Ground Water Monitoring Results and Surface Water – Ground Water Interaction, Helena Valley, Montana

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Table of Contents

Table of Contents (continued)

List of Figures

Table of Contents (continued)

List of Tables

Appendices (Electronic)

Appendix A	Laboratory Data Reports
Appendix B	MBMG-GWIC Data Water Type Determination
Appendix C	Monitoring Well Data Summary Tables and Plots
Appendix D	Helena Valley Water Quality Type Map
Appendix E	Monthly Nutrient Monitoring Program Data (2009-2010)
Appendix F	Coupled Piezometer and Surface Water Site Summary Tables and Plots

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- LCWQPD Board Members for providing feedback on project results
- Local Residents who provided access to their wells for the project

List of Acronyms

GWAP – Ground Water Assessment Program (MBMG)
GWIC – Ground Water Information Center (MBMG)
GWIP – Ground Water Information Program (MBMG)
HVID – Helena Valley Irrigation District
LCWQPD – Lewis and Clark County Water Quality Protection District
LMWL – Local Meteoric Water Line
MWL – Meteoric Water Line
mg/L – milligrams per liter
MBMG – Montana Bureau of Mines and Geology
MDEQ – Montana Department of Environmental Quality
METG – Montana Environmental Trust Group
RPD – Relative Percent Difference
SAP – Sampling and Analysis Plan
SAT – Soil Aquifer Treatment
TOC – Top of Casing
TDS – Total Dissolved Solids
TMDL – Total Maximum Daily Load
USEPA – United States Environmental Protection Agency
USGS – United States Geological Survey

Executive Summary

The Helena Area Ground Water Project was completed in two phases from July 2009 through September 2012. The study area comprised the Helena Valley and surrounding area. The project objectives included characterizing baseline nutrient concentrations in ground water across the Helena area, characterizing the interaction of surface water with ground water in the area, and evaluating potential non-point sources of excess nutrients in local waters.

The field sampling program focused on collecting samples from 25 monitoring wells in the Lewis and Clark Water Quality Protection District (LCWQPD) network. The well network includes 8 well clusters, with both shallow and deep wells at the same location. A total of six sampling events were conducted for major ions, nutrients and trace metals identified as the primary analytes. A monthly sampling program during 2009-2010 completed at residential wells where elevated concentrations of nitrate were confirmed by previous LCWQPD sampling supplemented the monitoring well sampling program. The results confirm that elevated levels of nitrate and nutrients are present in unsewered residential areas where Silver Creek and Prickly Pear Creek enter the Helena Valley.

The interaction of surface and ground utilized shallow piezometers installed at surface water monitoring locations adjacent to Silver Creek, Sevenmile Creek, Tenmile Creek, Prickly Pear Creek and the D2 Drain. The piezometers represent shallow wells installed to the top of the water table adjacent to streams for water quality sampling and water level monitoring. A total of 11 piezometers were monitored, with 7 installed for this project, and 4 installed by MBMG for their recent area studies. Water quality sampling events were conducted in winter, spring and late summer 2012, and water levels were monitored at regular hourly intervals using datalogging sensors for comparison with similar surface water datasets. The results are consistent with the conceptual model of the Helena Valley hydrogeology, as streams gain flow in bedrock areas with little alluvium upgradient from the valley, lose water to ground water where they enter the valley, and again gain flow from ground water as they approach the center of the valley.

The water quality results from this study were compiled into a database with available water quality data from other area studies. Major ion data were used to classify different water types across the Helena Valley and surrounding areas. The data results were used to construct stiff diagrams depicting major ion chemistry, which were used to construct a water quality map for the study area. The mapping effort identified several different water types, as defined by major ions. Local recharge waters, including streams and irrigation canals, are predominantly a Calcium-Magnesium/Bicarbonate water type. Ground water associated with hot springs and warm temperatures is predominantly a Sodium-Potassium/Sulfate-Bicarbonate water type. A mixed water quality type water, interpreted to result from mixing of local recharge with deep ground waters, are present in the northeastern and southeastern parts of the Helena Valley.

The project included a ground water isotope assessment, incorporating two types of isotopes. Oxygen and hydrogen isotopes of water represent a conservative tracer which can be used to delineate flowpaths from surface recharge. The water isotope dataset requires additional data to characterize seasonal trends; however, the preliminary results are consistent with conclusions derived from water levels and water quality assessments. The nitrogen and oxygen isotopes of dissolved nitrate in ground water samples were determined to characterize the potential sources of nitrate. The nitrate isotopes indicate that the majority of detected nitrate is from an animal source – either agricultural animal waste or from septic systems discharging to ground water. A single sample indicates agricultural fertilizer as a likely source.

Ground water temperatures observed during sampling indicated that ambient ground water temperatures are frequently higher than anticipated, based on normal hydrogeologic conditions. The background temperature gradient was determined from wells in the North Hills and Scratchgravel Hills. Ground water temperatures in the valley wells indicate areas where mixing of locally recharged ground waters occurs with deeper ground waters, resulting in warm waters with a mixed major ion chemistry. Ground water temperature in the piezometers and streams were used to evaluate the interaction of surface and ground water, with results confirming conclusions from water quality and water level data.

The combined results of the project identify the shallow ground water system present with a Calcium-Magnesium/Bicarbonate water type, with primary recharge from stream loss and direct infiltration of precipitation. The deep thermal (warm) ground water system mixes with locally recharged waters in the subsurface. Nutrient loading to local ground water is most evident in the areas around the valley margins where Silver Creek, Tenmile Creek and Prickly Pear Creek enter the valley. Nutrient concentrations in the central part of the valley are generally near background levels. A more complete characterization of nutrient loading sources for Lake Helena requires an assessment of the ground water drain system in the central part of the valley, so that a mass balance can be completed for nutrient cycling through the system.

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1.0 Introduction

Ground water in the Helena area provides a drinking water source to the majority of local residents through both public water supplies and private potable wells. Wastewater discharges to ground water impact local ground water quality from both onsite treatment systems (a/k/a septic systems) and community system treatment lagoons. Population growth in the area has increased loading of wastewater to the aquifer, stressing the capacity of the natural system to mitigate the magnitude of water quality impacts. Agriculture represents an additional source of nutrient loading to ground water from fertilizers and animal manure. Ground water in the Helena area occurs in bedrock aquifers along the margins of the Helena Valley, and in the Helena Valley Alluvial aquifer within the valley (Briar & Madison, 1992; Thamke, 2000). Lake Helena represents the downgradient discharge point for both surface and ground water in the area. During the summer, water from outside the drainage basin supplements the local hydrogeologic system for irrigation. Water from the Canyon Ferry Dam on the Missouri River is pumped into the Helena Regulating Reservoir, which discharges to the Helena Valley Irrigation District (HVID) Canal which flows around the valley. The HVID canal discharges to smaller surface water canals in the distribution system. Leakage from the base of the canals discharges to the ground water system. Along the valley margins, recent studies simplify the local system by treating bedrock and alluvial aquifers as a single aquifer system (Waren et al., 2012; Bobst et al., 2013; METG, 2011). While this assumption is consistent with regional scale assessments of the ground water flow system in the area, different aquifer types exhibit greatly different soil aquifer treatment (SAT) properties resulting in different fate and transport properties for nutrients within the local hydrologic system.

This report presents the results of a recent study implemented by the Lewis & Clark Water Quality Protection District (LCWQPD) to characterize the interaction of surface and ground water in the Helena area, with an emphasis on evaluating nutrient loading to Lake Helena (and the Missouri River) from non-point sources. The study area for this project represents the Helena Valley and adjacent areas in Lewis and Clark County (Figure 1-1). This study obtained and provides baseline data to support implementation of the Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area (Framework Restoration Plan) for the Lake Helena Watershed (USEPA, 2006). Primary funding for the project was obtained from two Section 319 – Non Point Source Program Grants awarded by the Montana Department of Environmental Quality (MDEQ) to LCWQPD. The project was completed following the sampling program design(s) outlined in the original sampling and analysis plan (SAP) for Phase I of the project, and modified for Phase II. The study incorporates historical data for the study area and the results of previous and ongoing investigations in the study area.

While the project focus is on the entire valley, the program activities in the southeast part of the Helena valley around East Helena were limited to not replicate work and data collected for remedial actions currently under implementation for the former Asarco Smelter superfund site.

Data for the site characterization work includes stratigraphic data from numerous soil borings and monitoring wells, water level and water quality data from the wells, datasets from piezometers installed adjacent to Prickly Pear Creek, and surface flow monitoring. While limited portions of this dataset have been provided to LCWQPD; however, Environmental Protection Agency (USEPA) staff and consultants have declined to participate in this research effort. As a result, the characterization of Prickly Pear Creek in the southern part of the valley is limited at this time.

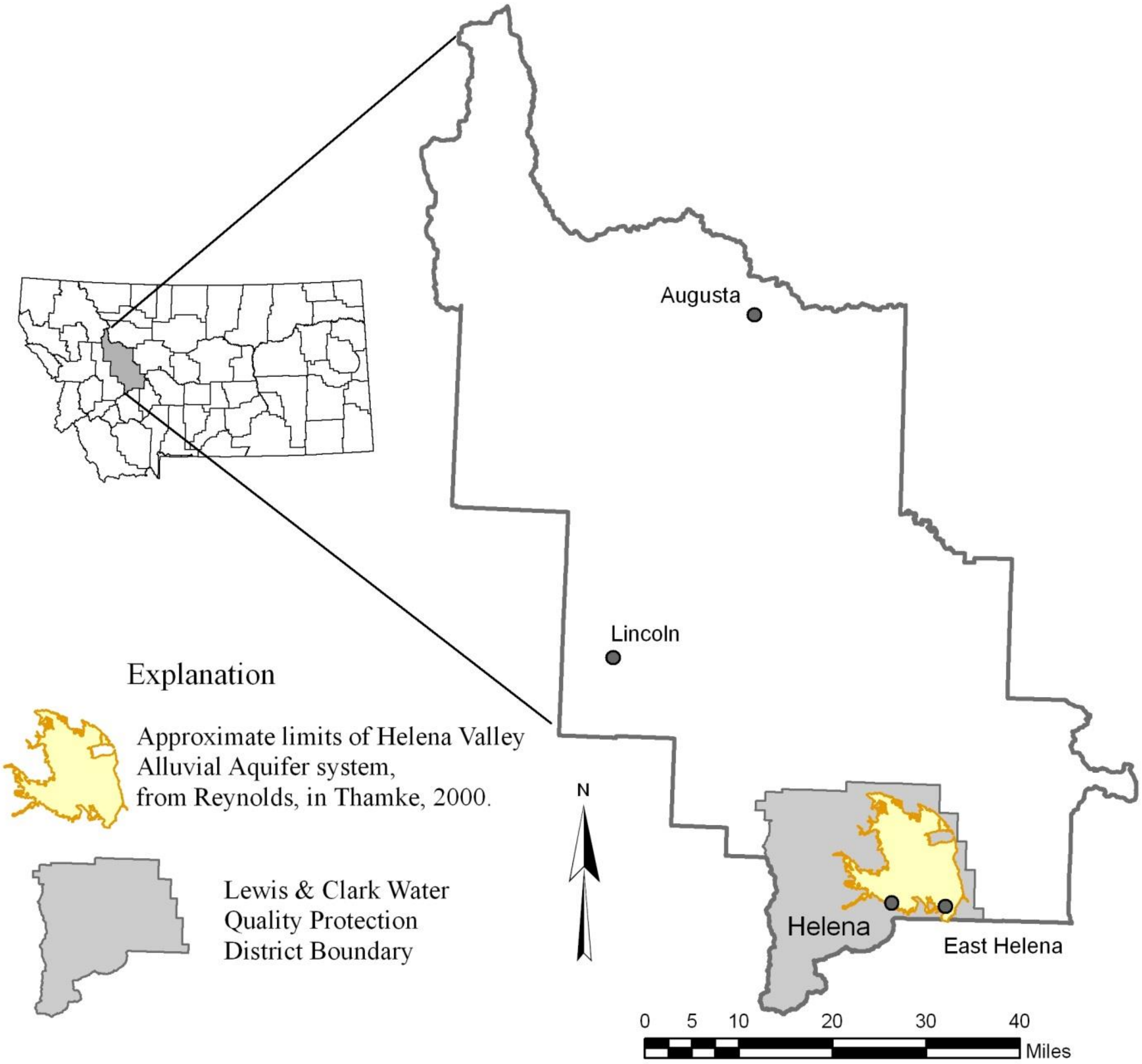


Figure 1-1 – Helena Valley Area Study Location

2.0 Background

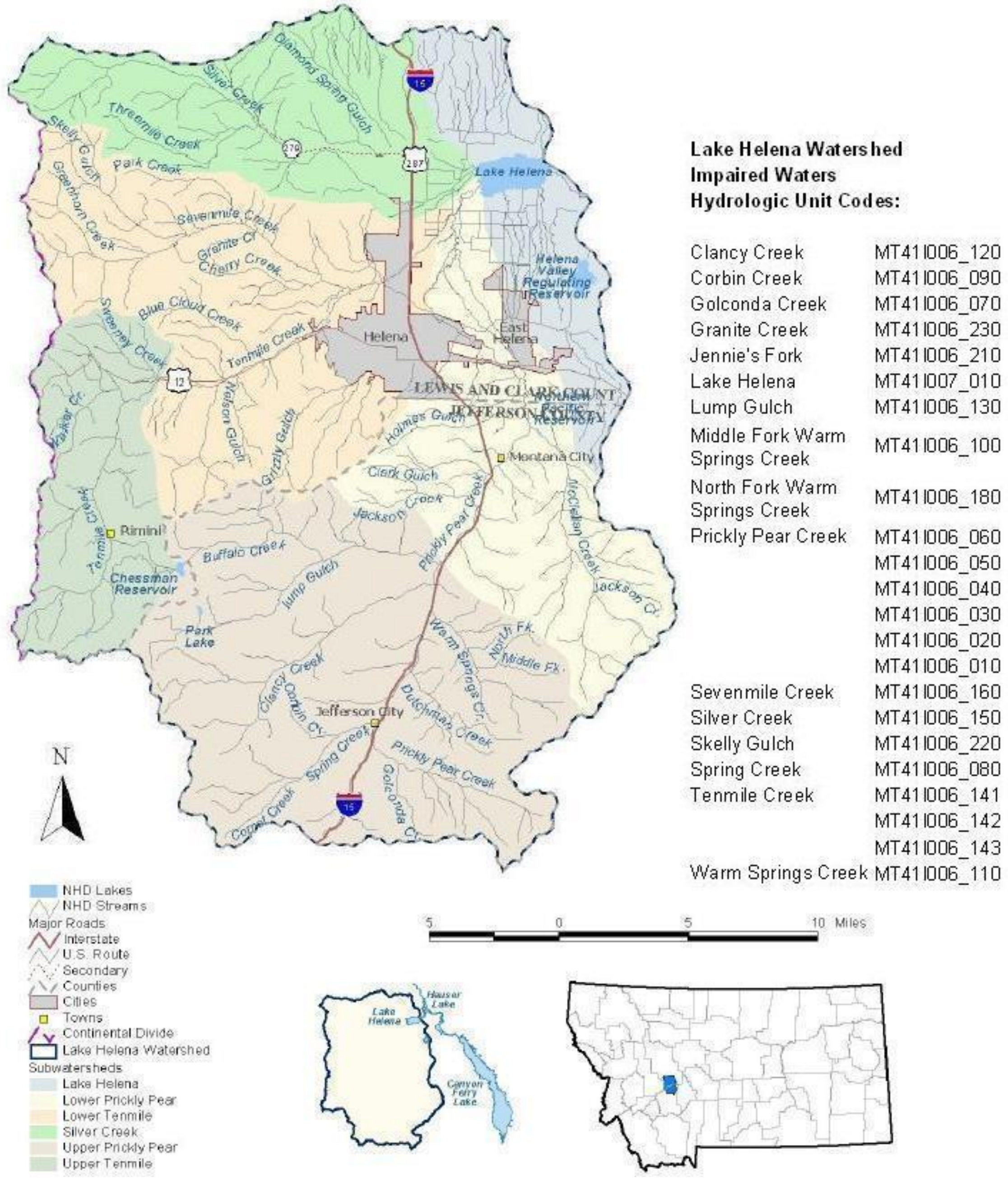
The Helena Valley is located within southern Lewis & Clark County, Montana (Figure 1-1). The continental divide is present west of the valley, with the Missouri River located to the east. The primary urban areas are located along the southern and southwestern part of the valley, with mixed residential and agriculture located across the remainder of the valley. The central part of the valley near Lake Helena is primarily undeveloped. The population of the greater Helena metropolitan area is estimated at 64,000, with approximately 30,000 people residing in Helena proper (Helena Area Chamber of Commerce, 2013). The LCWQPD encompasses the Helena Valley and surrounding area. The climate of the area is semi-arid and typical of the region, with low precipitation in the valleys, cold winters and mild summers (Kendy & Tresch, 1996). Monthly average precipitation data is summarized in Table 2-1.

The Lake Helena Watershed covers approximately 402,000 acres (620 square miles) within the Upper Missouri River Water Basin. The primary drainages are Silver Creek, Tenmile Creek, and Prickly Pear Creek with headwaters in high elevation mountains to the west and south (Figure 2-1). Elevations in the study area range from 9,381 feet above sea level at Elkhorn Peak, south of Helena, to approximately 3,650 ft at Lake Helena. All of the surface waters drain to Lake Helena, which discharges into Hauser Lake and the Missouri River. From the Framework Restoration Plan (USEPA, 2006), numerous surface streams and tributaries are impaired at various locations from combinations of sediment (turbidity), temperature, nutrients and trace metals. Approximately 68% of the Lake Helena watershed occurs within Lewis and Clark County, with the remaining 32% in Jefferson County. Lake Helena covers approximately 1,600 acres and is eutrophic with large algal blooms occurring during warm months.

Table 2-1 – Helena Weather Station Average Annual Climate Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg Max Temp (°F)	29.9	35.0	43.6	55.3	64.4	72.7	83.1	81.4	69.6	57.3	42.1	32.5	55.6
Avg Min Temp (°F)	11.5	15.5	22.6	31.8	40.4	47.7	53.6	51.8	42.6	33.4	22.6	14.6	32.3
Avg Total Precip (in)	0.59	0.46	0.70	0.97	1.92	2.12	1.10	1.00	1.09	0.73	0.60	0.58	11.85
Avg Total Snow (in)	8.8	7.1	8.2	5.1	1.6	0.1	0.0	0.1	1.1	3.0	6.6	8.1	49.5
Avg Snow Depth (in)	2	2	1	0	0	0	0	0	0	0	1	2	1

Data from Western Regional Climate center, obtained 12 Mar 2013 (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt4055). Period of Record is from 1/1/1893 to 9/30/2012.



Lake Helena Watershed Impaired Waters Hydrologic Unit Codes:

Clancy Creek	MT41I006_120
Corbin Creek	MT41I006_090
Golconda Creek	MT41I006_070
Granite Creek	MT41I006_230
Jennie's Fork	MT41I006_210
Lake Helena	MT41I007_010
Lump Gulch	MT41I006_130
Middle Fork Warm Springs Creek	MT41I006_100
North Fork Warm Springs Creek	MT41I006_180
Prickly Pear Creek	MT41I006_060 MT41I006_050 MT41I006_040 MT41I006_030 MT41I006_020 MT41I006_010
Sevenmile Creek	MT41I006_160
Silver Creek	MT41I006_150
Skelly Gulch	MT41I006_220
Spring Creek	MT41I006_080
Tenmile Creek	MT41I006_141 MT41I006_142 MT41I006_143
Warm Springs Creek	MT41I006_110

Figure 2-1 – Lake Helena Watershed

2.1 Geologic Setting and Regional Hydrogeology

The Helena Valley formed along the southwestern side of the confluence of two major regional fault systems in Montana. After continental-scale tectonic forces created mountains across western Montana, the valley formed as a the continental block relaxed and began to expand. The valley formed as a large bedrock block settled into the expanding space, with one end tied to the Scratchgravel Hills to the west, while the eastern side subsided to fill the expanding gap. As the eastern side of the block faulted downward, the depression was filled by a series of lakebed and riverine deposits with a total thickness estimated at approximately 6,000 feet of sediment (Briar & Madison, 1992; Thamke, 2000). The Helena Valley Alluvial Aquifer comprises coarse grained alluvial deposits at the top of the valley-fill sequence, present across the Helena Valley. The coarsest and most permeable parts of the alluvial aquifer are present where tributary drainages enter the valley, evidenced by gravel pits at near all of these locations. Grain size and permeability decreases towards the central part of the valley, with a layer of fine-grained lake deposits covering older materials (Stickney, 1987).

Bedrock at the surface defines the margins of the valley, where bedrock aquifers are locally developed as potable water sources. Semi-consolidated Tertiary deposits are present under the alluvial aquifer, and considered part of the aquifer where dominated by coarse grained sediments. Ground water in the Helena Valley alluvial aquifer flows towards Lake Helena (Figure 2-2), which acts as the primary discharge point for shallow ground water and surface water from the valley (Briar & Madison, 1992). Recharge to the aquifer occurs from stream loss along the valley margins, and from bedrock systems bounding the valley. The Helena Irrigation Canal flows around the central part of the valley (Figure 2-2), with discharge from the bed of the canal providing recharge to the local ground water system. Ground water is directly connected to surface water as the major tributary streams to Lake Helena (Silver Creek, Prickly Pear Creek and Tenmile/Sevenmile Creek) all experience stream loss where they enter the margins of the valley. A series of open channel and subsurface tile drain system installed in the central part of the valley to enhance agricultural productivity lowers the water table in areas with shallow ground water.

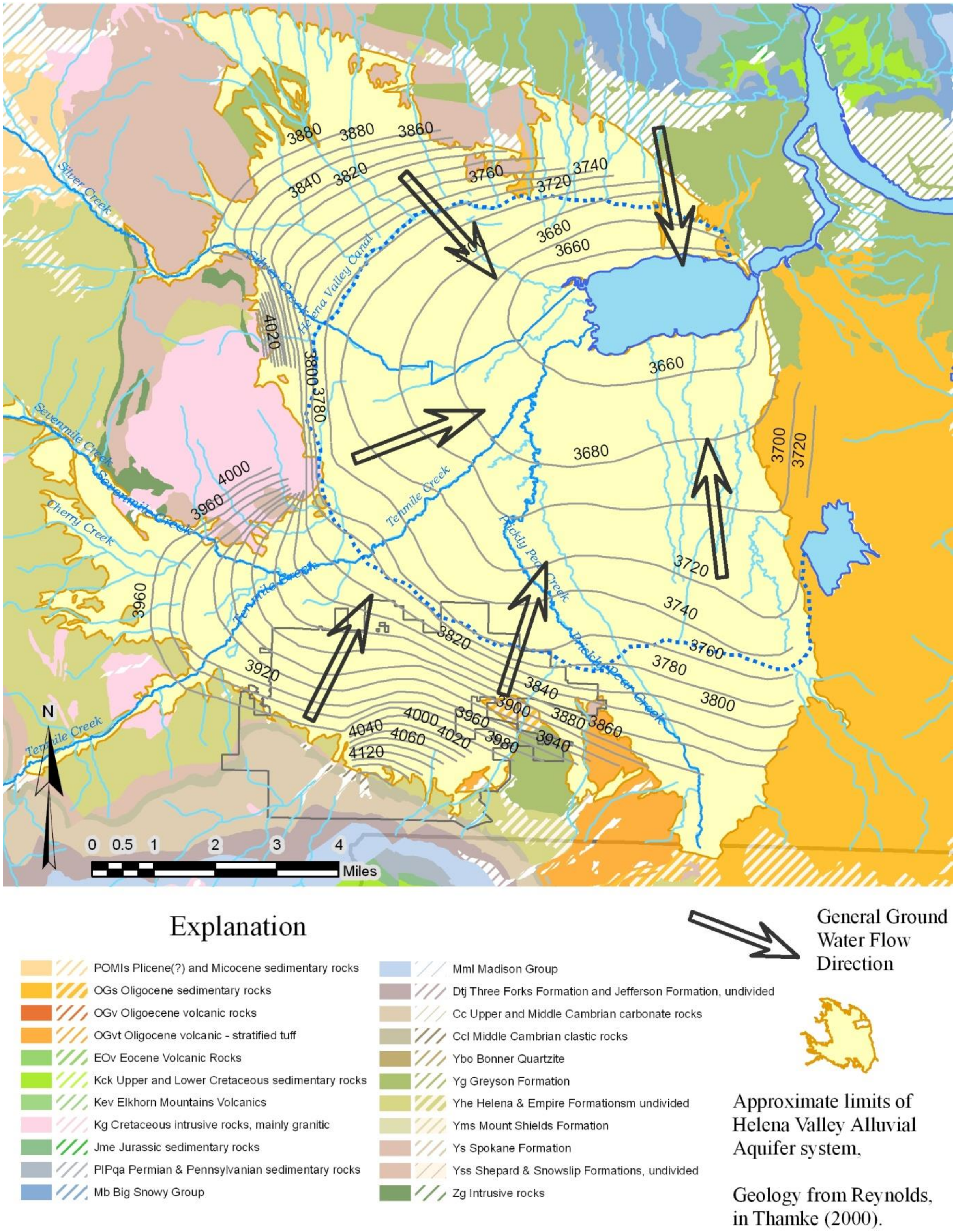


Figure 2-2 – Helena Area Geologic Map and Potentiometric Surface

2.2 Previous Hydrogeology Studies

The United States Geological Survey (USGS) completed several water quality studies of the Helena Valley. The initial study of the area comprised a reconnaissance study completed in 1948 to determine the general properties of ground water flow and chemistry in the valley (Lorenz & Swenson, 1951). This study presented major ion chemistry data for water samples from 17 wells at locations across the Helena Valley, including two wells drilled into the Tertiary sediments beneath unconsolidated valley fill material. With increased growth in the area, the USGS completed additional studies in 1971 (Wilke & Coffin, 1973) and 1978-79 (Moreland et al., 1979; Moreland & Leonard, 1980) to examine the impacts of urban growth on water quality, with limited sampling for major ions and trace metals, and more extensive sampling for nitrates. These studies concluded that urban growth was impacting ground water quality in the area. The most detailed study of the Helena Valley Aquifer was performed in 1989-90, with a detailed ground water numerical (computer) flow model completed for the aquifer coupled with an extensive ground water sampling and analysis program to characterize chemical water quality across the valley (Briar & Madison, 1992). The nature of the bedrock aquifers along the margins of the Helena Valley were investigated during the period 1993-98, with additional water quality sampling (Thamke, 2000). Focused ground water studies were performed on the impact of irrigation drainage to ground water quality in 1995 (Kendy et al., 1998) and on the hydrogeology of the North Hills area of the Helena Valley (Madison, 2006). More recently, the Montana Bureau of Mines and Geology (MBMG) completed focused studies on the hydrogeology and water quality of the North Hills area (Waren et al., 2012) and the Scratchgravel Hills area (Bobst et al., 2013). Additional unpublished ground water quality data for the Helena area is present in WQPD incident response files, with subdivision applications submitted to Lewis & Clark County and/or Montana Department of Environmental Quality, and for environmental sites within the study area.

2.3 Regional Conceptual Hydrogeologic Model

The conceptual model for the hydrogeology of the Helena Valley was developed based on the results of previous studies in the area. The conceptual model provides a baseline system for comparison with the different data results in the study. These results provide constraints to the model allowing for it to be refined, increasing the representativeness of the conceptual model to the actual system. For the Helena Valley Aquifer, the conceptual model reflects primary recharge to the aquifer from stream loss where streams enter into the valley. Recharge from bounding bedrock aquifers occurs in the subsurface, and maintains water levels during winter months when recharge is limited. Both the shallow and deep portions of the aquifer discharge vertically upward into Lake Helena as a discharge point in the central part of the valley.

3.0 Monitoring Program

The primary focus of the monitoring program comprised the collection of ground water quality data to assist with the assessment of non-point pollution sources of nutrients to surface and ground water in the Helena Valley. Data from this project is supplemented by surface water flow and water quality monitoring programs conducted by LCWQPD since 2007, in accordance with data needs outlined in the Framework Restoration Plan (USEPA, 2006). The combined surface and ground water monitoring program datasets represent baseline data for future evaluations of the efficacy of programs to reduce non-point source loading of nutrients to local waters. The program was completed with two phases; with Phase I implemented between July 1, 2009 and June 30, 2010; and Phase II between July 1, 2010 and September 30, 2012.

The primary monitoring points for the project represent the LCWQPD Monitoring Well network, installed during Summer 2001 at locations across the valley. These monitoring points represent locations where water quality sampling was conducted in addition to water level monitoring. A summary of the monitoring well sample locations is presented in Table 3-1. The well network was supplemented by select private potable wells in areas with known ground water impacts. The interaction of surface and ground water utilized piezometers installed at eleven surface water monitoring location in the watershed, listed in Table 3-2. All of the water quality monitoring locations are depicted in Figure 3-1. Secondary monitoring points represent locations where water level measurements were collected as part of continuing the long-term monthly water level measurements completed by LCWQPD in conjunction the MBMG programs.

Table 3-1 Primary Ground Water Monitoring Well Summary

Monitoring Wells#	MBMG GWIC ID #	Well Owner	Total Depth (ft)	Water Level (ft)	Date Installed	Geologic Unit Code	TOC Elevation
Buoy Road N (sh)	191524	LCWQPD	25	8.32	12/4/01	110 ALVM	3710.62
Buoy Road S (dp)	191525	LCWQPD	50	8.21	12/4/01	110 ALVM	3710.54
Sierra & Floweree N (dp)	191526	LCWQPD	46	6.90	12/4/01	110 ALVM	3685.48
Sierra & Floweree S (sh)	191527	LCWQPD	18	5.58	12/4/01	110 ALVM	3685.27
Airport West N (dp) *	191528	LCWQPD	90	5.69	11/29/01	120 SDMS	3864.98
Airport West S (sh) *	191529	LCWQPD	25	6.12	11/29/01	120 SDMS	3865.43
Regulating Reservoir	191530	LCWQPD	56	23.03	11/27/01	120 SDMS	3838.83
Motor Pool W (dp)	191531	LCWQPD	121	38.75	11/29/01	121 SDMS	4012.63
North Hills	191532	LCWQPD	100	59.28	11/28/01	110 ALVM	3882.50
Airport South N (dp)	191533	LCWQPD	121	21.81	11/30/01	120 SDMS	3879.62
Gravel Pit	191534	LCWQPD	100	71.41	11/28/01	110 ALVM	3799.56
Airport South S (sh)	191535	LCWQPD	55	34.83	11/30/01	120 SDMS	3880.57
Eichoff & Valley	191536	LCWQPD	70	39.73	11/27/01	110 ALVM	3766.55
Lincoln & Montana	191537	LCWQPD	43	28.86	11/28/01	110 ALVM	3756.62
Airport North N (dp)	191538	LCWQPD	80	27.47	11/30/01	110 ALVM	3782.54
Horseshoe Bend	191539	LCWQPD	19	9.84	11/30/01	110 ALVM	3832.44
Motor Pool E (sh)	191540	LCWQPD	61	34.42	11/29/01	120 SDMS	4012.65
Prairie Nest & Lone Prairie	191548	LCWQPD	136	112.55	12/7/01	120 SDMS	3928.83
Helberg Lane S (sh)	191549	LCWQPD	16	3.47	12/7/01	110 ALVM	3684.44

Table 3-1 Primary Ground Water Monitoring Well Summary (continued)

Monitoring Wells#	**MBMG GWIC ID #**	**Well Owner**	**Total Depth (ft)**	**Water Level (ft)**	**Date Installed**	**Geologic Unit Code**	**TOC Elevation**
Warren School N (dp)	191550	LCWQPD	47	13.11	12/7/01	110 ALVM	3740.16
Warren School S (sh)	191551	LCWQPD	19	13.00	12/7/01	110 ALVM	3739.82
Helberg Lane N (dp)	191554	LCWQPD	61	1.45	12/5/01	110 ALVM	3684.15
Applegate & Norris (sh)	191555	LCWQPD	29	14.22	12/5/01	110 ALVM	3736.39
Applegate & Norris MBMG**	257063	MBMG	58	13.00	7/6/10	110 ALVM	3737.12
Head Lane	191557	LCWQPD	80	3.51	12/5/01	400 BELT	3916.01
Airport North S (sh)	193012	LCWQPD	34	27.37	11/30/01	110 ALVM	3782.48
Collins Road MBMG***	257064	MBMG	51	7.00	7/6/10	110 ALVM	3702.36
Howard Rd W (dp)	123550	MBMG	78	21.56	6/7/90	110 ALVM	3757.44
Howard Rd E (sh)	892180	USGS	40	13.62	9/1/78	110 ALVM	3757.45
Hamer E (sh)	88214	MBMG	25	10.15	7/13/90	110 ALVM	3724.67
Hamer W (deep)	88213	MBMG	104	11.90	7/13/90	110 ALVM	3724.71

\# For well clusters, sh = shallow well and dp = deep well

* Well head lowered by gravel pit operation, recent water level indicated

** Replaced Original LCWQPD Well, GWIC 191552, TD - 60'

*** Replaced Original LCWQPD Well, GWIC 191556, TD - 50'

Table 3-2 Stream Piezometer Well Summary

Piezometers	**MBMG GWIC ID #**	**Well Owner**	**Total Depth (ft)**	**Water Level (ft)**	**Date Installed**	**Geologic Unit Code**	**TOC Elevation**
Tenmile Creek Crossings				(1/1/12)			
Country Club Lane (T-24)	*n/a*	LCWQPD	11.9	2.85	9/6/11	110 ALVM	3907.45
Green Meadow Road (T-4)	*n/a*	LCWQPD	11.4	9.49	9/8/11	110 ALVM	3817.20
Sierra Road (T-6)	*n/a*	LCWQPD	9.3	2.42	9/7/11	110 ALVM	3694.94
Prickly Pear Creek Crossings							
Canyon Ferry Road (P-5)	*n/a*	LCWQPD	10.2	4.89	9/7/11	110 ALVM	3767.28
Sierra Road (P-10)	*n/a*	LCWQPD	10.7	2.40	9/7/11	110 ALVM	3681.28
Winterbourne Property (P-12)	*n/a*	LCWQPD	15.9	5.18	9/7/11	110 ALVM	3661.96
Silver Creek Crossings							
Silver Creek Estates (SC-1)	254216	MBMG	16.9	11.29	11/11/09	110 ALVM	4026.53
Smelko Property (SC-2)	254237	MBMG	24.5	17.48	11/11/09	110 ALVM	3897.93
Arrowhead Road (D2B-D2)	*n/a*	LCWQPD	15.0	5.33	9/7/11	110 ALVM	3668.71
Sevenmile Creek Crossings							
Birdseye Road (7M-1)	255141	MBMG	16.7	8.41	3/24/10	110 ALVM	4090.76
Head Lane (7M-3, T-3)	255143	MBMG	14.3	2.38	3/24/10	110 ALVM	3929.68

(n/a - not assigned)

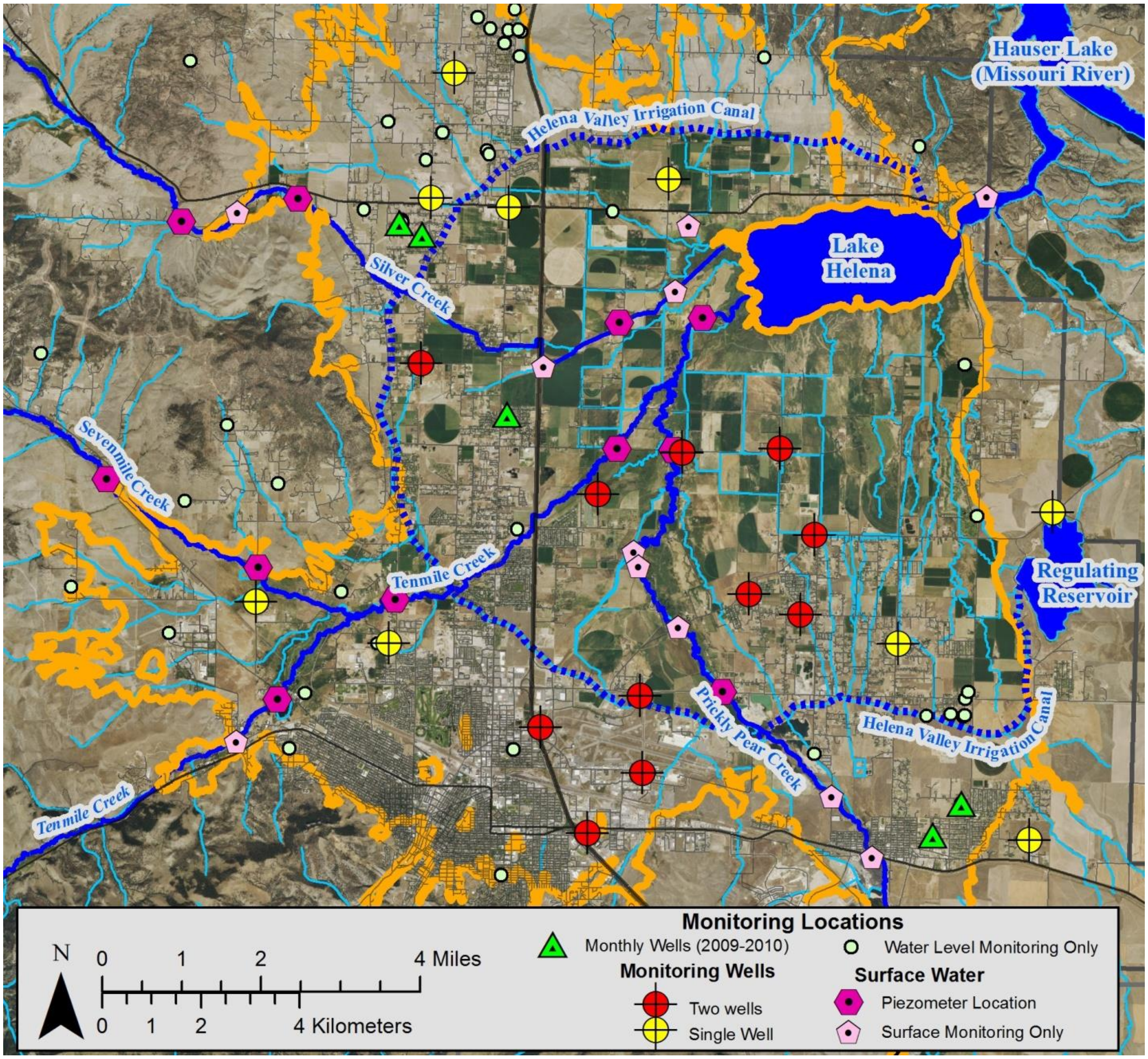


Figure 3-1 Study Monitoring Locations

3.1 Ground Water Quality Monitoring Program

The ground water sampling program included several phases. The primary program comprised ground water quality monitoring completed over the duration of the project. A monthly sampling program, implemented during the first year of the project, characterized seasonal changes in nutrient levels. The final component comprised sampling shallow ground water piezometers, installed at surface water monitoring locations, during the final year of the project. The ground water quality sampling program focused on nutrients and trace metals identified in the Framework Restoration Plan (USEPA, 2006) as analytes of concern, summarized in Table 3-3. The analyte list included major ions to characterize water quality types, and potential indicators of impacts from septic systems.

