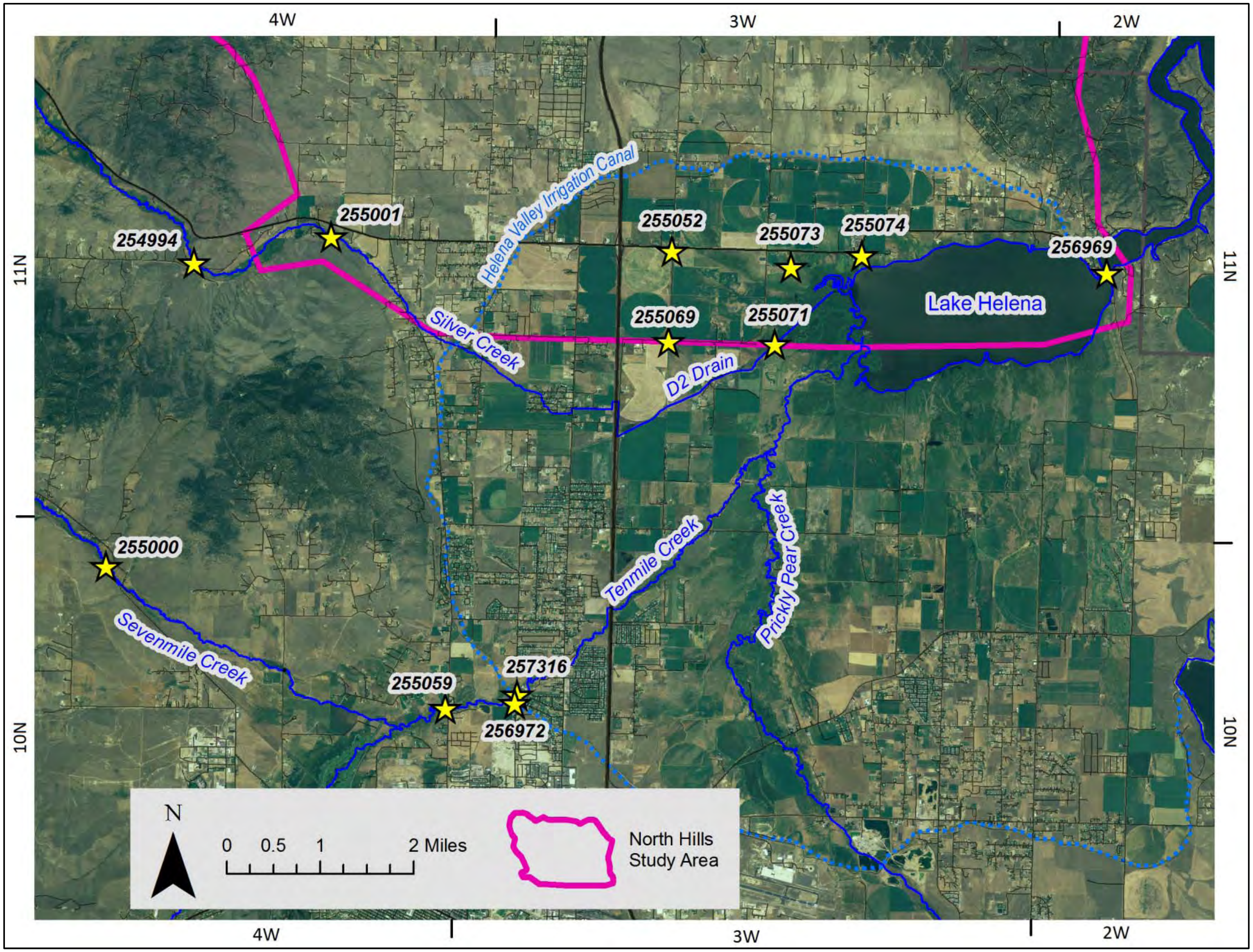


Figure 16: Thirty surface-water samples were collected at 12 sites in and near the North Hills. Numbers designate the GWIC ID number for each site.

RESULTS

Hydrogeologic Information

Well Logs, Cuttings, and Geophysics

The distribution of hydrogeologic units, as determined through evaluation of well logs and cuttings, was used to refine the conceptual model of the area and to evaluate the aquifer properties developed by inverse modeling. The cross sections and computer-generated three-dimensional representations generated in this analysis are described in the North Hills Modeling Report (Waren and others, in preparation) and are available in the GMS version of the groundwater model. The results support the basic aquifer distribution as mapped and described by Madison (2006).

In the hills and the upper pediment, well logs generally indicate wells were completed in bedrock. This is consistent with field observations, as bedrock is often seen to be exposed at the surface, particularly in the bottoms of coulees, in this area. Bedrock also underlies the unconsolidated Tertiary and Quaternary deposits.

In the eastern part of the study area, generally east of Interstate 15, well logs and available drill cuttings indicate wells are commonly completed in gravel layers buried beneath thick clays. In that area, clay-rich Tertiary sediments are exposed at the surface in places (fig. 8). West of Interstate 15, the Tertiary materials are generally covered by surficial colluvial or alluvial deposits. Well log descriptions are less consistent in this part of the study area, and drillers report variable conditions in the subsurface; both thick clays and thick gravelly materials have been reported. The description of “clay and gravel” is commonly reported on well logs. Gravel pits near the junction of Lincoln Road and Applegate Drive (fig. 2) expose gravel to depths of 30 to 40 ft. Well logs indicate gravel thicknesses of at least 200 ft in this area. Closer to Lake Helena the sediments are typically reported as silt and clay with lesser sand and gravel layers.

Numerous geophysical methods were applied by the Montana Tech Geophysics Department in the North Hills study area to test their equipment, train students, and explore which methods might produce useful products for the GWIP program. The resulting student reports were developed with oversight by the Geophysics Department professors in the short time available for their field studies. Hence, they are considered draft products demonstrating the capabilities of the methods, rather than refined products or correct and complete studies. Nevertheless, they do provide useful examples of applied geophysics, and will be available on the GWIP website to read or download (http://mbmg.mtech.edu/gwip/gwip.asp). A more detailed summary is presented in the North Hills Technical Report (Bobst and others, in preparation a). The technical report also includes a map of regional gravity anomalies and examples of gravity and magnetic anomaly images created by the students.

The gravity survey conducted by the students corresponds reasonably well with published regional gravity data (Davis and others, 1963), and detailed profiles suggest an abrupt increase in depth to bedrock (down to the south) in the vicinity of Valley View Drive along Applegate Drive, and just north of Valley View Drive along Montana Avenue. The resistivity and seismic surveys suggest that on North Montana Avenue between Valley View Drive and Prairie Road the unconsolidated materials are variable in the subsurface. Resistivity and seismic surveys across the Helena Valley Fault just east of Applegate Drive (near the Helena Valley Fault site; fig. 11) show that the fault zone may include two faults with shear zones between them.

Shallow magnetic surveys conducted by privately employed geophysicists in the vicinity of Diamond Springs Gulch just north of the end of W. Cabin Rd (12N, 4W, Sec. 34) indicate igneous bodies are present in the northwest part of the pediment beneath surficial gravels (Michaletz, written commun., 2011). Diorite cobbles were also observed at the surface in this area (Michaletz, oral commun., 2011). Anomalies on the magnetic map have been interpreted as at least five igneous bodies, each about 100 to 200 ft across, scattered around a 160-acre area (fig. 17, with permission). Also apparent in the images are bedrock faults where numerous igneous features are displaced. One of the faults appears to correspond to a mapped fault in the area while the other is unmapped (fig. 18, with permission).

Aquifer Properties

A statistical summary of aquifer test data is presented in table 2. Aquifer properties were also evaluated from previous hydrogeologic reports for the Helena vicinity and values from similar groundwater studies and flow models in Western Montana (Briar and Madison, 1992; Kauffman, 1999; MBMG, 2007; Uthman and Beck, 1998; Waren, 1998). A more detailed discussion of these values is included in the North Hills Modeling Report (Waren and others, in preparation).

Bedrock–granite. DNRC applications (P. Faber, written commun., 2010) include aquifer tests from two wells completed in granite. These tests indicate transmissivity values of 14 and 67 ft^2/day. Based on the saturated thickness penetrated (total depth less static water level), calculated hydraulic conductivity values were 0.14 and 0.74 ft/day. In the Scratchgravel Hills, the MBMG also recently conducted five aquifer tests of the granite bedrock. Transmissivity values from these tests ranged from 0.15 to 225 ft^2/day, and hydraulic conductivity values ranged from 0.001 to 1.5 ft/day (Bobst and others, in preparation b). PBS&J (2008) conducted an aquifer test in the Scratchgravel Hills granite, which resulted in a calculated transmissivity of 253 ft^2/day and a hydraulic conductivity value of 0.8 ft/day. PBS&J also calculated approximate values for transmissivity in the granite based on specific capacity (Driscoll, 1986), which resulted in estimated transmissivities from 11.3 to 27.3 ft^2/day and estimated hydraulic conductivities from 0.04 to 0.38 ft/day (PBS&J, 2008). Other groundwater studies in western Montana indicate that consolidated fractured bedrock typically has hydraulic conductivities that range from 0.1 to 2 ft/day (Waren and others, in preparation). Because there is little primary porosity in the granitic bedrock, the permeability results from the presence of secondary fractures.

Storativity values were not available for any of these tests; however, they are likely less than 0.1 (Freeze and Cherry, 1979, p. 37).

Bedrock–argillite. Transmissivity values from DNRC applications (P. Faber, written commun., 2010) for 13 aquifer tests in the argillite bedrock ranged from 43 to 11,100 ft^2/day, and calculated hydraulic conductivity values ranged from 0.09 to 163 ft/day. Storativity values from these tests ranged from 0.0002 to 0.0006. These tests were all conducted where the argillite was overlain by unconsolidated materials. Because there is little primary porosity in the argillite bedrock, the permeability results from the presence of secondary fractures.

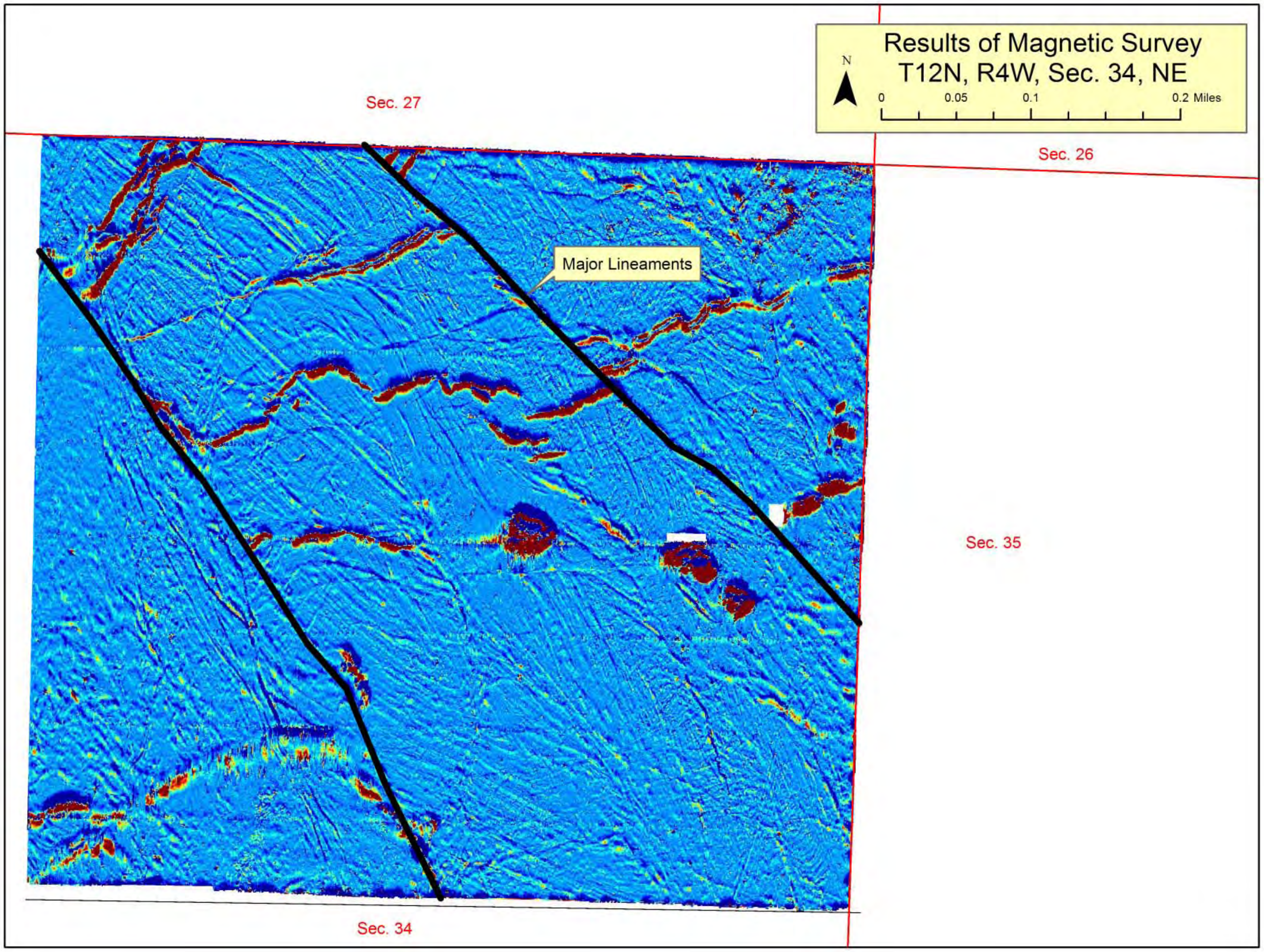


Figure 17. Near-surface magnetic survey work conducted by Joe Michaletz (written commun., 2011, with permission) in the NE of T12N, R4W, Section 34, shows that igneous bodies (dark bodies) are present in the bedrock. Diorite clasts have been found at the surface in this area. Offset of the igneous bodies have been interpreted as indicating two major lineaments. See also figure 18.

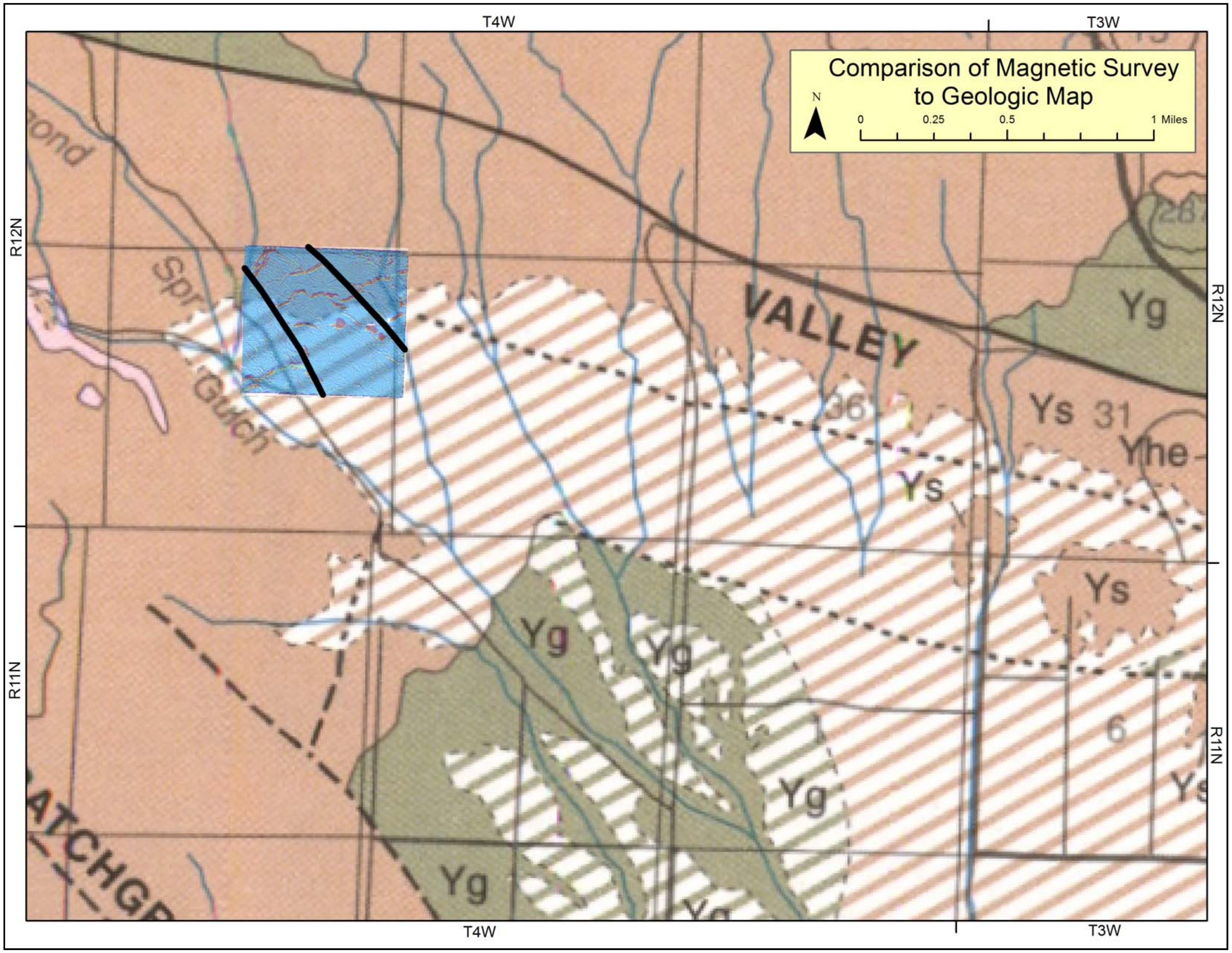


Figure 18. One of the major lineaments observed from magnetic information (with permission, from Michaletz) can be correlated with an inferred fault shown on the geologic map of the area (with permission, from Reynolds, 2000). The other is unmapped. Geophysical information is in T12N, R4W, Sec. 34 NE. See also figure 17.

Table 2: Summary of Aquifer Properties in the North Hills Study Area

Hydrogeologic Unit	**Source**	**Method**	**Number of tests**	**Hydraulic Conductivity (ft/day)**				**Storage**		
				min	**max**	**avg**	**geo mean**	**min**	**max**	**avg**
Quaternary	DNRC	Aq Tests	22	1	916	215	73	0.0008	0.046	0.013
	this study	Model	---	0.05	464	---	---	0.05	0.2	---
Tertiary	DNRC	Aq Tests	9	0.1	163	56	10.8	0.0005	0.0005	0.003
	this study	Aq Tests	1	160	160			0.006	0.006	
	this study	Model	---	0.007	12	---	---	0.02	0.05	---
Argillite Bedrock	DNRC	Aq Tests	10	0.09	19	7.1	3.6	0.0002	0.0006	0.011
	this study	Aq Tests	6	1.6	7.5			0.0011	0.02	
	this study	Model	---	0.006	6.4	---	---	0.02	0.02	---
Granite Bedrock	DNRC	Aq Tests	2	0.14	0.74	0.63	0.13	---	---	---
	SG Hills	Aq Tests	5	0.0009	1.5			---	---	

Note: Hydrologic conductivity values from aquifer tests are calculated from the reported transmissivities, divided by an aquifer thickness determined by analysis of well logs.

ft/day = feet per day
DNRC = Data from the Department of Natural Resources Conservation water rights applications
Aq Test = Aquifer Test
Model = The North Hills Area Model
SG Hills = The ongoing MBMG study in the Scratchgravel Hills (Bobst and others, in preparation)
min = minimum
max = maximum
geo mean = geometric mean
avg = average

An aquifer test was conducted at the Valley Excavation Site (fig. 11). The site is representative of fractured Belt bedrock away from fault zones and with no confining layer. For this test the pumping well was pumped at an average rate of 14 gallons per minute (gpm) for 6 days. Transmissivity was calculated to be 350 ft^2/day. The pumping well at this site was 200 ft deep, and the pre-test static water level was 80 ft below ground surface (bgs). Based on a saturated aquifer thickness of 120 ft, hydraulic conductivity was calculated to be 2.9 ft/day. The storage coefficient was calculated at 0.02.

The O'Reilly aquifer test (fig. 11) was conducted in argillite bedrock to evaluate the vertical connection between deep (260 ft) and shallow (45 ft) wells. For this test the deep well was pumped at 46 gpm for 24 hours. The shallow well immediately responded to pumping. This test produced a calculated transmissivity of 200 ft^2/day. The pumping well at this site was 260 ft deep, and the pre-test static water level was at 23 ft. Based on a saturated aquifer thickness of 237 ft, hydraulic conductivity was calculated to be 0.8 ft/day. The storage coefficient was calculated at 0.03.

The State Lands East aquifer test (fig. 11) was conducted in argillite bedrock for 48 hours; the average pumping rate was 30 gpm. Test data indicated that a barrier to flow was encountered; however, using data from before the barrier was encountered transmissivity was calculated at 475 ft^2/day. The pumping well at this site was 345 ft deep, and the pre-test static water level was at 195 ft. Based on a saturated aquifer thickness of 150 ft, hydraulic conductivity was calculated to be 3.2 ft/day. The storage coefficient was calculated at 0.001.

The State Lands West aquifer test (fig. 11) was conducted in argillite bedrock for 48 hours; the average pumping rate was 18 gpm. Test data indicated that a barrier to flow was encountered and that it was located between the pumping well and the observation well. As such, a storage coefficient could not be calculated. Data from before the barrier was encountered were used to calculate a transmissivity of 575 ft^2/day. The pumping well at this site was 160 ft deep, and the pre-test static water level was at 83 ft. Based on a saturated aquifer thickness of 77 ft, hydraulic conductivity was estimated to be 7.5 ft/day.

When the values from DNRC applications and this study are combined, the average and geometric mean hydraulic conductivities are 7.1 and 3.6 ft/day, respectively. Other groundwater studies in western Montana indicate that consolidated fractured bedrock typically has hydraulic conductivities that range from 0.1 to 2 ft/day. Model results indicate that Belt bedrock hydrologic conductivity for the North Hills ranges from 0.006 to 6.4 ft/day.

The combined values from DNRC applications and the tests from this study result in an average storativity of 0.011. Modeled storativity is about 0.02.