3.1.1 Monitoring Well Sampling Program

The primary monitoring well network comprises 31 monitoring wells at locations across the valley (Table 3-1). The LCWQPD monitoring well network installed in 2001 comprised 27 monitoring wells at 18 locations across the valley (9 locations with individual wells, and 9 locations with well clusters where two wells are installed to different depths into the aquifer). Within two years of installation, two of the wells (Applegate & Norris Deep and Collins Rd) were destroyed by road maintenance equipment. MBMG replaced the wells in 2010 as monitoring points for the local GWIP studies of the North Hills (Waren et al., 2012) and Scratchgravel Hills (Bobst et al., 2013). During the last year of the project two well clusters (four additional monitoring wells) in the central part of the valley from previous MBMG/USGS studies were incorporated as sampling points within the LCWQPD monitoring well network.

The primary sampling program comprised six events between October 2009 and November 2011. The sampling locations and dates for each sampling event are listed in Table 3-4. The initial program design reflected a semi-annual sampling frequency. Comparison of the recent data with results from 2001 and 2002 indicated no significant changes in major ion chemistry over that time. Due to the stability of this data, the sampling program for Phase II of the project was modified to incorporate a Fall 2010 sampling event and three sampling events for 2011. The Fall 2010 sampling event only included shallow wells due to problems with the deep sampling pump, and the early onset of winter snowcover to the region. The timing of the three events was to coincide with the generic surface water hydrograph, which reflects seasonal recharge to the local aquifer. The three 2011 sampling events comprised:

- Early Spring – April, during the rising portion of the spring runoff hydrograph when water levels are just starting to rise after winter, and prior to the start of irrigation season. This period reflects ambient ground water conditions after the winter
- Late Summer – August, after peak flows have subsided, and in the middle of irrigation season, to evaluate whether water quality changes associated with either recharge from peak surface flows or irrigation recharge are present, and
- Late Fall – November, after irrigation season has ended and surface water flows are generally at minimum levels, and ground water levels are generally starting to decline.

Table 3-3 Ground Water Monitoring Analytes, Analytical Methods and Reporting Limits

Analyte	**Units**	**Reporting Limit**	**Analytical Method**
Water Quality Characteristic Properties			
Solids, Total Dissolved (TDS) @ 180°C	mg/L	10	A2540 C
Alkalinity, Total as $CaCO_3$	mg/L	1	A2320 B
Hardness as $CaCO_3$	mg/L	1	A2340 B
Anions			
Bicarbonate as HCO_3	mg/L	1	A2320 B
Carbonate as CO_3	mg/L	1	A2320 B
Chloride (Cl)	mg/L	1	EPA 300.0
Sulfate (SO_4)	mg/L	1	EPA 300.0
Bromide (Br)**	mg/L	0.5	EPA 300.0
Nutrients			
Nitrogen, Ammonia as N	mg/L	0.05	EPA 350.1
Nitrate plus Nitrite as N	mg/L	0.01	EPA 353.2
Nitrogen -Total (Persulfate)	mg/L	0.05	A4500 N-C
Phosphorus, Orthophosphate as P	mg/L	0.001	EPA 365.1
Phosphorus, Total as P	mg/L	0.001	EPA 365.1
Phosphorus, Dissolved as P	mg/L	0.005	EPA 365.1
Major Cations (Dissolved Metals)			
Calcium (Ca)	mg/L	1	EPA 200.7
Magnesium (Mg)	mg/L	1	EPA 200.7
Potassium (K)	mg/L	1	EPA 200.7
Sodium (Na)	mg/L	1	EPA 200.7
Dissolved Trace Metals			
Arsenic (As)	mg/L	0.003	EPA 200.8
Cadmium (Cd)	mg/L	0.00008	EPA 200.8
Copper (Cu)	mg/L	0.001	EPA 200.8
Iron (Fe)	mg/L	0.03	EPA 200.8
Lead (Pb)	mg/L	0.0005	EPA 200.8
Selenium (Se)	mg/L	0.005	EPA 200.8
Uranium (U)	mg/L	0.001	EPA 200.8
Zinc (Zn)	mg/L	0.01	EPA 200.8
Boron (B) **	mg/L	0.1	EPA 200.8

** Bromide and Boron were monitored as potential indicators of septic system discharge; however, high detection limits used by the laboratory limited the usefulness of the dataset.

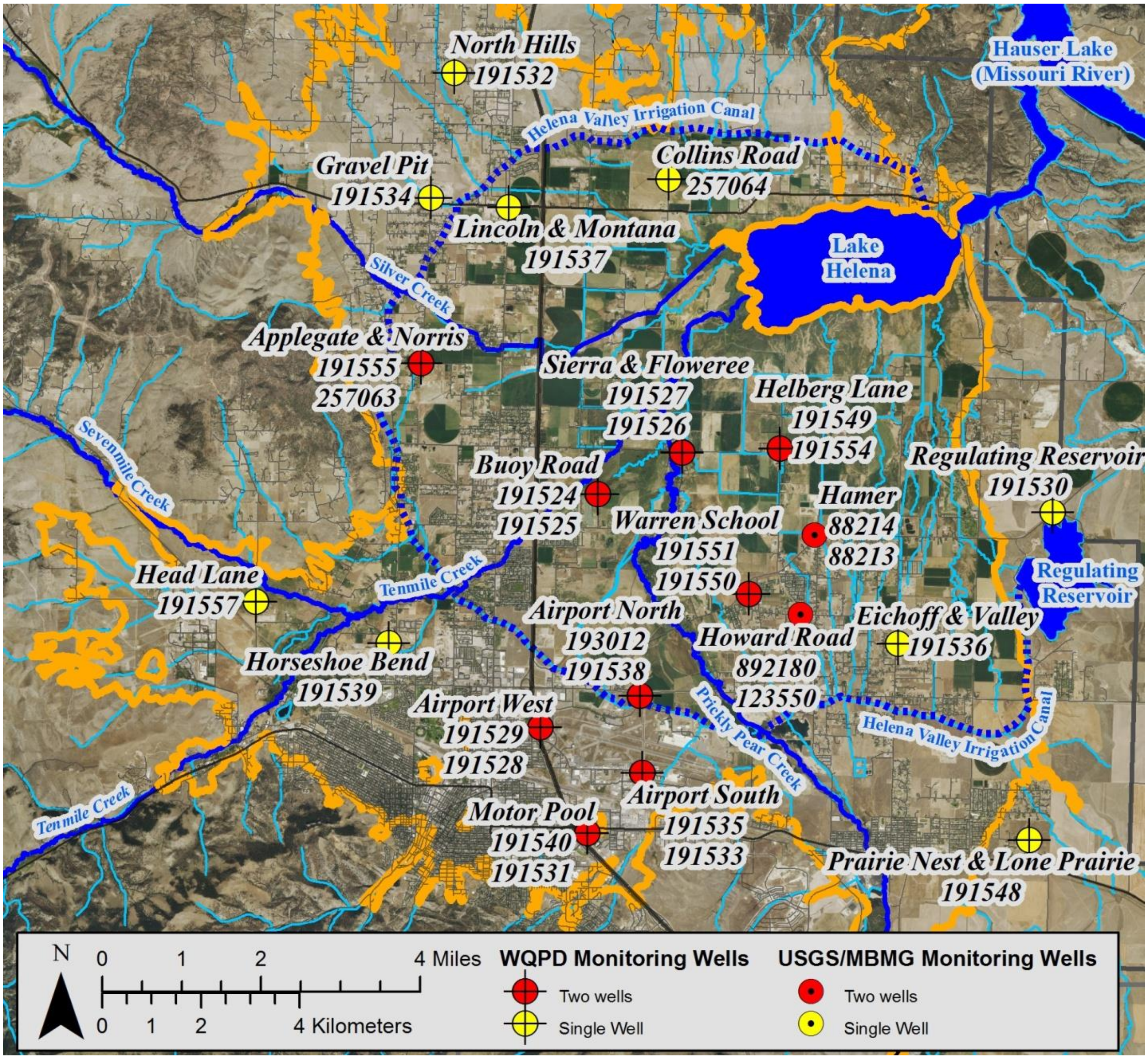


Figure 3-2 Study Primary Ground Water Monitoring Locations

Wells are identified with informal name and MBMG-GWIC identification numbers. When two wells and GWIC numbers are present, the shallow well is listed above the deeper well. Well information is summarized in Table 3-1.

The sample locations remained consistent during the duration of the project, with several minor modifications. During 2010, MBMG installed two replacement wells for original wells in the LCWQPD network. After the first year of sampling, the Airport West well cluster became inaccessible from expansion of a gravel pit in the area surrounding the wellheads, which lowered the ground surface by approximately ten feet. The two wells were preserved with small volumes of unmined gravel supporting the casing; however, access to the wellheads was not safe. The wellheads were rehabilitated in May 2012 by cutting off the extra riser and placing protective locking rise-up covers over the wells. The sampling program for these wells only included the first two events during Phase I of the project, and a special sampling event during Spring 2012. The final additions to the monitoring program were added to coincide with water level monitoring wells in the central part of the valley where datalogging transducers were installed. During the last year of the program, sampling was conducted at two additional well clusters in the central part of the valley. The addition of these four monitoring wells into the primary monitoring network results in 31 wells in the primary monitoring network at this time.

Table 3-4 Ground Water Monitoring Well Sampling Summary

Sample Location	**MBMG GWIC #**	**Phase I**		**Phase II ****				
Buoy Road N (sh)	191524	10/7/09	4/9/10	11/10/10	4/28/11	8/30/11	11/17/11	
Buoy Road S (dp)	191525	10/7/09	4/9/10		4/28/11	8/30/11	11/17/11	N
Sierra & Floweree N (dp)	191526	10/7/09	4/9/10		4/25/11	8/30/11	11/16/11	N
Sierra & Floweree S (sh)	191527	10/7/09	4/9/10	11/10/10	4/25/11	8/30/11	11/16/11	
Airport West N (dp)	191528	10/8/09	4/29/10				*5/24/12*	*N*
Airport West S (sh)	191529	10/8/09	4/29/10				*5/24/12*	*N*
Regulating Reservoir	191530	10/7/09	4/20/10		4/21/11	8/19/11	11/17/11	N
Motor Pool W (dp)	191531	10/6/09	4/28/10		4/20/11	8/16/11	11/17/11	N
North Hills	191532	10/15/09	4/15/10	10/20/10	4/20/11	8/18/11	11/14/11	N
Airport South N (dp)	191533	10/6/09	4/29/10		4/27/11	8/31/11	11/28/11	N
Gravel Pit	191534	10/15/09	4/19/10	10/20/10	4/20/11	8/18/11	11/14/11	N
Airport South S (sh)	191535	10/6/09	4/29/10		4/27/11	8/31/11	11/28/11	N
Eichoff & Valley	191536	10/7/09	4/8/10		4/21/11	8/18/11	11/29/11	N
Lincoln & Montana	191537	10/15/09	4/19/10	10/20/10	4/22/11	8/17/11	12/6/11	
Airport North N (dp)	191538	10/8/09	4/20/10		4/27/11	8/31/11	11/28/11	
Horseshoe Bend	191539	10/8/09	4/27/10	11/9/10	4/22/11	8/17/11	11/15/11	N
Motor Pool E (sh)	191540	10/6/09	4/28/10		4/20/11	8/16/11	11/17/11	N
Prairie Nest & Lone Prairie	191548	10/15/09	4/21/10		4/21/11	8/18/11	12/6/11	
Helberg Lane S (sh)	191549	10/7/09	4/8/10	11/9/10	4/21/11	8/30/11	11/16/11	
Warren School N (dp)	191550	10/6/09	4/27/10		4/28/11	8/19/11	11/29/11	N
Warren School S (sh)	191551	10/6/09	4/27/10	11/9/10	4/28/11	8/19/11	11/29/11	
Helberg Lane N (dp)	191554	10/7/09	4/8/10		4/21/11	8/30/11	11/16/11	N
Applegate & Norris (sh)	191555	10/14/09	4/15/10	10/20/10	4/25/11	8/17/11	11/15/11	N
Applegate & Norris MBMG (dp)	257063			10/20/10	4/25/11	8/17/11	11/15/11	
Head Lane	191557	10/8/09	4/27/10		4/26/11	8/31/11	11/16/11	
Airport North S (sh)	193012	10/8/09	4/20/10	11/10/10	4/27/11	8/31/11	11/28/11	
Collins Road MBMG	257064			10/20/10	4/20/11	8/18/11	11/14/11	
Howard Road (dp)	123550					7/19/11	11/29/11	
Hamer E (sh)	88214					7/19/11	11/29/11	N
Hamer W (deep)	88213					7/20/11	11/29/11	

** Isotope samples were collected during the last sampling event listed. Water isotopes were collected at all locations. Nitrogen and oxygen isotopes of nitrate samples were collected at locations noted with N

3.1.2 Biased Potable Well Sampling Programs

The sampling program included two specific components biased to locations where elevated nitrate levels were known present. These sampling programs utilized residential potable water wells as monitoring locations. Well sampling information is summarized in Table 3-5. During Phase I of the project, water samples were collected at five locations monthly for nutrients, with full suites of analyses included with the two initial major monitoring well sampling events in Fall 2009 and Spring 2010. The well locations are depicted in Figure 3-3. The monthly samples were collected from November 2009 to October 2010.

The second biased sampling program supported the isotope sampling program with samples collected during Spring 2012. Isotope samples of nitrogen and oxygen of nitrate (see Section 3.3) were collected from locations where elevated nitrate were present to help determine the source of the nitrate. Concurrent with isotope sample collection, water quality samples were obtained to compare water types with other waters in the valley. These locations are depicted in Figure 3-3.

Additional samples were collected in Fall 2012 to support the isotope sampling program, and to determine water types for comparison with other area waters. The wells and sampling dates are listed in Table 3-5, with locations depicted in Figure 3-3.

Table 3-5 Potable Well Monitoring Sampling Summary

Well Location	**MBMG GWIC**	**Total Depth (feet)**	**Sample Dates**
Monthly Monitoring Wells			
Hope Road	65388	87	*Monthly, Nov 2009 - Oct 2010*
Griffin Road	189417	155	*Monthly, Nov 2009 - Oct 2010*
Wildfire Road	153703	257	*Monthly, Nov 2009 - Oct 2010*
Clinton Road	60925	135	*Monthly, Nov 2009 - Oct 2010*
Hilmen Road	65088	53	*Monthly, Nov 2009 - Oct 2010*
Biased Isotope Sample Wells (Spring 2012)			
Sawbuck Place	*not assigned*	--	2-May-12
North Montana	*not assigned*	--	2-May-12
Green Meadow	5756	66	31-May-12
Mill Road	*not assigned*	--	29-May-12
Sun Valley	*not assigned*	--	29-May-12
Rawhide Court	*not assigned*	--	24-May-12
Biased Isotope Sample Wells (Fall 2012)			

Stoney Drive (dp)	258900	600	18-Sep-12
Stoney Drive (sh)	244157	245	18-Sep-12
Emerald Ridge Park Well	214268	400	18-Sep-12

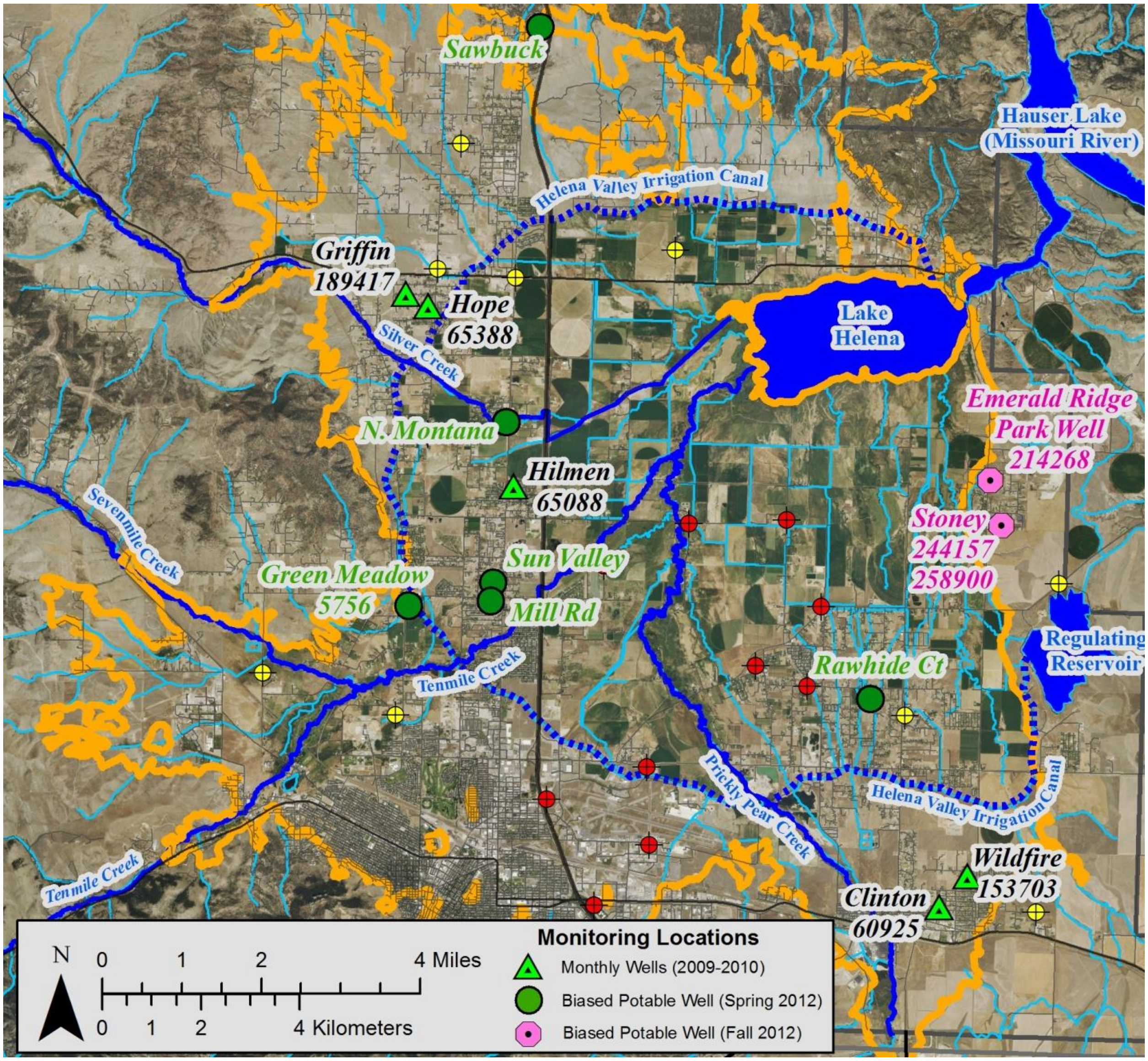


Figure 3-3 Potable Well Monitoring Locations
Wells are identified with informal name and MBMG-GWIC identification numbers. Well information is summarized in Table 3-4.

3.1.3 Piezometer Sampling Program

Piezometers represent shallow sand-point wells installed adjacent to streams at surface water monitoring locations. A total of eleven piezometers were used in this study at locations depicted in Figure 3-4. For this project, 4 piezometers from the MBMG studies in the area were supplemented with 7 new piezometers installed specifically for this project. The piezometers were sampled during three events as summarized in Table 3-6. The three sampling events comprised:

- Early Winter – late December/early January, when stream flow is minimal and ground water water levels are declining. This period reflects ambient ground water conditions during the winter when ground water recharge is minimal
- Early Spring – late April, as surface water flows are increasing with spring runoff, and at the start of irrigation season, to see if water quality changes are present associated with recharge from high surface flows, and
- Early Fall – late September, at the end of irrigation season where surface water flows are generally at low levels

Table 3-6 Piezometer Monitoring Sampling Summary

Piezometer Location	**Surface Water Monitoring Location**	**MBMG GWIC**	**Total Depth (feet)**	**Sample Dates**		
Tenmile Creek Crossings						
Country Club Lane	T-24	*not assigned*	11.9	12/29/11	4/27/12	9/26/12
Green Meadow Road	T-4	*not assigned*	11.4	12/29/11	4/26/12	9/27/12
Sierra Road	T-6	*not assigned*	9.3	12/30/11	4/26/12	9/27/12
Prickly Pear Creek Crossings						
Canyon Ferry Road	P-5	*not assigned*	10.2	12/30/11	4/25/12	9/26/12
Sierra Road	P-10	*not assigned*	10.7	12/30/11	4/26/12	9/27/12
Winterbourne Property	P-12	*not assigned*	15.9	12/30/11	4/24/12	9/27/12
Silver Creek Crossings						
Silver Creek Estates	SC-1	254216	16.9	1/5/12	4/25/12	9/27/12
Smelko Property	SC-2	254237	24.5	1/5/12	4/25/12	9/27/12
Arrowhead Road (D2 Drain)	D2B-D2	*not assigned*	15.0	12/29/11	4/26/12	9/26/12
Sevenmile Creek Crossings						
Birdseye Road	7M-1	255141	16.7	1/4/12	4/27/12	9/27/12
Head Lane **	7M-3	255143	14.3	1/4/12	4/27/12	9/27/12

** Site also referred to as T-3 from previous surface water monitoring efforts (USEPA, 2006)

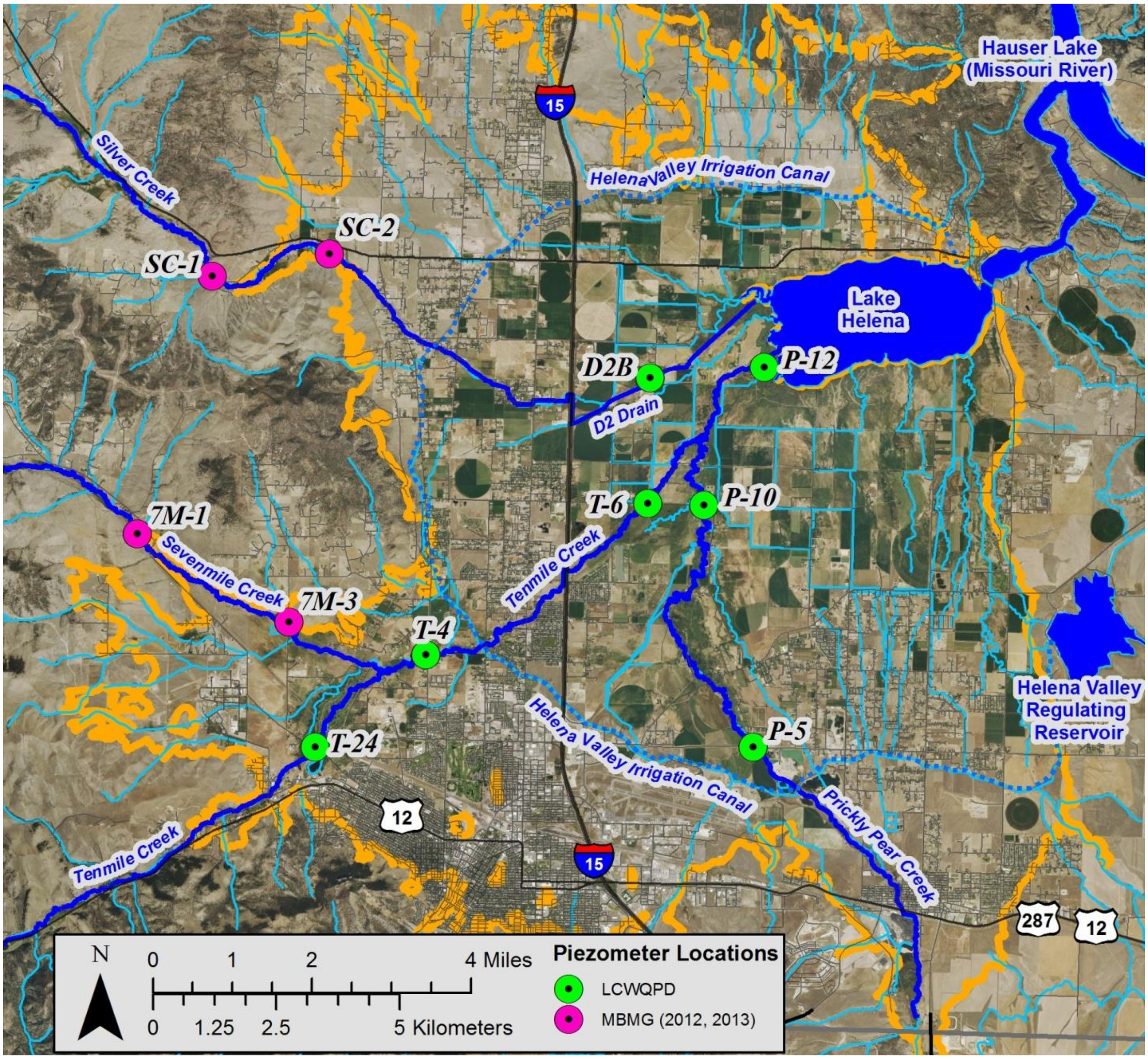


Figure 3-4 Piezometer Monitoring Locations
Piezometers are identified with informal name. Piezometer information is summarized in Table 3-1.

3.2 Ground Water Level Monitoring and Surface – Ground Water Interaction

Water levels were monitored on a monthly basis on all project wells as part of the MBMG Ground Water Assessent Program (GWAP). The MBMG water level monitoring program is conducted across the state, with levels monitored on a monthly or quarterly basis depending on location. LCWQPD staff monitor water levels in project wells, and additional wells in the area, under subcontract from MBMG (see Figure 3-1).

During the last year of the project, water level measuring datalogging pressure transducers were installed in the piezometers in the central part of the valley. A transducer is depicted in Figure 3-5. Transducers were not installed in MBMG piezometers since large data records were generated during the MBMG studies of the area (Waren et al., 2012; Bobst et al., 2013). This data is coupled with surface water monitoring data collected by LCWQPD staff as part of a surface water monitoring program not discussed with this report.

In order to evaluate the interaction of surface water recharge from streams and irrigation waters in the central part of the valley, transducers were also installed in wells to monitor water level changes with time. The transducers were installed at times at both wells in a cluster to determine whether both wells were in the same aquifer based on recharge response times as noted on hydrographs. After this determination had been made, for well clusters with wells in the same aquifer, the transducer from the shallow wells were removed and placed at additional locations. The transducer data is supplemented by the monthly water level data which provides calibration points for the regular water level data.

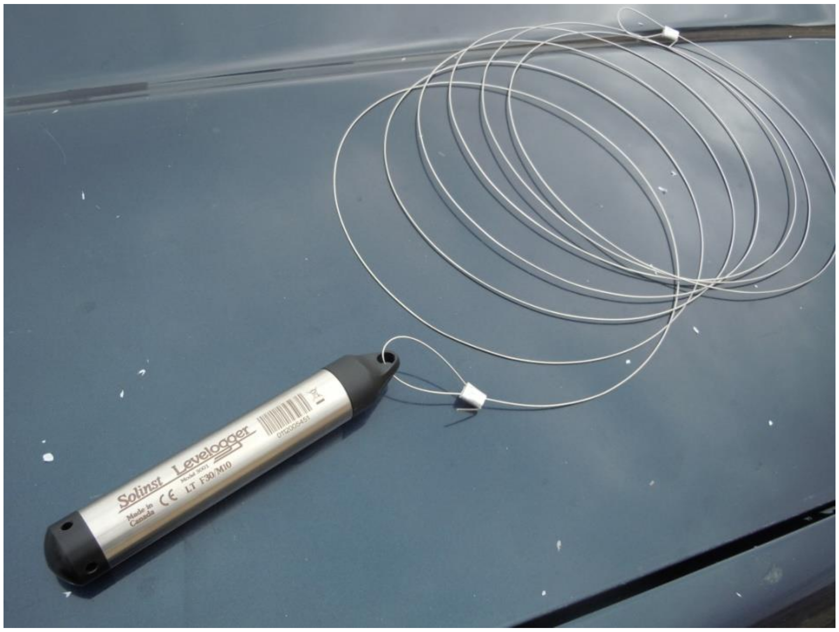


Figure 3-5 Datalogging Pressure Transducer
Solinst leveloggers were used to obtain regular water level measurements in both wells and piezometers

3.3 Ground Water and Nitrate Isotope Sampling Program

A ground water isotope sampling and analysis program was implemented as part of Phase II of the project. The isotope program included two components, with different objectives. Isotopes represent atoms of the same element with different numbers of neutrons in the atomic nucleus, resulting in different atomic weights. Ratios of stable isotopes are generally stable in nature, as opposed to unstable or radioactive isotopes where the elements transform in to different elements at different rates resulting in changing ratios. This study included only stable isotope analyses. The data results for stable isotopes are presented as ratios compared to an established standard value so that changes are observed relative to the ratios. The specifics of each type of isotopic analysis are discussed in the results section of this report (Section 9.0).

Nitrogen and oxygen isotopes of nitrate molecules represent a method of differentiating between agricultural fertilizers and organic waste as nitrate sources (Kendall, 1998). Nitrate isotope samples were collected from monitoring wells with elevated nitrate levels, as noted in Table 3-5. Additional samples were collected from the biased potable well locations noted in Table 3-6. These data results were collated with similar data from MBMG studies (Waren et al., 2012; Bobst et al., 2013) and USGS studies (Thamke, 2000).

Oxygen and hydrogen isotopes of water molecules are considered good conservative tracers, since the ratios are generally not affected by subsurface processes after recharge has occurred (Kendall & McDonnell, 1998). Water isotope samples were collected to support the assessment of the interaction of surface waters as recharge to the Helena Valley Aquifer. Water isotope samples were collected from all ground water monitoring wells during the last primary sampling event in late Fall 2011, and from private potable wells during the nitrate isotope sampling event in Spring 2012. The complete water isotope dataset for the project incorporated additional data presented from published MBMG studies (Waren et al., 2012; Bobst et al., 2013).

The piezometer ground water sampling program included collecting water isotope samples during each of the three events. Since the connection to surface water represents a major objective of this research, correlation of ground water to surface water required isotope data for the surface water. Samples were obtained during the early winter sampling event at surface water in streams adjacent to the piezometers. The second surface water event was completed in August during a comprehensive surface water monitoring effort implemented by LCWQPD.

3.4 Ground Water Temperature Measurement

Shallow ground water temperatures typically fluctuate with surface temperature, but are more stable with depth below the surface. The average ground water temperature is generally several degrees Celsius below the yearlong mean average surface temperature in an area (Heath, 1983). Ground water temperatures increase with depth due to the geothermal gradient, and in mountainous areas hot springs may occur where geologic conditions provide a conduit for deep waters to migrate towards the surface. In addition, summer surface water temperatures may widely vary resulting in changes in temperature of recharge waters. Under these different conditions, ground water temperature may be used as a conservative tracer to evaluate the connection between surface and ground water near streams (Constanz and Stonestrom, 2003).

During the Phase I ground water sampling events, ground water temperatures at several wells were present at temperatures elevated above the expected local geothermal gradient, based on local climate conditions. The data indicated that the local geothermal gradient varied across different parts of the study area. This information resulted in incorporation of additional ground water temperature data for the study area.

Ground water temperature data from both monitoring and potable water wells were obtained during sampling events, when water was pumped at constant rates for extended time periods as water parameters were recorded to verify the representativeness of the ground water. The ground water temperatures correlate to the total depth of the well.

The use of small datalogging thermistors in the piezometers to monitor surface water infiltration rates was proposed for Phase II of the project. This effort was discontinued since the water levels in the piezometers generally occurred above the screened interval during the periods of high surface runoff, when the link between losing streams and ground water would be strongest. Temperature data for this assessment utilized stream temperatures obtained from the LCWQPD surface water monitoring network, and the from the water level recording transducers installed at the total depth of the piezometers.

In order to evaluate the geothermal gradient in upgradient areas around the study area, datalogging transducers were installed into the base of several monitoring wells installed by MBMG. The initial attempt used thermistors placed into Ziploc bags with a rock for weight, and then duct taped shut and attached to string. These thermistor sets were lowered to the base of the wells; however, the water column depth greater than a hundred feet or more typically resulting in malfunction of the sensors. This approach was modified by placing the two sensors, with sand to fill void space, inside ¾-inch PVC caps and plugs screwed together. With string duct-taped to the outside of the PVC holder, the sensors were lowered to the base of the wells and then removed after several days. These are depicted in Figure 3-6.

Figure 3-6 Temperature Sensors

Temperature sensors were sealed into PVC containers, and placed to the base of the well with string.

4.0 Field Methods and Quality Assurance/Quality Control

This section presents the field methods used to collect samples and data during the project. All field activities were completed in accordance with protocols outlined in the Sampling and Analysis Plan (SAP) for the project. The following discussion notes general methods, and any deviations from the SAP.

4.1 Piezometer Installation and Development

The shallow piezometers were installed at seven locations during early September 2011. While planned for the spring, the installation was delayed to wait until streambank areas had dried after wetting during spring runoff to minimize damage by the weight of the drill rig. Additional delays occurred as a result of scheduling conflicts with the Geoprobe subcontractor during the summer work months. A piezometer planned for installation near the intersection of York Road over Prickly Pear Creek was not completed since wet surface conditions resulted in retraction of approval from a local landowner.

The shallow piezometers were constructed of two-inch steel sandpoint wells with 3.5 foot screened intervals (Figure 4-1). The sandpoint wells were coupled to threaded steel riser pipe to the surface. The wells were installed using a subcontracted Geoprobe drill rig, which hydraulically pressed the wells into the subsurface. The total depths of the wells were estimated based on the difference between the local ground surface and the adjacent streambed and water surface. The piezometers were completed with locking caps inside ground level covers cemented around the wellheads. The piezometers were developed for water sampling by surging and removing water with disposable bailers, followed by pumping with an electric sampling pump typically until water turbidity decreased.

4.2 Water Quality Sampling

Ground water samples were collected from monitoring wells and piezometers, with limited sampling from private residential potable water wells. All samples were collected into new, unused containers provided by the laboratory. When required, samples for dissolved analyses were filtered in the field using an in-line 0.45 µm filter placed directly onto the sample collection hose. Sample preservatives were added, as needed, to samples immediately after collection. All samples were placed directly into an ice-packed cooler for storage and transportation to the project laboratory. Sample coolers were transported by car directly to the project laboratory, Energy Laboratories, in Helena with proper chain of custody documentation. In order to meet holding times, all samples were submitted to the project laboratory within 48 hours of sample collection.

Figure 4-1 Piezometer Installation
Use of a Geoprobe to install Piezometer P-T4 adjacent to Tenmile Creek.

The sample analyte list was modified several times during the program. These modifications included:

- Analyses for ammonia were discontinued from the majority of wells after samples results consistently indicated no detectable concentrations. These results were associated with consistently high concentrations of dissolved oxygen, which indicates an oxidizing environment where ammonia would be not stable, or expected to occur.
- Analyses for trace metals in piezometers ground water were limited to major ions to ensure sufficient funds were available for all of the sampling programs.
- The monthly sampling program initially included samples for ammonia and hardness. These analyses were discontinued after the first several events due to the demonstrated stability of ground water quality parameters from these and other wells in the study.

4.2.1 Field parameters

Field parameters pH, specific conductivity, temperature and dissolved oxygen were monitored during all water sampling using a flow-through cell, which allowed ground water parameters to be determined prior to exposure to the atmosphere. Parameters were measured using a YSI ProPlus Multi-meter calibrated prior to each sampling event.

4.2.2 Ground Water Sample Collection – Monitoring Wells

Samples were collected from monitoring wells using either a stainless steel or PVC sampling pump using a modified low-flow method. The pumps were placed to depth across the screened interval of the well, with discharge tubing pumped directly into the flow-cell for the field parameter measurement (Figure 4-2). The pumps were operated using a flow regulating controller drawing power from a car battery, with the motor running. Drawdown was monitored during sampling with a manual water level meter to verify that pumping water levels stabilized, and that pumped water was recharged from ground water into the screened interval. Ground water parameters were used to verify the representativeness of the collected samples of ground water from the area where they were collected. Prior to sample collection, the wells were pumped a minimum of 20 minutes, or until three consecutive parameter readings at minimum four minute intervals, showed stable water chemistry.

The sample pump and tubing were thoroughly washed between use using an alconox detergent bath pumped through the pump and tubing, followed with a distilled water rinse pumped through the pump and tubing. The pump and tubing were stored in a clean plastic bag between uses.

Deviations from the SAP were limited during the sampling program. The sample at the Prairie Nest & Lone Prairie Well (GWIC 191548) from August 2011 was collected using a bailer as the pump malfunctioned. The bailer sample was collected after purging three full well volumes, and measuring parameters after each well volume. The second deviation occurred at the Head Lane Well (GWIC 191557), which did not show stable water levels after approximately one hour of pumping during each sample event. Water parameter monitoring showed stability only after the drawdown water level approached the total depth of the well. Water samples were collected only after the water parameters had stabilized.

4.2.3 Ground Water Sample Collection – Private Potable Wells

For private potable wells with dedicated, high volume pumps, samples were collected from frost-free hydrants located near the wellheads. Water from the hydrant was diverted into two streams, with primary discharge through a garden hose to a point away from the wellhead. The second water stream was directly into the flow-cell for the parameter meter, which represented the sampling tube. For the potable wells, water was pumped for a minimum of 20 to 30 minutes to ensure that a minimum of three well volumes were removed from the well prior to sample collection. Ground water parameters were monitored at regular intervals to verify the representativeness of the collected sample.

4.2.4 Ground Water Sample Collection – Piezometers

Ground water samples were collected from the piezometers using a peristaltic pump following low-flow sampling guidelines (Figure 4-3). Water levels were monitored during pumping to note that drawdown had not occurred. Samples were collected using dedicated sections of ¼-inch diameter polyethylene tubing for each well, placed to total depth. The discharge/sampling line was connected directly to the flow-cell for monitoring of field parameters. Samples were collected after a minimum of three consecutive readings, at four minute intervals, indicated water

Figure 4-2 Monitoring Well Sample Collection
Pump in well is powered by car battery, with discharge line to base of flow-cell. Sample collected directly from discharge line after purging is complete. In-line sample filtration directly into sample container.

Figure 4-3 Piezometer Sample Collection
Sampling apparatus at piezometers noted. Peristaltic pump was operated by battery powered drill. Discharge line to flow cell for parameter measurement visible.

quality had stabilized. In some cases, the wells were purged completely prior to sample collection. For these sites, samples were collected from the first recharge water to the piezometers.

4.2.5 Surface Water Samples

Surface water samples for water isotope analyses were collected concurrent with the early Winter 2011 piezometer sampling event. The surface water samples were collected as grab samples, directly into the sample containers. The second set of surface water isotope samples were collected in August 2011, as grab samples, with a comprehensive surface water monitoring event completed by LCWQPD.

4.3 Water Level Monitoring

Water levels were measured using a Solinst electric tape water level meter, with accuracy to 0.01 feet. Additional water level measurements were made with Solinst Levelogger datalogging pressure transducers installed into the upper part of the water column in wells, and at the base of piezometers. The Levelogger data was compensated for barometric pressure using data from Solinst Barologgers placed at a central location within the valley.

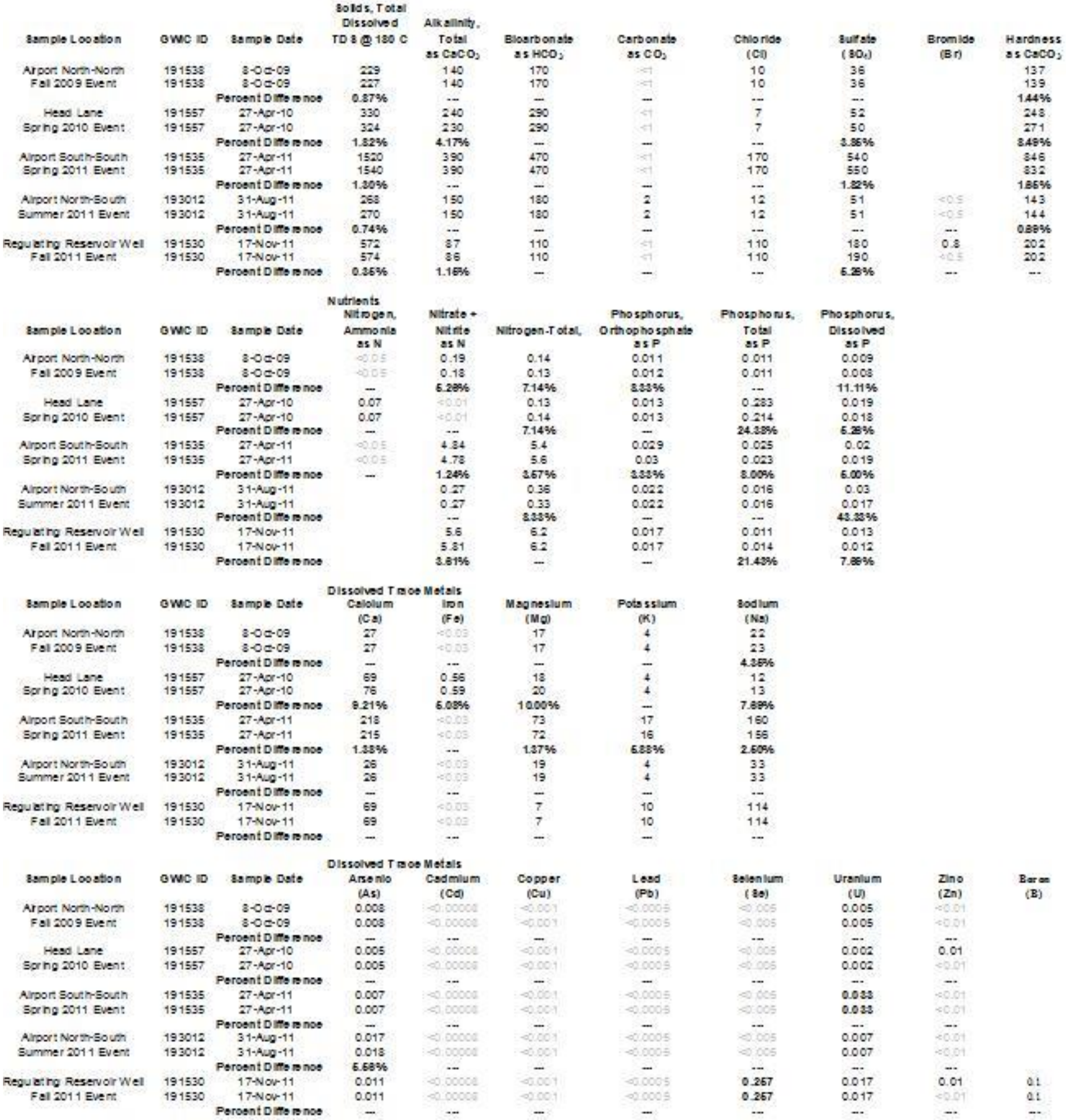
5.0 Laboratory Analytical Methods and Quality Assurance/Quality Control

All laboratory analyses were completed at Energy Laboratories, Inc., in Helena, Montana. As outlined in the project SAP, the laboratory is responsible for Quality Assurance of laboratory data provided. Laboratory analytical methods for each primary analyte are listed in Table 3-3. Electronic copies of all data reports for the project are included in Appendix A. LCWQPD staff monitored laboratory performance using blind duplicate samples submitted with the sampling events. The data results and comparability for each sampling event is listed in Table 5-1.

The duplicate sample data results show that for the majority of sample analyses, results exhibited very similar results. The largest discrepancies, based on relative percent difference (RPD) are noted for the total phosphorus results from the Spring 2010 (RPD 24%) and Fall 2011 events (RPD 21%); and the dissolved phosphorus from the Summer 2011 event (RPD 43%). These relatively high RPD results for the duplicate samples indicate that care must be taken when using the phosphorus data results.

Sample receipt temperature on chain-of-custody documents noted several sample shipments with temperatures above 4-6°C. These temperatures are attributed to ground water samples with naturally elevated ground water temperatures taken directly to the laboratory immediately after sample collection. While placed into ice-packed coolers, the samples did not have sufficient time to cool and equilibrate with the ambient temperature in the cooler. As a result of this, the elevated cooler temperatures noted on are attributed to sample management and quick transfer of samples to the laboratory. Based on this, the elevated sample temperatures are not considered to have affected the representativeness of the samples, nor the analytical results.

Table 5-1 Duplicate Sample Result Comparison



Sample Location	GWIC ID	Sample Date	Solids, Total Dissolved TDS @ 180 C	Alkalinity, Total as $CaCO_3$	Bicarbonate as HCO_3	Carbonate as CO_3	Chloride (Cl)	Sulfate (SO_4)	Bromide (Br)	Hardness as $CaCO_3$
Airport North-North	191538	8-Oct-09	229	140	170	<1	10	36		137
Fall 2009 Event	191538	8-Oct-09	227	140	170	<1	10	36		139
		Percent Difference	**0.87%**	---	---	---	---	---		**1.44%**
Head Lane	191557	27-Apr-10	330	240	290	<1	7	52		248
Spring 2010 Event	191557	27-Apr-10	324	230	290	<1	7	50		271
		Percent Difference	**1.82%**	**4.17%**	---	---	---	**3.85%**		**8.49%**
Airport South-South	191535	27-Apr-11	1520	390	470	<1	170	540		846
Spring 2011 Event	191535	27-Apr-11	1540	390	470	<1	170	550		832
		Percent Difference	**1.30%**	---	---	---	---	**1.82%**		**1.65%**
Airport North-South	193012	31-Aug-11	268	150	180	2	12	51	<0.5	143
Summer 2011 Event	193012	31-Aug-11	270	150	180	2	12	51	<0.5	144
		Percent Difference	**0.74%**	---	---	---	---	---	---	**0.69%**
Regulating Reservoir Well	191530	17-Nov-11	572	87	110	<1	110	180	0.8	202
Fall 2011 Event	191530	17-Nov-11	574	86	110	<1	110	190	<0.5	202
		Percent Difference	**0.35%**	**1.16%**	---	---	---	**5.26%**	---	---

Sample Location	GWIC ID	Sample Date	Nutrients Nitrogen, Ammonia as N	Nitrate + Nitrite as N	Nitrogen-Total,	Phosphorus, Orthophosphate as P	Phosphorus, Total as P	Phosphorus, Dissolved as P
Airport North-North	191538	8-Oct-09	<0.05	0.19	0.14	0.011	0.011	0.009
Fall 2009 Event	191538	8-Oct-09	<0.05	0.18	0.13	0.012	0.011	0.008
		Percent Difference	---	**5.26%**	**7.14%**	**8.33%**	---	**11.11%**
Head Lane	191557	27-Apr-10	0.07	<0.01	0.13	0.013	0.283	0.019
Spring 2010 Event	191557	27-Apr-10	0.07	<0.01	0.14	0.013	0.214	0.018
		Percent Difference	---	---	**7.14%**	---	**24.38%**	**5.26%**
Airport South-South	191535	27-Apr-11	<0.05	4.84	5.4	0.029	0.025	0.02
Spring 2011 Event	191535	27-Apr-11	<0.05	4.78	5.6	0.03	0.023	0.019
		Percent Difference	---	**1.24%**	**3.57%**	**3.33%**	**8.00%**	**5.00%**
Airport North-South	193012	31-Aug-11		0.27	0.36	0.022	0.016	0.03
Summer 2011 Event	193012	31-Aug-11		0.27	0.33	0.022	0.016	0.017
		Percent Difference		---	**8.33%**	---	---	**43.33%**
Regulating Reservoir Well	191530	17-Nov-11		5.6	6.2	0.017	0.011	0.013
Fall 2011 Event	191530	17-Nov-11		5.81	6.2	0.017	0.014	0.012
		Percent Difference		**3.61%**	---	---	**21.43%**	**7.69%**

Sample Location	GWIC ID	Sample Date	Dissolved Trace Metals Calcium (Ca)	Iron (Fe)	Magnesium (Mg)	Potassium (K)	Sodium (Na)
Airport North-North	191538	8-Oct-09	27	<0.03	17	4	22
Fall 2009 Event	191538	8-Oct-09	27	<0.03	17	4	23
		Percent Difference	---	---	---	---	**4.35%**
Head Lane	191557	27-Apr-10	69	0.56	18	4	12
Spring 2010 Event	191557	27-Apr-10	76	0.59	20	4	13
		Percent Difference	**9.21%**	**5.08%**	**10.00%**	---	**7.69%**
Airport South-South	191535	27-Apr-11	218	<0.03	73	17	160
Spring 2011 Event	191535	27-Apr-11	215	<0.03	72	16	156
		Percent Difference	**1.38%**	---	**1.37%**	**5.88%**	**2.50%**
Airport North-South	193012	31-Aug-11	26	<0.03	19	4	33
Summer 2011 Event	193012	31-Aug-11	26	<0.03	19	4	33
		Percent Difference	---	---	---	---	---
Regulating Reservoir Well	191530	17-Nov-11	69	<0.03	7	10	114
Fall 2011 Event	191530	17-Nov-11	69	<0.03	7	10	114
		Percent Difference	---	---	---	---	---

Sample Location	GWIC ID	Sample Date	Dissolved Trace Metals Arsenic (As)	Cadmium (Cd)	Copper (Cu)	Lead (Pb)	Selenium (Se)	Uranium (U)	Zinc (Zn)	Boron (B)
Airport North-North	191538	8-Oct-09	0.008	<0.00008	<0.001	<0.0005	<0.005	0.005	<0.01	
Fall 2009 Event	191538	8-Oct-09	0.008	<0.00008	<0.001	<0.0005	<0.005	0.005	<0.01	
		Percent Difference	---	---	---	---	---	---	---	
Head Lane	191557	27-Apr-10	0.005	<0.00008	<0.001	<0.0005	<0.005	0.002	0.01	
Spring 2010 Event	191557	27-Apr-10	0.005	<0.00008	<0.001	<0.0005	<0.005	0.002	<0.01	
		Percent Difference	---	---	---	---	---	---	---	
Airport South-South	191535	27-Apr-11	0.007	<0.00008	<0.001	<0.0005	<0.005	**0.033**	<0.01	
Spring 2011 Event	191535	27-Apr-11	0.007	<0.00008	<0.001	<0.0005	<0.005	**0.033**	<0.01	
		Percent Difference	---	---	---	---	---	---	---	
Airport North-South	193012	31-Aug-11	0.017	<0.00008	<0.001	<0.0005	<0.005	0.007	<0.01	
Summer 2011 Event	193012	31-Aug-11	0.018	<0.00008	<0.001	<0.0005	<0.005	0.007	<0.01	
		Percent Difference	**5.88%**	---	---	---	---	---	---	
Regulating Reservoir Well	191530	17-Nov-11	0.011	<0.00008	<0.001	<0.0005	**0.257**	0.017	0.01	0.1
Fall 2011 Event	191530	17-Nov-11	0.011	<0.00008	<0.001	<0.0005	**0.257**	0.017	<0.01	0.1
		Percent Difference	---	---	---	---	---	---	---	---

6.0 Ground Water Quality Assessment Database

The assessment of ground water in the Helena Valley included compiling all available water quality data into a database. The database was developed with assistance from Montana DEQ Source Water Protection Program staff. In addition to the data generated by the sampling programs in this project, additional data was compiled into the database from the following sources:

- Historical data compiled from the USGS/MBMG Reports – A number of different hydrologic studies have been completed in the Helena Valley for a variety of purposes and objectives, as discussed in Section 2.2 of this report. Data from these reports is available through the MBMG GWIC Database. The data supports the assessement of water quality conditions by comparing with historical data from the study area.

- Recent data from MBMG GWIP Studies of North Hills and Scratchgravel Hills – The two focused studies obtained detailed information on ground water quality in the study areas, with three sampling events conducted in 2010. LCWQPD Staff collaborated with MBMG researchers during completion of these studies.

- Miscellaneous data from LCWQPD Sampling Programs – Two sampling events were conducted after installation of the monitoring well network in 2001. An additional sampling event was conducted in 2007 with a focus on trace metals and health risks from ground water to local residents. LCWQPD staff routinely collects samples to evaluate ground water quality for local residents who have concerns over their water quality. This data was incorporated into the project database. The initial sampling events for the monitoring well network are considered to represent baseline data for comparison with current conditions.

- Miscellaneous data from various studies at Helena Valley environmental sites – Ground water monitoring and aquifer characterization are required for numerous types of sites in the Helena Valley, most notably the former Asarco site in East Helena. Additional sites include landfills, gravel pits, leaking underground storage tanks, and hazardous material release sites. Data from these sites, when available, was incorporated into the assessment dataset.

7.0 Ground Water Quality Assessment

The ground water quality sampling and analysis program focused on major ions, nutrients and trace metals. The relative proportions of major ions determine water quality type, which reflects recharge source. The concentration of nutrients in ground waters provides information on the impacts of non-point nutrient sources to water quality, a focus of this project. The concentration of trace metals in ground water supports the assessment of regional background occurrence of target metals of concern for aquatic life in surface waters. The nutrient and trace metal concentrations were compared with drinking water standards (USEPA, 2009; MDEQ, 2010) and surface water quality criteria set forth in the Framework Restoration Plan (USEPA, 2006). The assessment completed with this study incorporated available data from additional sources compiled into the water quality database, as outlined in Section 6.0.

The water quality data were supplemented with ground water temperature data, ground water oxygen and deuterium isotope data, and dissolved nitrate nitrogen and oxygen isotope date. The additional datasets supported the assessment of the interaction of surface and ground water in the area. These data provide additional constraints to support refining the conceptual model of the surface-ground water system in the Helena Valley (see Section 2.3). The following sections review the steps used to prepare a water quality map of water types in the Helena Valley area as the basis for the assessment of local water quality and hydrogeologic processes.

Constraints to the conceptual model from other data types are developed in subsequent chapters of this document. Chapter 8.0 evaluates water level data and flow gradients, both laterally and vertically, within the local aquifer system(s). Chapter 9.0 presents the isotope program data results. Chapter 10.0 presents ground water temperature data and the implications to the local ground water system. The final process conceptual model for the study area is developed and presented in Section 11.0.

7.1 Major Ions and Water Quality Type

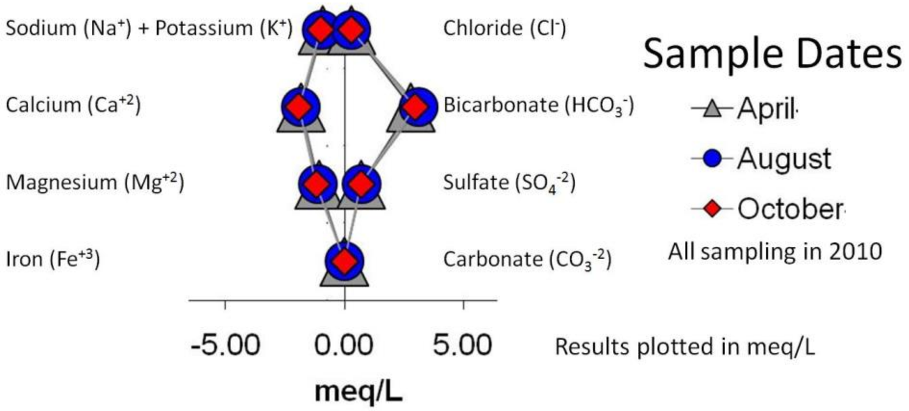
The relative proportions of major ions in the water define water quality types. Different types have different properties, best exemplified by water hardness. High concentrations of calcium bicarbonate in waters result in “hard” waters, where scaling, or mineralization, occurs in potable water lines from these types of waters. All waters have the same number of positively charged cations as negatively charged anions providing an electric balance. The major ions represent the majority of the total dissolved solids (TDS) in the water. The major positive ions, or cations, are Sodium (Na) and Potassium (K), Calcium (Ca), Magnesium (Mg), and in some waters Iron (Fe). The major negative ions, or anions, are Chloride (Cl), Bicarbonate (HCO_3), Sulfate (SO_4), and in some waters, Carbonate (CO_3). The relative concentrations between cations and anions are compared by converting the concentrations to milliequivalents using the following equation:

$$\text{meq/L} = \left(\frac{\text{Concentration (mg/L)}}{\text{Atomic Mass (mg/mmol)}} \right) \text{X Ionic Charge (meq/mmol)}$$

Converting concentrations to milliequivalents allows comparison of the relative charges provided by each major ion. In addition, summation of the total anion and cation milliequivalent concentrations provides a check on the water quality analytical results, since the total number of anion milliequivalents should be similar to the total number of cation milliequivalents.

To compare major ion water chemistry between sampling locations, the laboratory data were used to prepare stiff diagrams to compare major ion chemistry. Stiff diagrams, as depicted in Figure 7-1, compare the number of positive and negatively charged ions for a sample, with the size of the polygon reflecting the TDS of the water. Data from multiple sampling events at the same site are depicted on the diagrams, providing a visual method of assessing seasonal changes in water quality. The stiff diagrams provide a visual method to compare the major ion chemistry between different sampling events at the same location.

Figure 7-1
Sample Stiff Diagram
The stiff diagram compares the total charge distribution between positively charged cations and negatively charged anions, as milliequivalents. The milliequivalent of each ion represents its ionic charge, as shown in the diagram.



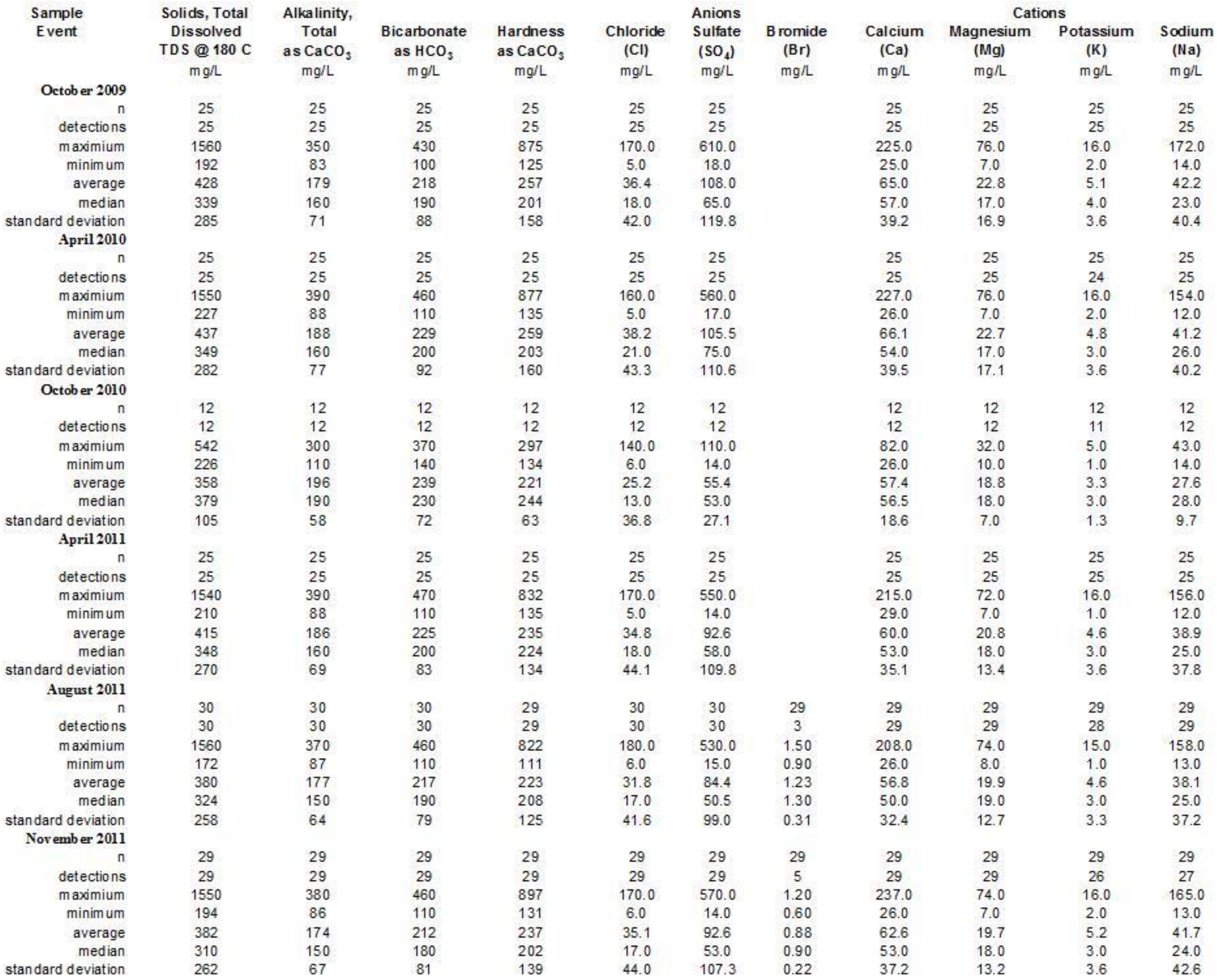
			April 2010		August 2010		October 2010	
Cations	g/mol	eq/mol	Conc (mg/L)	meq/L	Conc (mg/L)	meq/L	Conc (mg/L)	meq/L
Na	22.99	1	20.20	0.88	21.60	0.94	22.20	0.97
K	39.10	1	1.40	0.04	1.33	0.03	1.42	0.04
Ca	40.09	2	36.60	1.83	37.00	1.85	38.60	1.93
Mg	24.30	2	12.90	1.06	13.40	1.10	14.40	1.19
			sum	3.80	sum	3.92	sum	4.11
Anions	g/mol	eq/mol	Conc (mg/L)	meq/L	Conc (mg/L)	meq/L	Conc (mg/L)	meq/L
Cl	35.47	1	10.43	0.29	10.45	0.29	9.94	0.28
SO4	96.07	2	33.93	0.71	33.91	0.71	33.19	0.69
HCO3	61.02	1	170.80	2.80	189.10	3.10	180.10	2.95
CO3	60.01	2	0.00	0.00	0.00	0.00	0.00	0.00
			sum	3.80	sum	4.10	sum	3.92

Data used for Stiff Diagram in Figure 7-1

7.2 Water Quality Type Results and Mapping

In the majority of natural waters, major ions comprise the majority of the total dissolved solids within a sample. The major ion results from this study indicate that the dominant cation is calcium and dominant anion is bicarbonate for ground waters in the Helena Valley. The range of values detected in each sampling event is listed in Table 7-1.