Many faults are present in the argillite bedrock of the North Hills study area (Reynolds, 2000; fig. 8). At the Helena Valley Fault Site and the Purcell Site (fig. 11), aquifer tests were conducted on wells drilled near known faults. Both tests showed a delayed and muted or immeasurable response on the far side of the faults (fig. 19), indicating that the faults are barriers to flow. Because the locations of the barriers are not precisely known, and they are not

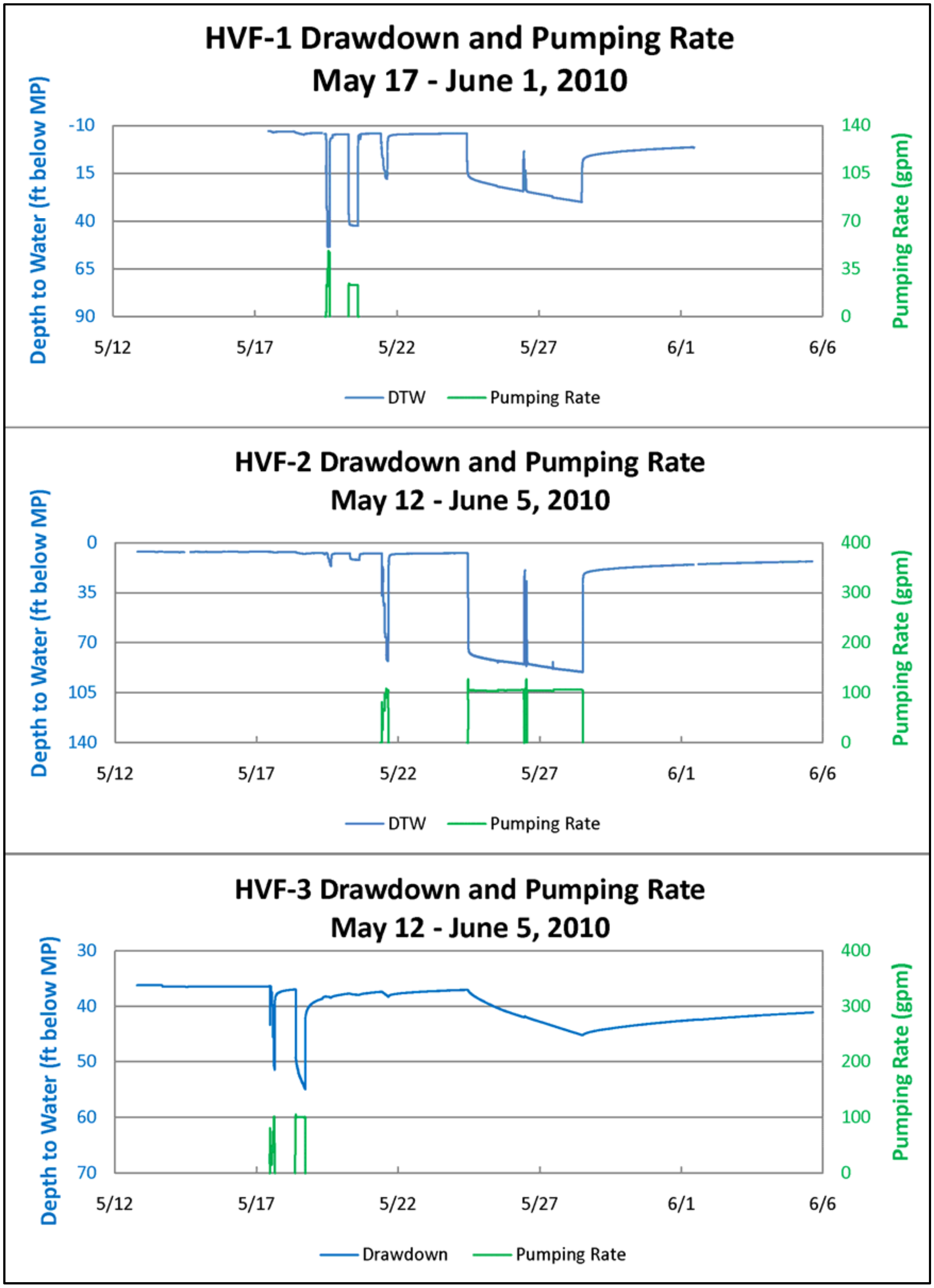


Figure 19. During the aquifer test at the Helena Valley Fault communication between wells HVF-1 and HVF-2 was immediate and of high magnitude. Communication between HVF-3 and the other two wells was muted and of low magnitude.

impermeable, analysis as bounded aquifers (ASTM, 2010) was not possible with the available data.

Tertiary aquifers (gravel and clay). The Tertiary deposits are a combination of clay- and gravel-sized sediments. Because the hydraulic conductivity of these materials spans a wide range of values, results of aquifer tests are quite variable.
Transmissivity values for nine aquifer tests in the Tertiary sediments from DNRC applications (P. Faber, written commun., 2010) ranged from 17 to 7,190 ft^2/day. Hydraulic conductivity ranged from 0.1 to 131 ft/day. No storativity values were obtained from these tests.

An aquifer test was conducted at the Panoramic Meadows Site for this study (fig. 11). For this test the well was pumped at an average rate of 38 gpm for 6 days. Transmissivity was calculated to be about 15,000 ft^2/day. The pumping well at this site was 134 ft deep, and the pre-test static water level was at 41 ft. Based on a saturated aquifer thickness of 93 ft, hydraulic conductivity was calculated to be 161 ft/day. The storage coefficient was calculated at 0.006.

When the hydraulic conductivity values from DNRC applications and this study are combined, the average and geometric mean are 56 and 10.8 ft/day, respectively. Other groundwater studies in western Montana indicate that Tertiary basin-fill materials typically have hydraulic conductivities that range from 0.05 to 10 ft/day. Model results indicate that hydrologic conductivity ranges from 0.007 to 12 ft/day, and storativity ranges from 0.02 to 0.05.

Helena Valley aquifer (Quaternary and Tertiary sand, gravel, and clay). DNRC applications include transmissivity values for 22 aquifer tests in the Helena Valley aquifer (P. Faber, written commun., 2010), that ranged from 108 to 75,500 ft^2/day. Hydraulic conductivity values from these tests ranged from 1.0 to 916 ft/day. The average hydraulic conductivity is 215 ft/day, and the geometric mean is 73 ft/day. Other groundwater studies in western Montana indicate that Quaternary alluvium typically has hydraulic conductivities that range from 10 to 1,800 ft/day. Model results indicate hydrologic conductivity ranges from 0.05 to 464 ft/day.

Storage coefficients from DNRC applications ranged from 0.0008 to 0.046. The average storativity was 0.013. Modeled storativity ranges from 0.05 to 0.2. No aquifer tests were conducted in the alluvium for this study.

Precipitation Distribution

Analysis of precipitation data shows that average annual precipitation in the North Hills study area varies from less than 10 in. at low altitudes to over 16 in. in the hills (fig. 20). This pattern is also reflected by soils classification data (NRCS, 2011). Integration of these data shows that a total of about 34,430 acre-ft/year of water are delivered to the study area by precipitation.

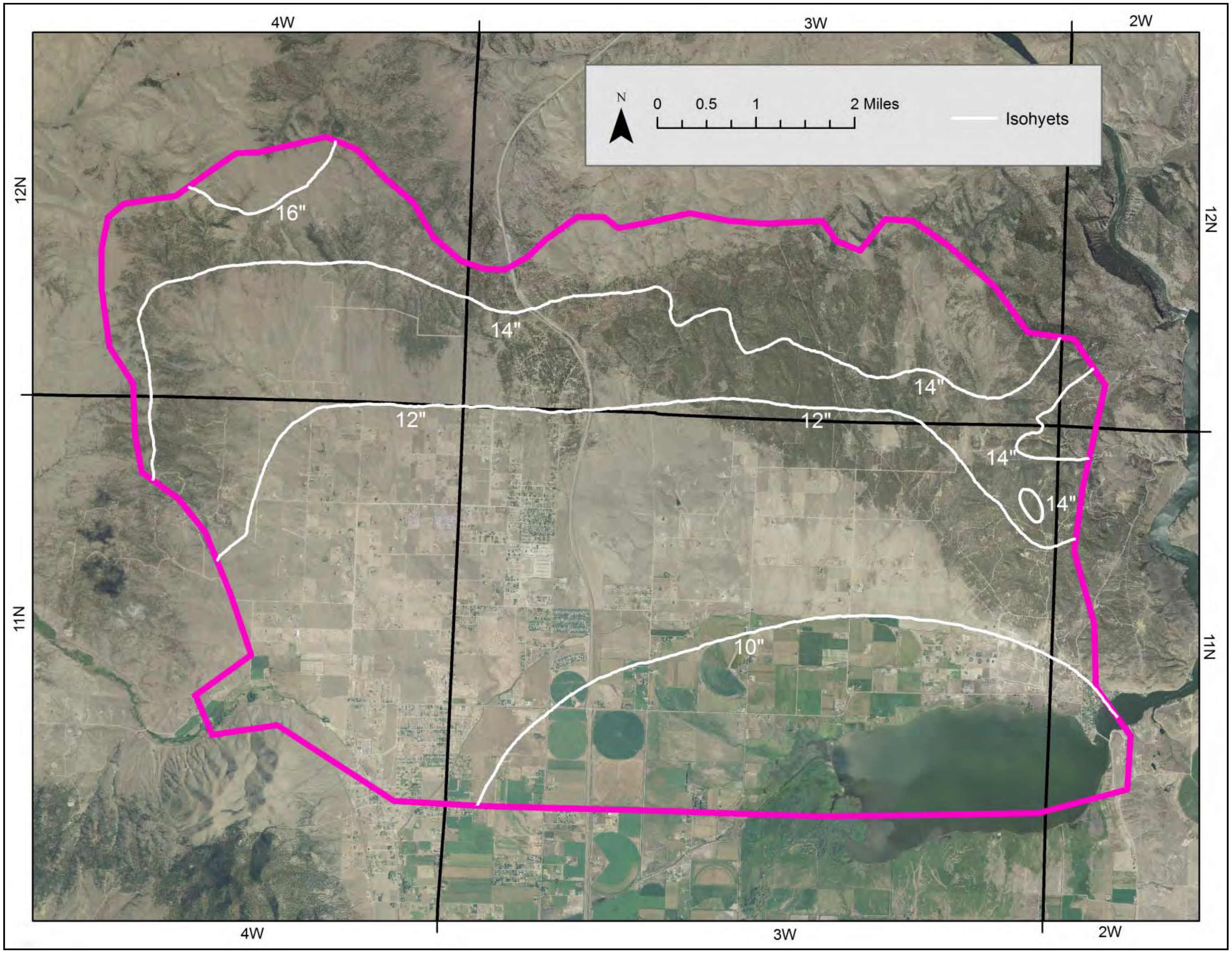


Figure 20. Average annual precipitation isohyets in the North Hills Study Area (1970-2000; P. Farnes, written commun., 2010) show that precipitation ranges from less than 10 inches in the Helena Valley to over 16 inches in the hills.

Groundwater Levels

Groundwater levels were monitored at 74 wells. These sites are identified in the North Hills Technical Report (Bobst and others, in preparation a), including each GWIC ID number. All water levels can be obtained from GWIC.

Hydrograph Trend Analysis

Groundwater-level data can be compared to historical values to determine if changes in groundwater levels are occurring over time. A graph of water levels over time is called a hydrograph (fig. 21).

Within the North Hills study area, hydrographs for 34 wells had sufficient data for a water-level trend to be determined. Of these, 11 had upward slopes and 23 had downward slopes. The resulting hydrographs are included in the North Hills Technical Report (Bobst and others, in preparation a). Selected hydrographs are included in this report (figs. 22–24). These slopes are also mapped to show their geographic distribution (fig. 25).

The only wells with upward trends greater than 0.5 ft/year are located near where Silver Creek enters the valley. Discussions with local residents indicate that there has been more flow in Silver Creek in recent years than in the years preceding 2005. This lends further support to the concept that water levels in this area are sensitive to flows in Silver Creek (Madison, 2006).

Most hydrographs from wells in the area near or topographically below the HVID canal have slopes between 0.5 (upward) and -0.5 (downward) ft/year. Thus minimal changes in water levels are seen in this area. This lends further support to the concept that water levels in this area are strongly affected by irrigation (Madison, 2006). This includes all monitoring near Pumping Centers B and C (fig. 25). The only exception is for well 191537, for which the trend is affected by the seasonality of data collection in 2005.

A cluster of wells with dropping water levels is present within and near Pumping Center A (fig. 25). These wells appear to be directly affected by pumping for irrigation in the summer; minimum water levels occurred in late summer. These include monitoring wells and wells used to supply domestic water. The decline in this area appears to result from total pumping in this area being at rates greater than the aquifer can supply (i.e. this is an area wide issue). Geologic mapping in this area (Reynolds, 2000) shows a fault trending east–west just north of Pumping Center A. Drawdown is not seen north of this fault. To the south, the HVID canal runs through this area along an east–west trend. As discussed above, near and below the HVID canal, hydrograph slopes are stable.

Although most of the wells that show a decline greater than 0.5 ft/yr are near Pumping Center A, there were other wells showing declines. These are all active wells (not dedicated monitoring wells) completed in the bedrock. In most cases there are other wells with stable hydrographs between Pumping Center A and the declining wells (fig. 25). It appears that the declines seen at these wells result from the wells themselves being pumped at rates greater than the aquifer can supply (i.e. these declines are site-specific issues).

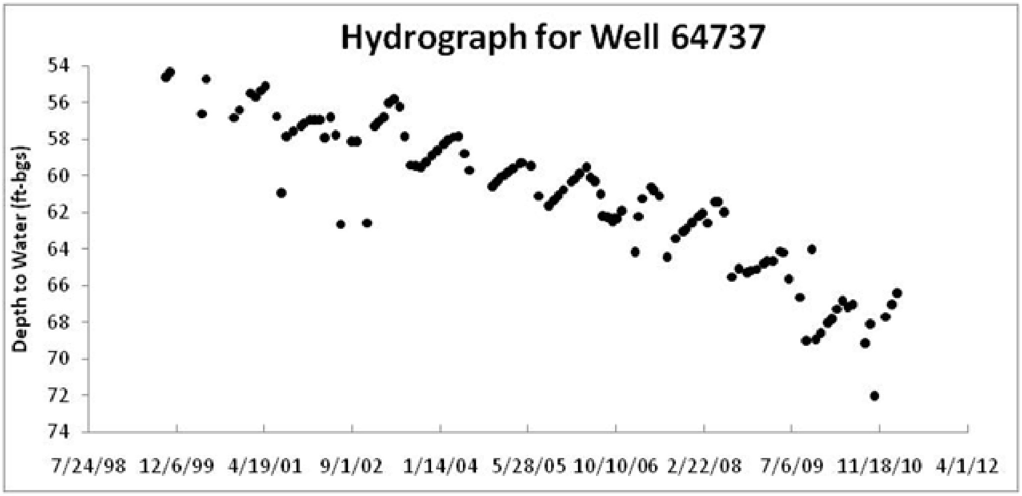


Figure 21. Hydrographs are used to chart water levels over time. This hydrograph from well 64737 provides an example. The hydrograph for well 64737 shows an overall gradual decline in water levels from 1998 to 2010; the prominent cyclic fluctuations in the curve represent declining water levels during the summer when water usage is high due to irrigation, and recovery during the winter when pumping rates are much lower. Water level data have been collected for 74 wells in the North Hills for this study.

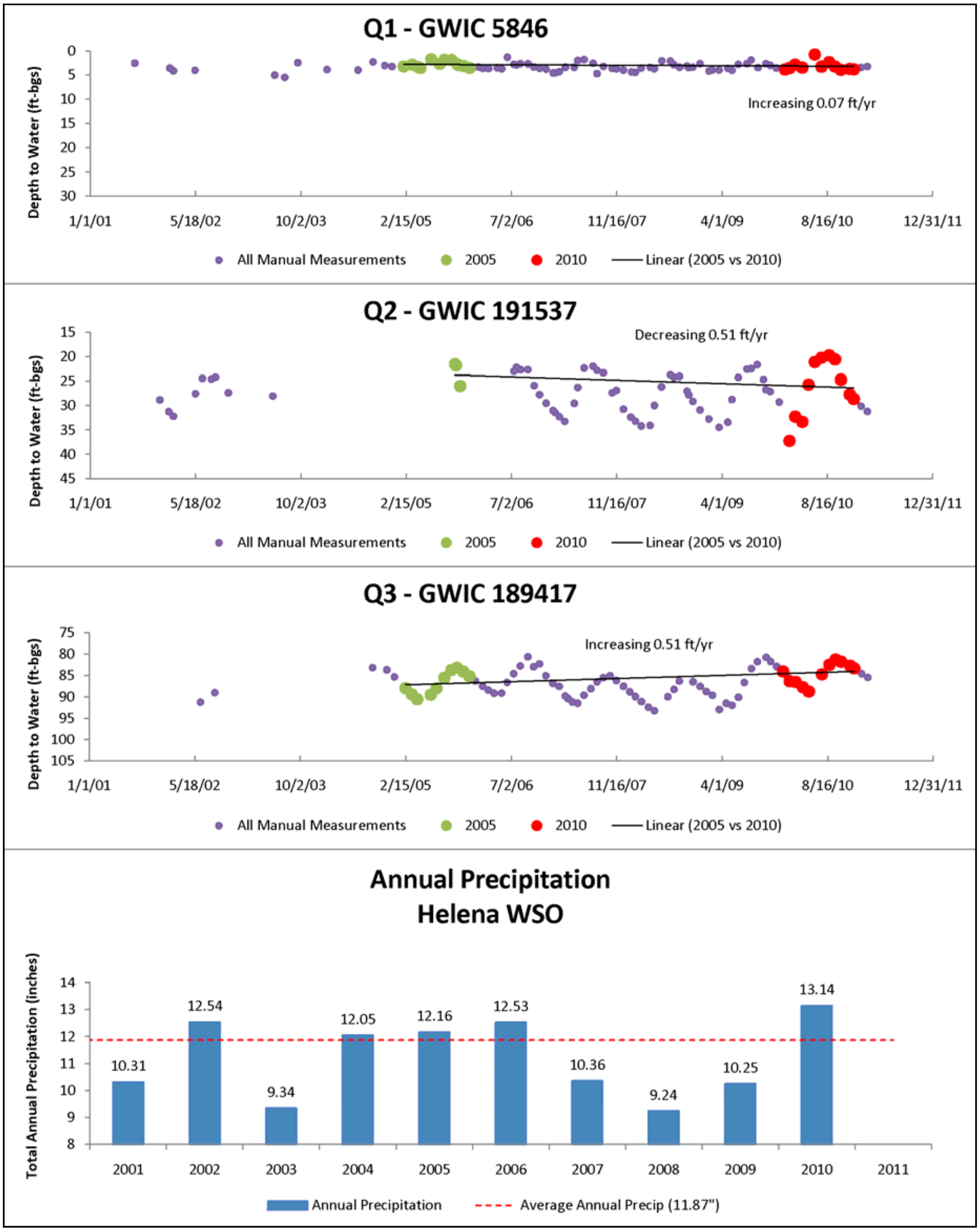


Figure 22. Hydrographs from the Helena Valley Aquifer reflect recharge from canal leakage and irrigation in the summer, with declining levels during the non-irrigation season. Overall these hydrographs are flat and show no correlation with precipitation. The locations of these wells are shown on Figure 17.

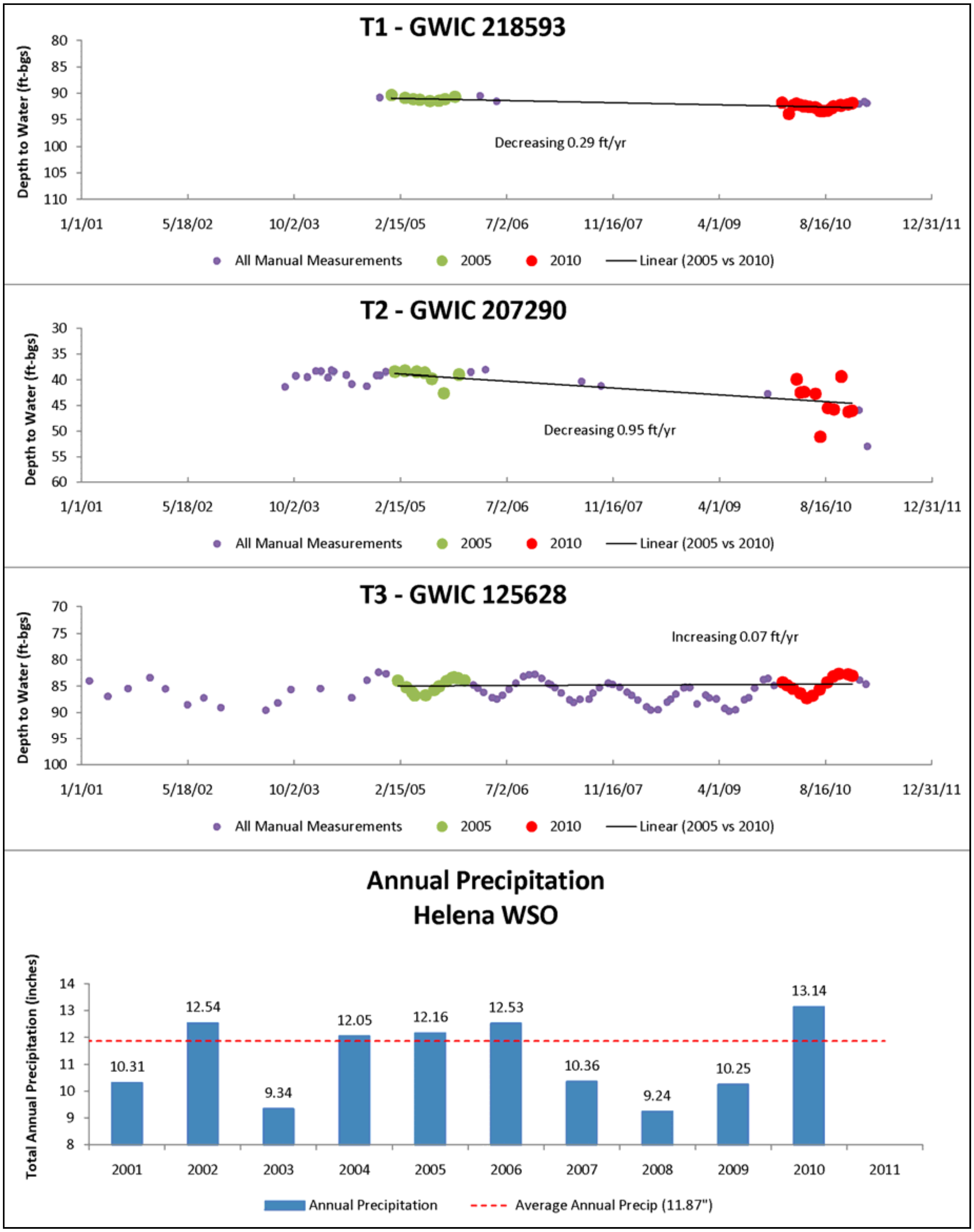


Figure 23. Some hydrographs from the Tertiary aquifer of the North Hills show effects of summer pumping (T1 &T2) and may show long term declines (T2). Others are affected by recharge from canal leakage and irrigation in the summer, and show a flat long-term trend. The locations of these wells are shown on Figure 17.