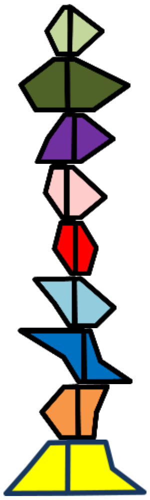
Table 7-1 Major Ion Summary Statistics by Sampling Event



Sample Event	Solids, Total Dissolved TDS @ 180 C mg/L	Alkalinity, Total as $CaCO_3$ mg/L	Bicarbonate as HCO_3 mg/L	Hardness as $CaCO_3$ mg/L	Anions			Cations			
					Chloride (Cl) mg/L	Sulfate (SO_4) mg/L	Bromide (Br) mg/L	Calcium (Ca) mg/L	Magnesium (Mg) mg/L	Potassium (K) mg/L	Sodium (Na) mg/L
October 2009											
n	25	25	25	25	25	25		25	25	25	25
detections	25	25	25	25	25	25		25	25	25	25
maximium	1560	350	430	875	170.0	610.0		225.0	76.0	16.0	172.0
minimum	192	83	100	125	5.0	18.0		25.0	7.0	2.0	14.0
average	428	179	218	257	36.4	108.0		65.0	22.8	5.1	42.2
median	339	160	190	201	18.0	65.0		57.0	17.0	4.0	23.0
standard deviation	285	71	88	158	42.0	119.8		39.2	16.9	3.6	40.4
April 2010											
n	25	25	25	25	25	25		25	25	25	25
detections	25	25	25	25	25	25		25	25	24	25
maximium	1550	390	460	877	160.0	560.0		227.0	76.0	16.0	154.0
minimum	227	88	110	135	5.0	17.0		26.0	7.0	2.0	12.0
average	437	188	229	259	38.2	105.5		66.1	22.7	4.8	41.2
median	349	160	200	203	21.0	75.0		54.0	17.0	3.0	26.0
standard deviation	282	77	92	160	43.3	110.6		39.5	17.1	3.6	40.2
October 2010											
n	12	12	12	12	12	12		12	12	12	12
detections	12	12	12	12	12	12		12	12	11	12
maximium	542	300	370	297	140.0	110.0		82.0	32.0	5.0	43.0
minimum	226	110	140	134	6.0	14.0		26.0	10.0	1.0	14.0
average	358	196	239	221	25.2	55.4		57.4	18.8	3.3	27.6
median	379	190	230	244	13.0	53.0		56.5	18.0	3.0	28.0
standard deviation	105	58	72	63	36.8	27.1		18.6	7.0	1.3	9.7
April 2011											
n	25	25	25	25	25	25		25	25	25	25
detections	25	25	25	25	25	25		25	25	25	25
maximium	1540	390	470	832	170.0	550.0		215.0	72.0	16.0	156.0
minimum	210	88	110	135	5.0	14.0		29.0	7.0	1.0	12.0
average	415	186	225	235	34.8	92.6		60.0	20.8	4.6	38.9
median	348	160	200	224	18.0	58.0		53.0	18.0	3.0	25.0
standard deviation	270	69	83	134	44.1	109.8		35.1	13.4	3.6	37.8
August 2011											
n	30	30	30	29	30	30	29	29	29	29	29
detections	30	30	30	29	30	30	3	29	29	28	29
maximium	1560	370	460	822	180.0	530.0	1.50	208.0	74.0	15.0	158.0
minimum	172	87	110	111	6.0	15.0	0.90	26.0	8.0	1.0	13.0
average	380	177	217	223	31.8	84.4	1.23	56.8	19.9	4.6	38.1
median	324	150	190	208	17.0	50.5	1.30	50.0	19.0	3.0	25.0
standard deviation	258	64	79	125	41.6	99.0	0.31	32.4	12.7	3.3	37.2
November 2011											
n	29	29	29	29	29	29	29	29	29	29	29
detections	29	29	29	29	29	29	5	29	29	26	27
maximium	1550	380	460	897	170.0	570.0	1.20	237.0	74.0	16.0	165.0
minimum	194	86	110	131	6.0	14.0	0.60	26.0	7.0	2.0	13.0
average	382	174	212	237	35.1	92.6	0.88	62.6	19.7	5.2	41.7
median	310	150	180	202	17.0	53.0	0.90	53.0	18.0	3.0	24.0
standard deviation	262	67	81	139	44.0	107.3	0.22	37.2	13.2	3.6	42.6

Water types are classified based on the major ions which dominate water chemistry, represented by the highest milli-equivalent levels. A single classification system has not been accepted in literature, since classification systems are typically developed for specific regions (e.g. Harvey et al., 2002). The convention is to identify the dominant cation followed by the dominant anion. The classification system for this study was originally developed by LCWQPD staff in support of the recent MBMG for studies of the area (Waren et al., 2012; Bobst et al., 2013). The classification system reflects increasing sodium and potassium concentrations from calcium and magnesium waters for cations, and increasing sulfate for anion classification. The classification system is listed in Table 7-2, which notes the relative percent of the concentrations of major ions, as milliequivalents, to the overall water chemistry. The classification system breaks were developed to highlight different water quality types in the Helena Valley study area.

Table 7-2 – Water Type Classification from Major Ions



Water Type	**Classification Criteria**
Ca-Mg Bicarbonate	(Na+K<20%; SO_4<25%)
Ca-Mg Bicarbonate-Sulfate	(Na+K<20%; SO_4>25%)
Mg-Ca Bicarbonate	(Mg>Ca>Na+K)
Mixed Cation Bicarbonate	(20%<Na+K<40%; SO_4<25%)
Mixed Cation Bicarbonate-Sulfate	(20%<Na+K<40%; SO_4>25%)
Na-K Bicarbonate	(Na+K>40%; SO_4<25%)
Na-K Bicarbonate-Sulfate	(Na+K>40%; SO_4>25%)
Ca-Mg Chloride/Mixed Anion	Chloride major anion
Mg-Ca/Na-K Sulfate Mixed Anion	Mixed cation, sulfate major anion, high TDS

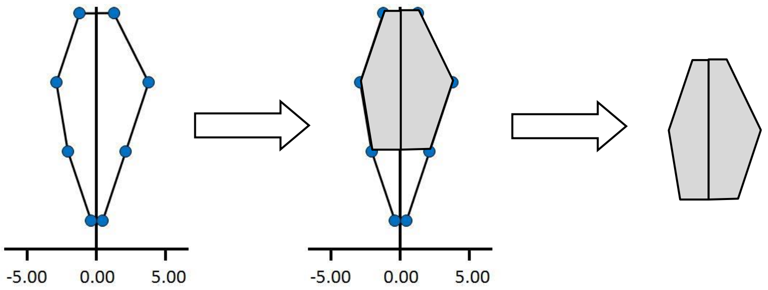
Differences in major ion concentrations and types between areas show how water quality may vary from different recharge sources and/or be impacted by anthropogenic activities. This study utilized available data, including data from previous published studies by the USGS, MBMG and other groups, to evaluate changes in water quality over time. For this assessment, stiff diagrams were constructed utilizing the major ion water quality data for all of the sites with data collected into the water quality database, including well sampling results with the current monitoring program (see data in Appendix B).

For each monitoring well sampled for this study, all of the major ion data from each sampling event was plotted on a single stiff diagram to provide a visual method to assess changes in major ion chemistry between sampling events. Data from wells with ground water linked to local surface water recharge show variability in water chemistry with time. A review of the stiff diagrams in Appendix C indicates that for the majority of wells, water quality chemistry remained stable with little seasonal change. As the stiff diagram mapping program was expanded to utilize the data from the sources listed in Section 6.0, data from some wells have only single sampling events. Since major ion water chemistry, including TDS, has been demonstrated to be generally stable across the study area, the use of single event data is considered representative of local conditions. The supplemental data used in the mapping program is summarized in Appendix B.

A water quality map was developed for the study area using stiff diagrams developed for all ground water monitoring locations in this study, and from all available data with major ion chemistry describe in Section 6.0. The recent ground water data from piezometers is not included with the mapping program. Stiff diagrams were converted into representative polygons, as depicted in Figure 7-2, for each well. The color of each polygon was coded to the water type, as illustrated in Table 7-2. A completed copy of the map is depicted in Figure 7-3, with the full map included in Appendix D. The map also differentiates data in two additional ways. For wells in a cluster, a gray oval was placed around the stiff diagram for the deeper well. Since data has been generated for several decades, stiffs for recent data utilize black outlines. Data from the late 1980s to 1999 utilize gray outlines, and older data uses red outlines. Data for the East Helena area is limited, since data for the characterization of the area for the Asarco site has not been released to the public.

Figure 7-2 Sample Stiff Diagram Polygon Construction

A representative polygon is constructed from the stiff diagram,



7.3 Nutrient Results

The sampling and analysis program included both nitrogen and phosphorus as primary analytes to assess nutrients in ground water quality. Nitrate represents the only specific nutrient with a drinking water standard at 10 mg/L. The Framework Restoration Plan (USEPA, 2006) identifies TMDL target goals for surface water concentrations of total nitrogen (0.33 mg/L) and total phosphorus (0.04 mg/L). In order to assess impacts from either point or nonpoint sources, concentrations are typically compared to background concentrations. Since there is no specific study or determination of background concentrations in the study area, this project considers nitrate concentrations above 2.0 mg/L as elevated above background conditions, based on a USGS study of nutrients in waters across the country (Mueller & Helsel, 1996). The assessement reflects the ground water monitoring wells and piezometers water quality data as separate datasets. The summary statistics for each ground water monitoring well sampling event are listed in Table 7-3. The summary statistics generally indicate that the average concentrations are biased by wells with high concentrations, as the median concentrations are typically below the averages for each event. The location of the individual wells is depicted in Figure 3-2, with all of the data for the wells included in Appendix C.

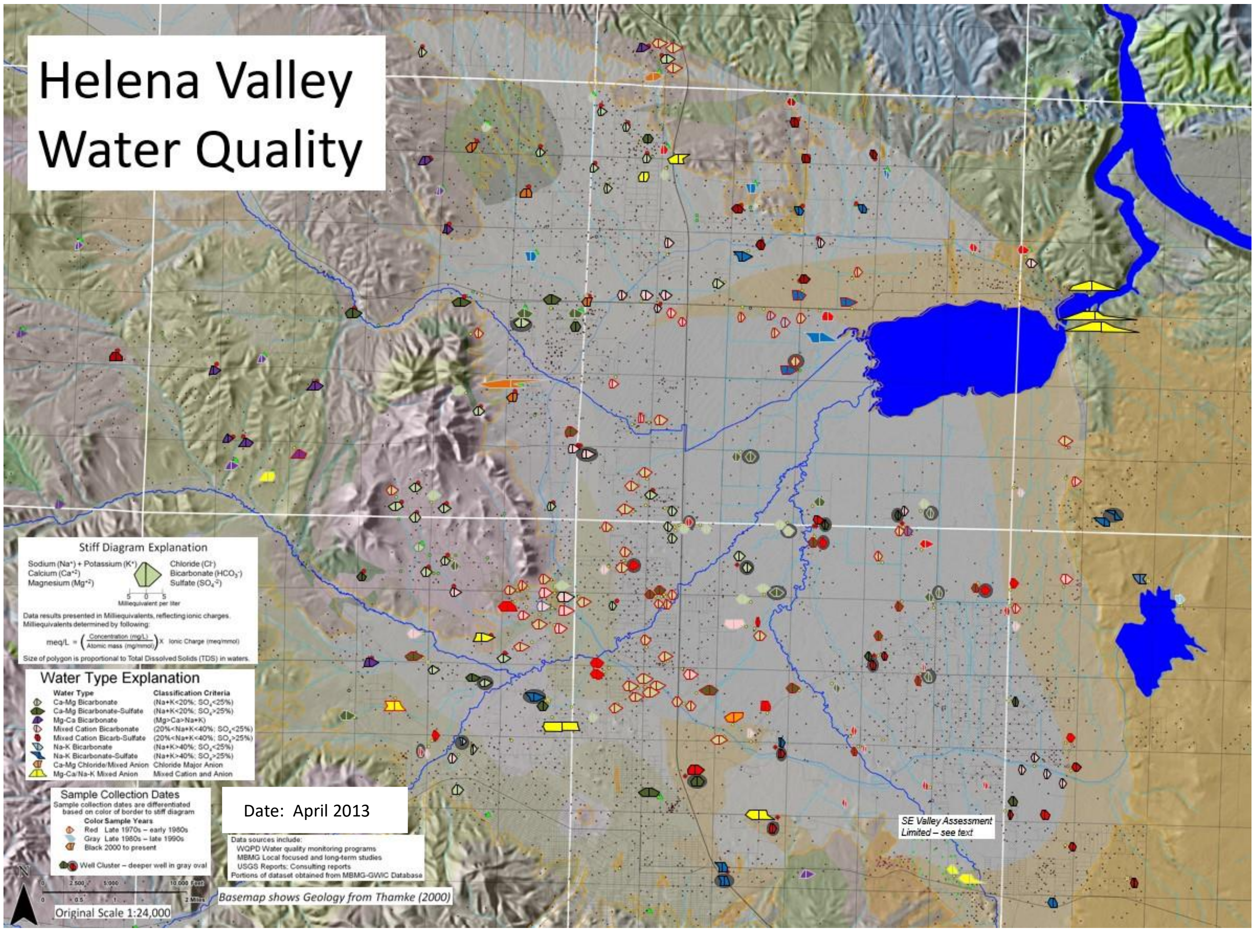


Figure 7-3 Water Type Map of Helena Valley Ground Water
The full size map is included in Appendix D

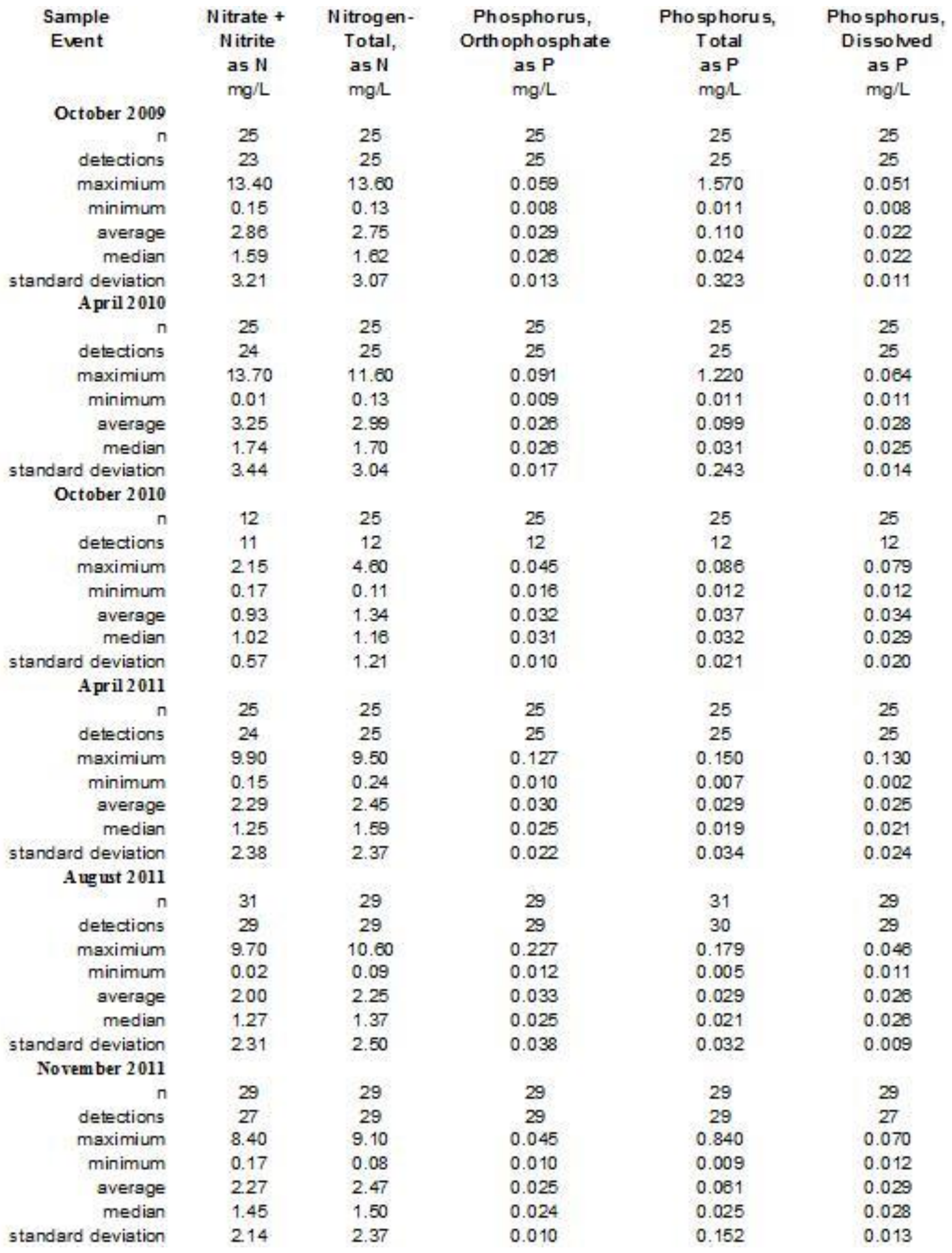
Nitrate and Nitrogen

For the ground water monitoring wells, the nutrient results indicate only one well with nitrate levels consistently exceeding the drinking water standard of 10 mg/L – the shallow Airport West well (GWIC 191529 Max NO_3 = 13.7 mg/L). Additional locations with concentrations exceeding 2.0 mg/L include:

- Buoy Road wells (GWIC 191524 Max NO_3 = 2.3 mg/L and 191525 Max NO_3 = 3.17 mg/L),
- Airport West deep well (GWIC 191528 Max NO_3 = 9.0 mg/L),
- Regulating Reservoir well (GWIC 191530 Max NO_3 = 6.2 mg/L),
- Motor Pool wells (GWIC 191531 Max NO_3 = 6.51 mg/L and 191540 Max NO_3 = 5.9 mg/L),
- Gravel Pit well (GWIC 191534 Max NO_3 = 4.63 mg/L),
- Airport South shallow well (GWIC 191535 Max NO_3 = 5.32 mg/L),
- Eichoff and Valley well (GWIC 191536 Max NO_3 = 9.9 mg/L) and
- Horseshoe Bend well (GWIC 191539 Max NO_3 = 2.33 mg/L).

The nitrate data from the piezometers sampling events, as summarized in Appendix F, showed that concentrations in ground water near the D2B drain are the only values exceeding the background level of 2.0 mg/L, with a maximum detected concentration of 3.05 mg/L.

Table 7-3 – Nutrient Summary Statistics by Sampling Event



Sample Event	Nitrate + Nitrite as N mg/L	Nitrogen-Total, as N mg/L	Phosphorus, Orthophosphate as P mg/L	Phosphorus, Total as P mg/L	Phosphorus, Dissolved as P mg/L
October 2009					
n	25	25	25	25	25
detections	23	25	25	25	25
maximium	13.40	13.60	0.059	1.570	0.051
minimum	0.15	0.13	0.008	0.011	0.008
average	2.86	2.75	0.029	0.110	0.022
median	1.59	1.62	0.026	0.024	0.022
standard deviation	3.21	3.07	0.013	0.323	0.011
April 2010					
n	25	25	25	25	25
detections	24	25	25	25	25
maximium	13.70	11.60	0.091	1.220	0.064
minimum	0.01	0.13	0.009	0.011	0.011
average	3.25	2.99	0.026	0.099	0.028
median	1.74	1.70	0.026	0.031	0.025
standard deviation	3.44	3.04	0.017	0.243	0.014
October 2010					
n	12	25	25	25	25
detections	11	12	12	12	12
maximium	2.15	4.60	0.045	0.086	0.079
minimum	0.17	0.11	0.016	0.012	0.012
average	0.93	1.34	0.032	0.037	0.034
median	1.02	1.16	0.031	0.032	0.029
standard deviation	0.57	1.21	0.010	0.021	0.020
April 2011					
n	25	25	25	25	25
detections	24	25	25	25	25
maximium	9.90	9.50	0.127	0.150	0.130
minimum	0.15	0.24	0.010	0.007	0.002
average	2.29	2.45	0.030	0.029	0.025
median	1.25	1.59	0.025	0.019	0.021
standard deviation	2.38	2.37	0.022	0.034	0.024
August 2011					
n	31	29	29	31	29
detections	29	29	29	30	29
maximium	9.70	10.60	0.227	0.179	0.046
minimum	0.02	0.09	0.012	0.005	0.011
average	2.00	2.25	0.033	0.029	0.026
median	1.27	1.37	0.025	0.021	0.026
standard deviation	2.31	2.50	0.038	0.032	0.009
November 2011					
n	29	29	29	29	29
detections	27	29	29	29	27
maximium	8.40	9.10	0.045	0.840	0.070
minimum	0.17	0.08	0.010	0.009	0.012
average	2.27	2.47	0.025	0.061	0.029
median	1.45	1.50	0.024	0.025	0.028
standard deviation	2.14	2.37	0.010	0.152	0.013

The only detections of ammonia in the program were at the Head Lane monitoring well (GWIC 191557), and at the Silver Creek Estates (P-SC1) and Head Lane (P-7M3) piezometers, with single detections during the early winter sampling event at 'Country Club Lane (P-T24) and Canyon Ferry Road (P-P5).

Phosphorus

Total phosphorus is the second nutrient with a TMDL target concentration for surface water. Data from two sites had total phosphate concentrations exceeding the 0.04 mg/L target concentration during each sampling event: at the Airport West shallow well (GWIC 191529, max P = 1.57 mg/L) and the Head Lane well (GWIC 191557, max P = 0.84 mg/L). In general, the results were variable between sampling events, and the result of the duplicate analyses for phosphate, as discussed in Section 5.0, indicate that the accuracy of these results may be limited. Several other locations had results from one to three analyses which showed phosphate levels above the target concentration. These locations generally correspond with locations where elevated nitrate levels were detected.

The phosphorus results from the piezometers showed variable results from all of the locations. In general, the highest concentrations were detected during the early winter sampling event, with results from the other two events variable. The results from two locations – Birdseye Road (P-7M1) and Canyon Ferry Road (P-P5) – had detected concentrations below the target concentration during each of the three events.

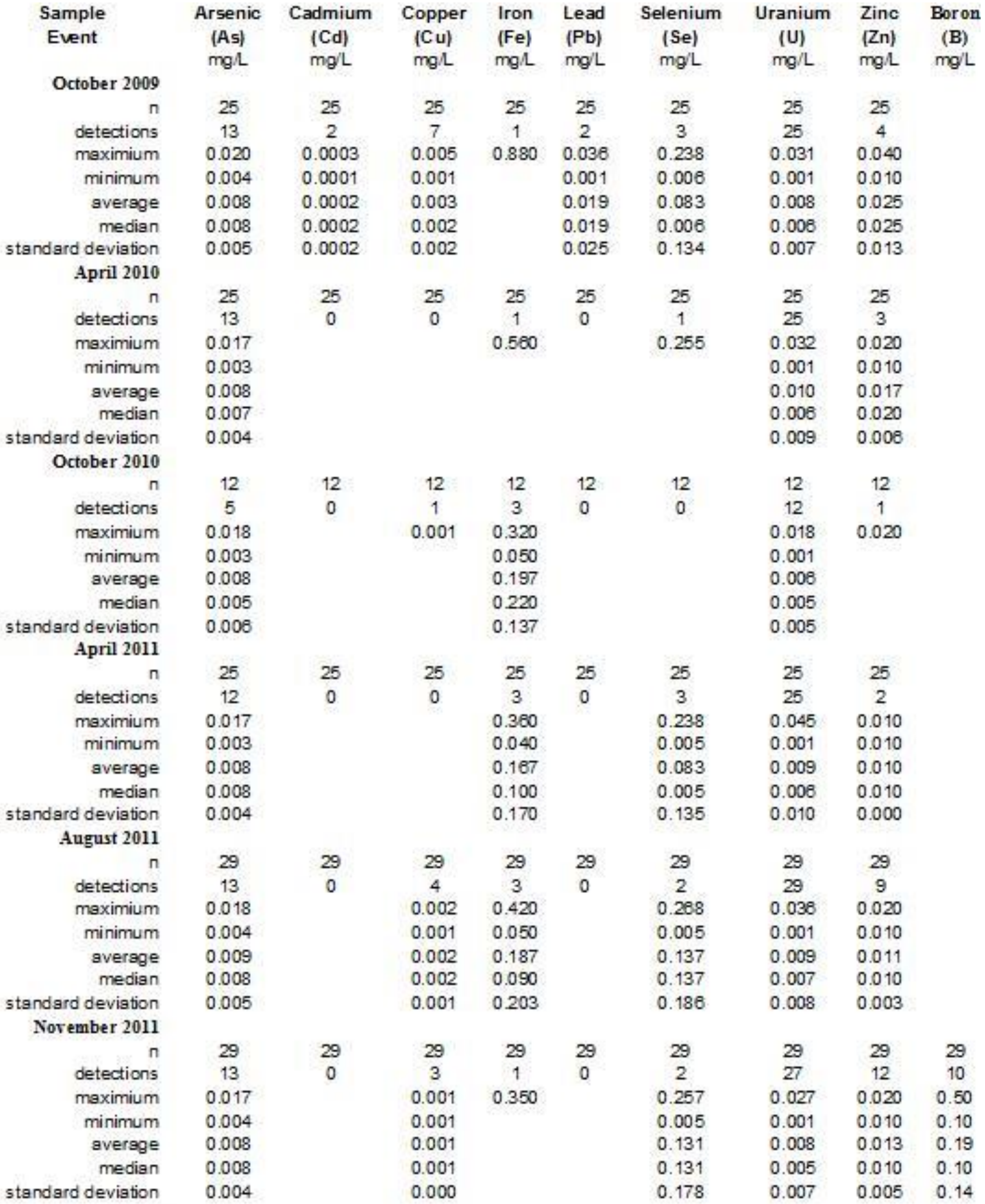
7.4 Trace Metal Results

The trace metal analyses conducted for this study indicated results below drinking water standards with several exceptions. Sample summary statistics for trace metals, as listed in Table 7-4, show the ranges of detected concentrations with each sampling event. Trace metals were not analyzed from the piezometers. The following represent results where exceedences of drinking water standards, or maximum contaminant levels (MCLs) were consistently detected:

- Regulating Reservoir Well (GWIC 191530) has arsenic between 0.011 and 0.015 mg/L, above the MCL of 0.010 mg/L; and selenium between 0.238 and 0.268 mg/L, above the MCL of 0.050 mg/L.
- Motor Pool deep well, with arsenic levels between 0.010 and 0.013 mg/L
- Airport South shallow well, with uranium concentrations in five of six samples ranging from 0.031 to 0.036 mg/L, above the MCL of 0.030 mg/L. The additional sample result was 0.027 mg/L.
- The Airport North shallow well, with arsenic levels between 0.017 and 0.020 mg/L.

The wells with elevated levels of arsenic and uranium are generally completed within the Tertiary aquifer systems.

Table 7-4 – Trace Metal Summary Statistics by Sampling Event



Sample Event	Arsenic (As) mg/L	Cadmium (Cd) mg/L	Copper (Cu) mg/L	Iron (Fe) mg/L	Lead (Pb) mg/L	Selenium (Se) mg/L	Uranium (U) mg/L	Zinc (Zn) mg/L	Boron (B) mg/L
October 2009									
n	25	25	25	25	25	25	25	25	
detections	13	2	7	1	2	3	25	4	
maximium	0.020	0.0003	0.005	0.880	0.036	0.238	0.031	0.040	
minimum	0.004	0.0001	0.001		0.001	0.006	0.001	0.010	
average	0.008	0.0002	0.003		0.019	0.083	0.008	0.025	
median	0.008	0.0002	0.002		0.019	0.006	0.006	0.025	
standard deviation	0.005	0.0002	0.002		0.025	0.134	0.007	0.013	
April 2010									
n	25	25	25	25	25	25	25	25	
detections	13	0	0	1	0	1	25	3	
maximium	0.017			0.560		0.255	0.032	0.020	
minimum	0.003						0.001	0.010	
average	0.008						0.010	0.017	
median	0.007						0.006	0.020	
standard deviation	0.004						0.009	0.006	
October 2010									
n	12	12	12	12	12	12	12	12	
detections	5	0	1	3	0	0	12	1	
maximium	0.018		0.001	0.320			0.018	0.020	
minimum	0.003			0.050			0.001		
average	0.008			0.197			0.006		
median	0.005			0.220			0.005		
standard deviation	0.006			0.137			0.005		
April 2011									
n	25	25	25	25	25	25	25	25	
detections	12	0	0	3	0	3	25	2	
maximium	0.017			0.360		0.238	0.045	0.010	
minimum	0.003			0.040		0.005	0.001	0.010	
average	0.008			0.167		0.083	0.009	0.010	
median	0.008			0.100		0.005	0.006	0.010	
standard deviation	0.004			0.170		0.135	0.010	0.000	
August 2011									
n	29	29	29	29	29	29	29	29	
detections	13	0	4	3	0	2	29	9	
maximium	0.018		0.002	0.420		0.268	0.036	0.020	
minimum	0.004		0.001	0.050		0.005	0.001	0.010	
average	0.009		0.002	0.187		0.137	0.009	0.011	
median	0.008		0.002	0.090		0.137	0.007	0.010	
standard deviation	0.005		0.001	0.203		0.186	0.008	0.003	
November 2011									
n	29	29	29	29	29	29	29	29	29
detections	13	0	3	1	0	2	27	12	10
maximium	0.017		0.001	0.350		0.257	0.027	0.020	0.50
minimum	0.004		0.001			0.005	0.001	0.010	0.10
average	0.008		0.001			0.131	0.008	0.013	0.19
median	0.008		0.001			0.131	0.005	0.010	0.10
standard deviation	0.004		0.000			0.178	0.007	0.005	0.14

7.5 Monthly Nutrient Monitoring Results

The monthly sampling program was implemented during the first year of the project. The goal of the monthly sampling was to characterize seasonal changes in nutrient concentrations with respect to changing ground water levels. The data from the monthly sampling program is summarized in Appendix E. The five sampling locations are depicted in Figure 3-3. The data from these five locations is used to characterize conditions in three different areas, summarized as follows:

Northwest Valley – Griffin and Hope. These two sites are present in the Griffin-Davis subdivision area where Silver Creek enters the Helena Valley, upgradient of the main Helena Valley Irrigation District canal (see Figure 3-3). Based on the stratigraphy reported in the well logs, these wells are located within coarse grained alluvium with a static water level approximately 70 feet below ground surface. Historical samples from LCWQPD staff have indicated that water quality problems related to nitrate are present within this area, including the Hope well. The Griffin well is screened below the top of the water table, while the Hope well has an intake near the top of the water table at approximately 150 feet below ground surface. Water levels were not measured from the Hope well at the request of the owner, who did not want the wellhead opened. The monthly nitrate and phosphate data compared with water levels are presented in Figures 7-4 and 7-5. These plots show a clear relationship between water level and nitate concentration, as nitrate levels increase with decreasing water levels. The total phosphorus data is less conclusive, with higher phosphate concentrations present in the deeper well, and concentration spikes in April and July.

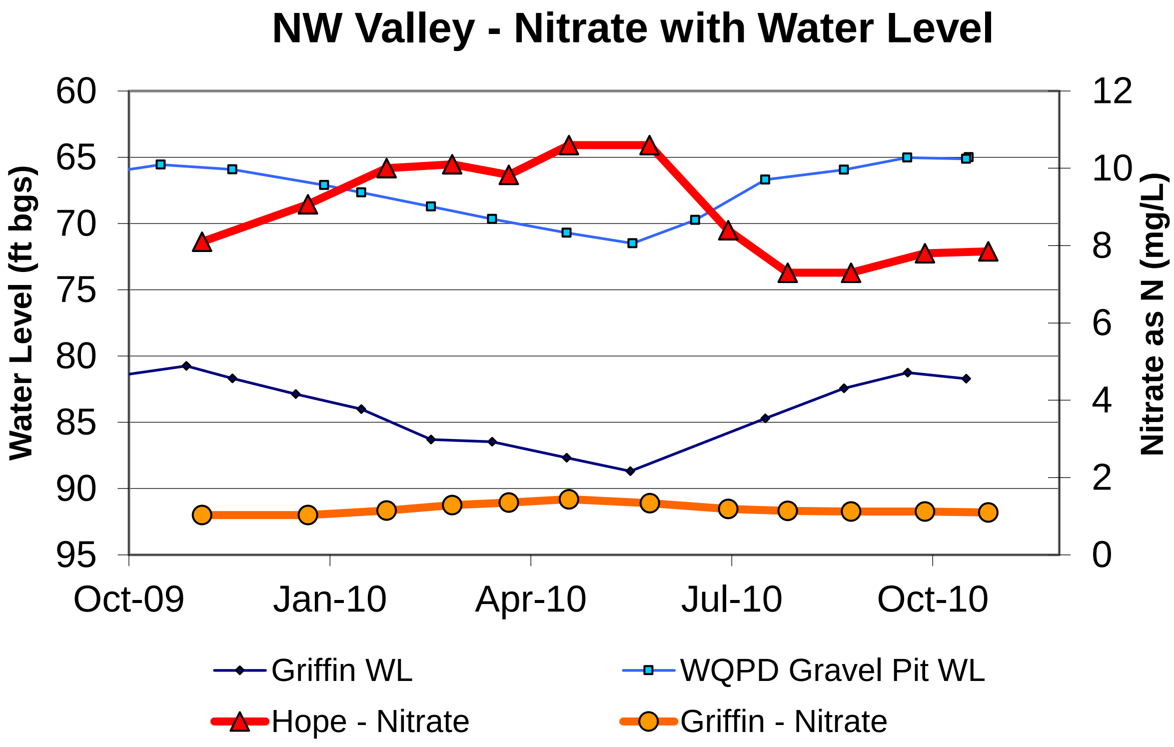


Figure 7-4 Monthly Nitrate Concentrations and Ground Water Levels, NW Valley

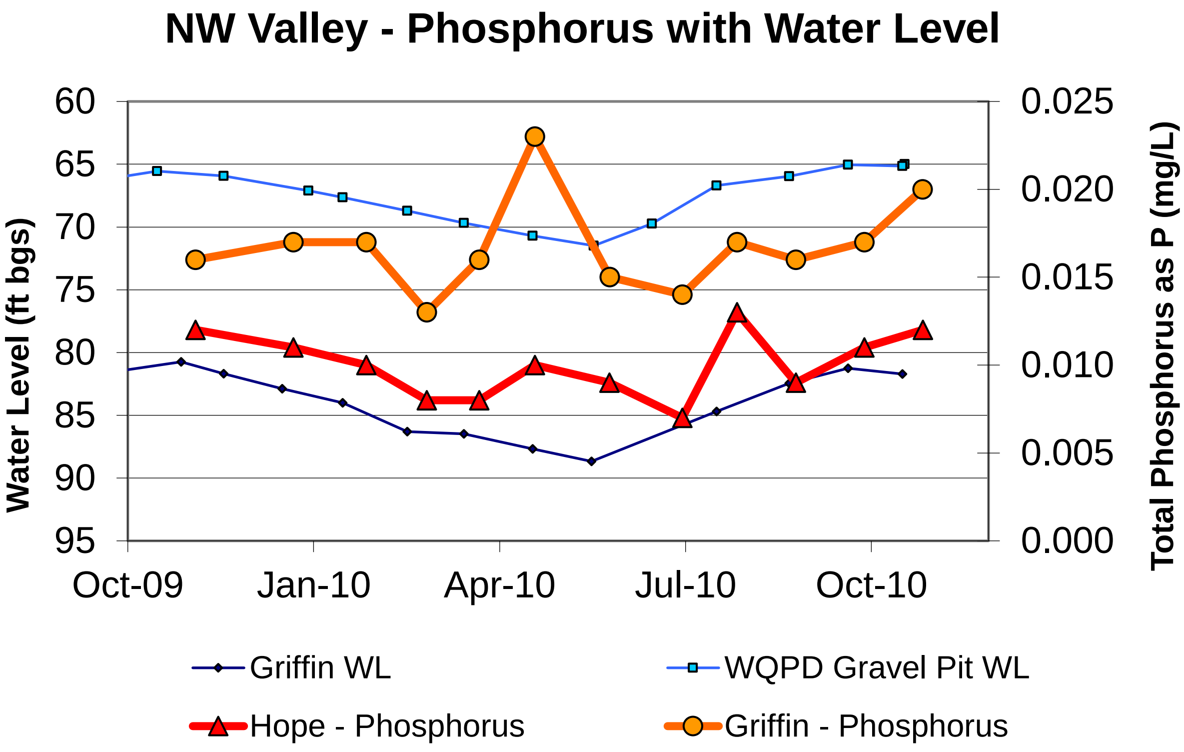


Figure 7-5 Monthly Phosphorus Concentrations and Ground Water Levels, NW Valley

Southeast Valley – Clinton and Wildfire. These two sites are present in the unsewered area east of East Helena (Clinton), and downgradient from this area (Wildfire) as shown in Figure 3-3. Nitrate levels in area wells had been determined as above background levels in previous LCWQPD studies. The water levels in this area range from 50 to 80 feet below ground surface, and the stratigraphy shows gravel alluvium with several clay lenses. The Clinton well intake is approximately 150 feet bgs, and the Wildfire intake is approximately 250 feet bgs. The nitrate and phosphorus results are depicted in Figure 7-6 and 7-7. The water level depicted with the data shows drawdown occurring in the area near Wildfire. Water levels were not available from the Clinton well. The data show relatively stable nitrate levels in the Wildfire well, with highest levels in the Clinton well occuring in late summer when water levels are lowest. The phosphorus data indicates higher phosphate concentrations in the deeper well. The results are inconclusive, however, the trend between the two wells is similar, with concentrations variable over time.

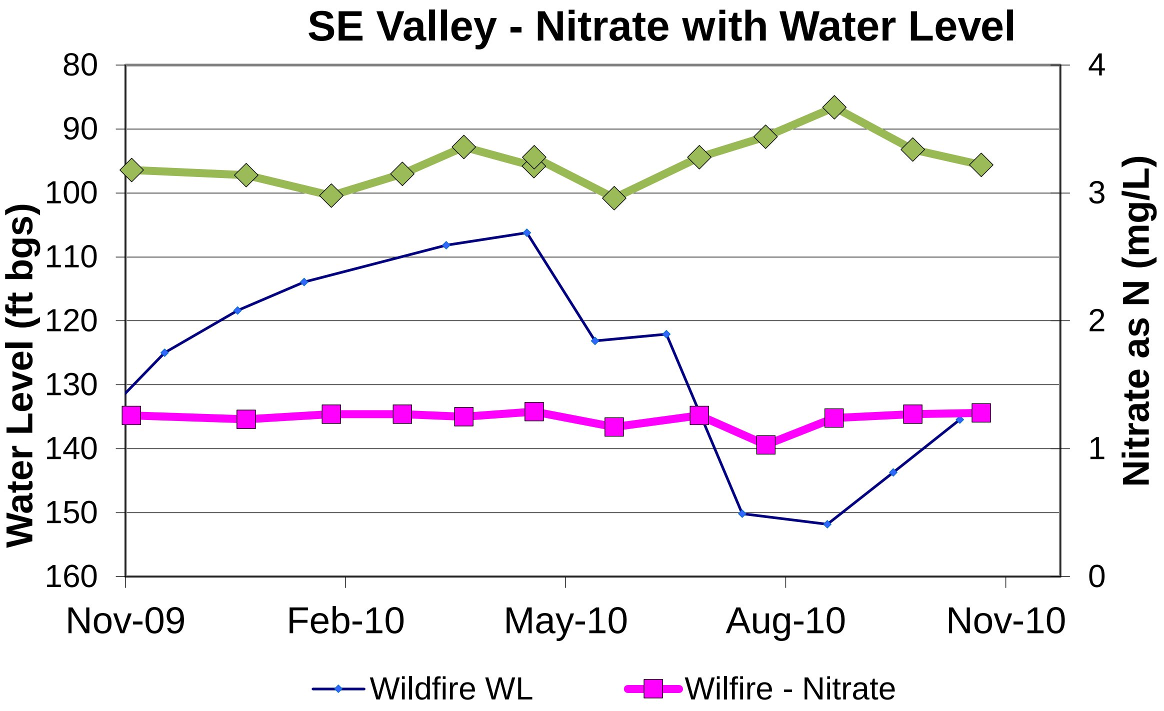


Figure 7-6 Monthly Nitrate Concentrations and Ground Water Levels, SE Valley

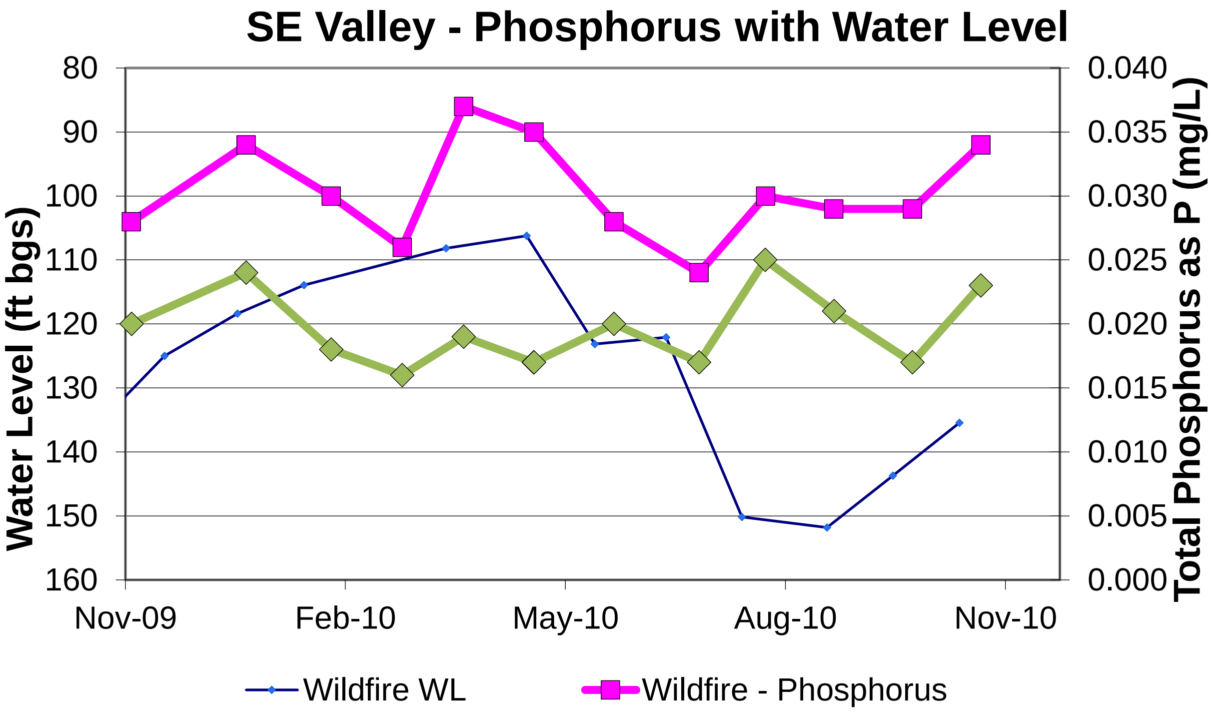


Figure 7-7 Monthly Phosphorus Concentrations and Ground Water Levels, SE Valley

West-Central Valley – Hilmen. This well is located in an area with shallow ground water in the unsewered area along the west side of the valley as shown in Figure 3-3. Nitrate levels in area wells had been determined as above background levels in previous LCWQPD studies. This well is approximately 50 feet deep with a water level consistently less than 10 feet bgs. The data results show generally stable nitrate levels with no noticeable seasonal change. The phosphate data is inconclusive, similar to the other site. This data is shown in Figures 7-8 and 7-9.

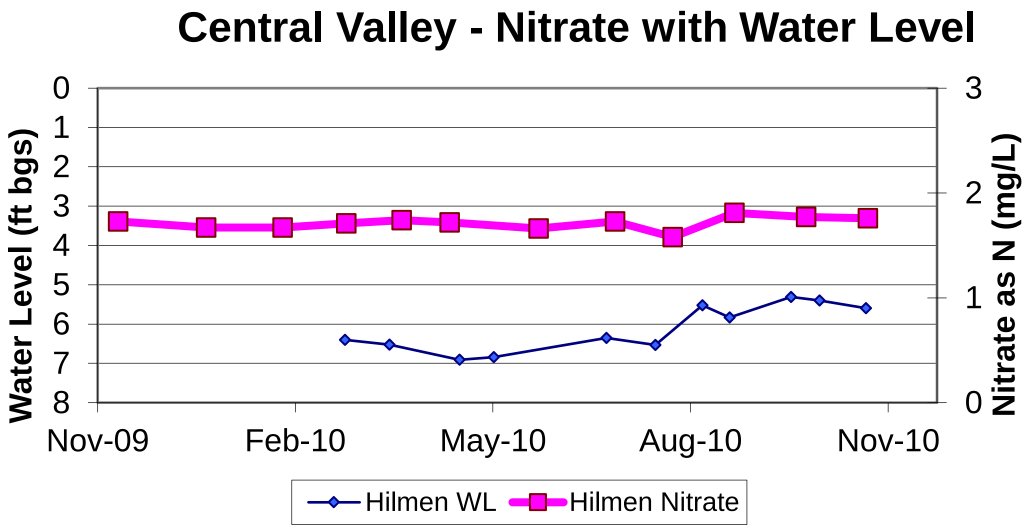


Figure 7-8 Monthly Nitrate Concentrations and Ground Water Levels, Central Valley

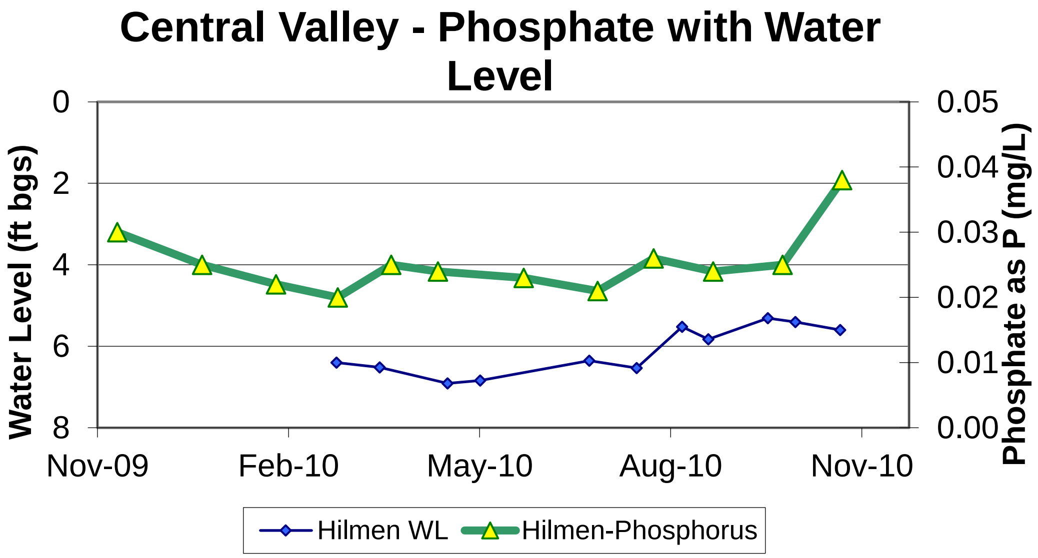


Figure 7-9 Monthly Phosphorus Concentrations and Ground Water Levels, Central Valley

7.6 Water Quality Map Conclusions

The water type map as presented in Appendix D provides the basis for interpreting the dynamics of the shallow ground water system in the study area. A goal of this study is to evaluate the interaction of surface and ground water in the central part of the valley, to help characterize the loading of nutrients from non-point sources to local surface waters.

The conceptual model of the Helena Valley reflects surface water recharge of the alluvial aquifes along the valley margins, where streams enter the valley. The link between surface and ground water in these areas is confirmed by the water quality data. Figure 7-10 shows surface water quality from LCWQPD monitoring results from August 2011 (see data in Appendix F). The data shows that surface waters in Tenmile and Silver Creek are predominantly Calcium-Bicarbonate, while Prickly Pear Creek water is Calcium Bicarbonate with more than 25% sulfate. The water in the drains near Lake Helena shows more than 20% sodium and potassium as the major cations, in addition to calcium. The sample from the wastewater treatment plant effluent discharge canal appears anomalous, with high TDS, chloride and sodium/potassium. The water in the Helena Valley Irrigation Canal, which loses water and strongly influences the local ground water system shows variable chemistry from four sampling events, as shown in Figure 7-11.

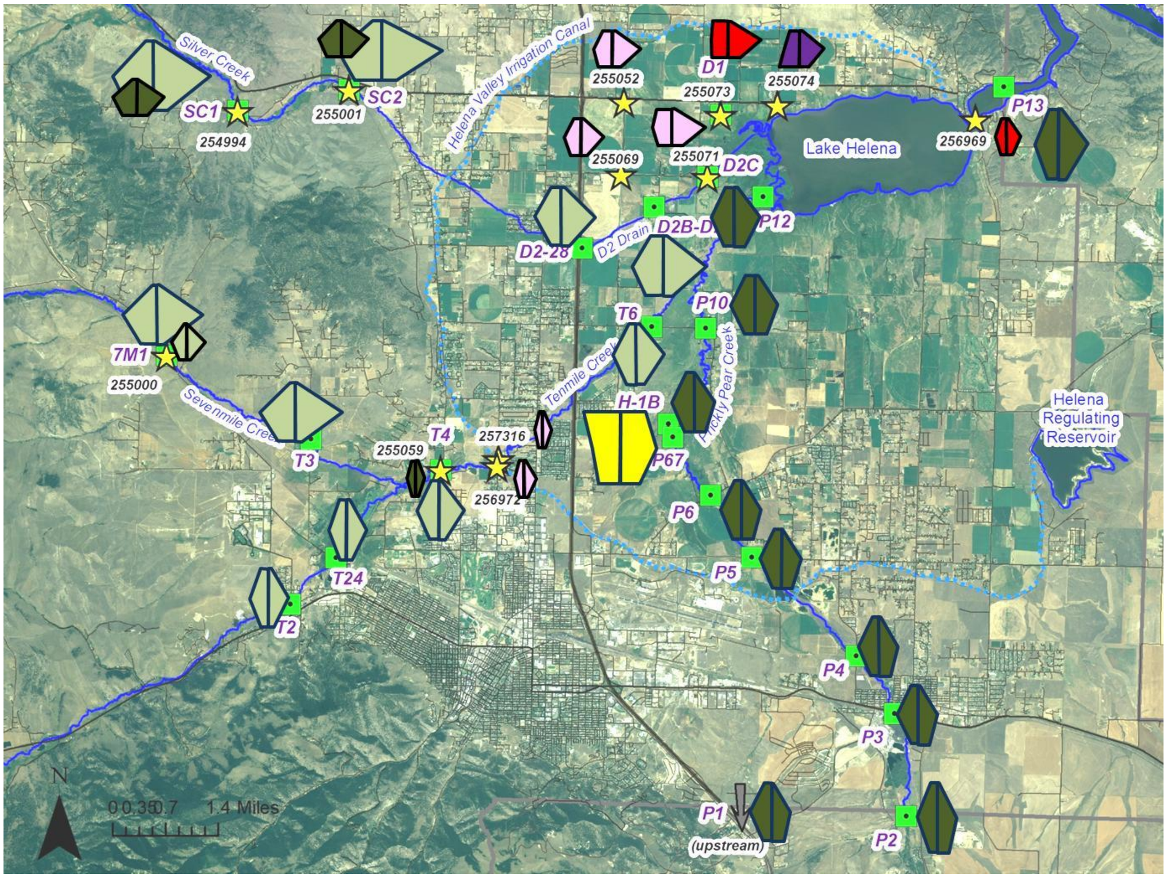
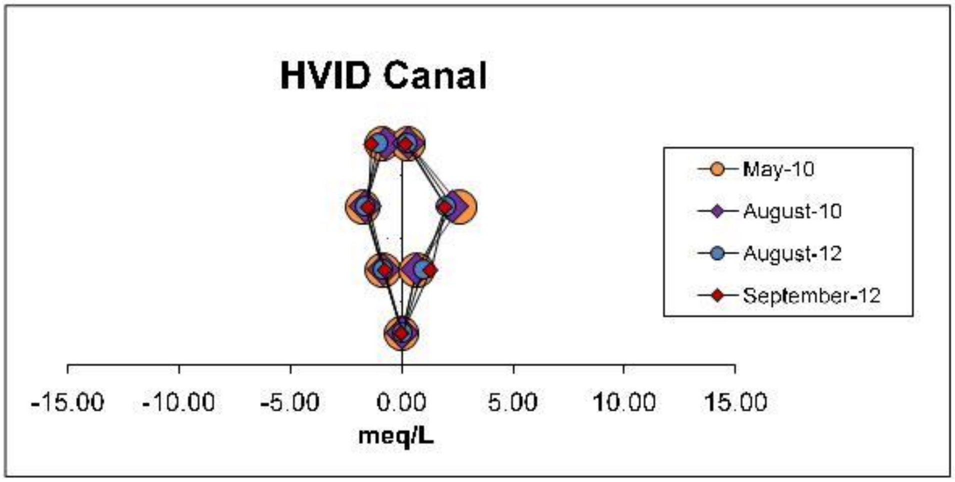
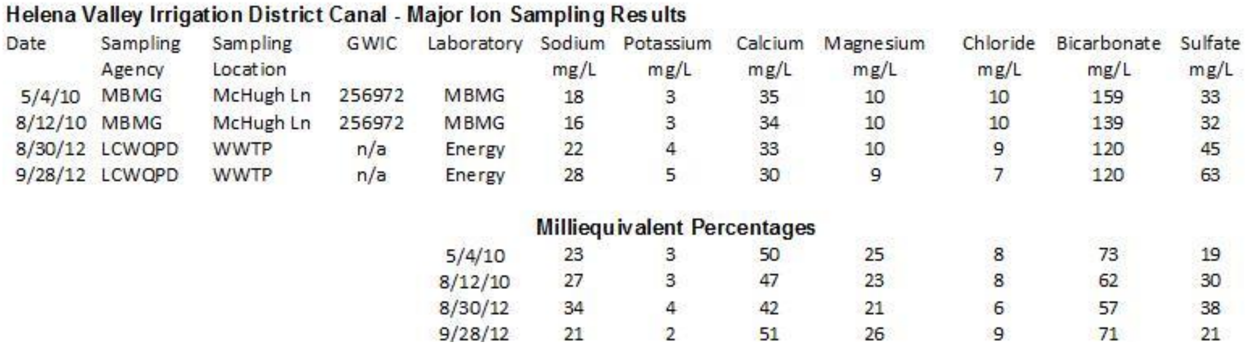


Figure 7-10 – Surface Water Quality Types, August 2011.
Stiff diagrams from surface water quality data collected in August 2011 at LCWQPD surface water monitoring locations. The smaller stiff diagrams with black outlines are from 2010 MBMG studies.





Helena Valley Irrigation District Canal - Major Ion Sampling Results

Date	Sampling Agency	Sampling Location	GWIC	Laboratory	Sodium mg/L	Potassium mg/L	Calcium mg/L	Magnesium mg/L	Chloride mg/L	Bicarbonate mg/L	Sulfate mg/L
5/4/10	MBMG	McHugh Ln	256972	MBMG	18	3	35	10	10	159	33
8/12/10	MBMG	McHugh Ln	256972	MBMG	16	3	34	10	10	139	32
8/30/12	LCWQPD	WWTP	n/a	Energy	22	4	33	10	9	120	45
9/28/12	LCWQPD	WWTP	n/a	Energy	28	5	30	9	7	120	63

Milliequivalent Percentages

	Sodium	Potassium	Calcium	Magnesium	Chloride	Bicarbonate	Sulfate
5/4/10	23	3	50	25	8	73	19
8/12/10	27	3	47	23	8	62	30
8/30/12	34	4	42	21	6	57	38
9/28/12	21	2	51	26	9	71	21

Figure 7-11 – Surface Water Type in Helena Valley Irrigation Canal.
Stiff diagrams from surface water quality data collected in August 2011 at LCWQPD surface water monitoring locations. The smaller stiff diagrams with black outlines are from 2010 MBMG studies.

The link between surface water and ground water recharge is depicted in Figure 7-12, which shows the ground water quality map results for calcium-bicarbonate waters, and magnesium-bicarbonate waters. Data from the MBMG studies of the North Hills (Waren et al., 2012) and Scratchgravel Hills (Bobst et al., 2013) show that calcium-bicarbonate waters are the predominate type in the upgradient recharge areas of the valley. Areas where the link betweens surface water recharge to ground water are identified. The magnesium-bicarbonate waters correspond with the Helena Formation, a proterozoic unit characterized by dolomites and limestone. Dolomites are similar to limestone but contain additional magnesium. The calcium-bicarbonate waters dominate the system on the western side of the valley.

Dissolved oxygen data from the ground water sampling program indicates that ground water in some areas is supersaturated with dissolved oxygen. Oxygen and other gases are most soluble in water at freezing temperatures, and decrease in solubility with increasing temperature. Primary local ground water recharge occurs from direct infiltration of snowmelt and precipitation and from high flows during spring runoff. These cold waters are typically saturated with oxygen from exposure to the atmosphere prior to recharge. The ground water temperature increases during percolation to the aquifer. Supersaturation occurs from the warming of the recharge waters in the subsurface, where the dissolved oxygen concentration exceeds the solubility of oxygen in water for the warmer temperature.

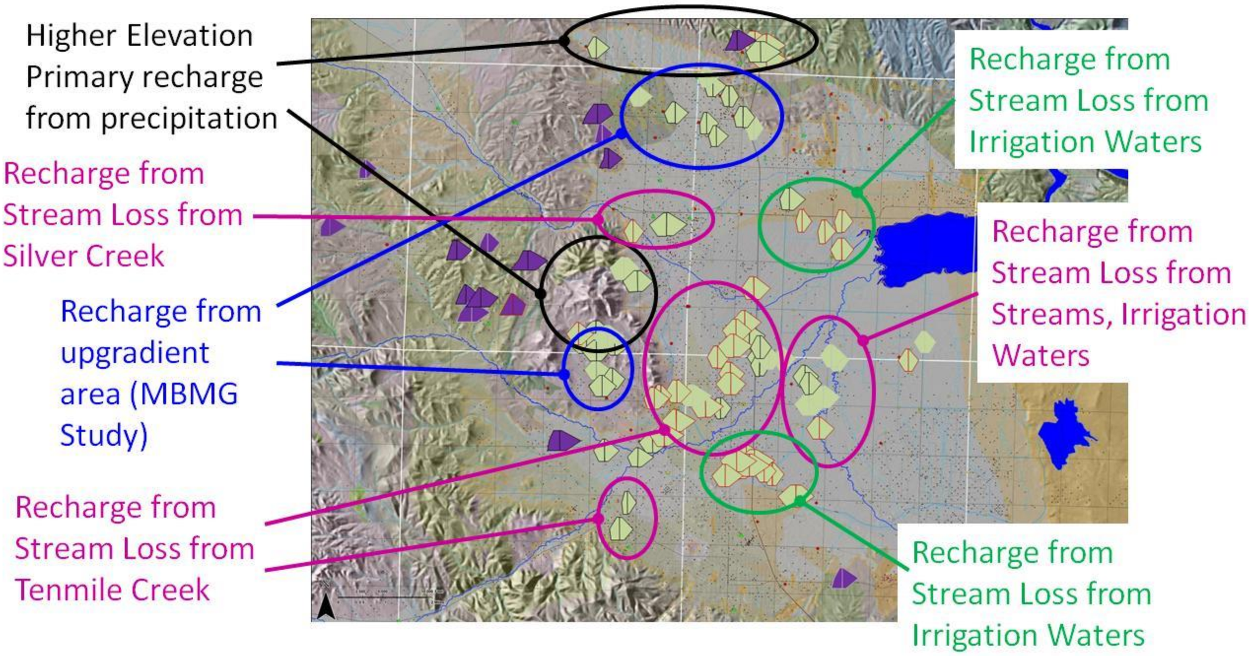


Figure 7-12 – Calcium/Magnesium – Bicarbonate Waters in Helena Valley.
Stiff diagrams from surface water quality data collected in August 2011 at LCWQPD surface water monitoring locations. The smaller stiff diagrams with black outlines are from 2010 MBMG studies.

Based on the surface and shallow ground water data, ground water recharge from local streams and precipitation results in a Calcium-Bicarbonate water, with slightly higher levels of sulfate in Prickly Pear Creek. The elevated sulfate is present in ground water areas downgradient from Prickly Pear Creek and near Silver Creek (Figure 7-13). However, in some areas of the valley study area, ground water is present with cations dominated by sodium and potassium associated with high sulfate concentrations, as depicted in Figure 7-13. These waters are typically present at temperatures elevated above the geothermal gradient (see Section 10.0). The dataset available from MBMG-GWIC (Appendix B) includes two sites in the area with high temperature waters, the Broadwater Hot Springs on the southwest side of the valley, and a thermal anomaly near Marysville, approximately 20 miles northwest of the study area. These sites are indicated on the recent map of geothermal resources in Montana (Laney & Brizee, 2003), with Marysville notes as having waters greater than 50°C. These data correlate high temperatures with sodium and potassium as major ions, and mixed sulfate and bicarbonate as anions (see Figure 7-13). From this information, recharge of water from heated water sources at depth occurs into the area, and is interpreted to represent a second water type defined by major ions for the study area.

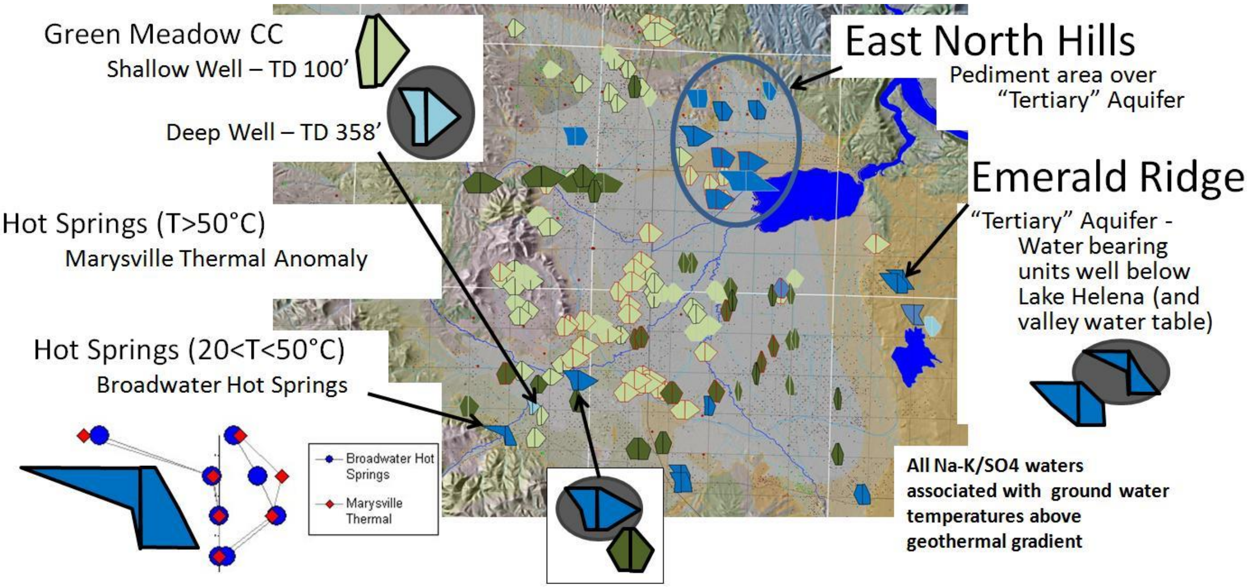


Figure 7-13 – Sodium/Potassium – Sulfate/Bicarbonate Waters in Helena Valley .
Stiff diagrams from surface water quality data collected in August 2011 at LCWQPD surface water monitoring locations. The smaller stiff diagrams with black outlines are from 2010 MBMG studies.

While characterizing the hot springs as different water chemistry is relatively straightforward, sodium & potassium dominated waters are also present at different locations along the valley margins. Where Tenmile Creek enters the valley, sodium & potassium waters are present at depth, below shallow calcium-bicarbonate waters. This infers the presence of a shallow ground water system superimposed over a deeper, bedrock system characterized by warm sodium potassium waters. The sodium potassium water type is also present a number of deep wells in the eastern part of the north hills area. Along the eastern margin of the valley, on the east side of the Spokane Bench fault, the Emerald Ridge subdivision was developed with a source aquifer in discontinuous coarse lenses within finer grained clay and silt rich Tertiary deposits. With time, the local aquifer was dewatered and residents installed new wells to depths of 600 feet or more, well below the surface of Lake Helena and the ground water potentiometric surface in the valley. While the temperature is not as high, the deep wells show similar water chemistry to the hot springs water (Figure 7-13). Since the sodium potassium waters are present along the northern and eastern margins of the valley, they are interpreted to result from deeper ground water recharging the system, with limited surface water recharge.

The southeastern and northeastern parts of the Helena Valley study area have numerous locations where the water types contain elevated sodium and potassium cations and sulfate as anions (Figure 7-14). Adjacent to the western margin of the valley, waters with elevated sodium and potassium are present, without elevated sodium. While anthropogenic sources of sodium and potassium may be present, both of these waters are interpreted as occurring from mixing of shallow calcium-bicarbonate waters with deeper sodium/potassium – sulfate/bicarbonate waters. This interpretation reflects both the stable nature of water chemistry in local ground waters, and the elevated geothermal gradient apparent at locations around the valley.

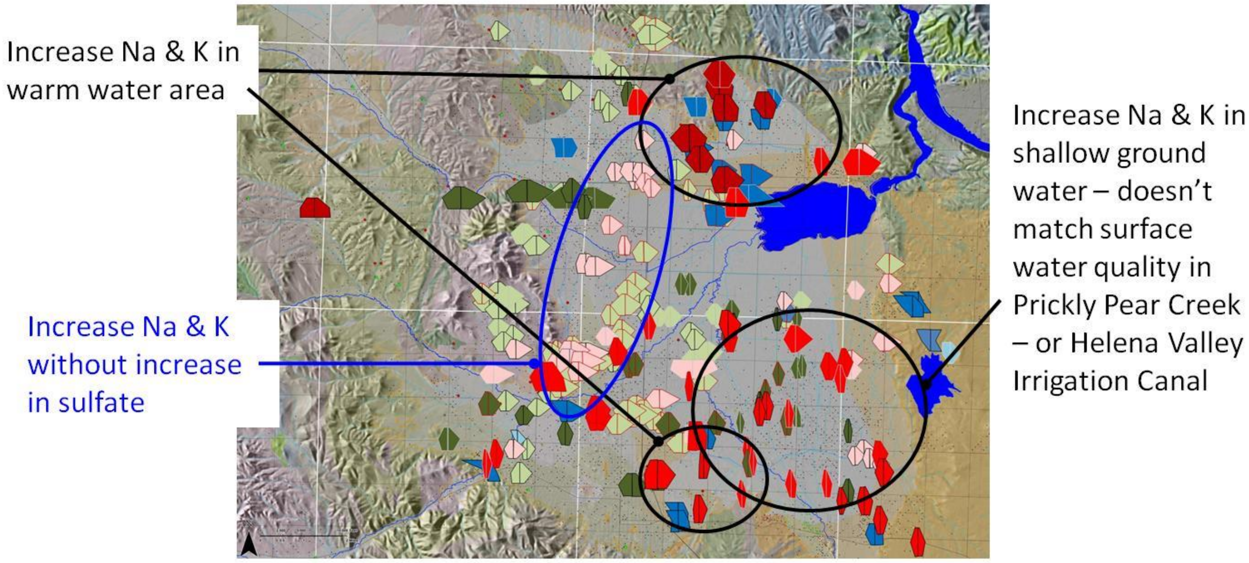


Figure 7-14 – Mixed Ion Water Types in Helena Valley.
Stiff diagrams from surface water quality data collected in August 2011 at LCWQPD surface water monitoring locations. The smaller stiff diagrams with black outlines are from 2010 MBMG studies.

Summary of Conclusions

The shallow ground water system receives recharge from direct infiltration of precipitation, and from stream loss during summer months. Water quality in the shallow ground water system is calcium–bicarbonate. Ground water in the shallow aquifer is supplemented by irrigation waters from outside the Helena Valley.

The deep ground water system, typically associated with thermal waters, provides limited recharge to areas along the margins of the Helena Valley. Water quality in the deep ground water system is sodium/potassium – sulfate/bicarbonate.

The deep ground water system mixes with the shallow system in the subsurface, resulting in an intermediate water quality type with mixed cations, and bicarbonate as the primary anion.

8.0 Ground Water Level Assessment and Surface/Ground Water Interaction

The conceptual model for the Helena Valley hydrogeologic system reflects Lake Helena as a discharge point for the combined surface and ground water system in the watershed. This system requires that ground water rise in the central part of the valley, with vertical gradients forming from having hydraulic head at depth higher than at the surface resulting in surface flowing wells. The vertical gradients have been noted in USGS studies (Moreland & Leonard, 1980; Briar & Madison, 1992). The presence of these vertical gradients are not reflected in maps of the regional potentiometric surface (Figure 8-1). The vertical flowpaths and communication between the deep ground waters and shallow ground water system in the valley are not well understood at this time.

Ground water levels provide definition of hydraulic gradients within the ground water system. This study utilized an extensive set of water levels collected by LCWQPD staff on wells in the study area during the past decade. This set of wells includes all the primary monitoring wells for this study, and additional private potable water wells monitored at additional locations. Concurrent with this study, MBMG completed studies with additional monitoring locations within their study areas, to provide additional calibration points for their numerical modeling programs (Waren et al., 2012; Bobst et al., 2013). All of the water level data presented with this study was obtained from the MBMG GWIC database. This study supplemented the MBMG-GWIC dataset by installing continuous water level recording transducers in numerous wells and the shallow piezometers in the central part of the valley.

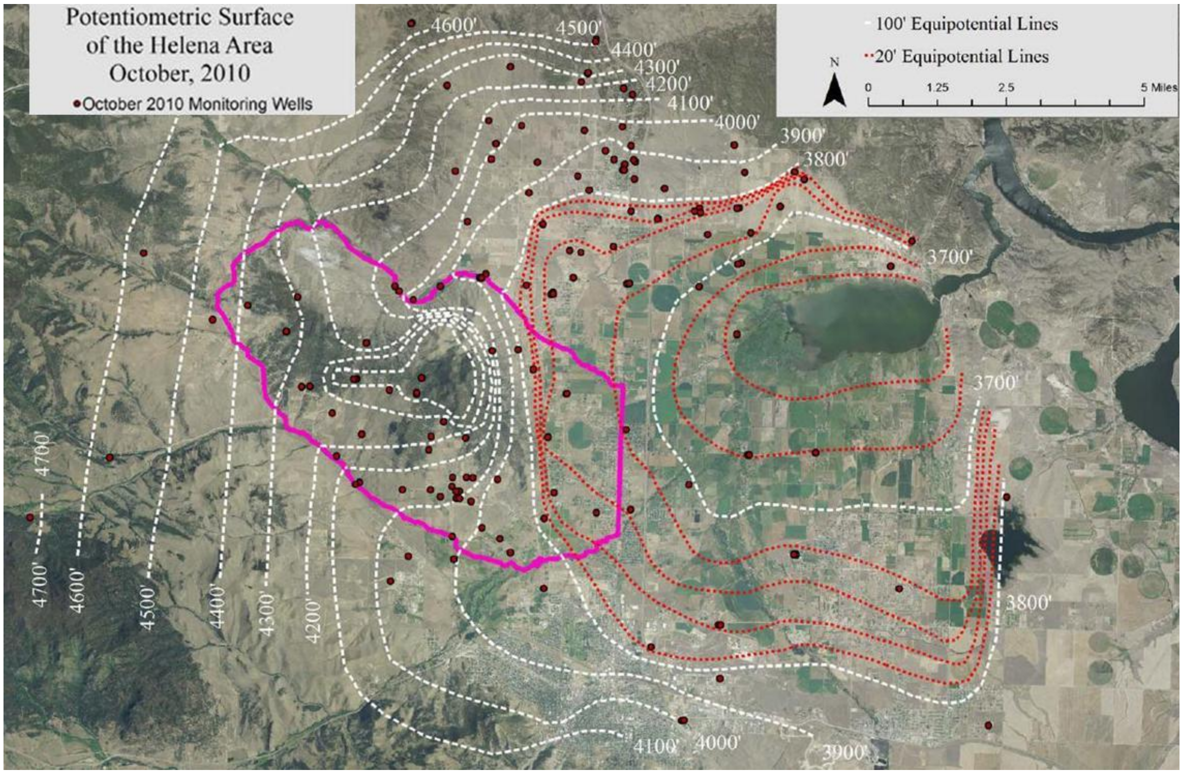


Figure 8-1 – Regional Ground Water Potentiometric Surface Map (Bobst et al., 2013).
Regional ground water flow map for the Helena Valley and surround area.