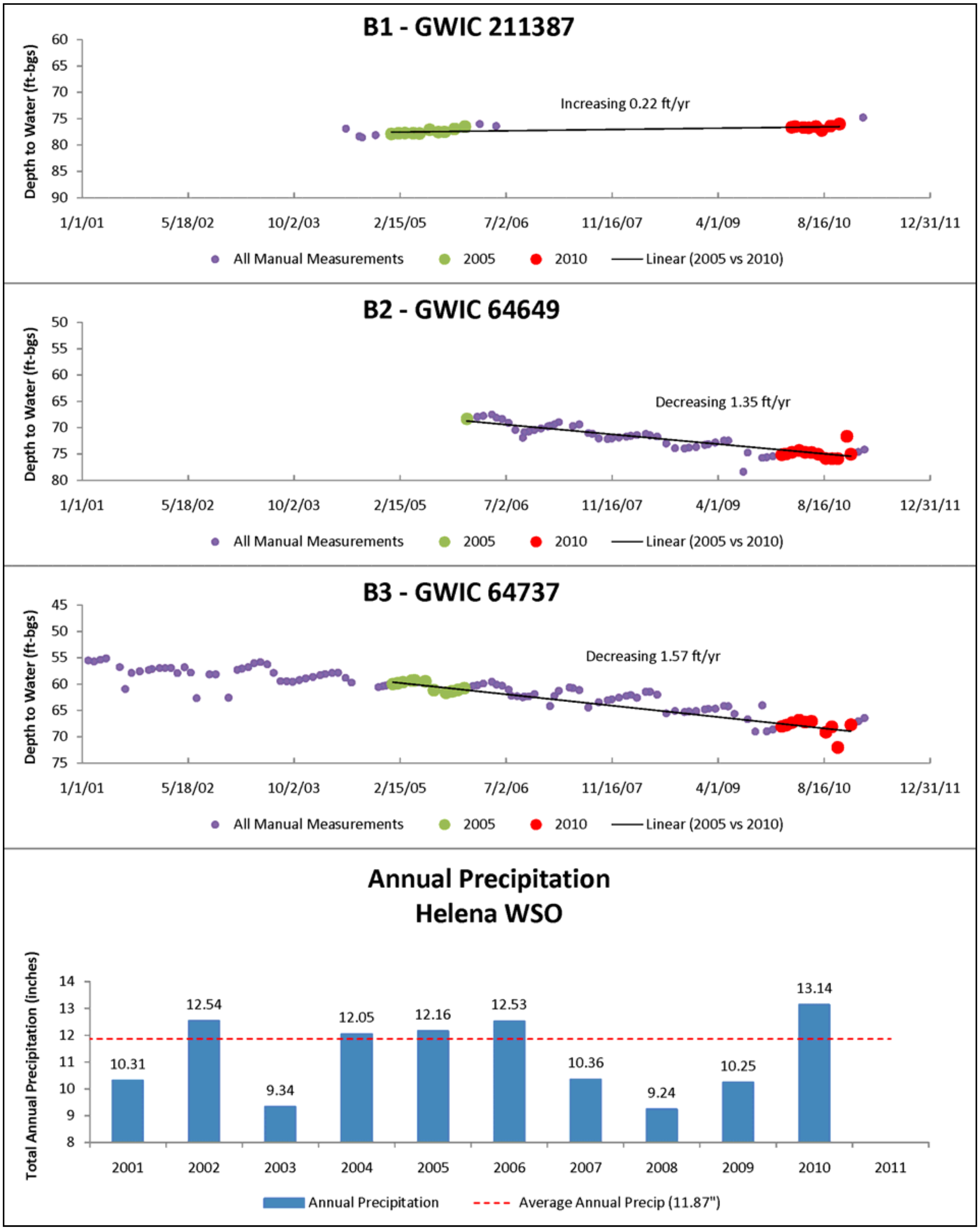


Figure 24. Some wells in the bedrock aquifer of the North Hills are separated from pumping by faults or distance, and show little seasonal variation or long term trend (B1). Other wells are affected by summer pumping and show long-term declines (B2 &B3). There does not appear to be a direct correlation with short term precipitation. The locations of these wells are shown on Figure 17.

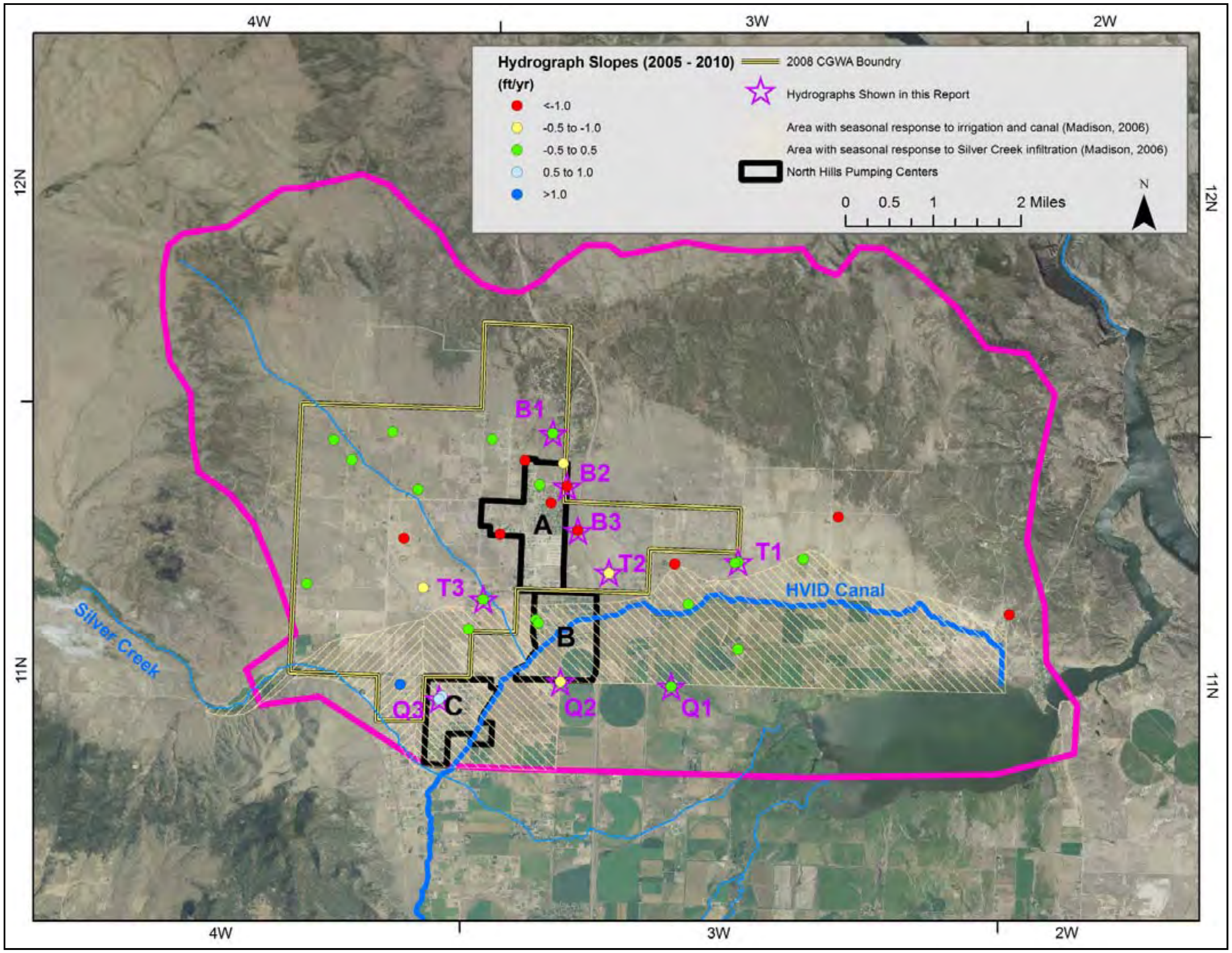


Figure 25. The slopes of hydrographs from the North Hills can be mapped to show their geographic distribution. Negative slopes indicate dropping water levels. Hydrographs are included in this report on figures 38, 39, and 40 for the locations indicated. There is a consistent downward trend near Pumping Center A, and there are isolated wells with downward trends in other areas. Areas of low-density development generally show flat trends, as do areas near and below the HVID Canal.

Evaluations of hydrographs show that seasonal variations in water level depend on the hydrogeologic setting of the well. For wells completed in the Helena Valley aquifer, peak water levels are seen in late summer, and minimum water levels are seen in the spring. This occurs because of recharge associated with irrigation using water brought in by irrigation canals during the summer. Wells completed in the Tertiary or bedrock aquifers typically have their lowest levels in late summer and their highest levels in the spring (figs. 22-24). This results from heavier usage during the summer for irrigation and lack of recharge from outside irrigation water.

Potentiometric Surface

Composite potentiometric surface maps generated for this study are presented in the North Hills Technical Report. The overall shape of the potentiometric surface changes little over time. The potentiometric surface map for October 2010 (fig. 26) is representative, and it shows that the potentiometric surface is generally a subdued reflection of the topographic surface, and that groundwater flows from the hills to Lake Helena. Water flows out of Lake Helena via its Causeway. This potentiometric surface is generally similar to those of Lorentz and Swenson (1951) and Briar and Madison (1992) where they overlap.

Surface-Water Flows

For this study, surface-water flow was measured at 17 sites on Silver Creek, on drains, on ephemeral drainages, and at the Lake Helena Causeway. These sites are identified in the North Hills Technical Report (Bobst and others, in preparation a), including each GWIC ID number. All stage and discharge measurements can be obtained from GWIC. These values provide information on the amount of water entering and leaving the North Hills area as surface water (fig. 12).

These measurements indicate that in an average year approximately 974 acre-ft/year (1.3 cfs) enter the study area through Silver Creek, much of which normally infiltrates to groundwater. Monitoring on drains shows that for the 3,065 irrigated acres in the North Hills study area, approximately 1 acre-ft per year flows through the drains per irrigated acre drained. Monitoring on ephemeral draws shows that surface-water runoff is very rare in the North Hills. Based on monitoring at the Lake Helena Causeway, and using previous USGS monitoring, it is estimated that the average annual out flow is about 110 cfs.

Groundwater–Surface-Water Interactions

Data from all three sites on Silver Creek showed that surface-water levels are above groundwater levels at all times; however, changes in surface-water levels are quickly reflected in changes in the underlying groundwater levels. Noticeable diurnal temperature variations are seen in the surface water, but they are not seen in the underlying groundwater (fig. 27). The amount of flow is also observed to decline downstream during both the irrigation and non-irrigation seasons (fig. 28). This is consistent with it being a losing stream (Winter and others, 1998). Based on

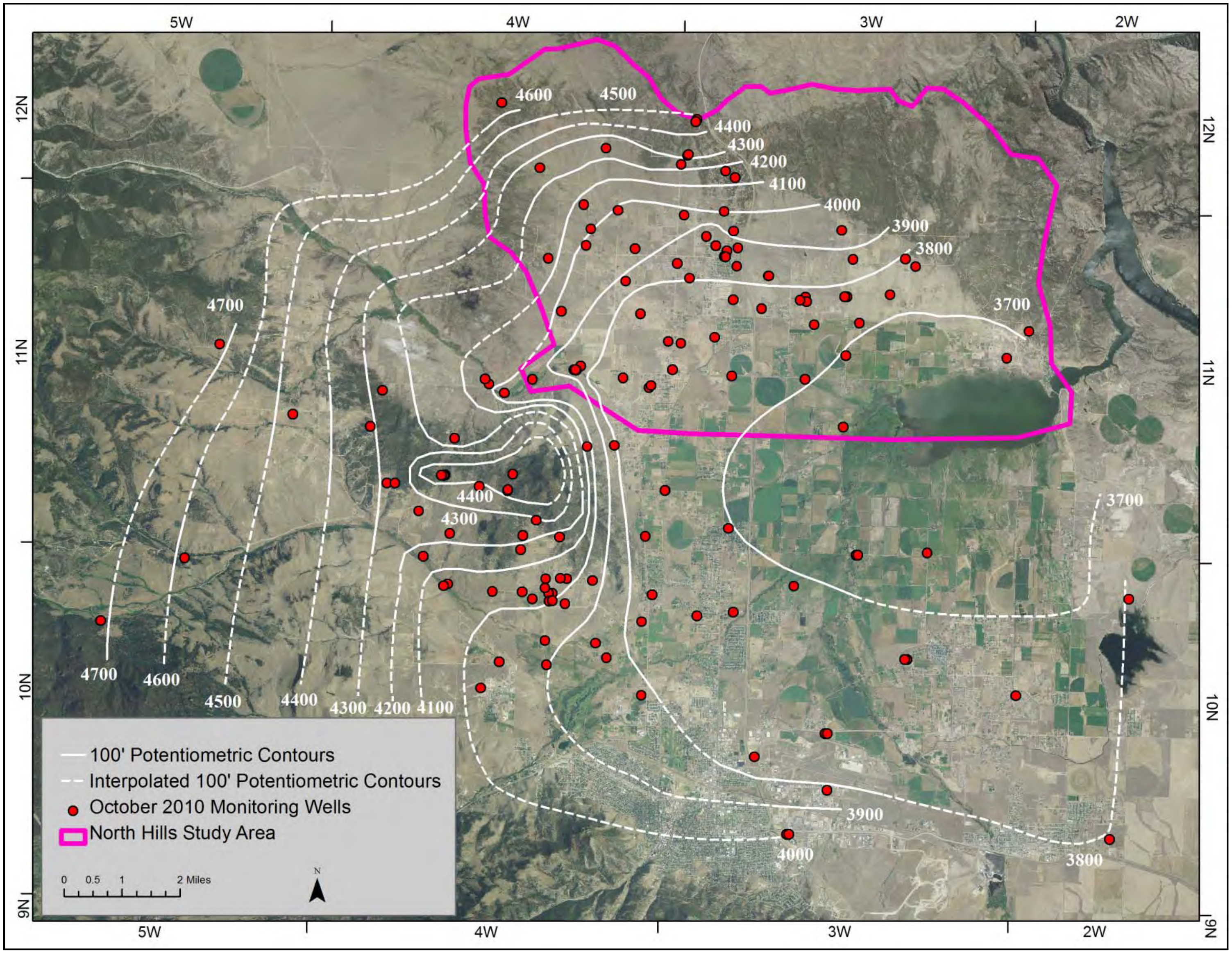


Figure 26. This composite potentiometric-surface map (October, 2010 data) indicates that groundwater flow is from the hills adjacent to the Helena Valley to Lake Helena. The greater spacing of the contours in the valley indicates that the aquifer is more permeable.

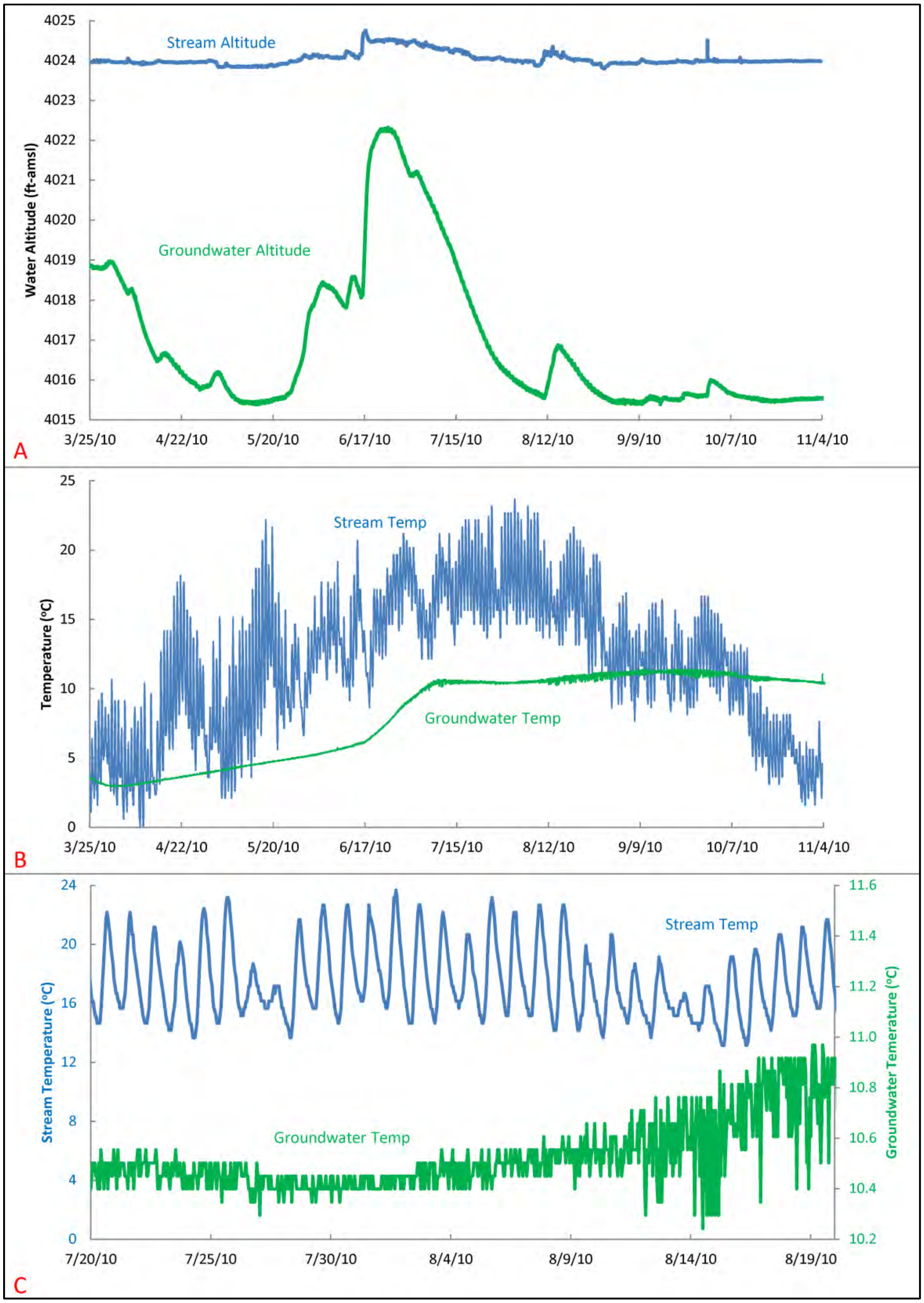


Figure 27. Comparison of groundwater and surface-water altitudes at the upper Silver Creek Site (SC1; well 254216 and stilling well 254994) shows that the stream is consistently higher than groundwater levels. Comparison of surface-water and groundwater temperatures shows a strong diurnal temperature signal in surface water; however groundwater shows no diurnal response. This indicates that the volume of water flowing from surface water to groundwater is relatively small. The monitored well is screened from 10.5 to 13 feet below the base of the stream.

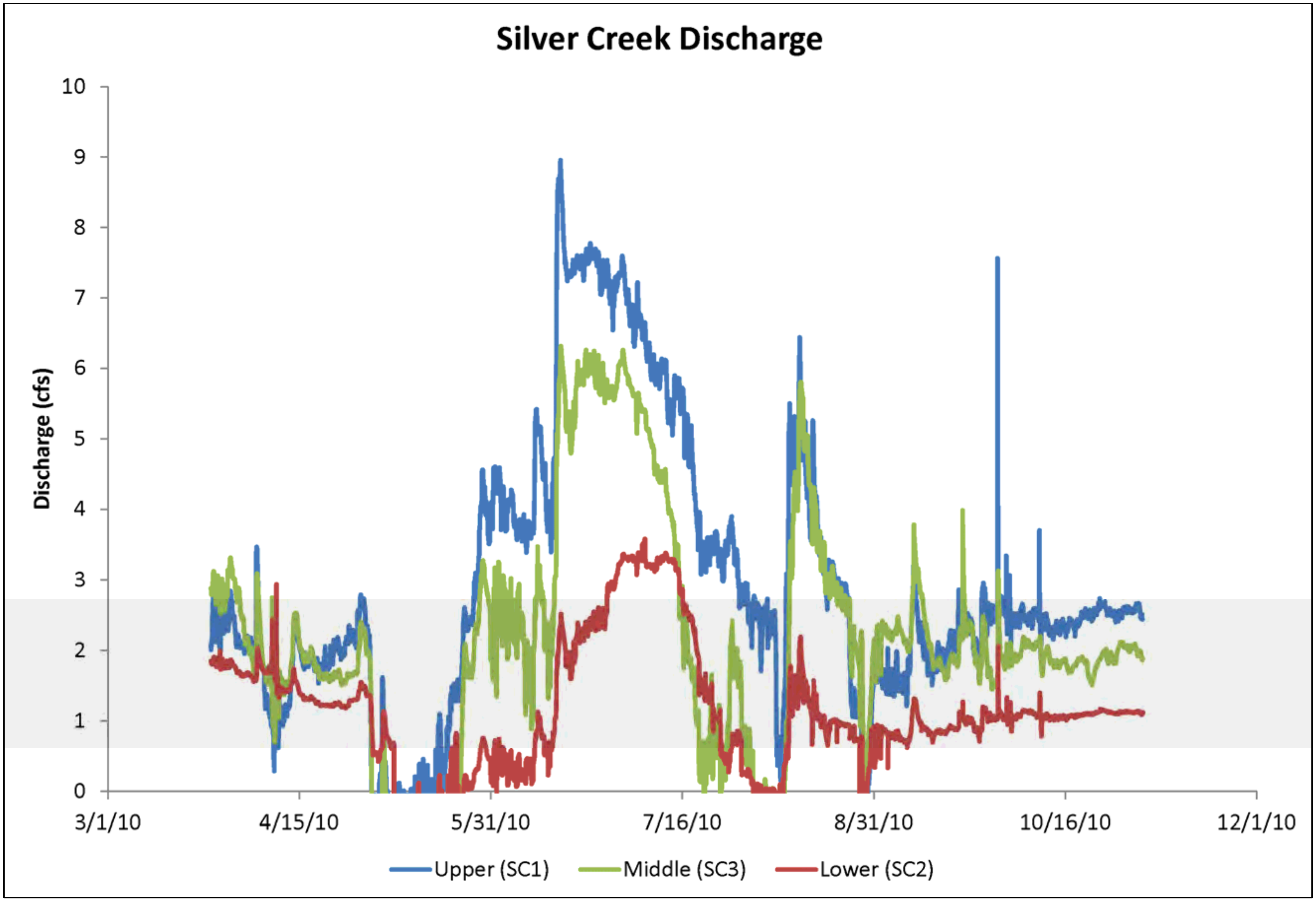


Figure 28: Flow in Silver Creek generally decreases downstream during both the irrigation and non-irrigation seasons. Short-term irrigation influences cause a few exceptions to this.

discussions with local residents, in most years Silver Creek infiltrates until it runs dry, typically above Green Meadow Drive.

Estimation of Evapotranspiration

The actual evapotranspiration for the North Hills has been estimated for this study by researchers at the University of Idaho using METRIC remote sensing techniques (Trezza and others, 2011; fig. 29). METRIC indicates an ET of 28 in. in irrigated areas, 13 in. on the non-irrigated pediment, and 22 in. in the forested hills.

The ET values calculated by METRIC in the irrigated areas match well with a previous estimate of 27 in calculated by the USGS (Briar and Madison, 1992). On the non-irrigated pediment the METRIC estimated ET is essentially equal to precipitation, which matches well with previous assessments (Briar and Madison, 1992; Madison, 2006). The METRIC-calculated ET values for the forested hills are significantly higher than precipitation. Precipitation in this area averages 15 in. Because the precipitation data are believed to have less potential for errors, alternative methods were used to estimate ET in the forested area. Thiros and others (1996) estimated that in alluvial basins in Utah receiving 8–16 in of precipitation, 1–25 percent infiltrates. Anthoni and others (1999) measured ET in a Ponderosa Pine stand in a semi-arid environment in central Oregon at 1.6 mm per day in the summer. This equates to approximately 11.6 in/year (April–October, assuming April and October are at half the summer rate), leaving 3.4 in for infiltration. The USGS has also noted that recharge in Montana ranges from “less than 1 in/year in parts of the eastern plains to several inches in parts of the western mountains” (USGS, 1985). Numerical modeling also provides a constraint on how much recharge is occurring. In the model, hydraulic conductivities for the argillite bedrock are on the low end of the range considered to be reasonable when 3 to 4 in of recharge is applied in the hills. Lower recharge values would require lower hydrologic conductivity values to reproduce observed water levels, which would cause the hydrologic conductivity values to be outside the range considered to be reasonable. Given these factors, it is estimated that infiltration is equal to approximately 25 percent of precipitation (3.75 in/year on average) in the forested hills. The remainder (11.25 in/year on average) is lost to ET.

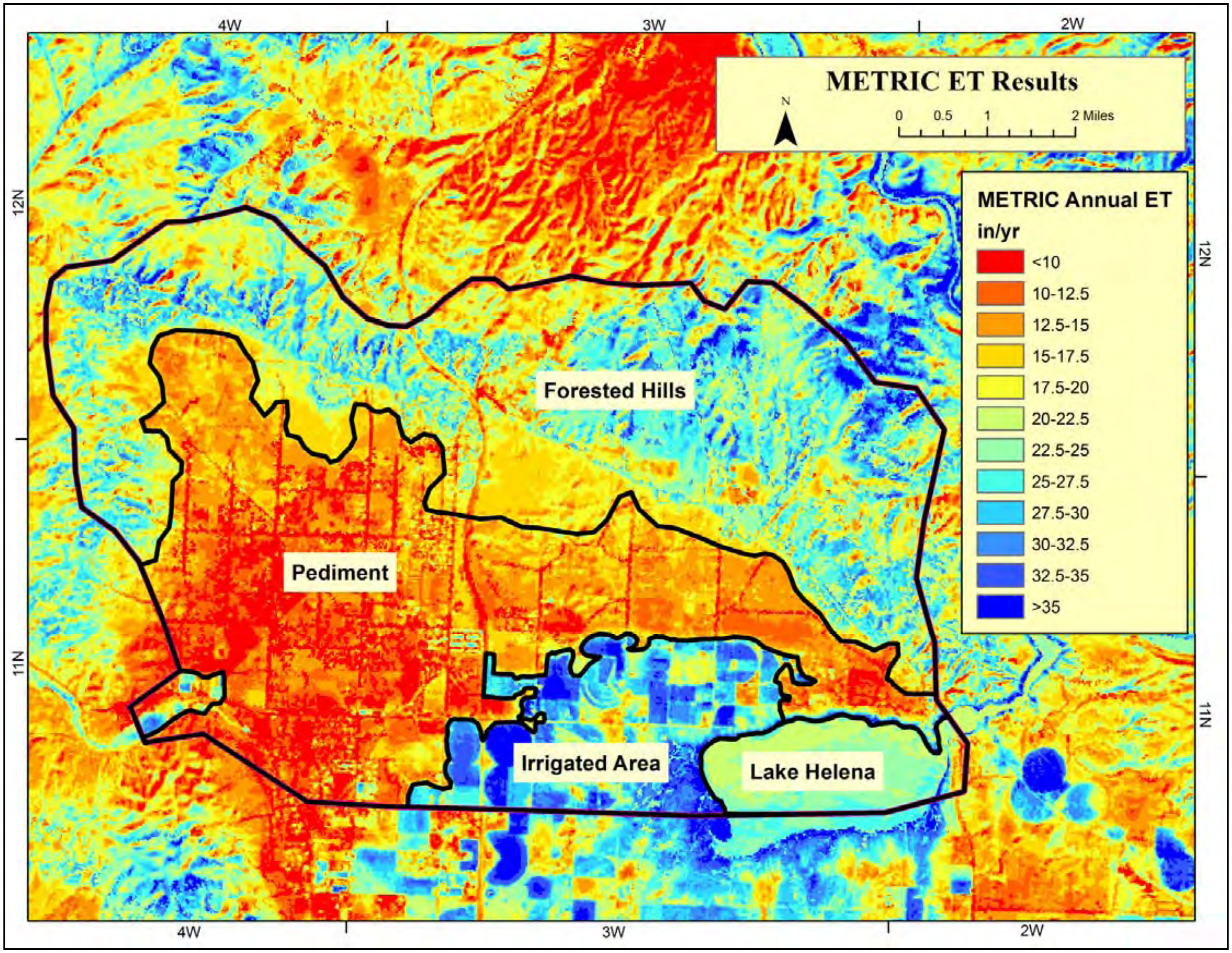


Figure 29: The METRIC ET analysis indicates that ET is approximately 28 inches per year in the irrigated area, 13 inches per year on the pediment, and 22 inches per year in the forested area. Note that calculated precipitation in the forested area averages 15 inches per year (fig. 20).

Groundwater Budget

A detailed report on the North Hills Groundwater Budget is included in the North Hills Technical Report (Bobst and others, in preparation a). A brief summary of the major components is discussed below. As discussed in the Methods section, the general form of the mass balance equation is:

$$\text{Inputs} = \text{Outputs} \pm \text{Changes in storage.}$$

Based upon the discussions above, this equation can be expanded for the North Hills study area to:

$$SCal + SG + SC + DI + CL + IR = WL + DR + LH \pm \Delta S,$$

where:

SCal, groundwater inflow from Silver Creek alluvium;
SG, groundwater inflow from the Scratchgravel Hills;
SC, infiltration of water from Silver Creek;
DI, diffuse infiltration;
CL, canal leakage;
IR, irrigation recharge;
WL, withdrawals by wells;
DR, flow to drains;
LH, flow to Lake Helena; and
ΔS, changes in storage.

For the North Hills groundwater inflow comes from the alluvium of Silver Creek (SCal; ~20 acre-ft/year) and from the bedrock of the Scratchgravel Hills in the southwest (SG; ~1,252 acre-ft/year). Measurements of surface-water flow at the edge of the study area indicate that Silver Creek (SC) brings in an average of about 959 acre-ft/year [1.3 cubic feet per second (cfs)]. Much of this infiltrates to the alluvium. All of these sources flow into the Helena Valley aquifer.

Diffuse infiltration (DI) occurs when the amount of precipitation is in excess of that which runs off, evaporates, or is used by plants (Lerner and others, 1990; deVries and Simmers, 2002; Ng and others, 2009). Diffuse infiltration was evaluated for the part of the study area that was not irrigated. Irrigation recharge took this into account in irrigated areas (see below). Diffuse infiltration only needed to be calculated for the forested hills, since ET and precipitation were equal on the pediment (see ET discussion above). As discussed in the ET section, the estimated recharge rate is 3.75 in/year in the forested hills. Given that the total forested hill area is about 14,000 acres, this equates to 4,380 acre-ft/year of diffuse infiltration.

The HVID canal runs through the study area for about 8.2 miles, and there are about 12.4 miles of laterals. This canal obtains its water from the Missouri River. Because this canal is unlined and was constructed well above natural groundwater levels, it leaks to the underlying groundwater (CL). Briar and Madison (1992) estimated that the HVID canal infiltrates at a rate of about 0.63 cfs per mile of canal, and smaller canals infiltrate at about 0.21 cfs/mile. Thus, a total of about 2,559 acre-ft/year is estimated to infiltrate from canals during the irrigation season. This water recharges the Helena Valley aquifer.

Approximately 3,000 acres of irrigated land are present in the North Hills study area (MT-DOR, 2010). The irrigated land is almost exclusively located hydrologically downgradient from the HVID canal. Briar and Madison (1992) calculated irrigation recharge in the Helena Valley using the amount of water applied by irrigation, the amount of precipitation, and crop demand. The result is an estimated irrigation recharge of 1.5 ft/year. Thus, irrigation recharge accounts for an input of about 4,529 acre-ft/year. This water recharges the Helena Valley aquifer.

In the area of Pumping Center A, detailed water use data from 1991 to 2009 were obtained (B. Thompson, written commun., 2010). Analysis of these data indicates that an average home with a septic system near Helena consumptively uses about 435 gallons of water per day, including irrigation of lawns and gardens (Bobst and others, in preparation a). Based on air photograph analysis there were 2,150 homes in the North Hills study area in 2009, so it is estimated that a total of about 1,055 acre-ft/year (1.5 cfs), of water is consumptively used for domestic purposes. Note that this includes withdrawals from PWS wells and exempt wells. Since PWS wells are located adjacent to homes in the North Hills, the effects of these different well types are negligible. Approximately 98 percent of the water that is consumptively used for domestic purposes (~1,027 acre-ft/year) is used for the irrigation of yards and gardens.

A 41-mile network of open and buried drains has been installed in the downgradient areas of the Helena Valley to drain areas that became boggy (waterlogged) due to irrigation in the valley. These drains collect shallow groundwater and direct it to Lake Helena (Briar and Madison, 1992). Measurements made during this study indicate that flow to surface drains is approximately 1 acre-ft per year per acre drained. Approximately 3,065 acres are drained in the North Hills study area. About 3,040 acre-ft/year of groundwater is calculated to leave the study area by drains.

Groundwater flows out the North Hills to Lake Helena. Briar and Madison (1992) estimated that total flow from groundwater to Lake Helena is approximately 50,000 acre-ft/year. Most of this water is derived from irrigation canal leakage and irrigation recharge; as such, the area topographically below the HVID canal can be used to approximate the amount of this water coming from the North Hills relative to the rest of the Helena Valley. Approximately 20 percent of the total area below the canal is in the North Hills study area. Thus it is estimated that about 10,155 acre-ft/year of groundwater flow from the North Hills to Lake Helena.

Table 3 also shows the best estimate values discussed above, along with a probable range of values, which takes into account the estimated uncertainty with each calculation. Based on this budget, wells remove about 7.4 percent of the water from the overall system; however, in localized areas in the uplands the percentage will be significantly greater.

The results of this water budget and the budget developed from the North Hills area steady-state model are also compared in table 3. The values are generally similar, and differences are due to minor differences in the model area and to how different components are modeled. A detailed discussion of this is included in the North Hills Model Report (Waren and others, in preparation).

Table 3
North Hills Water Budget
Calculated Values in Acre-feet per Year

	Best Estimate	Probable Range		Modeled Values
		Minimum	Maximum	
INPUTS				
Silver Creek Alluvium Inflow	20	14	28	N/A
Bedrock Inflow	1,252	834	1,669	797
Diffuse Infiltration	4,380	3,942	4,818	3,824
Silver Creek Infiltration	959	876	1,071	268
Irrigation Canal Leakage	2,559	2,339	2,858	1,650
Irrigation Recharge	4,529	4,138	5,057	8,712
TOTAL INPUTS	13,699	12,143	15,501	15,251
OUTPUTS				
Drains	3,040	2,704	3,304	3,039
Lake Helena	10,155	9,000	11,000	12,060
Wells	1,055	949	1,160	152
TOTAL OUTPUTS	14,250	12,653	15,465	15,251

Numerical Modeling

Calibrated steady-state and transient versions of the North Hills Area Model and the Pediment Focus Model result from the modeling effort. These models are single-layer, three dimensional finite-difference groundwater flow models. These models satisfactorily replicate past observations, so they can be used by qualified individuals to make predictions based upon specified scenarios. These models are available as GMS files, as native MODFLOW files, and as Groundwater Vistas files. The files needed to operate the models are available on the project web site (http://www.mbmg.mtech.edu/gwip/).

Most steady-state model-calculated water levels were within 10 ft of observed values. All modeled values were within 20 ft of observed values (figs. 30 and 31). The root mean square error for groundwater head in the North Hills Area Model is 6.5 ft. The Pediment Focus Model has a root mean square error of 4.4 ft. These represent less than one percent of the modeled ranges of groundwater elevation, which were about 1000 and 900 ft for the North Hills Area Model and Pediment Focus Model, respectively. Since root mean square errors are small relative to the overall changes in head, they represent a small part of the overall model response (Anderson and Woessner, 1992, p. 241).

The hydraulic conductivity field generated by the North Hills Area Model generally matches the conceptual model (fig. 32). The steady-state water budget of the North Hills Area Model is reasonably similar to water budget estimates described in the Water Budget section of this report. Table 3 shows the calculated groundwater budget from the model compared with the water budget values described in the Groundwater Budget section of this report.

The diffuse infiltration water representing recharge from precipitation in the North Hills, as modeled, generates 3,824 acre-ft/year of water. This is just less than the estimated range of 3,941-4,818 acre-ft/year. Madison (written commun., 2011) used a value of 3,352 acre-ft/year for groundwater flux from the North Hills area in his groundwater model of the Helena Valley aquifer. This model is documented in Madison (1993), and a steady-state version of the model is described in Briar and Madison (1992).

There are some other notable differences in the water budget estimates and modeled values. In the model effort, a smaller value was used for irrigation from Silver Creek to reflect conditions in drier years known to have preceded this study period. Modeled irrigation recharge varies from estimates mainly due to a difference in the areas evaluated. It also varied because water from laterals was considered part of the irrigation recharge in the model rather than being modeled independently. These differences are discussed in more detail in the model report.

The transient models used the hydraulic conductivities generated by the steady state models and also required storativity to be defined. Storativity allows time-dependent stresses to be evaluated (i.e. not just the system in equilibrium). Time-dependent stresses that were incorporated include simulated wells representing Pumping Center A, and in the North Hills Area Model the application of seasonal recharge from canals and irrigation from Silver Creek and the HVID canal. The simpler water budget of the Pediment Focus model did not require the application of seasonal recharge from canals and irrigation, but instead used specified head cells placed along

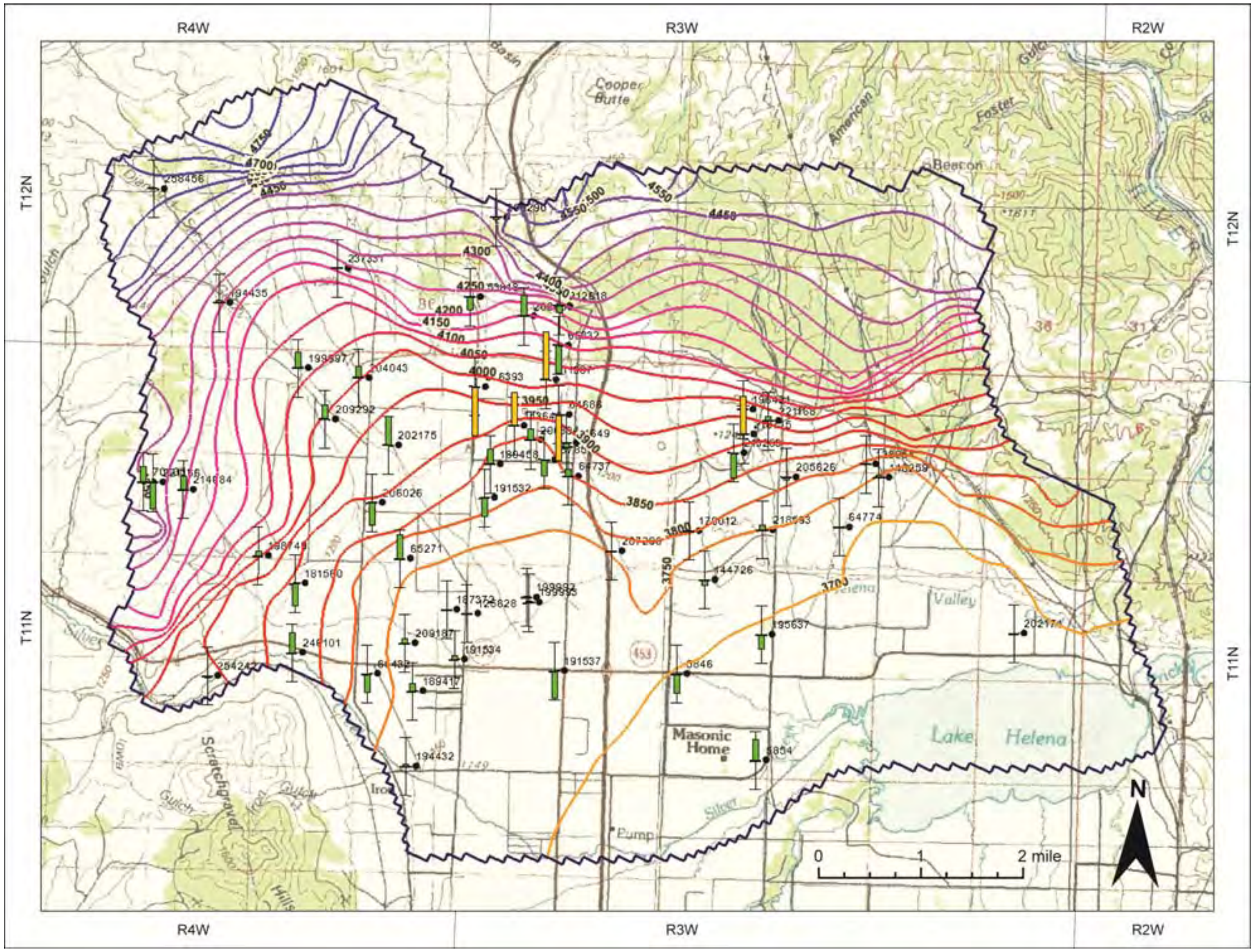
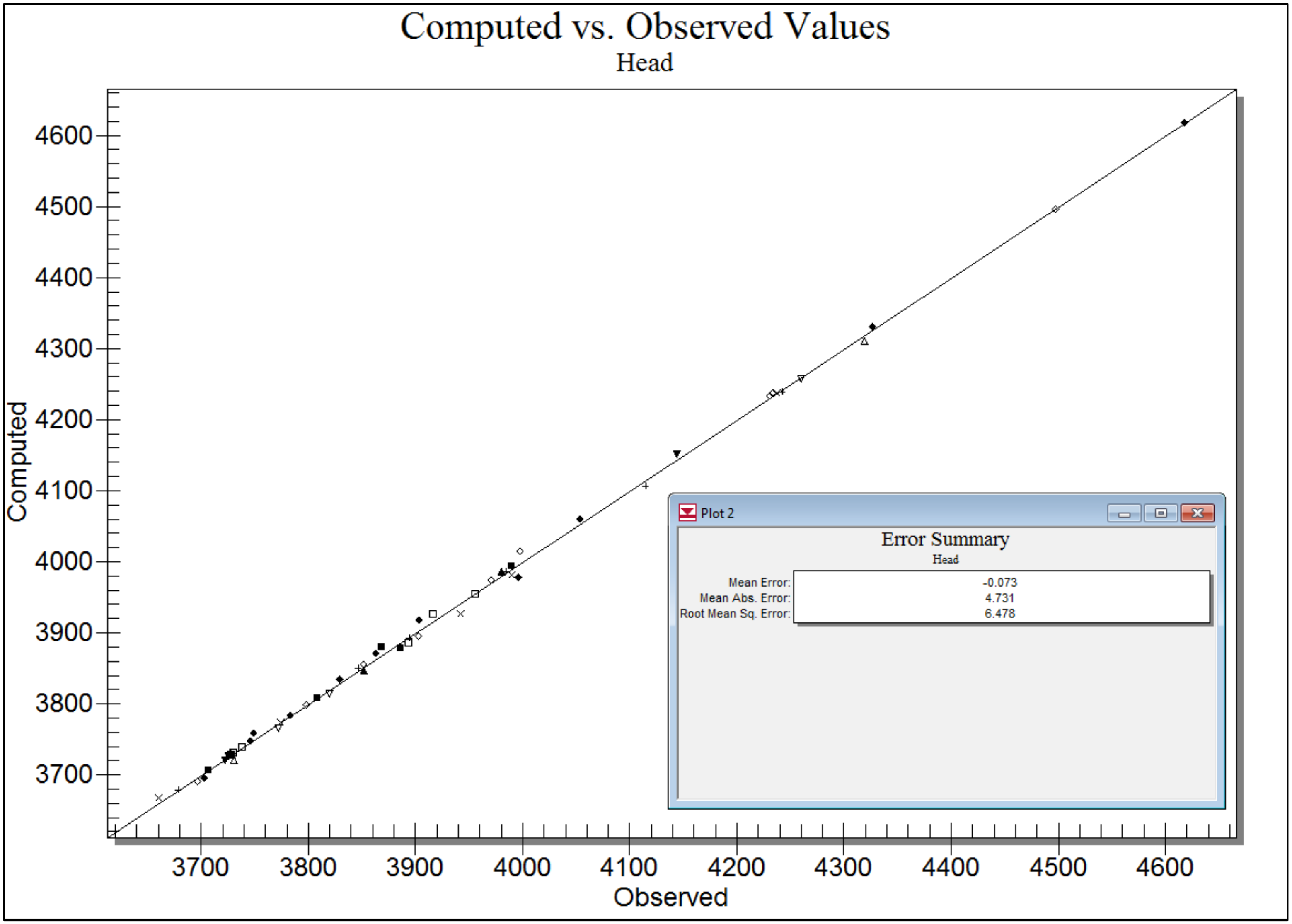


Figure 30. The pilot-point method was used calibrate the steady-state version of the North Hills Area Model. The resulting calculated potentiometric surface is shown above. Calibration targets are shown by the dots. The dots are labeled with the GWIC well identification number for the site. The vertical scales illustrate the target elevation (middle hachure); colored bars show the vertical difference between the target elevation and the calculated potentiometric surface. Green indicates the target is within the set calibration criteria, yellow indicates the value is within twice the calibration criteria interval. The calibration interval for this run was set to 10 feet.



Mean Error: -0.073
Mean Abs. Error: 4.731
Root Mean Sq. Error: 6.478

Figure 31. Comparison of computed versus observed head values at calibration targets in the North Hills Area Model shows a root mean square error of 6.5, with no systematic deviation from unity.

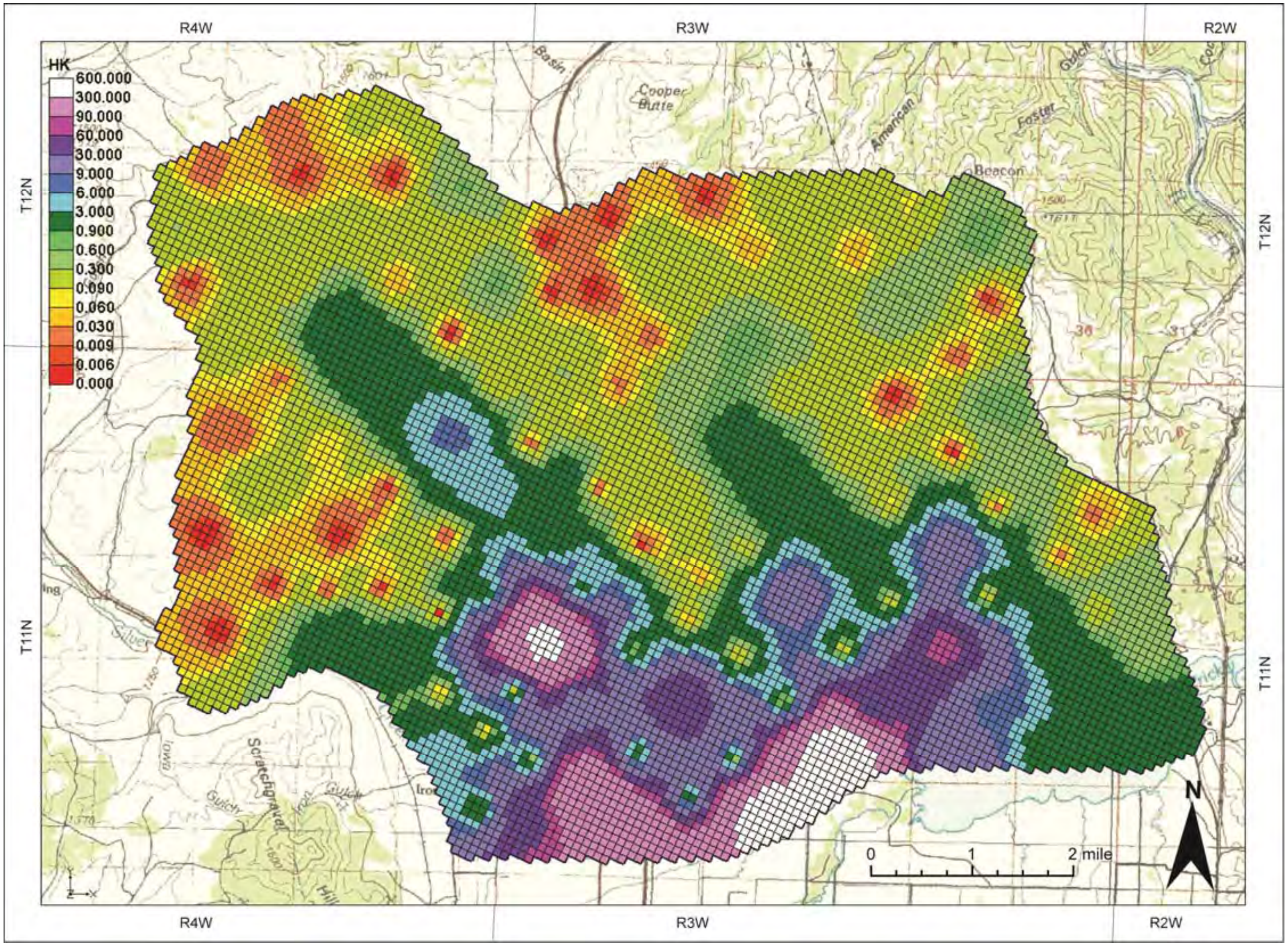


Figure 32. The modeled distribution of hydraulic conductivities is consistent with the conceptual model of the area (Madison, 2006). The bedrock has the lowest permeability, the Tertiary sediments are somewhat more permeable, and the Quaternary alluvium is the most permeable. Hydraulic conductivity is labeled as HK in the legend, and values are in ft/day. Individual cells have independent values within the specified range.

the edge of the model to simulate seasonal groundwater levels near the modeled location of the canal.