The local ground water potentiometric surface changes seasonally in response to annual recharge events. A primary source of recharge is interpreted as stream loss during spring runoff, with recharge rates decreasing after peak flows. This system is complicated by irrigation diversions, which typically lose water from the base of the channel similar to streams. The Helena Valley system also is significantly impacted by stream loss from the Helena Valley Irrigation Canal, which imports water into the valley from outside of the watershed.

The snowpack from the Winter of 2009-2010 and high spring precipitation created significant recharge levels to local wells, with this most evident in bedrock wells outside of the Helena Valley. Spring runoff in 2010 resulted in flooding in the western part of the Helena Valley with surface water flooding in low elevation areas and basement flooding from rising ground water levels. The primary impacted area was the west-central part of the valley in the Tenmile Creek floodplain. The changes in water levels in this area from pre-flooding to flooding conditions are depicted in Figure 8-2, with the floodplain where flooding occurred noted. During the high runoff period in June, the water table surface gradient increased with the rising water table. The difference between bedrock wells and alluvial wells is also visible for the area where Silver Creek enters the valley. The wells installed into bedrock indicate a greater gradient than in the valley, where high permeability unconsolidated aquifer materials are present and the water table surface becomes flatter as the local gradient decreases.

Hydrographs were prepared for all of the primary monitoring wells in this study, and are included in Appendix C. The hydrographs include an assessment of vertical gradients at well cluster locations. The assessment method for vertical gradients also determines hydraulic communication between upper and lower wells when hydrographs indicate different responses to recharge events. Vertical gradients for each location, as observed from the hydrographs in Appendix C, are consistent with previous studies noting the upward vertical gradient in the central part of the valley (Moreland & Leonard, 1980; Briar & Madison, 1992).

During the last year of the project, continuous water level data was collected by datalogging pressure transducers installed in wells and well clusters across the central part of the valley, at locations shown in Figure 8-3. The data was collected at one hour intervals so that the response to surface recharge events could be compared between locations. Additional transducers were located in select wells in the western part of the valley to specifically characterize the connection between runoff in Tenmile Creek and the alluvial aquifer system. The hydrographs from the wells are depicted in Figure 8-4. While the 2010-2011 water year had significant runoff resulting in flooding in the Helena Valley, transducers were not installed in the wells at that time to record data characterizing the relationship between surface runoff rates and ground water levels. The wells were instrumented for the 2011-2012 water year; however, there were no significantly high runoff rates limiting the effectiveness of the assessment. The hydrograph data shows the effects of irrigation season on water levels, but does not provide sufficient data to evaluate the effects of additional runoff water into the system. For wells in the central part of the valley, the hydrographs generally show a steady decline in water levels during winter months followed by rapid rises in water levels after irrigation season starts. The airport south and airport west wells, located upgradient from the irrigation canal, show no influences from irrigation season.

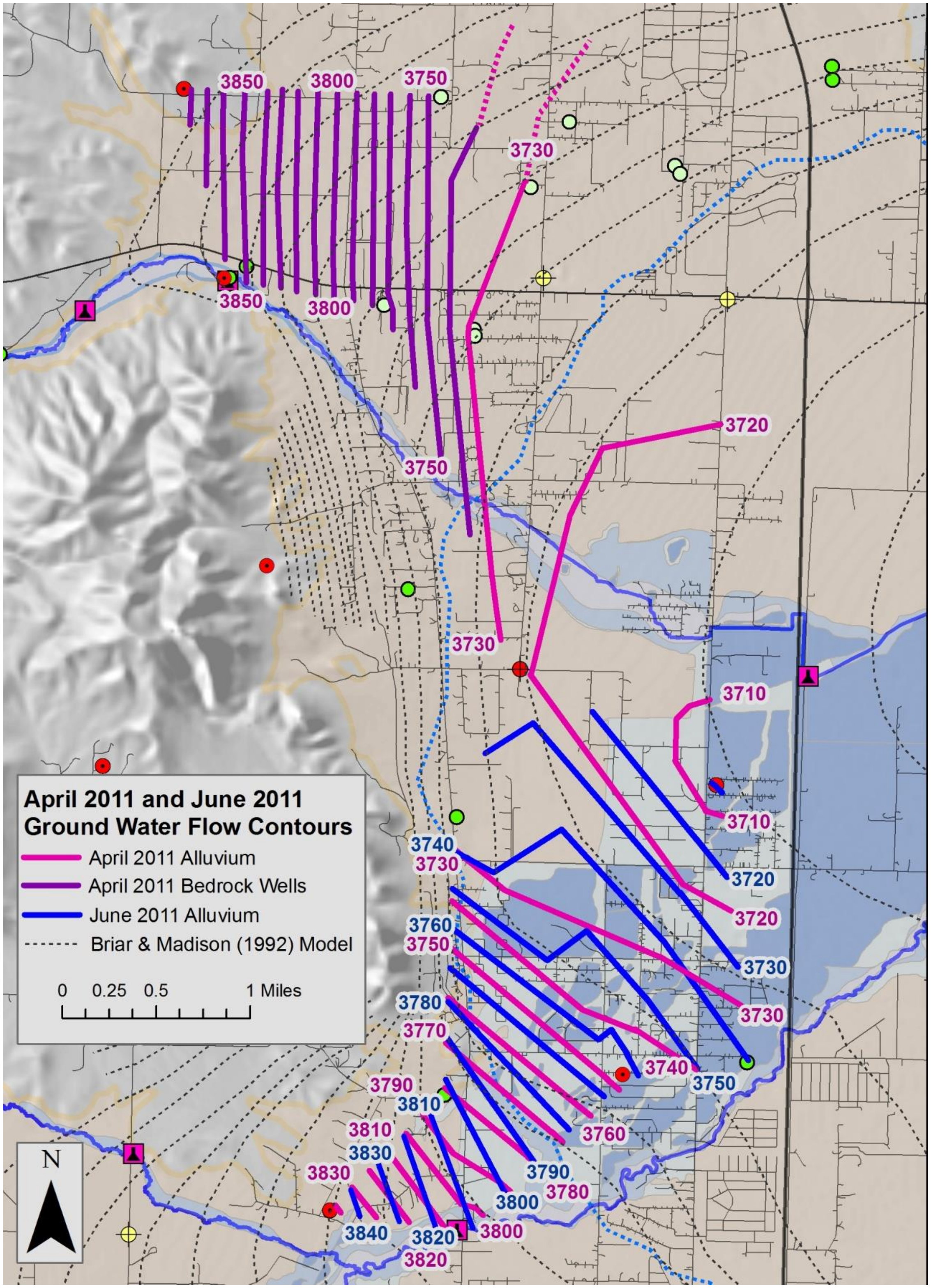


Figure 8-2 – West Valley Ground Water Potentiometric Surface Map Spring 2011
Ground water flow map for the West Helena Valley during Spring 2011 runoff.

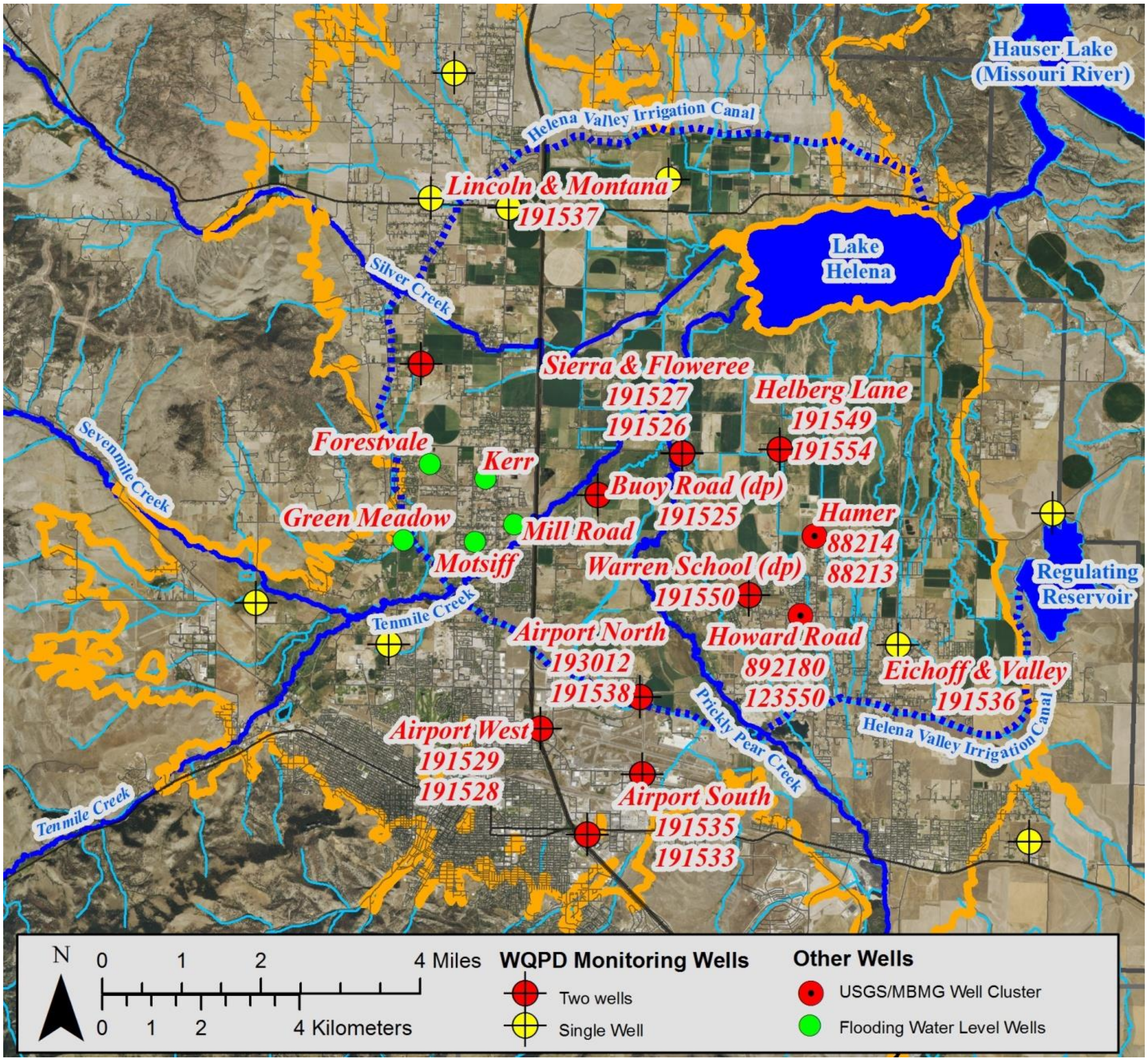


Figure 8-3 –Helena Valley Continuous Water Level Monitoring Locations
Regional ground water flow map for the Helena Valley and surround area.

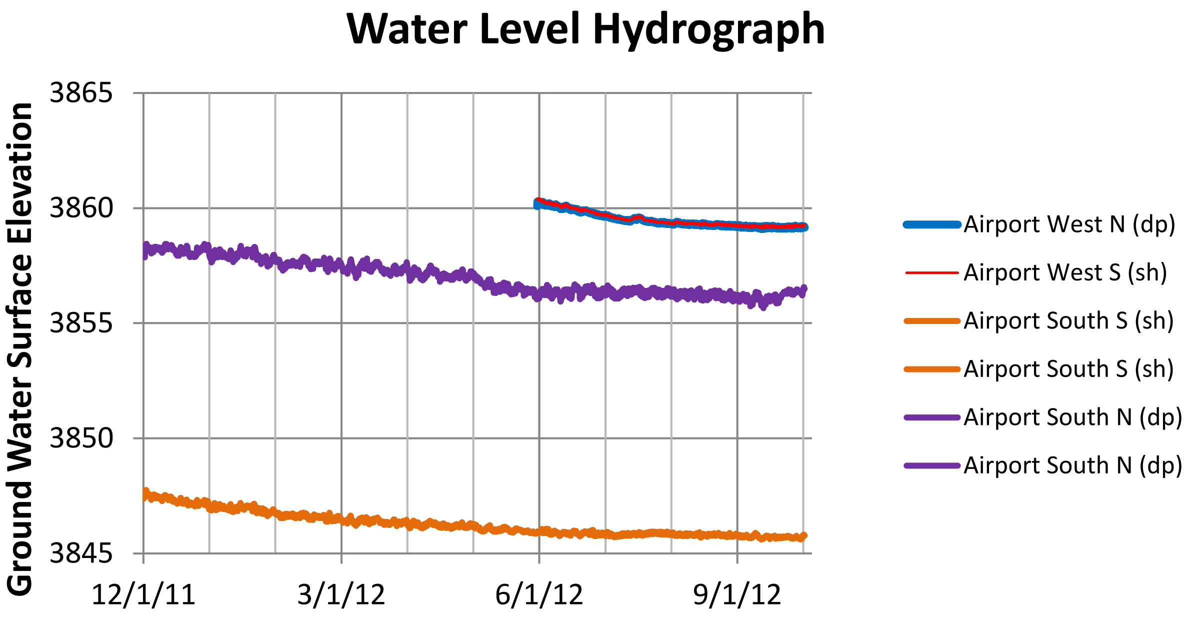


Figure 8-4 – Hydrograph of Helena Valley Continuous Water Level Monitoring

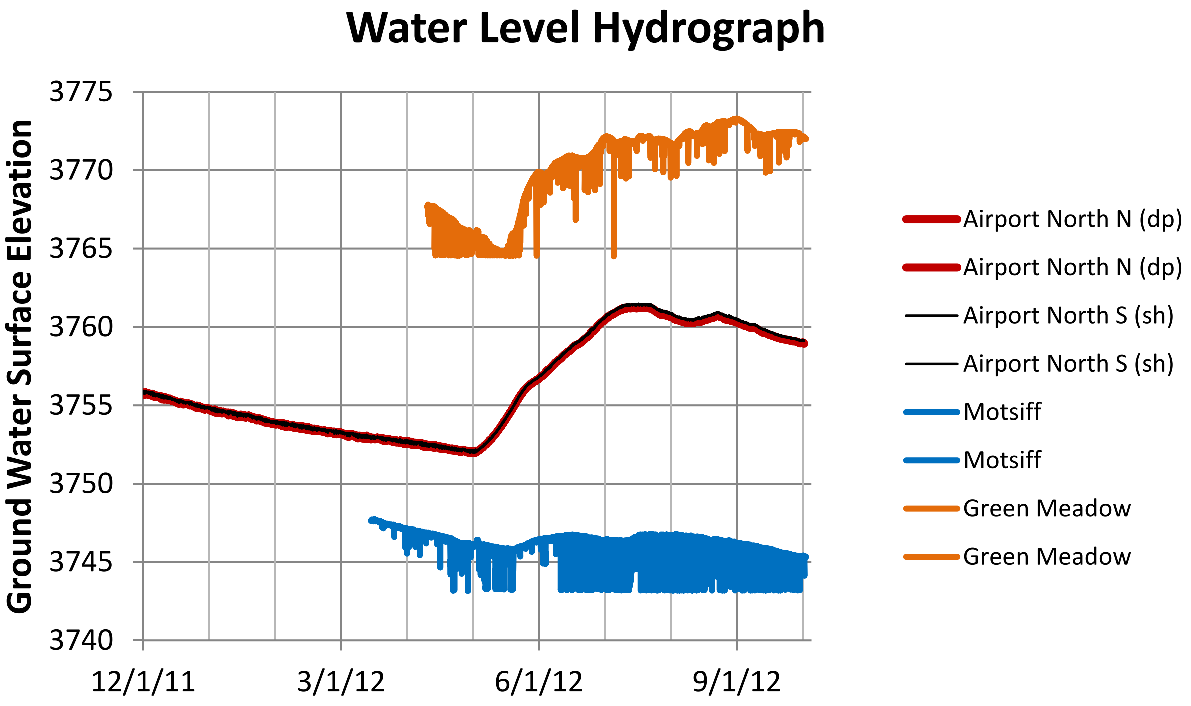


Figure 8-4 –Hydrograph of Helena Valley Continuous Water Level Monitoring (continued)

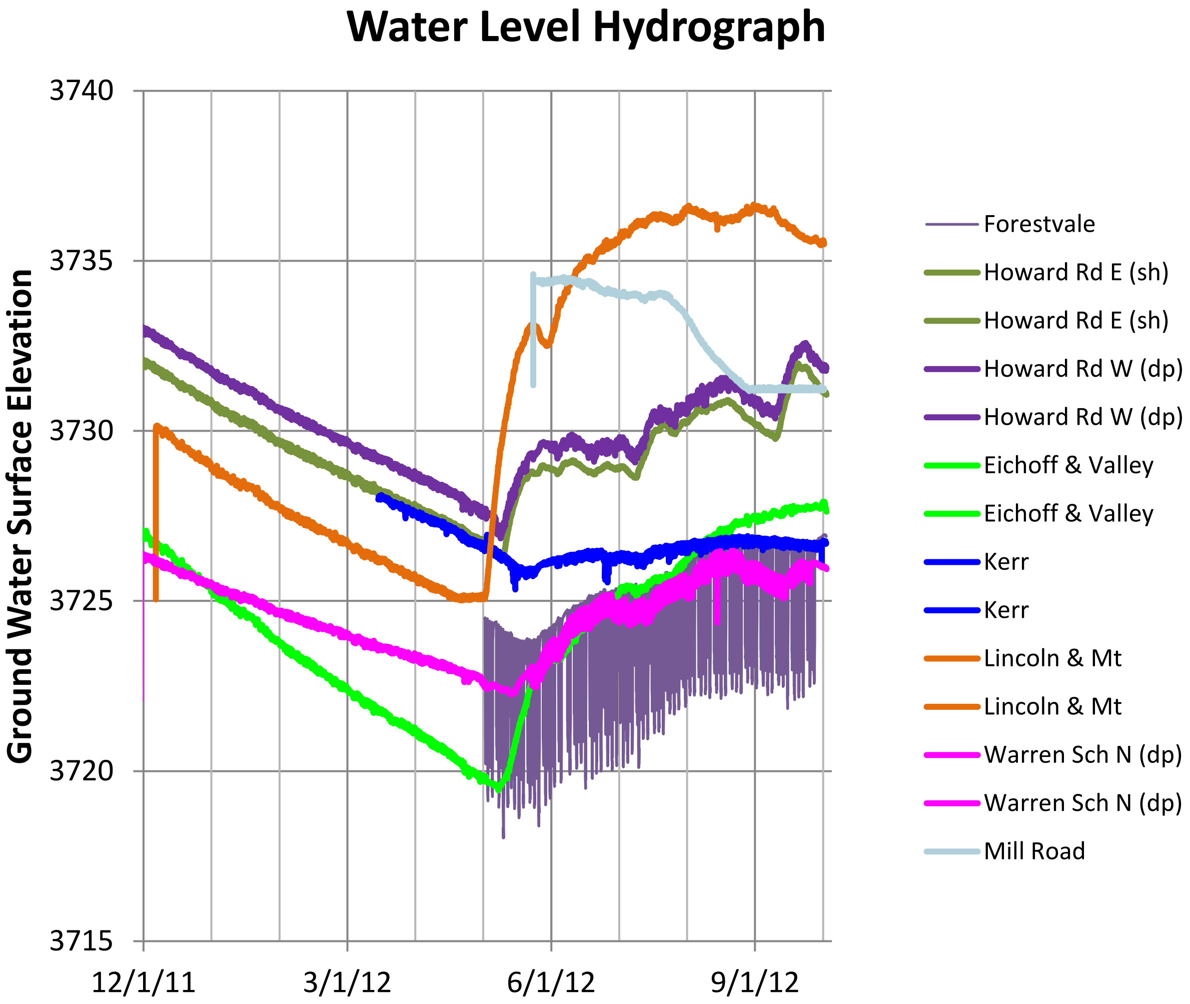


Figure 8-4 –Hydrograph of Helena Valley Continuous Water Level Monitoring (continued)

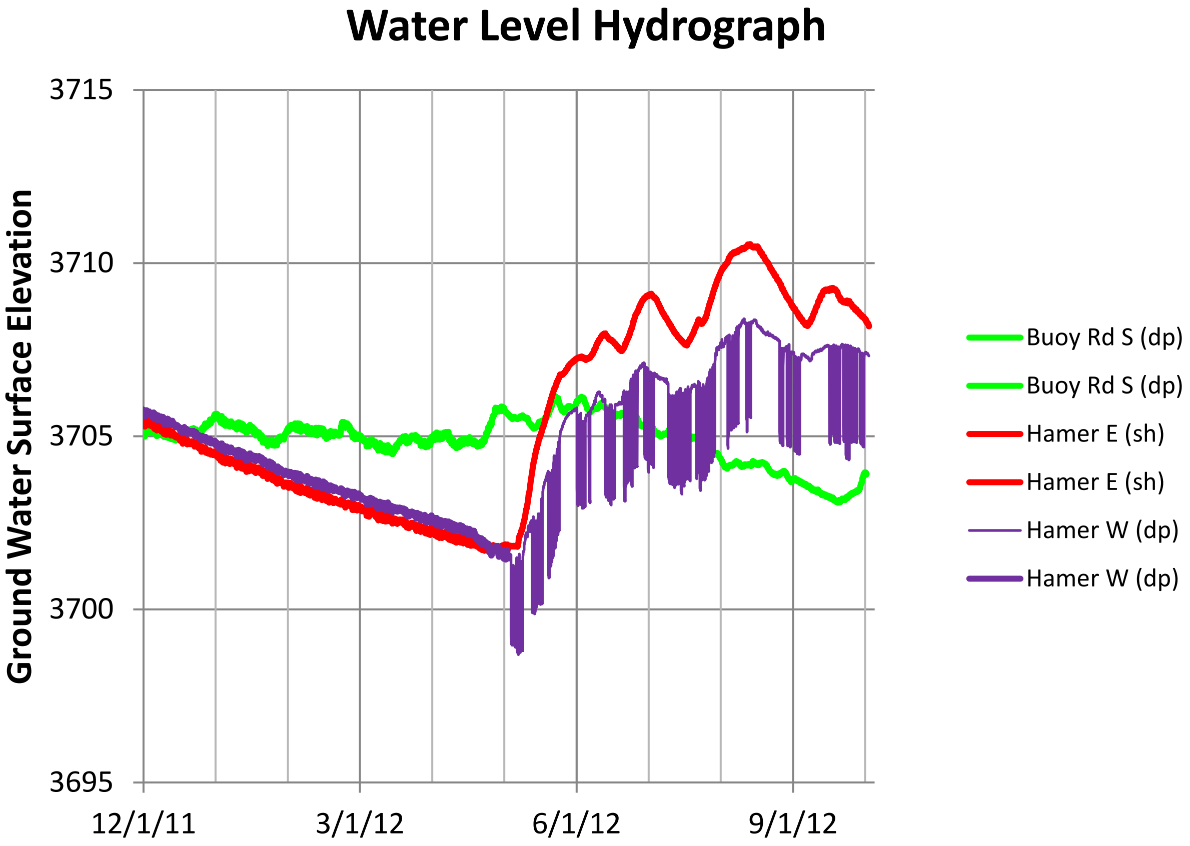


Figure 8-4 –Hydrograph of Helena Valley Continuous Water Level Monitoring (continued)

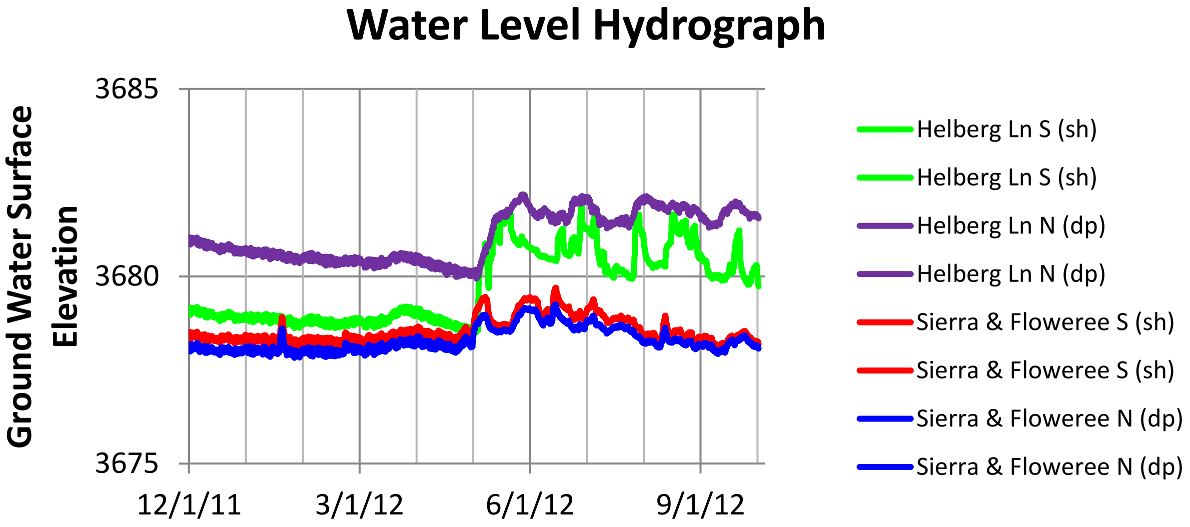


Figure 8-4 –Hydrograph of Helena Valley Continuous Water Level Monitoring (continued)

Water levels for the piezometers sites in the central valley were collected using the datalogging pressure transducers. Piezometers from previous MBMG studies were not instrumented with transducers since large datasets generated during the MBMG study allowed for interpretation of the interaction of surface and ground water at these sites. All piezometers water level data was correlated with surface water flow elevation data at each location. The plots for each site are included with Appendix F.

The results for each stream are as follows:

Tenmile Creek Sites:

Country Club Lane (T-24) – The ground water elevation mimics the surface water elevation; however, the surface water monitoring location is upgradient from the piezometers, so the actual elevation difference is not known. However, the link to surface water elevations shows a connection of surface water with shallow ground water at this location

Green Meadow Road (T-4) – The ground water elevation is below the surface water elevation, and can be seen to drop in elevation during the summer. This connection shows that surface water is recharging ground water at this point, with the stream perched above the ground water surface during the majority of the year.

Sierra Road (T-6) – The ground water elevation is above the surface water elevation at this site, inferring that ground water provides recharge to stream in this area. The site is located within an agricultural area that utilizes significant irrigation canals which provide recharge to the shallow ground water system during the irrigation season.

<u>Tenmile Creek Conclusion</u> – The stream loses water as it enters the Helena Valley, then begins gaining again towards the central part of the valley.

Prickly Pear Creek Sites:

Canyon Ferry Road (P-5) – The ground water elevation is below the surface water elevation, and can be seen to decline during the summer. This connection indicates that surface water is recharging ground water at this location, with the stream generally perched above the water table.

Sierra Road (P-10) – The ground water elevation is consistently above the surface water elevation, suggesting that ground water provides recharge to surface water in this area. This site is located within an agricultural area that utilizes significant irrigation canals providing recharge to the shallow ground water system. This site is located near the T-6 site on Tenmile Creek, but at a lower elevation, inferring that a component of flow in the shallow ground water system moves from Tenmile Creek east towards Prickly Pear Creek.

Winterbourne Property (P-12) – The ground water elevation is generally above the surface water elevation; however, during late summer it approaches the same elevation. This data infers that ground water is recharging the stream in this area near Lake Helena, consistent with the conceptual flow model for the valley.

<u>Prickly Pear Creek Conclusion</u> - The stream loses water as it enters the Helena Valley, then begins gaining again towards the central part of the valley.

Silver Creek Sites:

Silver Creek Estates (SC-1) – The ground water elevation is consistently below the surface water elevation; however, there does not appear to be a strong correlation between changes in surface water flow and ground water elevations. The stream is perched above the ground water system and will likely provide recharge; however, the fluctuations in ground water elevation suggest that additional recharge to this system occurs.

Smelko Property (SC-2) – The ground water elevation is below the surface water elevation in a similar trend to SC-1. However, during dry periods in late Summer, Silver Creek does not flow at this location. Shallow ground water is still present indicating the separation of the ground water system with surface waters in this area.

<u>Silver Creek Conclusion</u> – The stream is perched above ground water and loses flow to the ground water system; however, the ground water system is not strongly linked to surface waters with recharge from one or more sources other than surface water. This is interpreted to be the bedrock aquifer system, which receives recharge from direct infiltration of precipitation and snowmelt, especially during winter months; and from stream loss from Silver Creek upgradient from the study locations.

Central Valley Drain Site:

Arrowhead Road (D2 Drain) – The ground water elevation is consistently above the surface water elevation, showing that ground water recharges surface water at this site. This is expected since the drain was installed to lower ground water elevations in the area.

Sevenmile Creek Sites:

Birdseye Road (7M-1) – The ground water elevation is above the surface water elevation, and mimics the surface water elevation profile. This indicates that ground water provides recharge to the stream at this location.

Head Lane (7M-3) – the ground water is near the surface water elevation, and drops slightly below it during late summer. The stream is interpreted to be in communication with ground water at this location, with the recharge/discharge relationship to ground water varying with flow rates and ground water levels.

<u>Sevenmile Creek Conclusion</u> – The stream is interpreted to represent a discharge point from the bedrock aquifer system in the area

9.0 Isotope Hydrogeology

Most elements occur naturally in more than one isotope, with each isotope defined by the number of neutrons present in the atomic nucleus. Stable isotopes are present at relatively fixed ratios, while the ratios in radioactive elements change over time. This project included two stable isotope assessments: oxygen and hydrogen (deuterium) in water and nitrogen and oxygen in dissolved nitrate in ground water.

Natural hydrologic and biologic processes alter the isotopic ratios of the pairs. For water isotopes, during the transition between gas to liquid phases, heavier isotopes will concentrate in the liquid phase. For example, as rain forms during condensation in clouds, the heavier isotopes are more likely to condense than lighter molecules, so the isotopic ratio of the rainfall is biased to the heavier fraction at the beginning of the rain event. For nitrate, microbiologically mediated biodegradation processes result in enrichment of the heavier isotopes.

All isotope samples were collected during normal water sampling events following the same field protocols. All analyses were completed at Isotech Laboratories, Inc., in Champaign, Illinois. In addition to data from this project, additional data was obtained from local USGS studies (Thamke, 2000) and MBMG studies (Waren et al., 2012; Bobst et al., 2013). All stable isotope concentration results are reported in relative percentages of the ratios, in parts per thousand (‰) rather than percent as part per hundred (%).

9.1 Water Isotopes

The two most common isotopes of hydrogen are ^{1}H and ^{2}H (deuterium), while the most common isotopes of oxygen are ^{16}O and ^{18}O. The relative concentration ratio between hydrogen and oxygen isotopes is generally consistent, and approximated relative to a global standard as the meteoric water line (MWL, see Figure 9-1). Local geography results in local meteoric water lines (LMWL) parallel, but offset from the primary meteoric water line. In order to establish a LMWL, abundant seasonal precipitation data is required. While such a dataset has not been assembled for the Helena study area, Gammons et al (2006) developed a LMWL for the Butte area as part of a study of water isotopes in mine pit lakes. The water isotope dataset for this study includes surface water samples, shallow ground water from piezometers adjacent to streams, and from ground water wells.

9.1.1 Surface Water Isotope Data

Surface water samples were collected for analyses during January and August 2012 to assess the seasonal variation in isotopic signature. The surface water isotope data is summarized in Table 9-1, and the sample locations are depicted in Figure 9-1. The data is plotted in Figure 9-2. The surface water dataset is currently limited and insufficient to characterize seasonal variations in isotopic signatures. Specifically, more data is needed to determine the relationship between isotopic fractions in precipitation and runoff, and how surface water recharge can be tracked through the ground water system. However, the data is representative of conditions at the times that samples were collected. From the surface water isotope dataset, the following observations can be made:

- The results for the Lake Helena Causeway show the heaviest data result. The large deviation from the other results is interpreted to occur from lake evaporation, which enriches the water in heavier isotope fractions (Kendall & McDonnel, 1998). Data for the Causeway from March and April 2010 (Waren et al., 2012) do not show the effects of evaporation.
- Results from January 2012 are generally heavier than other data results. This is interpreted to result from snowmelt as a recharge source, resulting in water depleted of lighter isotope fractions.
- The data for the two Sevenmile Creek sites show similar results in both January and August, suggesting that the flow monitored in Sevenmile Creek during the summer is derived from snowmelt recharge into the bedrock aquifer system, which recharges flow in the stream
- The data for the D2 Drain show similar results in both January and August, suggesting a similar recharge source for the flow.