The distribution of storativity was determined by assigning values that render the right magnitude of calculated water-level changes in observation wells resulting from nearby stresses. In the portion of the model representing the pediment above the HVID canal, and therefore throughout the Pediment Focus Model, a storativity value of 0.02 was assigned. In the North Hills Area Model, the storativity was increased to 0.05 below the HVID canal, and further increased to 0.20 in the thickest part of the alluvium. These storativity values reasonably simulated observation well responses to both pumping wells and seasonal fluctuations near the HVID canal (fig. 33).

The models are both most sensitive to hydraulic conductivity and recharge. Since recharge estimates from the groundwater budget are in reasonable agreement with previous groundwater modeling and reports, this lends credence to the models. Only the transient models are sensitive to storativity, and then the difference is seen in the magnitude of changes resulting from seasonal stresses, rather than in the overall distribution of head.

In order to evaluate the eventual impacts from withdrawals in Pumping Center A, various scenarios were analyzed using the numerical models. First, a scenario was modeled to evaluate the time needed for water levels to stabilize near Pumping Center A if pumping remained at 2009 rates. Then the effects of increasing pumping to anticipated 2014 rates, and to four times 2009 rates, were evaluated.

The transient version of the Pediment Focus Model predicts that if pumping is held at 2009 rates, groundwater levels would be expected to stabilize (less than 0.25 ft of drawdown per year) in 2017, approximately 3 ft below modeled January 2011 levels. This stabilization occurs because the amount of water flowing to the specified head boundary is diminished.

To evaluate increased pumping in Pumping Center A, the rates anticipated in 2014 were evaluated using the Pediment Focus Model in transient mode. Pumping rates for 2014 were estimated based on the increase in pumping from 2005 through 2009. During that period, estimated average pumping increased from 94 to 133 gpm. For simplicity, and to better illustrate the impact of increased pumping, the entire 39 gpm increase was applied in the model entirely at the end of 2014. The increased average annual pumping rate is then sustained throughout the modeled time period that ends at the end of August, 2025. The model results suggest 10 to 12 ft of drawdown, relative to groundwater levels modeled and observed in 2009, would be expected if the rate of expansion seen in 2005 through 2009 continues during the next five years (2010 through 2014). This amount of drawdown occurs generally in the vicinity of the pumping wells, and less drawdown occurs at greater distances away from the pumping center (fig. 34). A steady-state model with the average annual stress applied yields average annual drawdown of about the same amount (up to 14 ft in the vicinity of the 12-ft contour shown in fig. 34).

The potential for increased pumping from wells in Pumping Center A was further evaluated with the steady-state North Hills Area Model by increasing pumping rates to four times the 2009 rate.

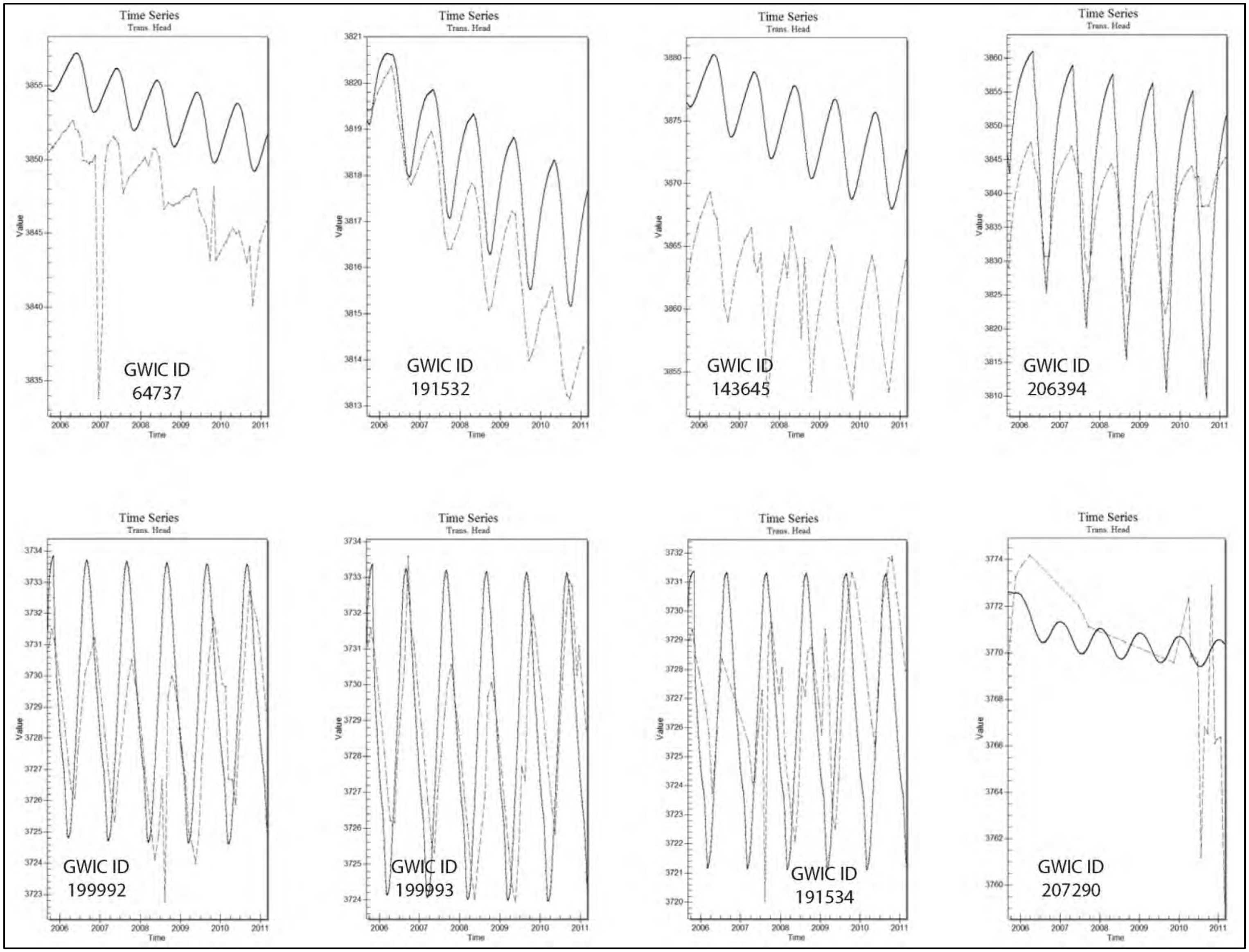


Figure 33. Hydrographs of observed data were used to set appropriate storativity values for the models. Observed values are dashed lines; modeled values are solid lines. The period from September 2005 through February 2011 was used for calibration.

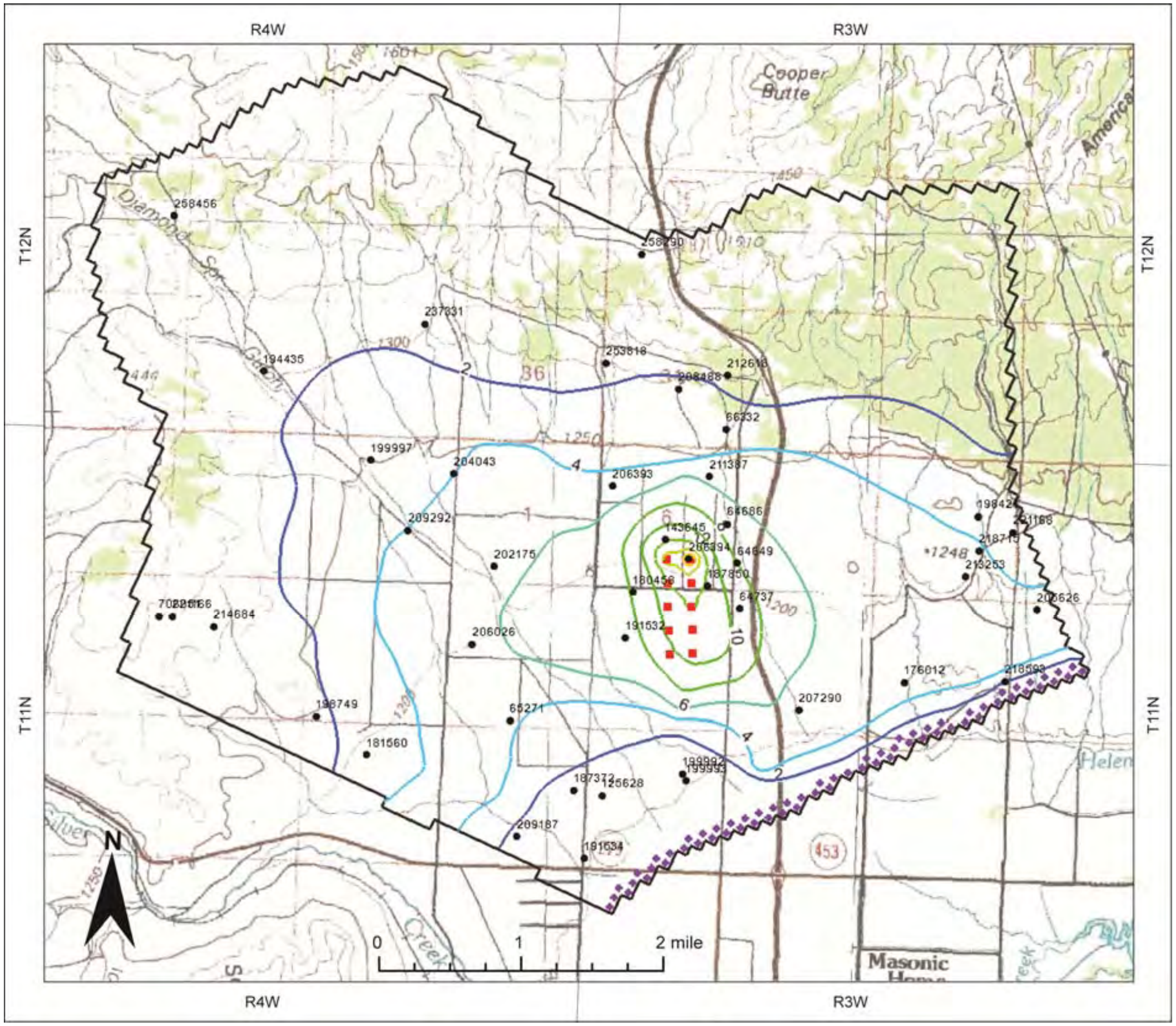


Figure 34. If the pumping rates continue to increase in Pumping Center A, it can be expected that additional drawdown will occur. The figure above shows the calculated result for increasing consumptive use in Pumping Center A until 2014, using the rate of increase seen between 2005 and 2009. The contour interval is two feet. After 2014 the consumptive use is assumed to remain constant. This map shows predicted additional drawdown (which results from the increase between 2009 and 2014) as of March 1, 2025.

This resulted in a maximum modeled additional drawdown in the well field of 123 ft, causing noticeable changes in the potentiometric surface (fig. 35).

Scenarios of development in a different area of the North Hills at different development densities, and using different water management approaches have also been modeled, and are presented in the North Hills Model Report. Scenarios of the affects from a 5-year drought and the impact of removing the HVID canal and all associated irrigation have also been modeled.

Predictive scenarios operated using these groundwater models represent system-scale estimates of effects of applied stresses, based on the available data at the time of its construction. There will undoubtedly be new information to incorporate into future groundwater model versions, and these could drive modifications of the groundwater models made by the MBMG or other users for their own purposes. Faults, fractures, and other localized anomalies can cause unexpected or complex subsurface conditions that result in localized drawdown that deviates significantly from predicted drawdown based on the groundwater models.

Smaller area, local groundwater models for areas within the model domain may be appropriate for a variety of problems addressing specific issues as needed. For example, the general aquifer characteristics and groundwater flux from the present models can be used as a starting point for the development of a local model, one which could have multiple layers defining known local conditions where data are sufficient. Model results for any particular new stress applied must be considered only an approximation based on the available data when the models were developed. Model parameters such as hydraulic conductivity may best be adjusted to reflect new data if the new data shows properties significantly different than those modeled, especially in areas where observation well data are sparse.

It is recommended that anyone planning to operate the models should obtain and read the model reports (http://www.mbmg.mtech.edu/gwip/) and use caution in interpreting results, especially if any stress is located near boundaries of the models. It should also be stressed that while models can show the types of issues which may arise, monitoring data are needed to verify the model, and to drive the decision making process.

Water Chemistry

Seventy-nine groundwater samples from 28 sites (fig. 15) and 30 surface-water samples from 12 sites (fig. 16) have been analyzed for this study. The North Hills Technical Report (Bobst and others, in preparation a) provides a listing of all locations sampled, including the GWIC ID. All results are available from GWIC.

Groundwater: Major Ions

Stiff diagrams use polygons to compare the ionic strength of positive ions (cations) and negative ions (anions) for a sample; the size of the polygon reflects the total ionic strength of the water. Stiff diagrams provide a visual method to compare the major-ion chemistry between different waters. Data from this study were combined with USGS data (Thamke, 2000) for this analysis (fig. 36). Because the water chemistry did not change significantly between events,

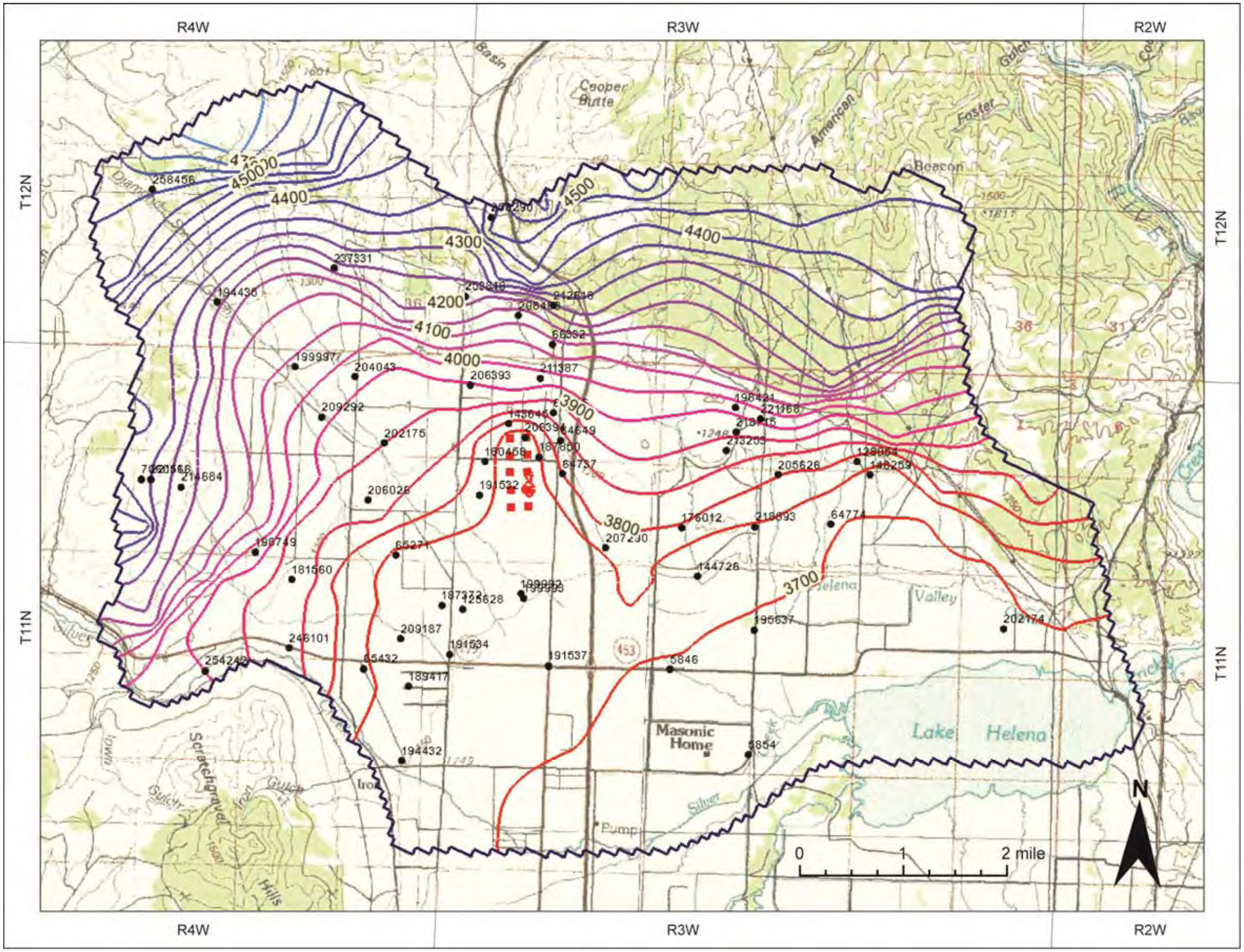


Figure 35. If Pumping Center A were to pump at four times its 2009 rates, the potentiometric surface shown above is calculated to result. Note the strong deflection of the potentiometric contours towards the pumping wells.

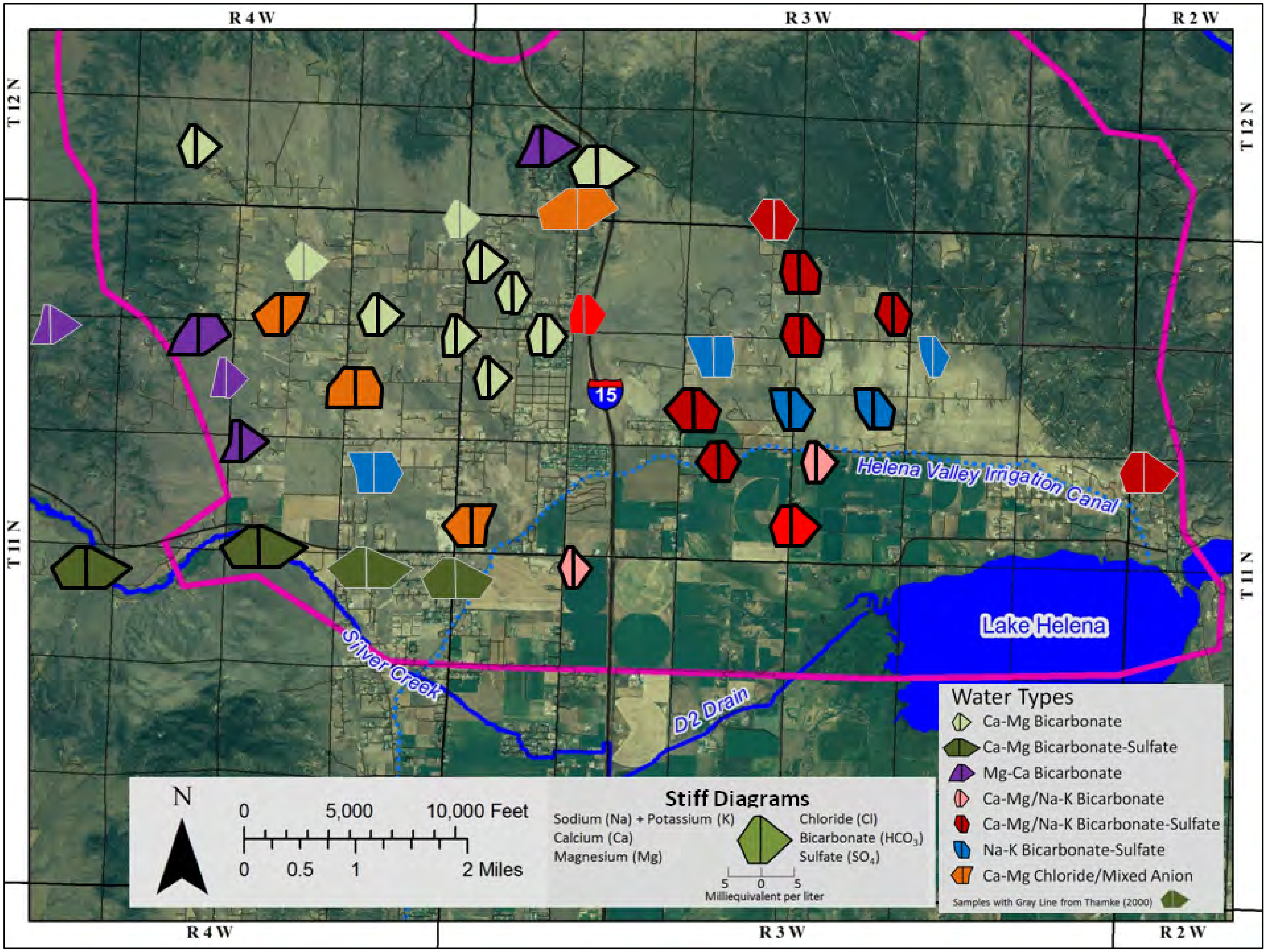


Figure 36. Stiff diagrams show that there are six general groundwater types in the North Hills. Data are from the August 2010 sampling event unless the site was not sampled for that event. There was little variation in major ions between sampling events.

representative Stiff diagram polygons were prepared using the August 2010 data, unless the site was not sampled for that event.

Piper diagrams plot the same constituents as Stiff plots, but on ternary diagrams. Piper diagrams allow for water chemistry from multiple sampling locations to be compared and may allow mixing and reaction pathways to be identified (fig. 37).

Six types of groundwater major-ion chemistry were observed in the North Hills study area (fig. 36). The majority of water samples contained bicarbonate as the major anion. In a few areas, relatively high concentrations of chloride and sulfate were present. The general groundwater types can be described as follows:

- Calcium–magnesium bicarbonate water was present in the northwest part of the study area.
- Calcium–magnesium bicarbonate–sulfate water was present in the southwest portion of the study area, near Silver Creek.
- Magnesium–calcium bicarbonate water (Mg>Ca) was present in the western part of the study area. A single well of this water type was also present in the north-central part of the study area.
- Mixed-cation water that had significant calcium, magnesium, sodium, and potassium concentrations was present in the eastern part of the study area. The anions in these waters included both bicarbonate and sulfate.
- Sodium–potassium water with anions of bicarbonate and sulfate was present at a few locations in the eastern part of the study area, and also at a single site in the western part of the area. This water was generally similar to other waters in the eastern part of the study area; however, sodium and potassium dominated the cations.
- Calcium–magnesium water with elevated chloride was present in several locations. While the chemistry of these waters varied, the high levels of chloride were used to classify the waters.

Calcium–magnesium bicarbonate type groundwater is the dominant bedrock groundwater type west of the interstate (fig. 36). Calcium–magnesium–sodium–potassium bicarbonate water and sodium–potassium bicarbonate–sulfate type water are found east of the interstate. Recent work (Swierc, 2011) shows that hydrothermal waters in the Helena Valley typically have sodium as the dominant cation. The magnesium-calcium bicarbonate type groundwater in the west is consistent with the water quality reported from the Helena Formation (Swierc, 2011); however, this area is mapped as being the Spokane Formation (Reynolds, 2000). Most of the water samples from the Spokane have a calcium bicarbonate composition. Small exposures of the Helena Formation occur near the magnesium–calcium bicarbonate well in the north-central part of the study area. Calcium–magnesium bicarbonate–sulfate type groundwater occurs near Silver Creek. Silver Creek has similar major-ion chemistry. Groundwater of calcium–magnesium chloride type is found in scattered locations west of the interstate. In this area, higher chloride often indicates septic system influence (Thamke, 2000).

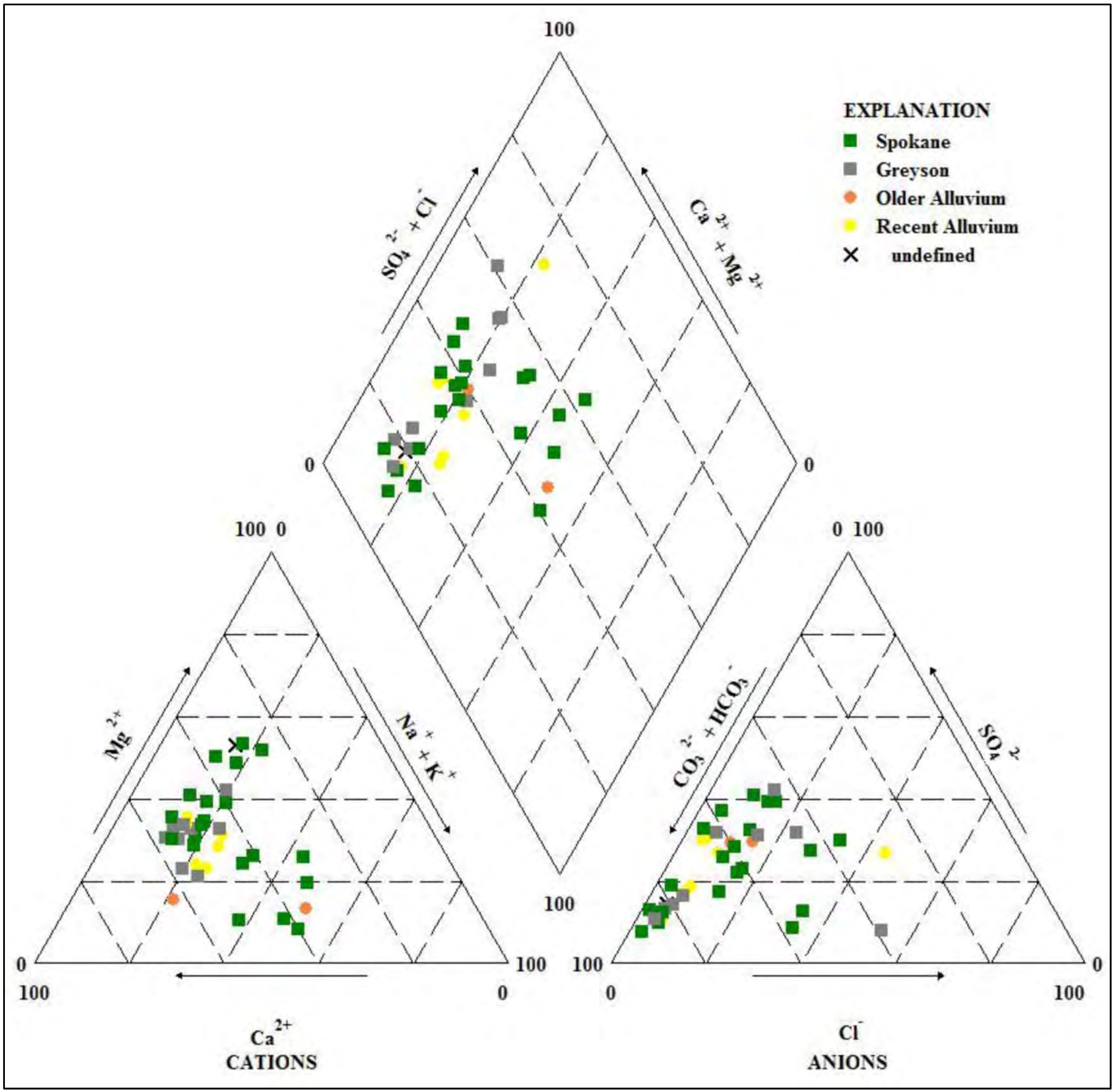


Figure 37. Groundwater in the North Hills Study Area typically has calcium (Ca^{2+}) and magnesium (Mg^{2+}) as the major cations, and bicarbonate (HCO_3^-) and sulfate (SO_4^{2-}) as the major anions. This appears to be the case regardless of which formation is sampled. While this is the general water type, there are outliers. For eight samples (out of 28) sodium (Na^+) makes up more than 30% of the cations (in milliequivalents). Elevated sodium may be related to hydrothermal inputs (Swierc, 2011). For seven samples (out of 28) chloride (Cl^-) makes up more than 20% of the anions (in milliequivalents). Elevated chloride values have been associated with septic effluent (Thamke, 2000). Data are from the August 2010 sampling event unless the site was not sampled for that event. There was little variation in major ions between sampling events.

Groundwater: Trace Elements

The laboratory analytical program for this study included 34 trace elements, of which 10 have established drinking water primary Maximum Contaminant Levels (MCLs) and 3 have secondary maximum contaminant levels (SMCLs). MCLs are based on potential health impacts while SMCLs are established for aesthetic purposes. In groundwater the only trace element drinking water standard exceedance was the SMCL for iron. Summary information about the trace element detections in this study from each of the three sampling events is included in table 4. All of the analytical data are available on GWIC.

The Lake Helena Watershed Planning Area Restoration Plan (EPA, 2006) identified arsenic, cadmium, copper, lead, and zinc as the primary trace elements of concern for the Lake Helena Watershed. This reflects the nature of local geology and the occurrence of mineralized zones in fracture systems proximal to igneous bodies in the region. Arsenic levels are also high in the Missouri River, and in the irrigation water derived from it (HVID canal). The analytical results for these trace elements of concern in water samples are summarized as follows:

- Arsenic (As) was detected in all samples; the maximum was of 9.01 μg/L (MCL=10 μg/L).
- Cadmium (Cd) was not detected above the laboratory detection limit (0.1 μg/L) in any groundwater samples.
- Copper (Cu) was detected at low levels in more than half of the wells; the maximum was 8.76 μg/L (MCL=1,300 μg/L).
- Lead (Pb) was detected at low levels in a few locations; the maximum was 2.4 μg/L (MCL=15 μg/L).
- Zinc (Zn) was detected at most sample locations; the maximum was 202 of μg/L (MCL=5,000 μg/L).

Additional trace elements of concern may be present in the study area. Selenium is associated with the East Helena Superfund site (across the Helena Valley to the south from the study area) and is found at elevated concentrations in wells installed into Tertiary sediments in the area. Selenium concentrations have exceeded 200 μg/L, well above the drinking water MCL (50 μg/L) in a Lewis and Clark County Water Quality Protection District monitoring well in Tertiary sediments adjacent to the Helena Regulating Reservoir several miles south of the study area (Swierc, 2011). The presence of Tertiary sediments in the study area indicates that selenium should be considered a potential trace element of concern. However, although the results show that selenium was detected in all but one of the samples from the three sampling events, the maximum level was 7.0 μg/L, well below the drinking water MCL. Uranium is a concern due to elevated concentrations detected at seemingly random locations in the valley, and at areas proximal to igneous rocks in the region (Swierc, 2011). The results for uranium show detections at most wells during all sample events, with values ranging from non-detect (<0.1 μg/L) to 10.7 μg/L. Uranium concentrations were relatively consistent, and were below the drinking water MCL (30 μg/L).

Table 4. Statistical Summary of Selected Trace Elements in Groundwater - North Hills Study Area.
(full results are available on GWIC at http://mbmggwic.mtech.edu)

	As **µg/L**	**Ba** **µg/L**	**Cd** **µg/L**	**Cr** **µg/L**	**Cu** **µg/L**	**Fe** **mg/L**	**Mn** **mg/L**	**Mo** **µg/L**	**Ni** **µg/L**	**Pb** **µg/L**	**Sb** **µg/L**	**Se** **µg/L**	**Tl** **µg/L**	**U** **µg/L**	**Zn** **µg/L**
Drinking Water Standard (s=secondary standard)	**10**	**2000**	**5**	**100**	**1,300**	**0.3 s**	**0.05 s**	**NA**	**NA**	**15**	**6**	**50**	**2**	**30**	**5,000 s**
April 2010 Sampling Event	n=23 Total Samples														
Detections	23	23	0	4	17	9	12	23	1	8	3	23	1	23	22
Maximum	9.01	188.00	0.00	0.19	8.76	0.045	0.002	7.12	0.32	2.40	0.92	4.45	0.10	6.73	202.00
Minimum	0.62	18.00	0.00	0.16	0.47	0.003	0.001	1.14	0.32	0.11	0.42	0.34	0.10	1.17	1.85
Average	2.69	74.05	NA	0.18	1.85	0.012	0.001	2.84	0.32	0.61	0.65	1.74	0.10	3.97	26.00
Median	2.00	67.90	NA	0.19	0.89	0.005	0.001	2.41	0.32	0.35	0.62	1.68	0.10	4.61	12.08
Standard Deviation	2.14	46.45	NA	0.02	2.28	0.013	0.000	1.53	NA	0.77	0.25	0.99	NA	1.74	43.01
August 2010 Sampling Event	n=26 Total Samples														
Detections	26	26	0	3	12	3	1	25	0	4	3	26	0	26	21
Maximum	7.93	182.00	0.00	0.46	4.43	0.040	0.033	7.45	0.00	0.64	0.62	5.29	0.00	9.90	90.80
Minimum	0.44	19.10	0.00	0.24	0.51	0.004	0.033	0.94	0.00	0.22	0.42	0.26	0.00	1.40	1.03
Average	2.28	68.02	NA	0.35	1.46	0.021	0.033	2.64	NA	0.34	0.55	1.58	NA	4.17	11.00
Median	1.77	62.75	NA	0.34	0.88	0.020	0.033	2.18	NA	0.25	0.61	1.43	NA	4.04	4.64
Standard Deviation	1.80	39.97	NA	0.11	1.38	0.018	NA	1.49	NA	0.20	0.11	1.04	NA	2.13	19.06
October 2010 Sampling Event	n=26 Total Samples														
Detections	26	26	0	4	14	5	4	25	3	3	3	25	0	26	22
Maximum	8.28	180.00	0.00	0.47	6.06	0.384	0.021	7.96	0.53	0.82	0.64	7.03	0.00	10.70	132.00
Minimum	0.58	19.00	0.00	0.20	0.58	0.008	0.001	1.07	0.28	0.20	0.40	0.26	0.00	1.31	0.95
Average	2.47	68.44	NA	0.29	1.68	0.103	0.008	2.62	0.40	0.44	0.55	1.85	NA	4.25	12.65
Median	2.01	64.20	NA	0.23	0.78	0.041	0.005	2.04	0.38	0.31	0.60	1.56	NA	4.01	5.95
Standard Deviation	1.88	40.35	NA	0.13	1.76	0.158	0.009	1.53	0.13	0.33	0.13	1.45	NA	2.35	27.31

µg/L=micrograms per liter (ppb)   NA = Not Applicable   --- = No drinking water standard

mg/L=milligrams per liter (ppm)   Highlighted indicates exceedance of a standard

Groundwater: Nutrients

Nutrients, nitrogen and phosphorus compounds, are essential for plant growth. In groundwater and for drinking water, nitrate is the most common form of nitrogen, and has a drinking water MCL of 10 mg/L. According to the EPA (2011), the major health effect from nitrate is that "infants below 6 months who drink water containing nitrate in excess of the maximum contaminant level (MCL) could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome." Phosphorus compounds do not currently have any drinking water standards because they are not linked to health impacts.

Nitrogen is present in the biosphere in many different forms. For example, nitrogen is the most abundant gas in the atmosphere (78 percent; Glass, 1982). Nitrogen naturally moves between phases as part of the nitrogen cycle. In the nitrogen cycle, nitrogen changes molecular form as it moves to and from the atmosphere into plants and organic matter, soils and water. The majority of molecular changes are mediated by natural bacteria present in soils. Plants obtain soil nitrogen through roots and nitrogen is incorporated into the plant structure. Plant decay creates soil humus where organic nitrogen compounds break down. Nitrification occurs in soils; however, nitrate readily leaches from the soils with infiltrating water. As a result, natural nitrate concentrations are generally low in soils, as well as in groundwater (typically less than 2 mg/L in groundwater; Mueller and Helsel, 1996).

Anthropogenic activities typically change the local nitrogen cycle by adding additional nitrogen to the system or by mobilizing natural nitrate. Septic tanks discharge high-nitrate effluent and allow it to percolate through the unsaturated part of the soil column to groundwater. These systems rely on a healthy soil profile (and the attendant natural bacteria) and generally are efficient in processing organic nitrogen to atmospheric nitrogen. Unfortunately, in areas with high-permeability soils, thin soils, fractured bedrock, or where shallow groundwater is present, the transformation processes may be incomplete and groundwater nitrate levels may become elevated (Nolan, 2001). Infiltration of water in areas where there is livestock manure, or where agricultural fertilizers are applied at rates greater than plant utilization, can similarly increase groundwater nitrate levels. It has also been shown that ground disturbance can mobilize nitrate (Wakida and Lerner, 2002).

A statistical summary of nitrate from the groundwater sampling program is presented in table 5. A single exceedance of the drinking water MCL was detected in the April 2010 sampling event at a location in the north-central part of the study area (fig. 38). For the other two events, concentrations at this well were less than half of the drinking water MCL. In general, for sites sampled in all three events, nitrate concentrations were greatest in the spring and decreased with the other two events. Of the 79 groundwater samples analyzed for nitrate, 24 (30 percent) had concentrations greater than 2 mg/L. Phosphorus compounds were not detected above the laboratory detection limit of 0.1 mg/L during any sampling event.

The isotopes of nitrogen and oxygen in a nitrate molecule (NO_3^-) provide a method to characterize the potential source of the nitrate molecule (Kendall, 1998). Another method uses the fact that groundwater in this area is naturally low in chloride (Cl^-), and that chloride is typically elevated in septic effluent. Thus elevated chloride with elevated nutrients may help link the source of nitrate to septic tanks (Thamke, 2000). The chlorine to bromine ratio (Cl/Br) can also be indicative of septic inputs. Values in the range of 300–1,100 are generally considered to be due to septic influence (Katz and others, 2011).

Table 5 – Summary of Groundwater Nitrate Data - North Hills
(concentrations in mg/L)

	April 2010	August 2010	October 2010
Total Number of Samples	23	26	26
Number of Detections	18	25	26
Maximum	10.21	4.20	4.22
Minimum	0.37	0.16	0.14
Average	2.29	1.62	1.65
Median	1.35	0.99	1.10
Standard Deviation	2.43	1.32	1.41

Highlighted indicates exceedance of the drinking water standard

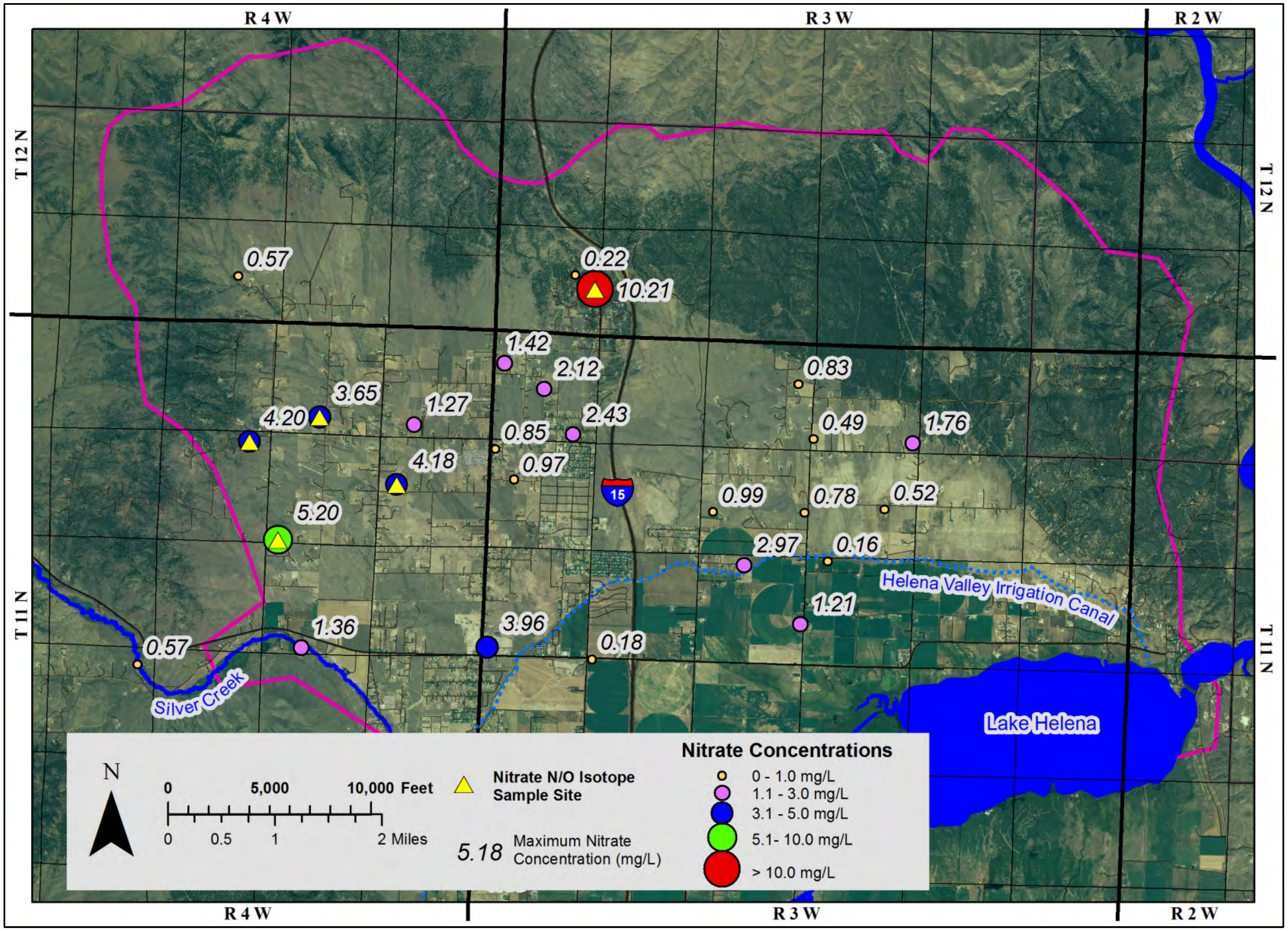


Figure 38. Maximum recorded nitrate concentrations in wells east of Interstate 15 are generally low. West of the interstate nitrate concentrations are generally higher; however there is little correlation with housing density or location on the flow path. One sample exceeded the drinking water standard for nitrate (10 mg/L) during the first sampling event (April 7, 2010); however this well had concentrations at less than half the standard for the other two sampling events.

Nitrogen and oxygen constitute the atoms of nitrate molecules; therefore, the isotopic fraction of these atoms reflect processes during both nitrification and denitrification. The method compares the relative concentration of the two primary isotopes of oxygen (^{18}O and ^{16}O) with the relative concentrations of the two primary isotopes of nitrogen (^{15}N and ^{14}N). Results for the isotopes are presented in parts per thousand (‰; per mil) difference (δ) in ^{18}O ($\delta^{18}O$) and ^{15}N ($\delta^{15}N$) relative to standards.

Samples were collected for nitrate isotope analysis during the second sampling event at the locations where nitrate was previously detected at greater than 3 mg/L. Data for this study were compiled with nitrate isotope data from a previous USGS study of the bedrock in the Helena area (Thamke, 2000) and an ongoing MBMG study in the Scratchgravel Hills (fig. 39).

All of these samples plot in the field identified by Kendall (1998) as being indicative of manure and/or septic waste; however, about half also plot within the overlapping field indicative of soil nitrate. As noted above, natural groundwater nitrate levels resulting from soil nitrogen are typically less than 2 mg/L, and these samples were obtained from wells that had nitrate in excess of 3 mg/L. Soil-nitrate levels can become elevated due to disturbance as natural soil nitrate is mobilized (Wakida and Lerner, 2002). It has also been reported (Madison, oral commun., 2011) that a feed lot existed in the area of Pumping Center A. The distribution of maximum nitrate values shows that the highest values are in areas where there has been little recent construction activity, and to the north and west of Pumping Center A.

Comparison of nitrate to Cl^- and the Cl/Br ratio indicates that for some samples there is a correlation of nitrate to Cl^- and Cl/Br, while for other samples there is not. If a septic system was working properly there would be elevated Cl^- and Cl/Br, but low nitrate. If nitrate was not being fully broken down there would be a correlation of nitrate to Cl^- and Cl/Br. These trends may represent site specific differences.

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. As a result, closely spaced wells can have significantly different nitrate concentrations. For example, in the Douglas Circle area at the north end of Montana Avenue (fig. 2) two wells approximately 1,040 ft apart (wells 138527 and 187438) were sampled, and the maximum resultant nitrate concentrations were 0.22 and 10.21 mg/L. The majority of wells sampled in this 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 in the area near the well.