Table 9-1 Surface Water Oxygen and Hydrogen Isotope Data

Sample Site	**January 2012**		**August 2012**	
	δD H_2O ‰	**δ^{18}O H_2O** ‰	**δD H_2O** ‰	**δ^{18}O H_2O** ‰
7M-1	-146.3	-18.75	-145.7	-18.51
7M-3	-145.8	-18.58	-143.1	-18.14
T-24	-141.3	-17.85	-139.6	-17.51
T-4	-143.3	-18.10	-139.7	-17.52
T-6	-142.4	-18.22	-136.7	-17.16
P-1			-139.8	-17.67
P-2			-139.0	-17.71
P-5	-141.7	-17.91	-137.8	-17.47
P-10	-141.4	-17.86	-137.9	-17.35
P-12	-141.2	-17.92	-137.5	-17.22
P-13			-128.1	-15.43
SC-1	-145.6	-18.48	-139.6	-17.34
SC-2	-144.7	-18.44		
D2B	-137.8	-17.13	-136.4	-17.23

Table 9-2 Surface Water Oxygen and Hydrogen Isotope Data from MBMG Studies

Sample Site	Gwic Id	Sample Date	δD H_2O ‰	$\delta^{18}O$ H_2O ‰
HVID D-2-2.3-1 (DA)	255052	3/2/2010	-133.2	-16.84
Lake Helena Causeway	256969	3/3/2010	-136.7	-17.45
Lake Helena Causeway	256969	4/7/2010	-134.6	-17.05
HVID D-2-0.7-1 (DD)	255071	4/7/2010	-134.6	-17.02
HVID-1 (McHugh Ln)	256972	5/4/2010	-135.4	-17.13

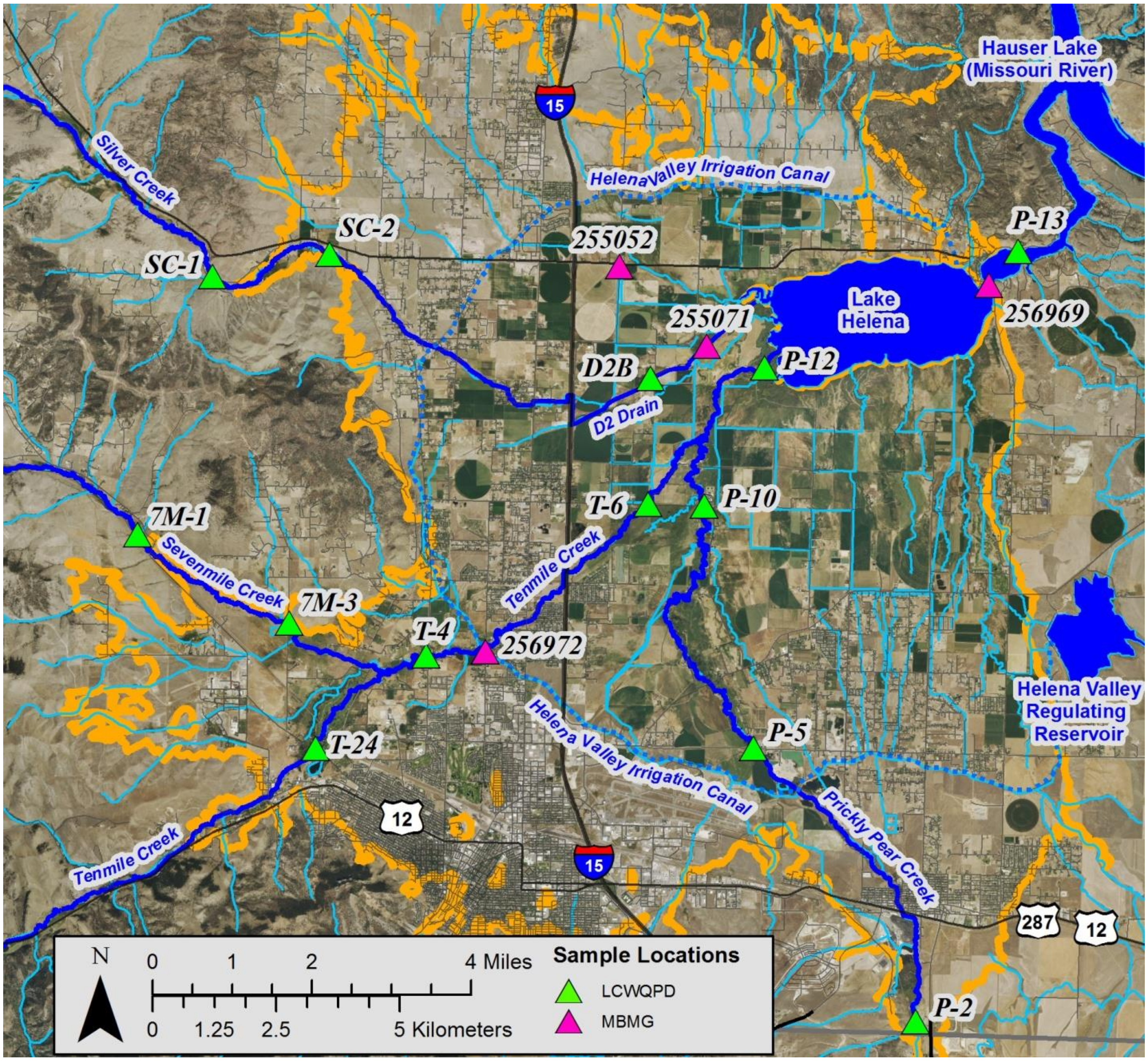


Figure 9-1 Surface Water Isotope Sample Locations

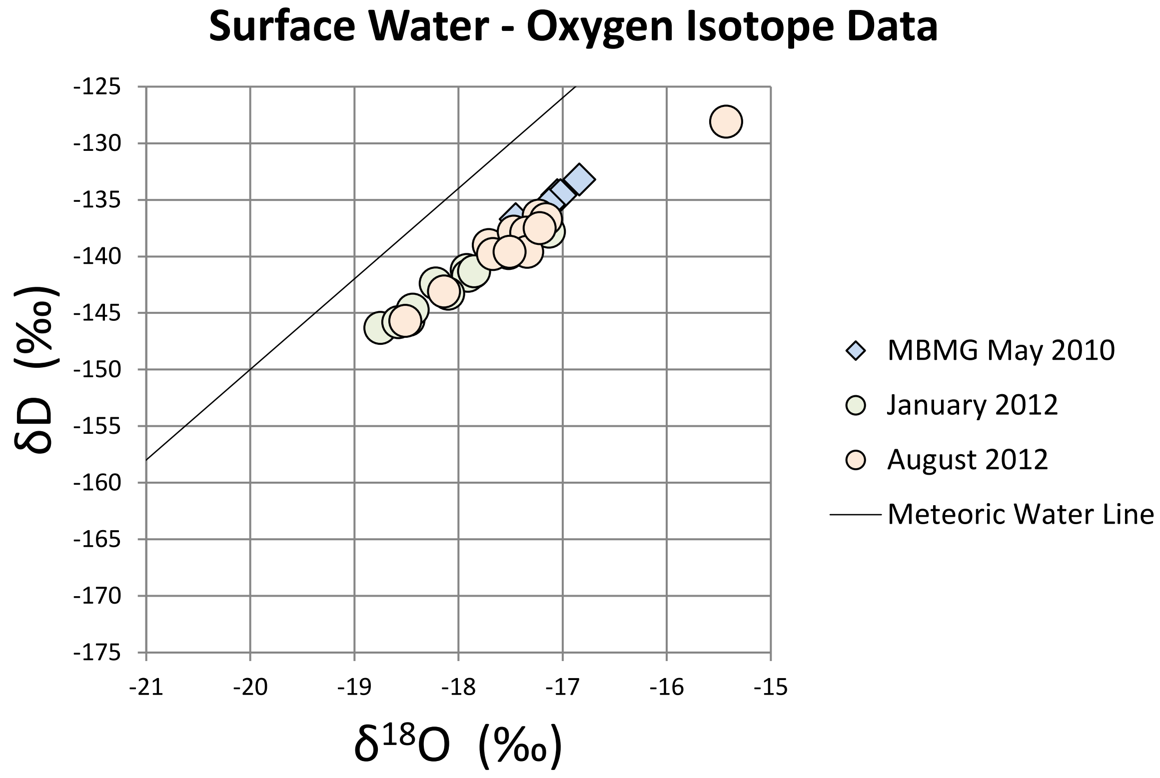


Figure 9-2 Surface Water Oxygen and Hydrogen Isotope Data
Data for specific locations is included with plots in Appendix F.

9.1.2 Piezometer Ground Water Isotope Data

Water isotope samples were collected concurrent with the January, April and September 2012 piezometer sampling events. The data from the piezometers sampling events is summarized in Table 9-3, and plotted related to the surface water data in Figure 9-3. The data for each specific site is visible in the data summary plots in Appendix F. The results generally show that the ground water isotopes for each site are generally similar seasonally; however, the correlation with surface water data provides evidence for stream gain or loss at the locations.

Table 9-3 Piezometer Water Oxygen and Hydrogen Isotope Data

Sample	**January 2012**		**April 2012**		**September 2012**	
Site	**δD H_2O**	**$\delta^{18}O$ H_2O**	**δD H_2O**	**$\delta^{18}O$ H_2O**	**δD H_2O**	**$\delta^{18}O$ H_2O**
P-7M1	-150.2	-18.63	-150.0	-18.67	-146.8	-18.18
P-7M3	-142.7	-17.92	-142.1	-17.94	-141.9	-17.65
P-T24	-141.0	-18.23	-141.1	-17.99	-139.8	-17.87
P-T4	-140.4	-18.03	-140.5	-18.02	-139.9	-17.58
P-T6	-142.7	-18.19	-138.8	-17.92	-137.2	-17.16
P-P5	-141.1	-17.93	-139.5	-17.83	-138.4	-17.43
P-P10	-142.5	-18.16	-141.2	-18.03	-141.8	-17.91
P-P12	-147.9	-18.88	-146.7	-18.68	-147.1	-18.74
P-SC1	-144.4	-17.88	-144.1	-18.13	-144.7	-18.17
P-SC2	-142.9	-17.69	-142.9	-18.03	-143.3	-17.88
P-D2	-136.1	-17.13	-135.4	-16.86	-136.3	-16.95

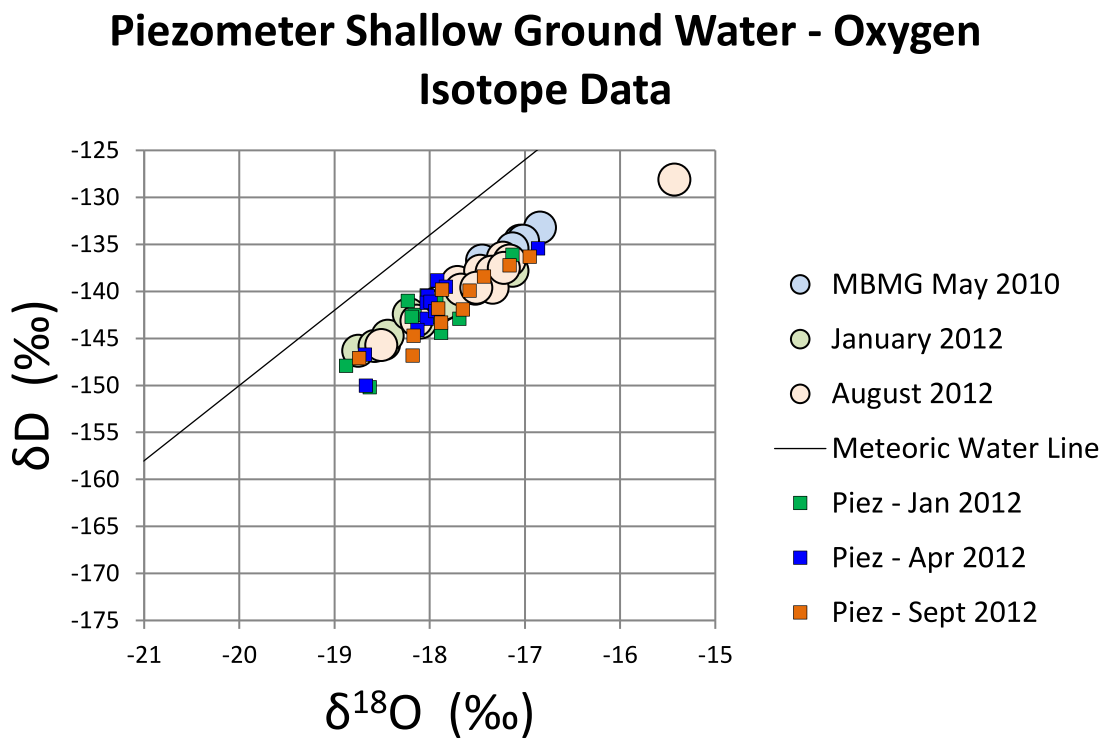


Figure 9-3 Piezometer Ground Water Oxygen and Hydrogen Isotope Data
Data for specific locations is included with plots in Appendix F.

9.1.3 Well Ground Water Isotope Data

Ground water isotope samples were collected with the Late Fall sampling event, the biased Spring 2012 sampling, and from East Bench sites in Fall 2012 (Figure 3-3). The data is summarized in Table 9-4, and plotted Figure 9-4. The data results show generally similar results to shallow ground and surface water, supporting conclusions of recharge from surface water runoff to the shallow ground water system. However, additional data showing lighter fractions are associated with wells in the Tertiary geologic formation.

Table 9-4 Well Ground Water Oxygen and Hydrogen Isotope Data

Gwic Id	**Site Name**	**Aquifer**	**Sample Date**	**d^{18}O H_2O ‰**	**dD H_2O ‰**	**Data Source**
64798	*Private Well*	110UDFD	5/25/2010	-17.49	-137.4	MBMG
180976	*Private Well*	400SPKN	5/25/2010	-19.18	-153.5	MBMG
187438	*Private Well*	400SPKN	5/25/2010	-17.5	-139.8	MBMG
194435	*Private Well*	400SPKN	5/25/2010	-19.49	-154.6	MBMG
191532	LCWQPD - North Hills	111ALVM	6/1/2010	-19.36	-153.5	MBMG
5854	USGS - Masonic West	110ALVM	6/2/2010	-17.77	-142.5	MBMG
62523	*Private Well*	110ALVM	4/7/2010	-19.1	-148.6	MBMG
62369	*Private Well*	211SCGR	4/15/2010	-17.63	-142	MBMG
65615	*Private Well*	211SCGR	4/15/2010	-18.15	-146.2	MBMG
65088	*Private Well*	110ALVM	5/27/2010	-18.02	-140.8	MBMG
191555	LCWQPD - Applegate & Norris N (sh)	110ALVM	6/1/2010	-16.89	-133.7	MBMG
191524	LCWQPD - Buoy Road N (sh)	110 ALVM	11/17/2011	-15.64	-130.1	This Study
191525	LCWQPD - Buoy Road S (dp)	110 ALVM	11/17/2011	-16.37	-134.1	This Study
191526	LCWQPD - Sierra & Floweree N (dp)	110 ALVM	11/16/2011	-17.41	-138.5	This Study
191527	LCWQPD - Sierra & Floweree S (sh)	110 ALVM	11/16/2011	-17.41	-137.2	This Study
191530	LCWQPD - Regulating Reservoir	120 SDMS	11/17/2011	-17.49	-150.0	This Study
191531	LCWQPD - Motor Pool W (dp)	121 SDMS	11/17/2011	-20.01	-160.0	This Study
191532	LCWQPD - North Hills	110 ALVM	11/14/2011	-19.10	-153.5	This Study
191533	LCWQPD - Airport South N (dp)	120 SDMS	11/28/2011	-20.45	-163.1	This Study
191534	LCWQPD - Gravel Pit	110 ALVM	11/14/2011	-18.24	-147.7	This Study
191535	LCWQPD - Airport South S (sh)	120 SDMS	11/28/2011	-17.73	-143.3	This Study
191536	LCWQPD - Eichoff & Valley	110 ALVM	11/29/2011	-17.35	-138.1	This Study
191537	LCWQPD - Lincoln & Montana	110 ALVM	12/6/2011	-17.83	-140.5	This Study
191538	LCWQPD - Airport North N (dp)	110 ALVM	11/28/2011	-17.48	-139.2	This Study
191539	LCWQPD - Horseshoe Bend	110 ALVM	11/15/2011	-17.96	-144.1	This Study
191540	LCWQPD - Motor Pool E (sh)	120 SDMS	11/17/2011	-18.74	-152.3	This Study
191548	LCWQPD - Prairie Nest & Lone Prairie	120 SDMS	12/7/2011	-19.32	-150.8	This Study
191549	LCWQPD - Helberg Lane S (sh)	110 ALVM	11/16/2011	-17.74	-139.9	This Study
191550	LCWQPD - Warren School N (dp)	110 ALVM	11/29/2011	-17.09	-136.2	This Study

Table 9-4 Well Ground Water Oxygen and Hydrogen Isotope Data (continued)

Gwic Id	Site Name	Aquifer	Sample Date	d^{18}O H_2O ‰	dD H_2O ‰	Data Source
191551	LCWQPD - Warren School S (sh)	110 ALVM	11/29/2011	-16.69	-134.4	This Study
191554	LCWQPD - Helberg Lane N (dp)	110 ALVM	11/16/2011	-17.41	-138.6	This Study
191555	LCWQPD - Applegate & Norris (sh)	110 ALVM	11/15/2011	-16.91	-136.6	This Study
191557	LCWQPD - Head Lane	400 SPKN	11/16/2011	-19.32	-151.7	This Study
193012	LCWQPD - Airport North S (sh)	110 ALVM	11/28/2011	-17.14	-137.1	This Study
257063	Applegate & Norris (dp) MBMG	110 ALVM	11/15/2011	-16.44	-132.7	This Study
257064	Collins Road MBMG	110 ALVM	11/14/2011	-17.59	-141.8	This Study
88213	Hamer W (dp)	110 ALVM	11/29/2011	-17.47	-138.4	This Study
88214	Hamer E (sh)	110 ALVM	11/29/2011	-17.56	-140.2	This Study
123550	Howard Rd W (dp)	110 ALVM	11/29/2011	-17.70	-139.5	This Study
191528	LCWQPD - Airport West N (dp)	120 SDMS	5/23/2012	-17.06	-136.6	This Study
191529	LCWQPD - Airport West S (sh)	120 SDMS	5/23/2012	-17.59	-141.8	This Study
n/a	*Private Well*	110 ALVM	5/2/2012	-16.81	-135.6	This Study
n/a	*Private Well*	400 SPKN	5/3/2012	-17.04	-141.6	This Study
n/a	*Private Well*	110 ALVM	5/23/2012	-17.45	-137.4	This Study
n/a	*Private Well*	110 ALVM	5/29/2012	-17.61	-139.4	This Study
n/a	*Private Well*	110 ALVM	5/29/2012	-17.18	-137.4	This Study
5756	*Private Well*	110 ALVM	5/31/2012	-17.53	-142.0	This Study
258900	*Private Well*	121 SDMS	9/18/2012	-20.31	-165.7	This Study
244157	*Private Well*	121 SDMS	9/18/2012	-20.82	-170.8	This Study
214268	Emerald Ridge Park Well	121 SDMS	9/18/2012	-19.92	-164.2	This Study

9.1.4 Water Isotope Conclusions and Data Gaps

The water isotope data from the monitoring wells seems to show that the majority of waters are recharged by surface water and local precipitation, consistent with the regional conceptual model for the Helena Valley. However, some results associated with warm waters show lighter factions than other waters, suggesting that this is related to a different recharge source, interpreted as deep thermal ground waters. The mixing conclusion is tentative from this data alone, and requires a more comprehensive sampling program to confirm. As a result, conclusions from the isotope assessment support results from other assessment methods presented in this report.

For the surface water and piezometers data, with data from individual sites included in Appendix F, the following conclusions can be made:

Tenmile Creek Sites:
Country Club Lane (T-24) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water
Green Meadow Road (T-4) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water

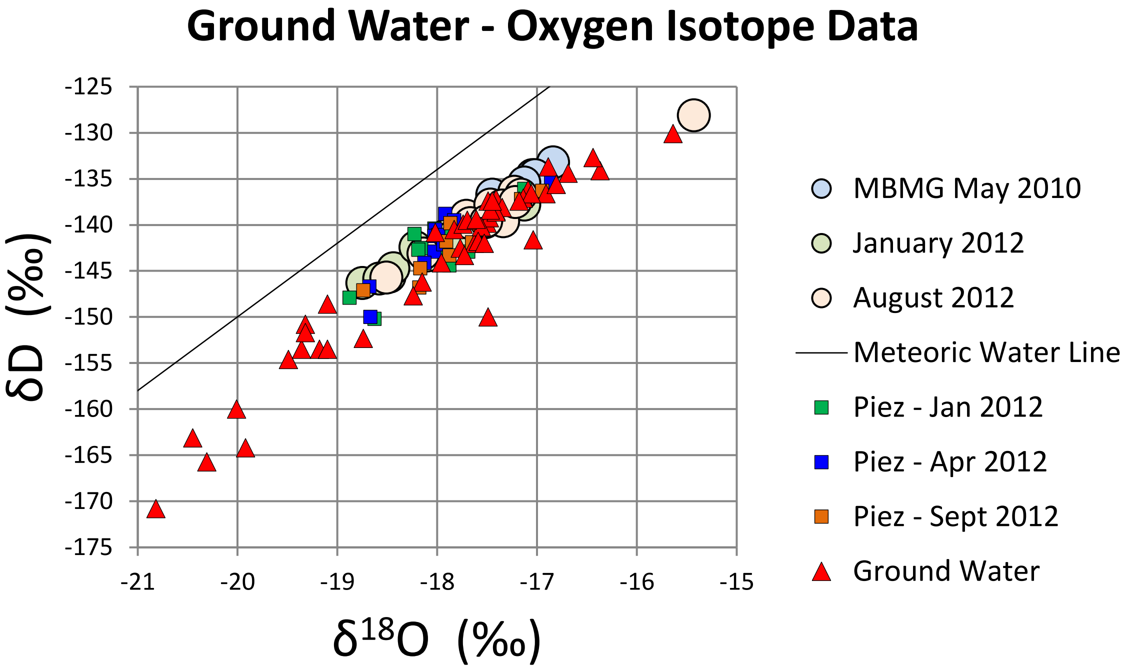


Figure 9-4 Ground Water Oxygen and Hydrogen Isotope Data
Data for specific locations is included with plots in Appendix F.

Sierra Road (T-6) – While there is more variability than at other sites, surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water at this site.

Prickly Pear Creek Sites:
Canyon Ferry Road (P-5) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water.
Sierra Road (P-10) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water.
Winterbourne Property (P-12) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water.

Silver Creek Sites:
Silver Creek Estates (SC-1) – The ground water results are consistent with the January surface water data but not the August data. This is interpreted to support the limited connection of the surface water system with shallow ground water in the area.
Smelko Property (SC-2) – The ground water results are consistent with the January surface water data. Unfortunately, since there was no flow in August there is no data for this time at this site.

Valley Drain Site:
Arrowhead Road (D2 Drain) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water.

Sevenmile Creek Sites:
Birdseye Road (7M-1) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water. The results generally show lighter fractions, interpreted as the result of recharge to the local aquifer from snowmelt.
Head Lane (7M-3) – Surface water and piezometers data are similar, supporting conclusion of connection between surface water and shallow ground water

9.2 Nitrate Isotopes

The isotopes of nitrogen and oxygen in nitrate can be used to differentiate source of nitrate between ammonium fertilizers and animal waste (Kendall, 1998). This study compiled data with previous studies to assess potential nitrate sources. The nitrate isotope data is summarized in Table 9-5, and plotted in Figure 9-5. The data for specific sites is included with Appendix C. The data generally reflect an animal waste source, not differentiated between agricultural manure fertilizers and septic system discharge. A single sample, from the central part of the valley near Silver Creek, is interpreted to result from fertilizers in the upgradient area.

Table 9-5 Ground Water Nitrogen and Oxygen Isotopes of Nitrate Data

Site ID	Site Name	Sample Date	Aquifer	d^{18}O NO$_3^-$ ‰	d^{15}N NO$_3^-$ ‰	Max Nitrate
						USGS
62006	*Private Well*	5/13/97	420 HELN	-3.99	8.98	24.00
62369	*Private Well*	5/12/97	211 SCGR	1.23	6.13	2.60
134705	*Private Well*	5/13/97	420 HELN	-2.68	9.32	6.90
156392	*Private Well*	5/13/97	211 BLDB	3.48	6.33	5.40
65389	*Private Well*	5/13/97	420 SPKN	-3.75	6.39	3.20
706018	*Private Well*	5/12/97	211 SGVH	-1.56	7.91	4.20
120031	*Private Well*	5/13/97	420 HELN	3.36	3.12	0.70
65672	*Private Well*	5/13/97	420 MRSH	-1.9	6.05	10.00
132822	*Private Well*	5/13/97	420 SPKN	-6.09	10.04	17.00
						MBMG
152551	*Private Well*	8/20/10	420 GRSN	-11	8	3.65
206026	*Private Well*	8/20/10	420 GRSN	-7.9	8.1	4.18
198749	*Private Well*	8/24/10	420 SPKN	-6.6	7	5.20
180976	*Private Well*	8/24/10	420 SPKN	-11.5	8.5	4.20
187438	*Private Well*	8/20/10	420 SPKN	-5.8	9.3	10.21
65536	*Private Well*	8/9/10	211 SCGR	-10.1	8.3	10.82
706058	*Private Well*	8/9/10	211 SCGR	-4.6	7.6	3.51
706001	*Private Well*	8/9/10	211 SCGR	-3.9	10.2	10.18
62369	*Private Well*	8/9/10	211 SCGR	-3.6	7.4	5.84
65615	*Private Well*	8/9/10	211 SCGR	-10.3	7.5	3.51

Table 9-5 Ground Water Nitrogen and Oxygen Isotopes of Nitrate Data (continued)

Site ID	**Site Name**	**Sample Date**	**Aquifer**	**$d^{18}O$ NO_3^- ‰**	**$d^{15}N$ NO_3^- ‰**	**Max Nitrate**
						MBMG
254703	*Private Well*	8/10/10	211 SCGR	-11.2	8.6	14.36
254703	*Private Well*	9/10/10	211 SCGR	-9.9	9.2	14.36
						(Current Study)
191534	LCWQPD - Gravel Pit	11/14/11	110 ALVM	-6.8	7.2	4.63
191532	LCWQPD - North Hills	11/14/11	110 ALVM	-9.2	7.6	1.14
191555	LCWQPD - Applegate & Norris	11/15/11	110 ALVM	-10.5	7.1	2.40
191539	LCWQPD - Horseshoe Bend	11/15/11	110 ALVM	-5.9	12.5	2.33
191526	LCWQPD – Sierra & Floweree N	11/16/11	110 ALVM	-7.9	5.3	1.32
191554	LCWQPD - Helberg Lane N (dp)	11/16/11	110 ALVM	-8.0	5.6	1.59
191530	LCWQPD - Regulating Reservoir	11/17/11	120 SDMS	-6.4	6.9	6.20
191525	LCWQPD - Buoy Road S (dp)	11/17/11	110 ALVM	-8.6	7.3	3.17
191531	LCWQPD - Motor Pool W (dp)	11/17/11	121 SDMS	-6.4	6.7	6.51
191540	LCWQPD - Motor Pool E (sh)	11/17/11	120 SDMS	-7.5	6.1	5.88
191535	LCWQPD - Airport South S (sh)	11/28/11	120 SDMS	-7.2	6.3	5.32
191533	LCWQPD - Airport South N (dp)	11/28/11	120 SDMS	-7.1	5.7	1.79
88214	LCWQPD - Hamer E (sh)	11/29/11	110 ALVM	-11.1	6.0	1.66
191536	LCWQPD - Eichoff & Valley	11/29/11	110 ALVM	-7.7	8.0	9.90
191550	LCWQPD - Warren School N (dp)	11/29/11	110 ALVM	-8.7	6.6	0.83
n/a	*Private Well*	5/2/12	110 ALVM	-2.9	4.2	8.60
n/a	*Private Well*	5/3/12	420 SPKN	-3.2	11.7	8.40
n/a	*Private Well*	5/23/12	110 ALVM	-5.6	7.3	1.51
191528	LCWQPD - Airport West N (dp)	5/23/12	120 SDMS	-3.8	11.9	10.00
191529	LCWQPD - Airport West S (sh)	5/23/12	120 SDMS	-2.3	11.6	13.80
n/a	*Private Well*	5/29/12	110 ALVM	-5.5	6.6	2.15
n/a	*Private Well*	5/29/12	110 ALVM	-5.0	7.5	5.25
5756	*Private Well*	5/31/12	110 CLVM	-5.4	7.7	4.11

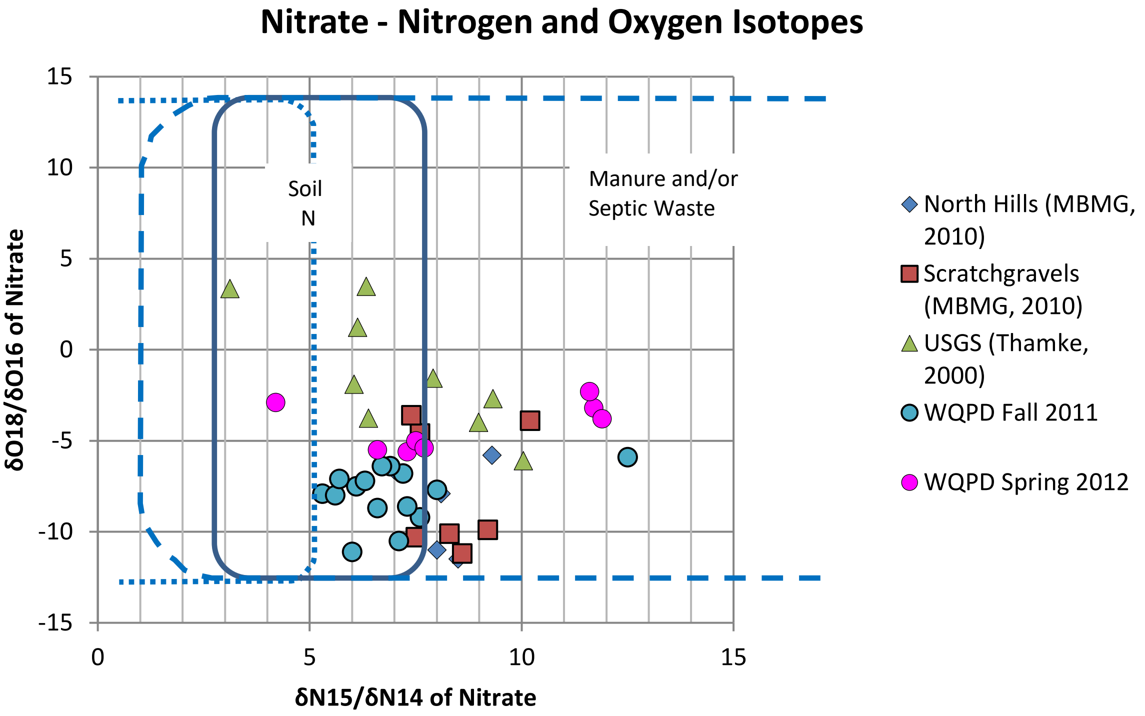


Figure 9-5 Ground Water Nitrogen and Oxygen Isotopes of Nitrate Data

Data for specific locations is included with plots in Appendix C. Plot from Kendall, 1998.

10.0 Ground Water Temperature Assessment

Ground water temperature represents a conservative tracer that can be used for several purposes. For this study, temperature was utilized for two primary assessment methods. Temperature differences between stream water and shallow ground water adjacent to streams were used to characterize the connection between surface and ground water along streams. The second method represents identifying warm ground water at depth within the aquifer system as an indicator of recharge source, differentiating between surface water recharge with cool waters and deeper thermally heated bedrock waters.

10.1 Piezometers and Surface/Ground Water Connection

Ground water temperature adjacent to streams allows differentiation of gaining and losing reaches in streams, and the connection to ground water (Constanz & Stonestrom, 2003). This relationship is conceptually depicted in Figure 10-1. For streams gaining flow from ground water, the ground water temperature is stable compared to daily fluctuations in the surface water body. For losing reaches, the daily surface water temperature fluctuations can be observed in the shallow ground water temperature, confirming that the stream is recharging the ground water system. The magnitude of the ground water temperature fluctuations is greatest for stream directly connected to ground water, and is less when the stream is perched above the ground water system. The system becomes more complex with ephemeral streams.

For the stream bank piezometers used in this study, temperatures were measured with water level datalogging pressure transducers, which also recorded temperature. The dataloggers were installed to the total depth of the piezometers to ensure that measured temperatures were representative of ground water at the depth of the screened intervals. Surface water data was obtained from surface water monitoring stations located in the same area as the piezometers.

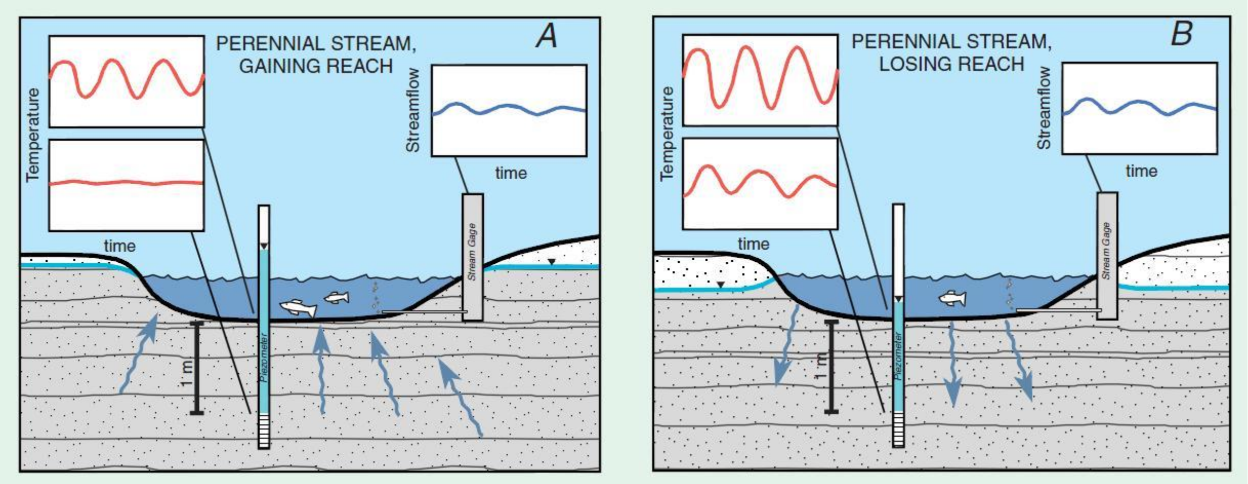


Figure 10-1 Stream and Ground Water Temperature in Gaining and Losing Reaches (from Constanz & Stonestrom, 2003)

Ground water adjacent to gaining streams show stable temperatures, while the daily fluctuations in surface water temperatures result in ground water temperature fluctuations in losing reaches. Piezometers for this study were not installed in streambeds, rather on the banks immediately adjacent to the streams.