Groundwater: Radon

Radon is an odorless, colorless gas produced in the decay series of uranium-238, which occurs naturally in soils and bedrock. As a gas having a half life of only 3.6 days, persistent radon concentrations indicate that a constant flux of the gas is being provided to the system. Radon in groundwater can come from rocks or soils, or waters can also absorb radon from atmospheric sources where it has accumulated in air at the surface. The EPA has proposed a drinking water MCL of 4,000 picoCuries/Liter (pCi/L), which generally correlates to a household air

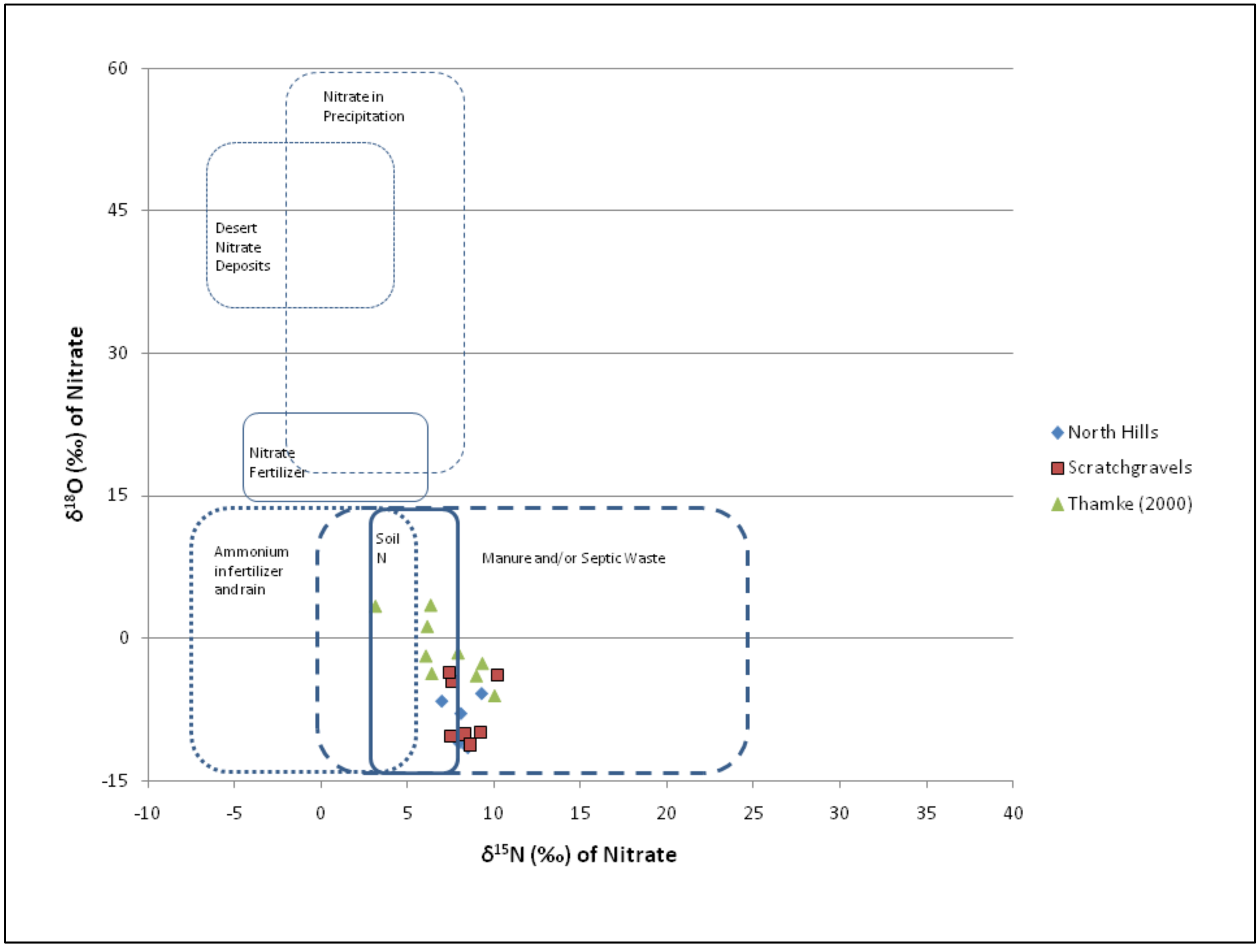


Figure 39. Results of nitrogen and oxygen isotopic analysis of nitrate show that all samples plot in region where manure and/or septic waste are commonly nitrate sources; about half also plot within the overlapping soil-nitrogen region (regions from Kendall, 1998). This indicates that septic effluent is likely a major contributor to nitrate levels in the North Hills. Some, but not all, of the elevated nitrate could be due to mobilization of soil nitrate by disturbance. Some of the nitrate may also be due to past feed lots in this area; however the dispersed distribution of elevated nitrate levels (fig. 38) make it unlikely that this was the source for many samples.

concentration of 0.4 pCi/L. MCLs for public water supplies will likely be more strict (EPA, 1999).

The geology of the study area includes intrusive igneous rocks and Proterozoic shales, which have been associated with high levels of radon. However, radon concentrations in the groundwater samples for the North Hills study area ranged from 250 to 2,951 pCi/L; well less than the proposed MCL. The highest radon concentrations in groundwater are associated with argillite bedrock areas with thin layers of soil cover, primarily in the western part of the North Hills study area (fig. 40).

Groundwater: Organic Waste-Water Chemicals

OWCs originate from human or animal waste-water discharges (treated or untreated) and encompass a wide variety of chemicals, including pharmaceuticals, hormones, fire retardants, industrial chemicals, personal care products, and pesticides. Many of these chemicals have been shown to interfere with the endocrine system of both animals and humans at very low concentrations, and therefore understanding their occurrence and distribution is important. It has been shown that these chemicals are often found in low concentrations in many drinking water supplies (Focazio and others, 2008). No human or aquatic health standards have been established for these compounds; therefore, the significance of detected OWCs is difficult to evaluate. However, these contaminants are indicators of waste-water discharge and may be important for assessing the present and future impact of continued waste-water discharges.

Three sites in the North Hills were sampled for OWCs. OWCs were detected at one site. At this site sulfamethoxazole and phenytoin were detected at concentrations of 29 and 6.4 ppt (ng/L), respectively. Sulfamethoxazole is a bacteriostatic antibiotic, which is sold under the brand names Bacterim, Septerin, or Septra. Phenytoin is an anticonvulsant, which is sold under the brand names Bi-Phen Dilanthin, and Phenytek. Sulfamethoxazole is commonly found in groundwater because it is typically not well attenuated (Avisar and others, 2009; Barber and others, 2009; Underwood and others, 2011). Because only three wells were sampled for OWCs, no significant conclusions can be drawn from these data.

Surface Water: Major Ions

Surface-water major-ion chemistry was evaluated using Stiff diagrams (fig. 41). Water chemistry showed few changes over time, and the data from all three events are plotted together on a Piper diagram (fig. 42). Water in Silver Creek was a calcium–magnesium bicarbonate–sulfate type, similar to groundwater chemistry in this area. The drain water was generally a mixed-ion type, similar to groundwater in the eastern part of the North Hills study area. One drain differed from other drain samples by having a magnesium concentration higher than calcium; that drain was sampled only once during the April event, when water was present. The Lake Helena causeway, downgradient from the study area, had a calcium–magnesium bicarbonate water chemistry, similar to that observed in Sevenmile Creek, Tenmile Creek, and the HVID canal. These sources, along with Prickly Pear Creek, are the major contributors of surface water to Lake Helena.

Surface Water: Trace Elements

Surface-water-quality impairments in the Lake Helena watershed have been documented through a total maximum daily load (TMDL) assessment (EPA, 2006). Trace elements of concern identified with the TMDL include arsenic, cadmium, copper, lead, zinc, and mercury. Trace-element standards for surface water include aquatic-life criteria. Aquatic-life standards reflect

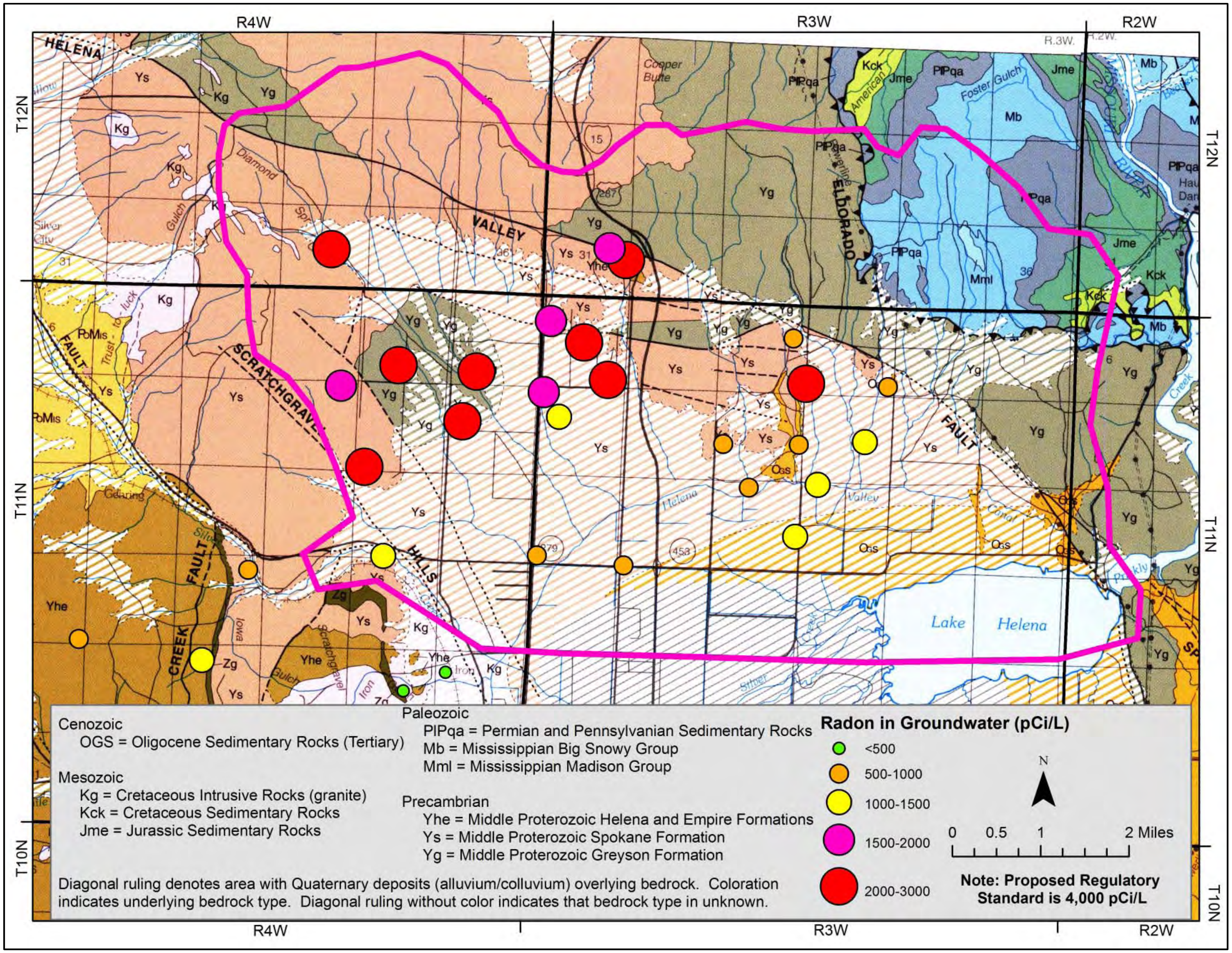


Figure 40: Analysis for radon in groundwater shows that all values are less than the proposed standard. The highest values are observed in areas underlain by shallow argillite. Geologic map was prepared by Reynolds (2000).

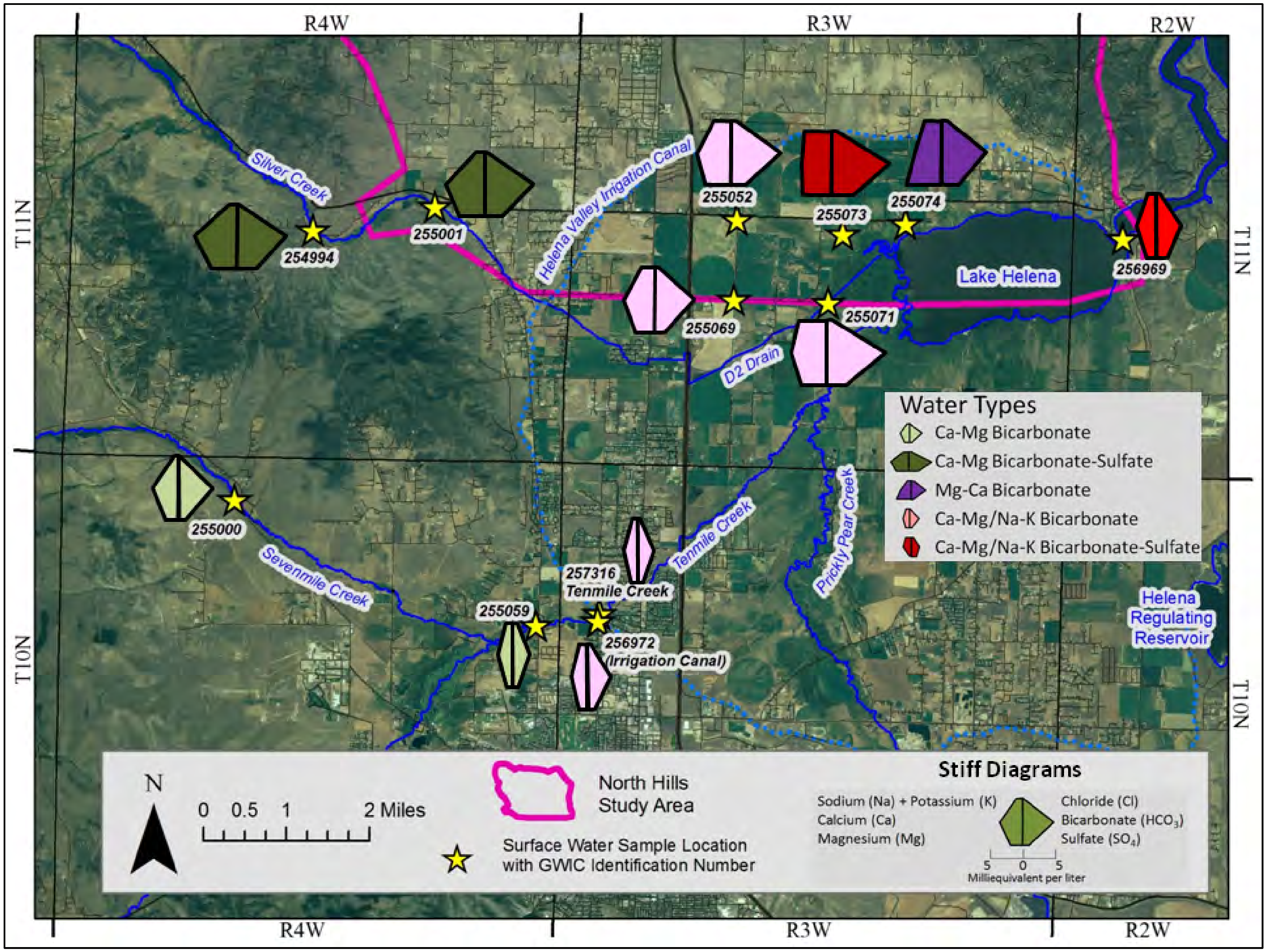


Figure 41. There are four general surface-water types in the North Hills. Data are from the August 2010 sampling event unless the site was not sampled for that event. These data also show that the water flowing out the Lake Helena Causeway is quite similar to water from Tenmile Creek and the HVID Canal. Waters from Silver Creek and the drains have the highest salinity, while Tenmile Creek has the lowest.

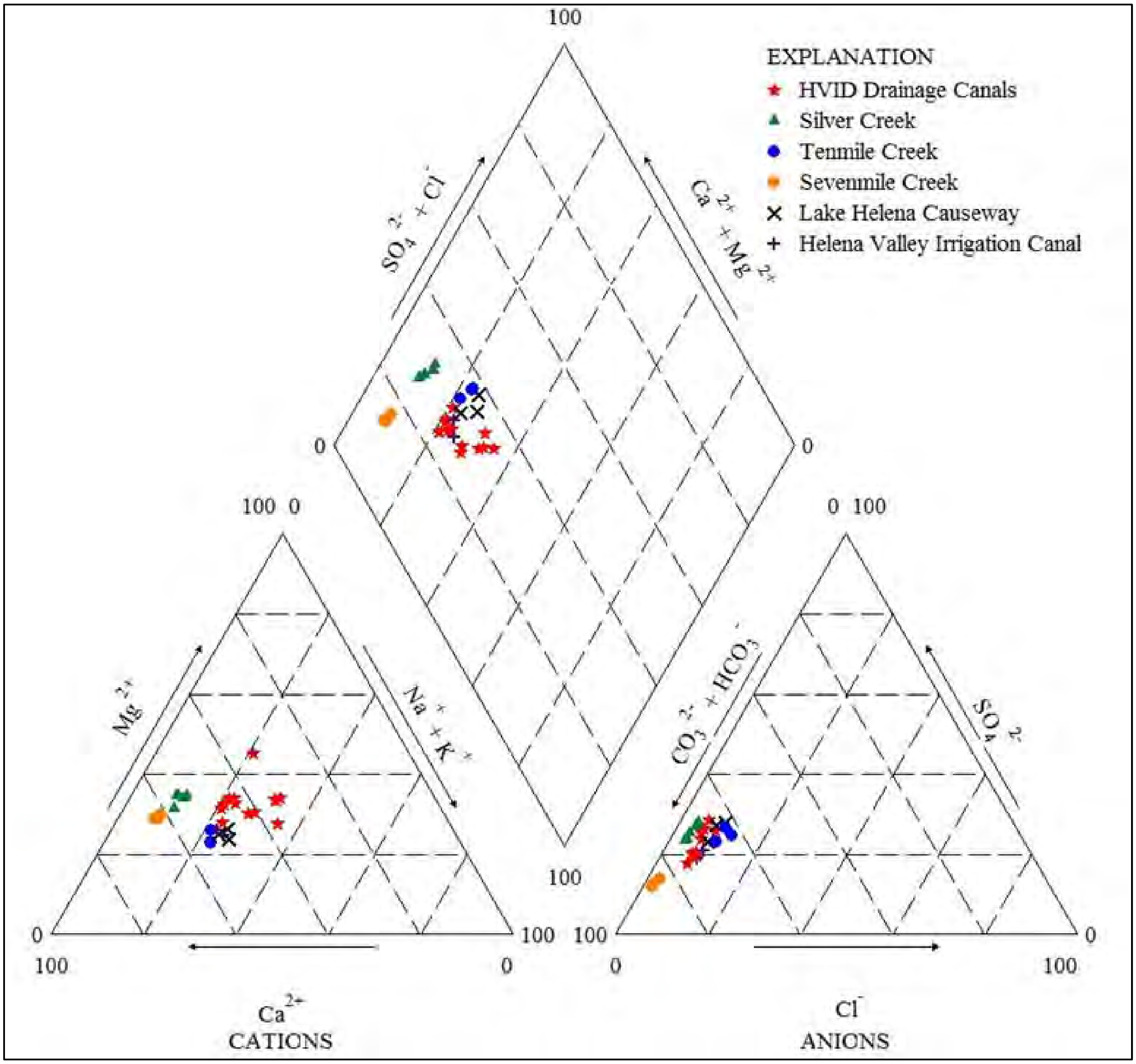


Figure 42. Samples from Sevenmile Creek and Silver Creek have less sodium (Na^+) and less chloride (Cl^-) than the other samples. Samples from the drains have less calcium (Ca^{2+}) and more sodium (Na^+) and magnesium (Mg^{2+}) than the other samples. Samples from Sevenmile Creek are also more dominated by bicarbonate (HCO_3^-). Samples from Tenmile Creek, the HVID Canal, and the Lake Helena Causeway have generally similar water quality.

both acute and chronic conditions. The aquatic-life standards for trace elements are determined based on the hardness of the water, and are generally less than drinking water MCLs for human health protection.

The only trace-element drinking water MCL exceeded was for arsenic (table 6). Arsenic was detected in samples from Silver Creek and Tenmile Creek at concentrations slightly above the drinking water MCL, consistent with the TMDL designation of impairment for those streams. In addition, arsenic concentrations above the drinking water MCL was detected in the HVID canal, consistent with a previous USGS study (Kendy and others, 1998).

The aquatic-life standard for cadmium was exceeded in two samples from Tenmile Creek (table 6). All surface-water samples for copper, lead, and zinc were below the acute and chronic TMDL target goals.

Surface Water: Nutrients

Elevated levels of nutrients in surface-water bodies may lead to eutrophication of the water body, where plant and algal growth overwhelms the system and their decay consumes most of the oxygen. The Lake Helena TMDL (EPA, 2006) includes target concentrations for nutrients set at 0.33 mg/L for total nitrogen (including nitrate) and at 0.04 mg/L for total phosphorus. These are based on concentrations in non-impacted reference streams, and given the development in the Helena Valley over the last 150 years, the EPA has determined that they generally are not considered feasible for both technological and economic reasons (EPA, 2006).

Total nitrogen was detected above the target goal concentration from at least one event at most locations; however, the highest levels were detected in the drain samples during all sampling events (table 6).

Hydrogen and Oxygen Isotopes

These isotopes represent the isotopes of atoms that make up water molecules. The method compares the relative concentration of the two primary isotopes of oxygen (^{18}O and ^{16}O) with the relative concentrations of the two primary isotopes of hydrogen [^{1}H and deuterium (D; ^{2}H)]. Results for the isotopes are presented in parts per thousand (‰; per mil) difference (δ) in the ratio of these isotopes in a sample (δ^{18}O and δD) relative to Vienna Standard Mean Ocean Water. The Meteoric Water Line (MWL) represents the global average ratio of δ^{18}O to δD in precipitation, where the ratio between the two is generally consistent, even with changes in relative concentrations. While local variations may occur, precipitation data typically plot following the trend of the MWL. Because geography can result in minor variations from the MWL, a Local MWL (LMWL) may be developed with samples from precipitation in specific areas. Development of a LMWL requires a large number of data points collected seasonally. Based on a literature review, the closest area with sufficient data to develop a LMWL is Butte, approximately 60 miles south of Helena (Gammons and others, 2006).

Natural processes can change δ^{18}O and δD values. For example, during evaporation from a lake, lighter molecules evaporate more easily than heavier molecules, so the concentration of δ^{18}O in the lake is enriched and data plot away from the MWL. Any groundwater derived from this source will show isotope concentrations away from the MWL, allowing for an assessment of the recharge source of the groundwater.

Table 6. Summary of Surface Water Parameters that Exceed some Standard

Site Name	Sample Date	As (ug/L) - MCL = 10			Cd (ug/L) - MCL = 5			N (mg/L) - MCL = 10		
		Result	Acute	Chronic	Result	Acute	Chronic	NO_3-N	Total N	TMDL
HVID D-2-2.3-1 (DA)	4/6/10	2.4	340	150	<0.1	6.7	0.6	1.89	NA	0.33
HVID D-2-2.3-1 (DA)	8/12/10	3.6	340	150	<0.2	6.1	0.6	3.21	4.14	0.33
HVID D-2-2.3-1 (DA)	10/11/10	2.8	340	150	<0.2	6.7	0.6	4.69	5.02	0.33
HVID D-2-2.3-2L (DC)	4/6/10	3.0	340	150	<0.1	6.1	0.6	2.65	NA	0.33
HVID D-2-2.3-2L (DC)	8/13/10	15.9	340	150	<0.2	3.4	0.4	0.72	1.61	0.33
HVID D-2-2.3-2L (DC)	10/11/10	3.2	340	150	<0.2	6.3	0.6	4.50	5.19	0.33
HVID D-2-0.7-1 (DD)	4/7/10	4.9	340	150	<0.1	6.6	0.6	0.99	NA	0.33
HVID D-2-0.7-1 (DD)	8/12/10	9.2	340	150	<0.2	6.6	0.6	0.51	2.61	0.33
HVID D-2-0.7-1 (DD)	10/11/10	4.4	340	150	<0.2	6.4	0.6	0.87	1.22	0.33
HVID D-1_UPPER (DE)	4/6/10	3.7	340	150	<0.1	6.7	0.6	1.57	NA	0.33
HVID D-1_UPPER (DE)	8/13/10	3.8	340	150	<0.2	6.4	0.6	2.20	3.11	0.33
HVID D-1_UPPER (DE)	10/11/10	3.6	340	150	<0.2	6.3	0.6	2.30	2.95	0.33
HVID D-0 ARMSTRONG (DG)	4/6/10	8.1	340	150	<0.1	6.9	0.6	2.05	NA	0.33
SILVER CREEK; SW-SC1	4/7/10	5.2	340	150	<0.1	7.4	0.7	<0.5	NA	0.33
SILVER CREEK; SW-SC1	8/12/10	11.1	340	150	<0.2	7.8	0.7	<0.05	1.64	0.33
SILVER CREEK; SW-SC1	10/8/10	8.1	340	150	<0.2	6.9	0.6	<0.05	<1.0	0.33
SEVENMILE CREEK * 7M-SW1	4/7/10	5.7	340	150	<0.1	4.6	0.5	<0.5	NA	0.33
SEVENMILE CREEK * 7M-SW1	8/13/10	7.5	340	150	<0.2	3.9	0.4	0.13	<1.0	0.33
SEVENMILE CREEK * 7M-SW1	10/11/10	6.9	340	150	<0.2	4.5	0.5	<0.05	2.54	0.33
SILVER CREEK; SC-2 * SC-SW2	4/6/10	5.6	340	150	<0.1	7.0	0.6	0.26	NA	0.33
SILVER CREEK; SC-2 * SC-SW2	8/12/10	10.7	340	150	<0.2	7.7	0.7	<0.05	1.13	0.33
SILVER CREEK; SC-2 * SC-SW2	10/8/10	8.0	340	150	<0.2	6.6	0.6	<0.05	<1.0	0.33
LAKE HELENA CAUSEWAY	4/7/10	5.9	340	150	<0.1	3.1	0.4	<0.5	NA	0.33
LAKE HELENA CAUSEWAY	8/13/10	13.7	340	150	<0.2	3.1	0.4	<0.05	1.29	0.33
LAKE HELENA CAUSEWAY	10/11/10	10.4	340	150	<0.2	3.3	0.4	0.08	<1.0	0.33
TENMILE AT GREEN MEADOW	4/6/10	10.2	340	150	0.48	2.4	0.3	<0.5	NA	0.33
TENMILE CREEK AT MCHUGH LANE	8/12/10	9.7	340	150	0.20	1.2	0.2	0.07	1.31	0.33
TENMILE CREEK AT MCHUGH LANE	10/7/10	12.4	340	150	<0.2	2.8	0.3	0.13	<1.0	0.33
HVID-1 (MCHUGH LN)	5/4/10	24.7	340	150	<0.1	2.8	0.3	0.33	NA	0.33
HVID-1 (MCHUGH LN)	8/12/10	19.9	340	150	<0.2	2.7	0.3	<0.05	<1.0	0.33

NA = Not Analyzed

<0.2 = less than the specified detection limit

Highlighted values indicate exceedences of some standard

$\delta^{18}O$ and δD data from this study, from an ongoing MBMG study in the Scratchgravel Hills (Bobst and others, in preparation b), from a previous USGS study of the bedrock near Helena (Thamke, 2000), and data from Butte (Gammons and others, 2006) are plotted with respect to the MWL (fig. 43). Precipitation samples (snow) were collected in early March 2010 from locations within the North Hills and from higher altitudes in the Silver Creek watershed west of the North Hills study area. Samples from drains, the HVID canal, springs, streams, and wells were collected from March to June, 2011.

Snow data, being winter precipitation, plotted on the lower portion of the MWL. δD and $\delta^{18}O$ values were comparable to the lower end of Butte precipitation values. The remaining data plotted parallel to but offset to the right of the MWL and the Butte data. Given that the surface waters are shifted similar to groundwater, this is consistent with minor evaporation and exchange of oxygen with calcite (Drever, 1997).

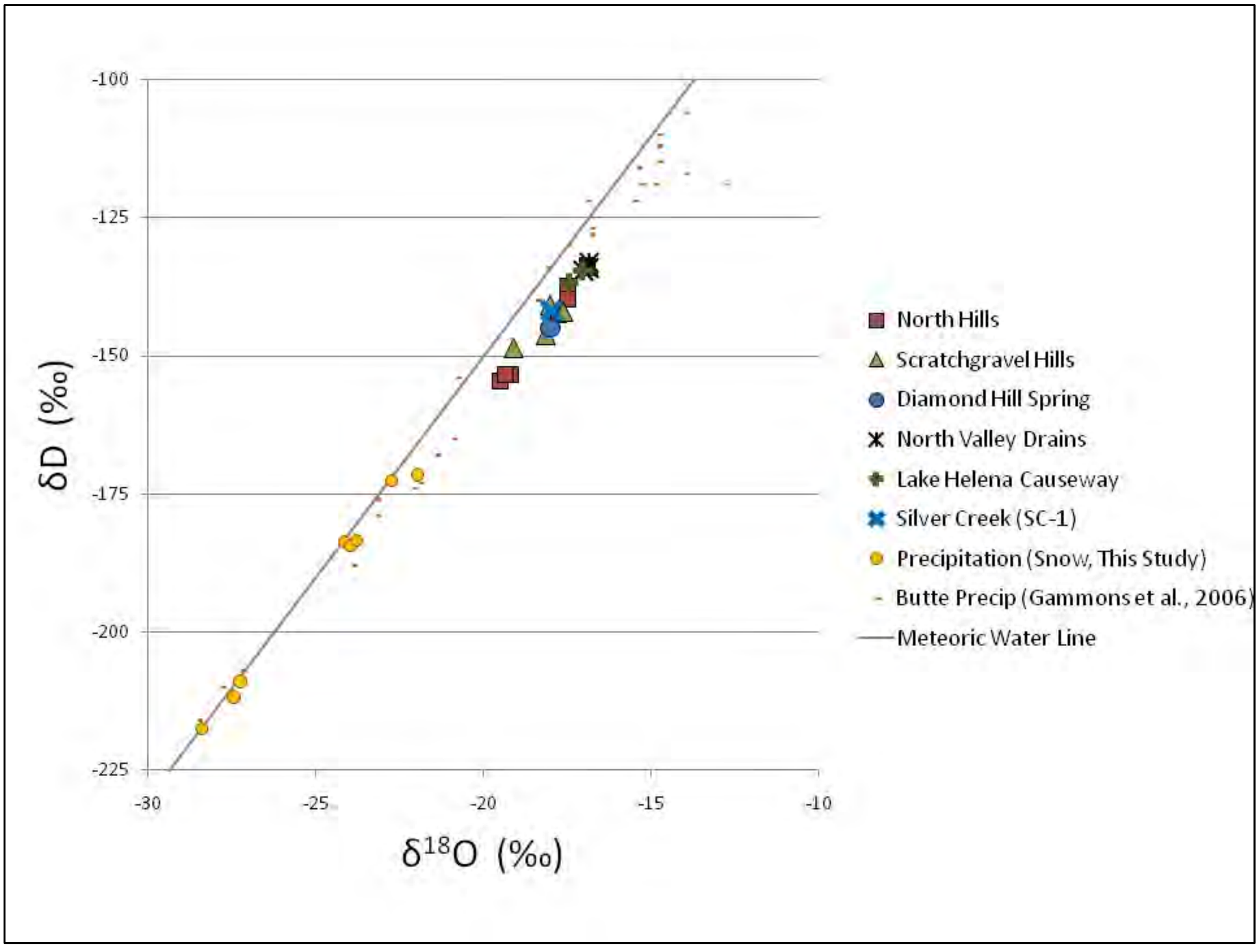


Figure 43. $\delta^{18}O$ and δD data from this study show that snow data plot on the MWL while data from other sources plot parallel to the MWL, but with heavier $\delta^{18}O$. The only precipitation data collected for this study were snow samples. The samples identified as North Hills and Scratchgravel are groundwater samples from wells. The Diamond Hills Spring sample is from a spring in the North Hills. The North Valley Drains are surface water samples from the drains near Lake Helena. The Lake Helena Causeway and Silver Creek samples are surface water samples. The modestly heavier $\delta^{18}O$ values are consistent with water that has been slightly affected by exchange with calcite (Drever, 1997, p. 315).

DISCUSSION

The purpose of this groundwater investigation was to determine if there are groundwater declines occurring in the North Hills, how much future decline is likely to occur, and if septic discharges are adversely impacting groundwater quality. In order to address these points, an improved understanding of the hydrogeologic system was also needed. Our interpretations of the available data with regard to each of the major goals of this study are presented below.

Groundwater-Level Trends

An area of sustained drawdown was observed between 2005 and 2010 in the area where there is the highest density of development, and where water is obtained from the Tertiary and bedrock aquifers (Pumping Center A). Drawdown in this area is observed in both pumped wells and monitoring wells. This downward trend cannot be explained by relationships to precipitation or stream flow, because other wells in the area would be expected to respond to these in the same way. As such, it appears that the groundwater levels are declining in response to increasing pumping in this area. The maximum current drawdown from housing developments in this area is about 20 ft. If pumping rates remain constant, the aquifer will adjust to this stress over time through a reduction in flow to Lake Helena. Modeling results suggest that if pumping rates were held to 2009 levels, the aquifer would stabilize in 2017, approximately 3 ft below current levels (23 ft of total drawdown). If pumping rates continue to increase as they have in the past, water levels will continue to drop and groundwater discharge to Lake Helena will continue to decrease. Modeling results indicate that if pumping rates increase from 2009-2014 at the same rate as they increased from 2005-2009, an additional 10 ft of drawdown would occur by 2025.

These changes in water levels may impact the utility of wells. A comparison of the total well depth with the static water level will provide a rough estimate of the amount of available drawdown that a well had at the time of installation. If it is assumed that 20 ft of available drawdown are needed for a well to be reasonably useful in these aquifers, the number of wells impacted by a particular drawdown can be calculated. Within Pumping Center A there are 141 wells that have sufficient data to evaluate the significance of these declines (GWIC, 7/13/11). Based on the need for 20 ft of available drawdown, 6 of the wells (4 percent) were unusable when they were installed. A 23 ft drop in water levels, which is projected to result from current development levels, is calculated to cause an additional 20 wells (14 percent; 18 percent cumulatively) to become unusable. The projected additional 10 ft drop (33 ft total) from development through 2014 would cause 19 more wells (14 percent; 32 percent cumulatively) to become unusable. A total drawdown of 45 ft would cause 50 percent of the wells to become unusable. Once wells become unusable they would need to be deepened, or abandoned and replaced.

Mitigation measures could be used to reduce the magnitude of drawdown in Pumping Center A. For example if the projected development (2009-2014) was conducted using xeriscaping (no irrigation) the additional consumptive use of water would be reduced by about 98%. This reduced consumption would cause the drawdown from such development to be about 0.2 ft, rather than 10 ft.

Water levels in much of the North Hills study area showed a flat trend between 2005 and 2010. This includes some areas of high-density development (Pumping Centers B and C). These pumping centers draw groundwater from the Helena Valley aquifer that is recharged by the HVID canal and associated irrigation activities. This enhanced recharge causes excess groundwater in these areas, and drains have been installed to prevent waterlogging. The water being pumped from wells in these areas diverts water that would otherwise flow to the drains, and to Lake Helena.

Those parts of the study area with less dense development generally have flat water-level trends. Some isolated wells do have downward water-level trends; however, these are attributed to poor aquifer productivity rather than regional aquifer drawdown.

Groundwater Chemistry

The chemistry of groundwater in the North Hills was generally good. The major-ion signatures reflected a combination of the chemistry of recharging waters and the geology of the source aquifer. Water-quality data revealed that of 87 samples, only 1 exceeded the primary drinking water MCL for nitrate (10 mg/L). No other MCLs were exceeded. Twenty-four samples had nitrate levels greater than typical background levels (2 mg/L; Mueller and Helsel, 1996). Evaluation of nitrate isotopes suggested that elevated nitrate is primarily from septic effluent. The bedrock portion of the study area typically has shallow soils underlain by fractured bedrock. Such a setting generally is not conducive to the natural biological activity needed to break down nitrate (Nolan, 2001).

Aquifer Properties

Three major aquifers are present in the North Hills. The three units form a single groundwater flow system and can be viewed as one aquifer system, where aquifer properties vary by unit. Aquifer properties are geologically controlled, and have somewhat predictable distributions (fig. 32).

1) The bedrock aquifer is primarily composed of Precambrian argillite (Spokane and Grayson Formations). Bedrock is present at the surface in the hills in the west, north, and east portions of the study area. The bedrock is overlain by colluvium in the upper portion of the pediment, and by Tertiary materials in the lower pediment and in the Helena Valley. The bedrock has little primary permeability; however, it has been extensively fractured. These fractures provide conduits for flow, and provide for the storage of groundwater. These fractures are extensive enough that when it is viewed at the level of the study area, this fractured bedrock can be treated as equivalent porous media. Aquifer tests conducted as a part of this study had K values ranging from 1.6 to 7.5 ft/day and S values from 0.001 to 0.03. These values fall within the range of previous investigations. The groundwater model (which integrates K over a larger area than any one aquifer test) used bulk K values ranging from 0.006 to 6.4 ft/day and an S value of 0.02 for the bedrock aquifer. This lower range of K is considered reasonable because of the effects of faulting, igneous intrusions, and fractures on bulk K.

2) Unconsolidated Tertiary sediments overlie the bedrock on the lower portion of the pediment and in the Helena Valley. The upper portion of the Tertiary sediments is commonly high in clay; however, layers of sand and gravel are present. Gravels of variable thickness and extent are frequently reported in well logs in the lower portion of the Tertiary aquifer. The Tertiary materials are typically overlain by colluvium on the pediment. The thickness of the upper clay-rich portion increases to the east, and is thin to non-existent in some areas in the west. One aquifer test from this study in the lower Tertiary indicated a *K* of 160 ft/day and an *S* of 0.006. These values are on the high end of the range from other investigations. The groundwater flow model used hydraulic conductivity values from 0.007 to 12 ft/day and *S* ranges from 0.02 to 0.05 for the Tertiary aquifer. These relatively wide ranges reflect the variable nature of this unit (from clay to gravel).
3) Unconsolidated Quaternary alluvium, composed of sand, gravel, and some silt, overlies the coarse-grained Tertiary sediments within the Helena Valley (generally below the irrigation canal). The coarse-grained Tertiary sediments and the Quaternary alluvium together form the Helena Valley aquifer. Aquifer tests conducted during previous investigations showed *K* values from 1 to 916 ft/day, and have a geometric mean of 73 ft/day. *S* values ranged from 0.0008 to 0.05. No aquifer tests were conducted in the alluvium for this study. The groundwater flow model results used alluvial bulk *K* values ranging from 0.05 to 464 ft/day and S ranges from 0.05 to 0.20.

Faults

Investigations at sites along faults in the North Hills indicated that bedrock faults are typically barriers to flow due to the formation of fine-grained fault gouge. Water does move through the faults, but at a slower rate than through surrounding bedrock. A breccia zone that can be pumped at relatively high rates is often present adjacent to faults; however, recharge of these zones is slow due to limited flow from surrounding bedrock and across the fault. Thus, from an aquifer system perspective, faults have the effect of lowering bulk K.

Potentiometric Surface

The potentiometric surface in the North Hills is generally a subdued reflection of the ground surface. Groundwater flows from the hills toward Lake Helena. Irrigation recharge and canal leakage cause groundwater levels below the HVID canal to rise during the irrigation season and to decline during the non-irrigation season. In the uplands above the canal, where there is significant irrigation from wells (e.g., yards, gardens, and fields), groundwater levels decline during the irrigation season and rise during the non-irrigation season.

Groundwater–Surface-Water Interactions

Silver Creek is the only perennial stream within the study area. Monitoring of this stream and the underlying alluvium showed that in Silver Creek water flows from the stream into the underlying alluvium, making it a losing stream. Similarly, the HVID canal also loses water to the underlying aquifer.

Lake Helena receives most (93 percent) of the groundwater flowing through the North Hills aquifers either as flow through the base of the lake or as groundwater intercepted by drains. The other 7 percent is diverted by wells and consumptively used (i.e. not returned by septic systems). Pumping water from any of the aquifers can potentially cause a decrease in the volume of water flowing out of the Lake Helena Causeway. Distance and faults may affect the timing of these impacts; however, over the long term, groundwater pumping will result in diminished groundwater discharge to Lake Helena. Because lake levels are controlled by Hauser Dam, changes in groundwater discharge will cause little variation in lake levels.

Groundwater Budget

Analysis shows that approximately 14,000 acre-ft/year flows through the North Hills study area. Of this, approximately 52 percent is derived from leaky irrigation canals or is from irrigation recharge, 32 percent is from infiltration of precipitation in the hills, 9 percent is from groundwater inflow, and 7 percent is from the infiltration of Silver Creek. Only the infiltration in the hills (32 percent; ~4500 acre-ft per year) is generally available to wells completed in the upland areas north of both the HVID canal and the alluvium associated with Silver Creek.

Recharge from the infiltration of irrigation water is an important contributor to the groundwater system. Land-use changes or changes in ditch management may significantly impact groundwater levels. For the extreme case of abandoning the HVID canal, and discontinuing irrigation in the Helena Valley, model results indicate that groundwater levels would drop by 35 ft near the canal, and, due to the loss of this artificial base level, groundwater levels would drop by as much as 15 ft 4 miles upgradient (northwest) from the canal.

Wells account for about 7 percent of the water removed from the groundwater system and consumed; the remainder flows to Lake Helena, either as surface water flowing from drains or as discharge through the bottom of Lake Helena. About 98 percent of the consumptive use from domestic wells is for the irrigation of lawns and gardens.

Groundwater withdrawals in the areas of denser housing (Pumping Centers A, B, and C) utilize a mixture of individual exempt wells and public water supply wells. The groundwater models were used to estimate the drawdowns associated with many individual wells and compared to the drawdown associated with a public water supply well (details are provided in the North Hills Modeling Report; Waren and others, in preparation). If a public water supply well is placed in the center of a multiple-house area to serve those households, the drawdown effect at the edge of the property and beyond is virtually the same as would result from the combined effect of individual exempt wells. In terms of water management, there are certain advantages to public water supply wells. It is easier to locate them in a more productive aquifer or strategically place them within a property to minimize drawdown impacts on neighboring wells. Also, it may be easier to implement water conservation strategies with a metered water system. From a regulatory perspective public water supply wells receive more scrutiny in that there is an evaluation of potential impacts and the acceptability of those impacts is assessed.

Numerical Models

Two groundwater models were developed for the North Hills study area. The models are single-layer, three-dimensional finite-difference groundwater flow models. These models will be available in several formats: as GMS files, as native MODFLOW files, and as Groundwater Vistas files. Steady-state and transient versions of each model have been constructed. The files needed to operate the models are available on the project website (http://www.mbmg.mtech.edu/gwip/).

The North Hills Area Model is a larger area groundwater model that utilizes water budget information from this and previous studies to develop a reasonable approximation of the water budget in the study area. It includes modeling of the north end of the Helena Valley’s irrigated areas serviced by the HVID canal and Silver Creek. This model was designed as a tool for evaluating the overall water budget of the groundwater system, and for determining the approximate timing of impacts of various water resource activities to Lake Helena and the Missouri River.

The Pediment Focus Model is a smaller area groundwater model developed specifically to address the issues in the core area of interest in the study area, which is that area most recently designated by the Montana DNRC as a CGWA. This model was designed as a tool to evaluate the water budget of the North Hills and the pediment above the Helena Valley Canal, and to predict the drawdown or recovery effects of changes in the groundwater withdrawals from the aquifers beneath the pediment.

RECOMMENDATIONS

Reduced groundwater levels were shown in this investigation in the bedrock and Tertiary aquifers of Pumping Center A due to groundwater withdrawals for housing developments. Existing development is anticipated to result in 23 ft of drawdown. It is estimated that about 14 percent of the wells in Pumping Center A will become unusable as a result of pumping at current levels. These wells would need to be deepened, or abandoned and replaced. Model results indicate that projected development will continue to reduce groundwater levels. If development continues from 2009-2014 in the same way that it did from 2005-2009 it is estimated that 32 percent of the wells in Pumping Center A will become unusable. Drawdown of 45 ft would cause 50 percent of the wells to become unusable.

Therefore, it is recommended that the minimum groundwater levels needed to allow water right holders to reasonably exercise their water rights be defined. These target groundwater levels would likely be defined by groundwater elevations measured in dedicated monitoring wells. Once these levels are established the groundwater models can be used to test different water management approaches that could be used to maintain these levels, and determine which, if any, controls are needed. This should allow effective, but not overly restrictive, controls to be adopted. A CGWA would be one way to implement controls. If changes in water management are implemented, monitoring will be needed in and near Pumping Center A to ensure that target levels are maintained. It is recommended that in, and surrounding, Pumping Center A, one dedicated monitoring well be monitored per quarter section, with water levels being recorded at least monthly. Modification of the controls may be needed if the desired results are not achieved.

Many approaches can be taken to attempt to achieve desired groundwater levels. For example, if lawn and garden irrigation were not allowed in new housing developments, the resulting drawdown from projected 2009-2014 development would be 0.2 ft rather than 10 ft. It is also possible that water could be obtained from off-site, such as from PWS wells in the Helena Valley aquifer, and pumped to new housing developments. Other possible controls include prohibiting exempt wells, limiting the use of exempt wells to specific purposes (e.g., in-house use), limiting the acreage irrigated from exempt wells, or decreasing the volume limit for exempt wells. The appropriateness of any control should be tested through modeling before it is implemented, and verified by monitoring after it has been adopted.

It is also recommended that wells installed in this area be designed to allow for anticipated drawdown in Pumping Center A. Based on model projections, an additional 13 ft of drawdown is expected to occur as a result of development through 2014. If control measures become effective at that time, water levels would stabilize near that level. As such, it is recommended that wells be drilled somewhat deeper than would normally be done to allow for future drawdown. At the time of the writing of this report (2012) it is recommended that wells be drilled so that there is at least 35 ft of available drawdown above the pump. If control measures are not implemented, water levels may fall further, and wells would need to be deeper.

Groundwater samples collected during this study show that the drinking water standard for nitrate was exceeded in one sample, and 28 percent of the samples were above background nitrate levels. While not an immediate threat, this indicates that current methods are not fully breaking down nitrate from septic systems. In particular, those areas that are immediately underlain by fractured bedrock are more susceptible because of the lower potential for biologic breakdown of nitrates where soils are thin and few organic materials are present. Continued installation of septic systems in parts of the North Hills, particularly where there is dense development, may lead to exceedances of drinking water standards for nitrate. It is recommended that groundwater samples continue to be analyzed from the North Hills, to determine if this is becoming a more wide-spread problem, and to determine if changes are needed. It is recommended that samples be collected once per year, in the spring, from wells throughout the area, with more emphasis placed on areas of dense development, and where bedrock is shallow (e.g. the north end of Montana Avenue). Possible solutions could include modifications in septic system design or construction of public sewage treatment systems.

As a part of this study the area-wide monitoring network of the LCWQPD was evaluated, and modifications of the network 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 is to be assessed. This network should also be reassessed on a regular basis to ensure that the objectives of the network are being met, and to respond to changes in the area.

Water levels in the area near where Silver Creek enters the valley are susceptible to significant changes as flows in Silver Creek change. These fluctuations are mainly linked to climatic patterns and irrigation practices. As such, it is recommended that wells completed in this area 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 this area is strongly dependent on the infiltration of irrigation water. As such, impacts to the groundwater system should be considered when major changes in land use, or ditch management are proposed. Abandonment of the HVID canal and associated irrigated fields would cause major groundwater-level declines. The models developed in this study can be used to assess the impacts from such proposed changes.

It is also recommended that if site-specific decisions are needed, detailed site specific data should be collected and incorporated into the models. 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 methods to consider the entire area; however, they should be considered a starting point for any site-specific decisions, rather than the final analysis. They can be used for providing estimates of impacts from large subdivisions (greater than about 100 acres). Analysis at smaller scales could be done; however, the potential error becomes much higher. While it is considered to be 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 may have a strong control over local groundwater conditions and responses.

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