Graphs of the surface and ground water temperatures for each location are included in Appendix F. For this study, the piezometers were installed on streambanks adjacent to streams, and not within the actual streambed. As a result, some of the expected temperature fluctuations are not present; however, ground water temperatures matching or approaching surface water temperatures are interpreted as resulting from stream loss since ground water temperatures near gaining streams do not correspond with changes in surface water temperatures. From the data and plots in Appendix F, the following observations can be made for each piezometers site:

Tenmile Creek Sites:

Country Club Lane (T-24) – The ground water temperature is stable and independent of surface water temperature, supporting an interpretation that the stream is gaining at this location.

Green Meadow Road (T-4) – The ground water temperature does not show daily fluctuations; however, the temperature is similar to surface water temperatures and interpreted to indicate that the stream is losing at this location.

Sierra Road (T-6) – The ground water temperature during the winter approaches freezing indicating that the stream is losing in this reach. During the summer irrigation season the system becomes more complex due to irrigation canals located near the piezometer. The ground water temperature in summer shows some fluctuations and rises above background, supporting the interpretation that the stream is losing in this reach. However, since ground water in this location is within a few feet of the surface, shallow ground water heating may occur from direct sunlight on the ground surface. The ground water elevation exceeds the surface water elevation during the summer indicating that the stream is gaining. The lack of a visible relationship between changes in surface and ground water elevations infers that the stream and ground water are not connected. The irrigation canals are considered responsible for the incongruity in the results.

Prickly Pear Creek Sites:

Canyon Ferry Road (P-5) – The ground water temperature does show periodic fluctuations but not daily; however, the ground water temperature is elevated to near surface water temperatures, with noticeable changes and is interpreted to indicate that the stream is losing at this location.

Sierra Road (P-10) – The ground water temperature is stable and slowly rising during the monitoring period, supporting an interpretation that the stream is gaining at this location.

Winterbourne Property (P-12) – The ground water temperature is stable and slowly rising during the monitoring period, supporting an interpretation that the stream is gaining at this location.

Silver Creek Sites:

Silver Creek Estates (SC-1) – The surface water elevation is consistently above the ground water elevation indicating that the stream is losing in this reach, providing recharge to the shallow ground water system. There is not a strong correlation between changes in surface water flow and ground water elevations. Fluctuations in ground water elevation suggest that recharge to this system occurs from a second source, interpreted as the bedrock aquifer system beneath the alluvium. Unfortunately, surface water temperature data is not available. Ground water temperatures indicate a seasonal fluctuation; however, summer temperatures remain relatively low compared to other sites where stream loss is confirmed (e.g. T-4, P-5). The ground water system is interpreted to result from mixing between the bedrock aquifer and shallow alluvium, with interaction at top, as noted in slight temperature fluctuations during Summer 2010 when flow was consistent.

Smelko Property (SC-2) – This site is similar to SC-1, with the same interpretation. Note that during Summer 2012, flow in Silver Creek at this location was not present for much of the summer; however, ground water was present in the piezometer.

Drain Site:

Arrowhead Road (D2 Drain) – The ground water temperature is stable and slowly rising during the monitoring period, supporting an interpretation that the stream is gaining at this location.

Sevenmile Creek Sites:

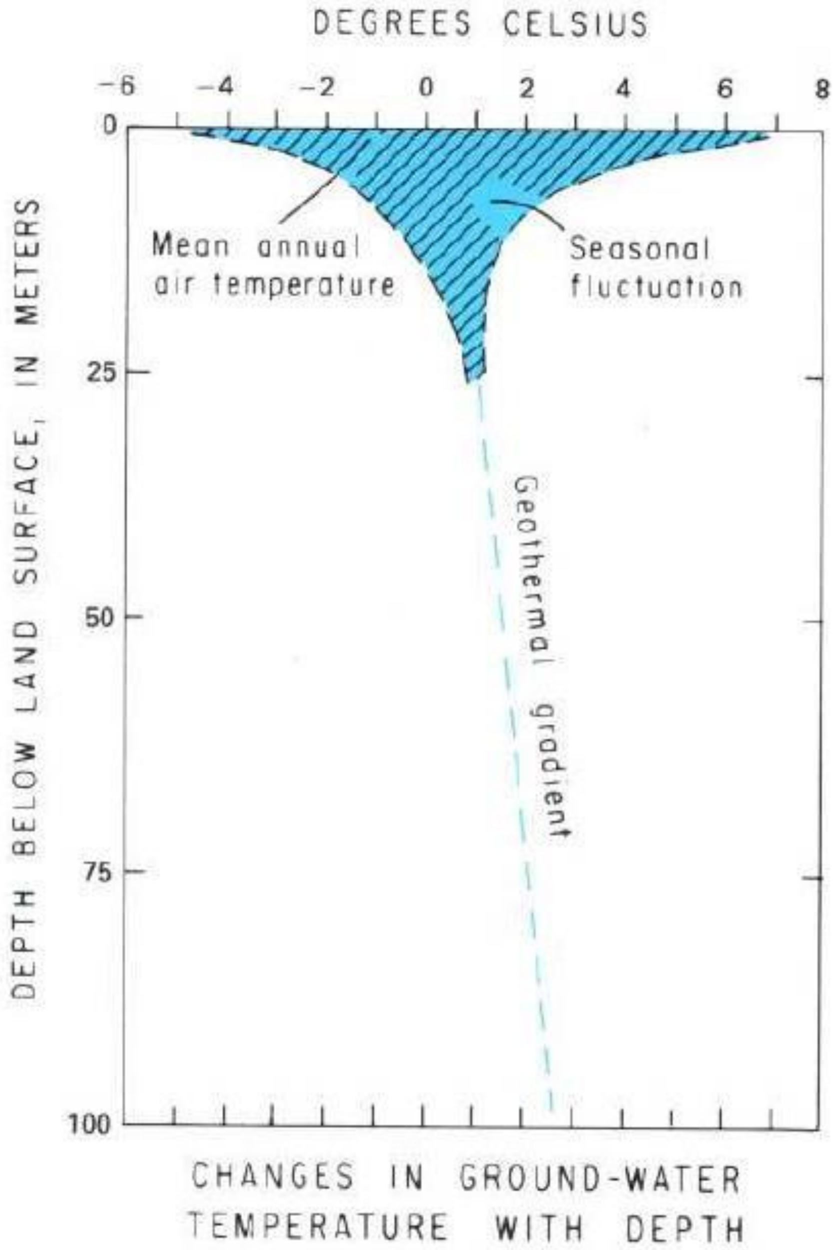
Birdseye Road (7M-1) – The ground water temperature is stable and slowly rising during the monitoring period, supporting an interpretation that the stream is gaining at this location.

Head Lane (7M-3) – The ground water temperature is stable and slowly rising during the monitoring period, supporting an interpretation that the stream is gaining at this location.

10.2 Ground Water Recharge Source Assessment

Ground water temperature is generally fairly consistent, increasing with depth at a consistent rate referred to as the geothermal gradient (Heath, 1983). The average ground water temperature is approximately 1 to 2 °C above the mean annual surface temperature for an area, with temperatures potentially fluctuating several degrees near the surface, as depicted in Figure 10-2. The geothermal gradient results in increases in temperature of approximately 0.55 C per 100 feet depth in normal sedimentary basins, and may be as high as 1.1 C per 100 feet in active volcanic areas (Heath, 1983). For Helena, the average daily maximum air temperature is approximately 13 C and that average daily minimum air temperature is near freezing (see Table 2-1). The average daily air temperature, reflecting all temperatures and daily fluctuations, for the study area is not reported and cannot be accurately estimated from daily average endpoints since temperature changes can occur rapidly and not follow a linear pattern. As previously stated, during ground water sampling activities warm ground water was observed at locations around the Helena valley. The data indicated that water temperatures were frequently present at levels exceeding what would be expected for specific a specific depth based on the geothermal gradient. Data from April 2010 LCWQPD ground water sampling events and concurrent MBMG events (Waren et al. 2012; Bobst et al., 2013) are plotted on Figure 10-3 with both "normal" and "volcanic area" potential geothermal gradients. The April data is considered likely to reflect the coolest possible ground water temperatures when local recharge would be cold waters from snowmelt and runoff. The April ground water temperatures are considered to be the most representative of natural ground water temperatures, occurring prior to summer irrigation season. The data plot in Figure 10-3 shows that a majority of ground water temperatures are above what would be expected by the geothermal gradient for the area. Figure 10-4 illustrates seasonal trends in ground water temperature with data from the monthly ground water sampling program, and comparison to the geothermal gradient. The monthly data shows relatively stable temperatures exceeding temperatures predicted by the normal geothermal gradient.

In order to detemine the average “background” temperature for the area, temperature buttons were placed into background wells as discussed in Section 3.4. The background temperature monitoring was conducted in wells installed in the North Hills and Scratchgravel Hills areas as part of the recent MBMG investigations. The well locations and data results are depicted in Figure 10-5. The data is primarily from the Scratch Gravel Hills wells, as earlier data were lost due to a computer virus. The current dataset includes one point from the North Hills, from May 2012 indicating a water temperature below what would be expected by the geothermal gradient.



(Adapted from Heath, 1983)

Figure 10-2 Geothermal Gradient and Near Surface Temperature Fluctuations

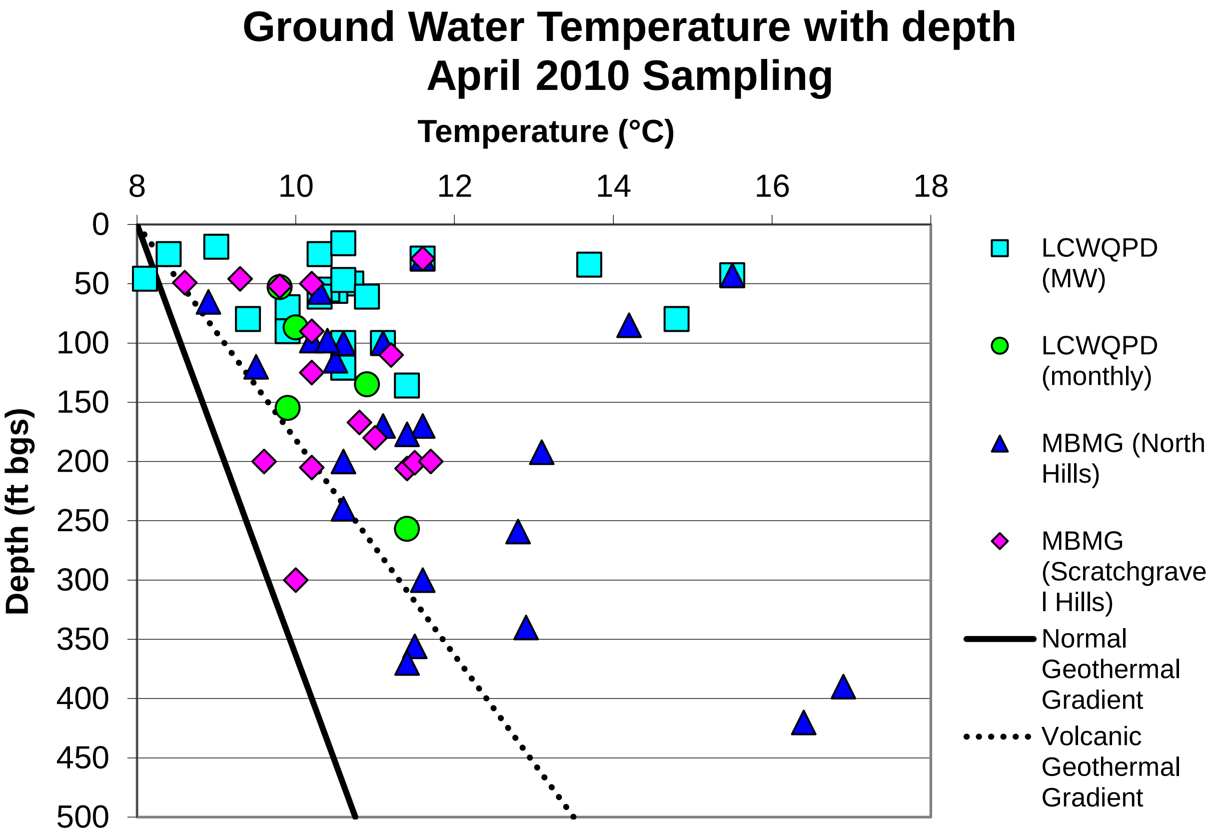


Figure 10-3 Ground Water Temperatures April 2010 compared with Geothermal Gradient
Data from LCWQD sampling programs, with MW for monitoring wells, and monthly wells. Data from the MBMG study areas include North Hills and Scratchgravel Hills. The normal geothermal gradient, and gradient for volcanic areas are depicted. Data from April event will minimize effects of sunlight heating shallow ground water.

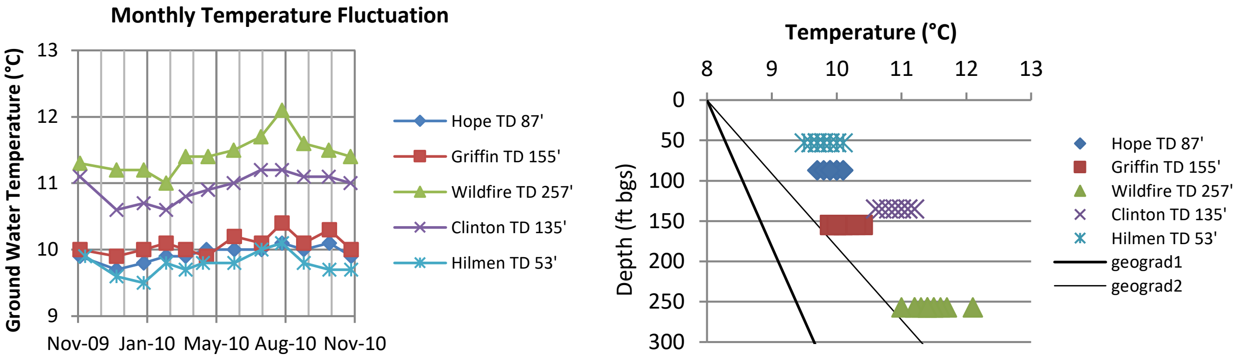


Figure 10-4 Fluctuation of Ground Water Temperatures from Monthly Sampling Program
Data from monthly sampling program showing seasonal fluctuations in temperature, and temperatures relative to geothermal gradient. In the temperature plot, geograd1 represents the normal geothermal gradient, and geograd2 represents the volcanic geothermal gradient.

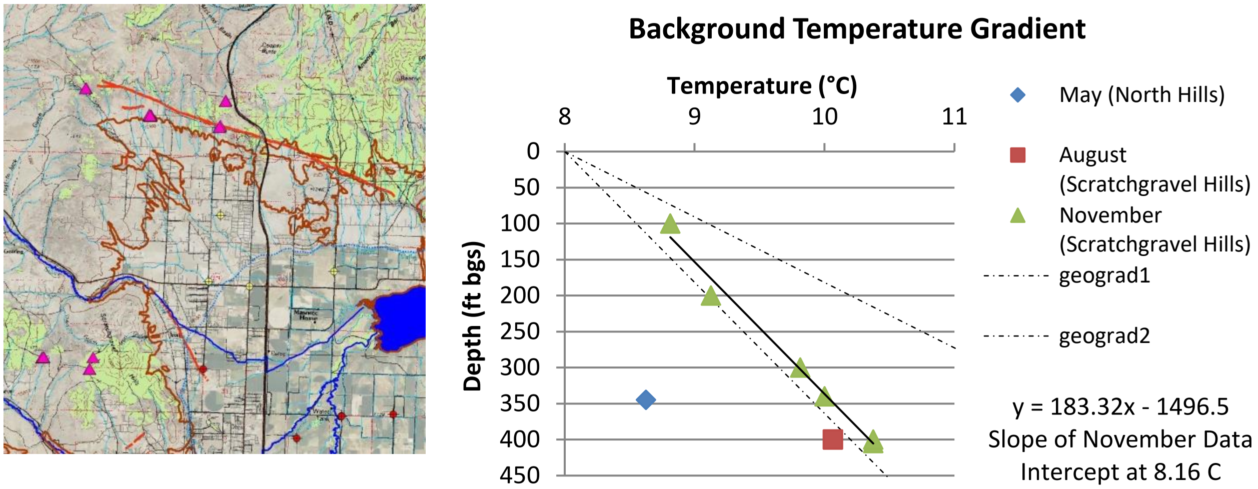


Figure 10-5 Determination of Background Ground Water Temperature

Data from background wells showing temperature with depth illustrating normal geothermal gradient. Geograd1 represents the normal geothermal gradient, and geograd2 represents the volcanic geothermal gradient.

This is interpreted to represent primary recharge of cold water occuring from infiltration of snowmelt and precipitation during winter/spring months. The dataset from the Scratchgravel Hills includes one point from August 2012, and a set from November 2012.   The November data are considered representative of warm conditions for ground water, after the summer warming period and before infiltration of near-freezing waters from winter precipitation and snowmelt. The emperical relationship between depth and temperature from the November data is depicted as a linear trendline, calculated by Microsoft Excel software. The relationship is:

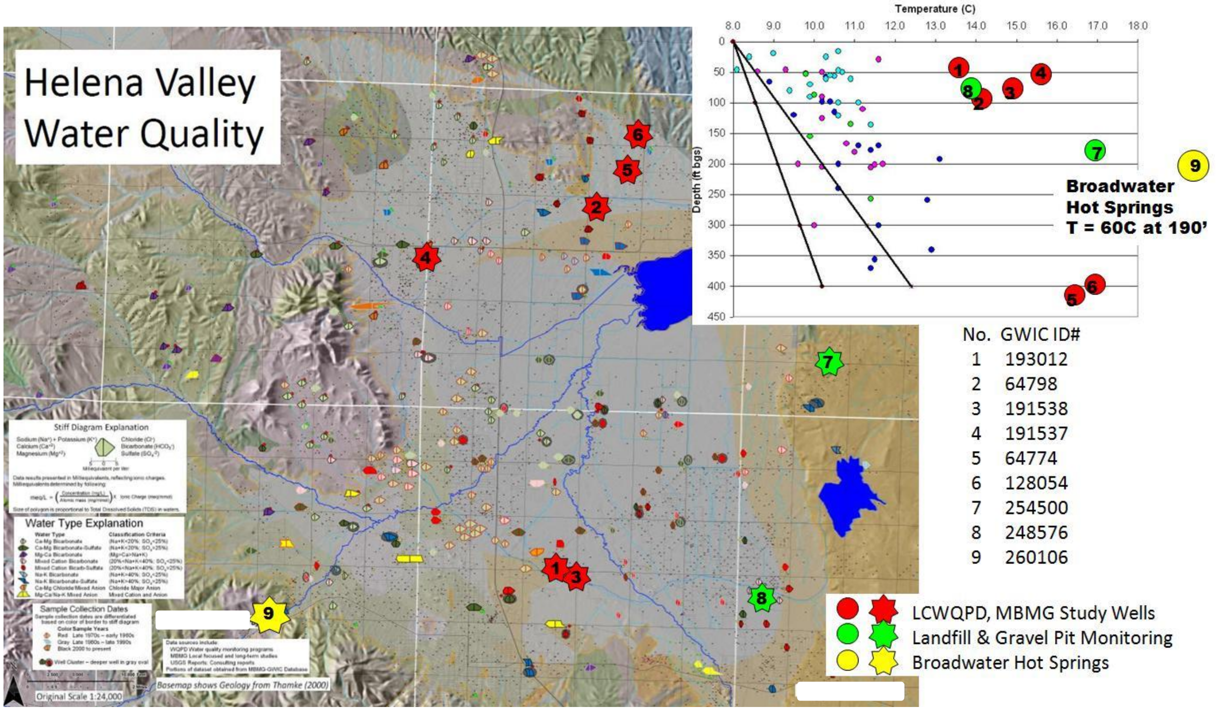
$$\text{Depth (ft bgs)} = [184.76 * \text{Temperature(°C)}] - 1513.5. \qquad (1)$$

Reworking this equation to obtain the temperature as a function of depth is:

$$\text{Temperature (°C)} = \frac{\text{Depth (ft bgs)} + 1513.5}{184.76} \qquad (2)$$

Setting the depth to zero at the surface results in an estimate of the ground surface temperature of approximately 8.2°C. The trendline is parallel to the normal geothermal gradient, confirming the normal geothermal gradient relationship for the area. The background temperature is consistent with an approximation of the base temperature for the local geothermal gradient at 8°C as shown in Figure 10-3.

A comprehensive spatial analyses of ground water temperatures with depth and location has not been completed at this time. The general location of different warm and cool waters are depicted in Figures 10-6 and 10-7, respectively. These data indicate that warm waters are located, when present, around the margins of the Helena Valley. Cool waters are located in the upgradient bedrock areas north and west of the valley, and in shallow wells in the central part of the valley. The data is interpreted to represent two components of the ground water system. The shallow ground water system receives recharge from stream loss (including from irrigation canals) and



No.	GWIC ID#
1	193012
2	64798
3	191538
4	191537
5	64774
6	128054
7	254500
8	248576
9	260106

Figure 10-6 Location of Warm Waters in Helena Valley
Wells with temperatures noticeably above geothermal gradient conditions. Deep wells are located in eastern part of North Hills area, with MBMG data from Waren et al (2012). Landfill and gravel pit data obtained from annual monitoring reports. Broadwater Hot Springs data obtained from MBMG-GWIC.

direct infiltration of precipitation, and flows towards and discharges into Lake Helena. The deep ground water system, characterized by temperatures above the geothermal gradient, receives recharge from outside the Helena Valley and discharges in the subsurface along the margins of the Helena Valley where the waters mix with the shallow ground water system.

The difference between the measured ground water temperature and the estimated temperature under a normal geothermal gradient is considered the thermal overprint for this assessment. The thermal overprint can be estimated subtracting the normal geothermal gradient temperature, estimated from the well depth using equation (2), from the measured well temperatures. The thermal overprints for the monitoring wells sampled in this study are included in Table 10-1. The measured actual ground water temperatures are used with equation (1) to estimate the depth necessary to reach that temperature under a normal geothermal gradient.   The ground water depth estimated by these temperatures are interpreted to reflect the minimum depth below ground surface for deep recharge waters to be heated to the measured temperature. The estimated depths represent minimum depths since cooler surface recharge water mixes with deeper thermal waters resulting in cooler ground water temperatures. The upwelling of deep ground water is consistent with the conceptual model for the valley where deep basin ground water upwells towards Lake Helena in the central part of the valley. When heated, warm ground water will always rise towards the surface as a result of the difference in density between more dense cool waters, and less dense heated waters.

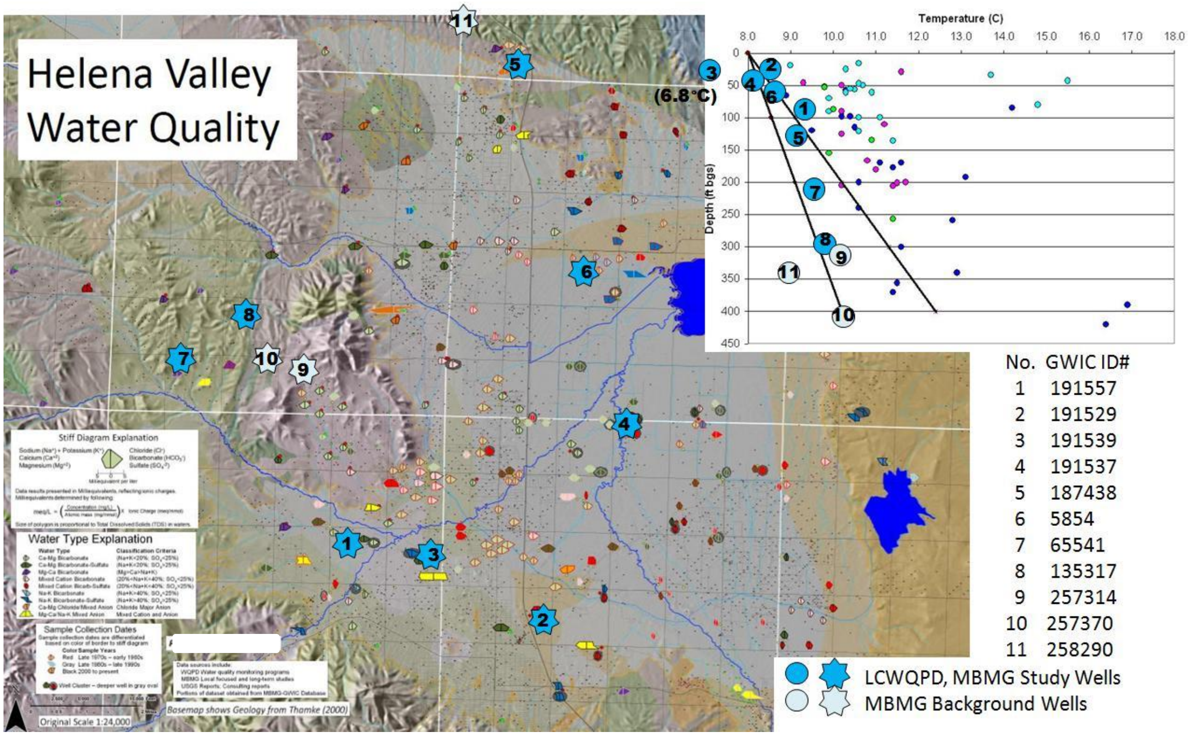


Figure 10-7 Location of Cool Waters in Helena Valley
Wells with temperature at geothermal gradient conditions. MBMG data from Waren et al (2012) and Bobst et al (2013) includes background wells from pump tests and deep wells located in Scratchgravel Hills and North Hills.

Several potential sources are present for ground water heating in the Helena Valley. Since there are no active volcanic areas in the region, the heating method reflects ground water infiltrating to depth with heating from the geothermal gradient. Deep ground water in bedrock areas rise to the surface along faults where rock bodies are most permeable, resulting in surface hot springs such as the Broadwater thermal area west of Helena. Based on the temperature of approximately 60°C at the Broadwater Hot Springs, the heating depth can be approximated from equation (1) as over 9,500 feet below ground surface.   Sedimentary basins are interpreted to have deep aquifer systems where ground waters are heated and can rise to the surface when conduits such as fault planes are present. The Helena Valley is interpreted to have approximately 6,000 feet of fill material (Briar & Madison, 1992). The ground water temperature from this depth, based on equation (2), would be approximately 40°C, noting that water temperature at lesser depths closer to the surface would be less. The difference between bedrock systems and sedimentary basins is that bedrock typically has less permeability, and flow is limited to fault planes and other discrete conduits. In sedimentary basins, aquifers with primary porosity are present, resulting in more potential conduits for movement of heated ground waters. The final potential source for the Helena Valley reflects the area along the southwestern, western and northern valley margins, where topographic relief is high. In these areas, ground water may be warmed under normal geothermal gradient conditions followed with a more lateral flowpath towards the valley, rather than upwelling adjacent to and/or within the valley. The data in Table 10-1 includes only deeper wells in well clusters as shallow wells are susceptible to surface temperature fluctuations. The temperature data indicates that deep basin waters from depths exceeding 1000 feet are mixing with shallow ground water.

Table 10-1 Ground Water Temperature Data

Sample Location GWIC Identification No	TD ft	Sample Date	Geothermal Gradient Temp (°C)	Temp Overprint (°C)	Heating Depth (no mixing) - ft bgs	Water Level (ft bgs)	Temp (°C)	Comments
Buoy Rd S (dp) 191525	50	10/7/09	8.44	1.96	410	4.2	10.4	Recharge from nearby lake, doesn't explain early spring water temperatures/overprint
	50	4/9/10	8.44	2.26	465	4.06	10.7	
	50	4/28/11	8.44	1.96	410	4.17	10.4	
	50	8/30/11	8.44	1.66	355	3.2	10.1	
	50	11/17/11	8.44	1.46	318	3.58	9.9	
Sierra & Floweree N (dp) 191526	46	10/7/09	8.41	0.09	62	5.42	8.5	Normal geothermal gradient area, center of Helena Valley
	46	4/9/10	8.41	-0.31	-12	5.63	8.1	
	46	4/25/11	8.41	-0.41	-30	4.73	8	
	46	8/30/11	8.41	-0.01	43	4.67	8.4	
	46	11/16/11	8.41	-0.41	-30	5.53	8	
Airport West N (dp) 191528	90	10/8/09	8.65	1.45	355	12.39	10.1	West side Tertiary, possibly lateral flow source
	90	4/29/10	8.65	1.25	318	12.46	9.9	
Regulating Reservoir 191530	56	10/7/09	8.47	1.83	392	20.93	10.3	Upwelling of deep basin water along east valley fault lines, mixing with shallow recharge water
	56	4/20/10	8.47	2.03	428	23.06	10.5	
	56	4/21/11	8.47	1.83	392	20.98	10.3	
	56	8/19/11	8.47	2.03	428	19.91	10.5	
	56	11/17/11	8.47	1.73	373	20.51	10.2	
Motor Pool E (sh) 191540	61	10/6/09	8.50	2.00	428	32.6	10.5	West side Tertiary, possibly lateral flow source mixing with local recharge
	61	4/28/10	8.50	1.80	392	34.39	10.3	
	61	4/20/11	8.50	1.90	410	33.49	10.4	
	61	8/16/11	8.50	3.20	648	30.7	11.7	
	61	11/17/11	8.50	0.70	190	30.51	9.2	
Motor Pool W (dp) 191531	121	10/6/09	8.82	1.78	447	35.51	10.6	West side Tertiary, possibly lateral flow source
	121	4/28/10	8.82	1.78	447	37.1	10.6	
	121	4/20/11	8.82	1.78	447	35.49	10.6	
	121	8/16/11	8.82	1.88	465	31.81	10.7	
	121	11/17/11	8.82	1.28	355	31.81	10.1	
North Hills 191532	100	10/15/09	8.71	2.59	575	68.56	11.3	Lateral flow source in North Hills, possibly mixing with deeper waters
	100	4/15/10	8.71	2.39	538	67.01	11.1	
	100	10/20/10	8.71	2.99	648	69.21	11.7	
	100	4/20/11	8.71	2.59	575	67.44	11.3	
	100	8/18/11	8.71	3.19	685	69.64	11.9	
	100	11/14/11	8.71	2.59	575	69.14	11.3	
Airport South S (sh) 191535	55	10/6/09	8.46	3.54	703	32.58	12	Southwest side Tertiary, possibly lateral flow source
	55	4/29/10	8.46	1.94	410	33.05	10.4	
	55	4/27/11	8.46	2.34	483	32.58	10.8	
	55	4/27/11	8.46	2.34	483	32.58	10.8	
	55	8/31/11	8.46	2.24	465	30.47	10.7	
	55	11/28/11	8.46	1.64	355	31.13	10.1	
Airport South N (dp) 191533	121	10/6/09	8.82	1.88	465	20.03	10.7	Southwest side Tertiary, possibly lateral flow source
	121	4/29/10	8.82	1.78	447	20.58	10.6	
	121	4/27/11	8.82	1.78	447	20.62	10.6	
	121	8/31/11	8.82	1.98	483	19.21	10.8	
	121	11/28/11	8.82	1.48	392	19.64	10.3	
Gravel Pit 191534	100	10/15/09	8.71	1.99	465	68.28	10.7	Lateral flow source in North Hills, possibly mixing with deeper waters, areas recharged by Silver Creek
	100	4/19/10	8.71	1.89	447	73.43	10.6	
	100	10/20/10	8.71	2.09	483	67.71	10.8	
	100	4/20/11	8.71	2.09	483	72.91	10.8	
	100	8/18/11	8.71	2.39	538	66.14	11.1	
	100	11/14/11	8.71	2.29	520	64.17	11	

Table 10-1 Ground Water Temperature Data (continued)

Sample Location GWIC Identification No	TD ft	Sample Date	Geothermal Gradient Temp (°C)	Temp Overprint (°C)	Heating Depth (no mixing) - ft bgs	Water Level (ft bgs)	Temp (°C)	Comments
Eichoff and Valley	70	10/7/09	8.55	1.35	318	33.32	9.9	Deeper basin waters mixing with shallow recharge
191536	70	4/8/10	8.55	1.35	318	43.34	9.9	
	70	4/21/11	8.55	1.25	300	44.76	9.8	
	70	8/18/11	8.55	1.75	392	37.4	10.3	
	70	11/29/11	8.55	1.05	263	37.65	9.6	
Lincoln & Montana	43	10/15/09	8.40	8.90	1675	24.67	17.3	Deeper basin waters mixing with shallow recharge
191537	43	4/19/10	8.40	7.10	1345	33.33	15.5	
	43	10/20/10	8.40	8.10	1528	24.72	16.5	
	43	4/22/11	8.40	6.20	1180	31.11	14.6	
	43	8/17/11	8.40	8.30	1565	18.81	16.7	
	43	12/6/11	8.40	7.60	1437	24.68	16	
Airport North N (dp)	80	10/8/09	8.60	5.60	1107	22.27	14.2	Deeper basin waters mixing with shallow recharge from HVID Canal
191538	80	4/20/10	8.60	6.20	1217	29.01	14.8	
	80	4/27/11	8.60	6.00	1180	28.25	14.6	
	80	8/31/11	8.60	5.50	1088	20.9	14.1	
	80	11/28/11	8.60	5.30	1052	24.8	13.9	
Prairie Nest & Lone Prairie	136	10/15/09	8.91	2.59	612	115.65	11.5	East side Tertiary, shallow recharge warmed by upwelling thermal waters mixing
191548	136	4/21/10	8.91	2.49	593	112.97	11.4	
	136	4/21/11	8.91	2.89	667	112.42	11.8	
	136	12/6/11	8.91	2.79	648	114.19	11.7	
Warren School N (dp)	47	10/6/09	8.42	2.28	465	10.63	10.7	Deeper basin waters upwelling
191550	47	4/27/10	8.42	2.18	447	16.03	10.6	
	47	4/28/11	8.42	1.98	410	16.07	10.4	
	47	8/19/11	8.42	2.08	428	10.3	10.5	
	47	11/29/11	8.42	2.08	428	11.88	10.5	
Helberg Lane N (dp)	61	10/7/09	8.50	2.40	502	0.5	10.9	Deeper basin waters upwelling
191554	61	4/8/10	8.50	2.40	502	1.8	10.9	
	61	4/21/11	8.50	2.10	447	2.02	10.6	
	61	8/30/11	8.50	2.70	557	0.35	11.2	
	61	11/16/11	8.50	2.00	428	1.21	10.5	
Applegate & Norris (dp)	58	10/20/10	8.48	3.72	740	11.45	12.2	Lateral flow source in Scratchgravel Hills, possibly mixing with deeper waters
257063	58	4/25/11	8.48	3.82	758	16.5	12.3	
	58	8/17/11	8.48	3.92	777	7.96	12.4	
	58	11/15/11	8.48	3.52	703	9.81	12	
Head Lane	80	10/8/09	8.60	1.30	318	3.81	9.9	West valley, lateral flow source?
191557	80	4/27/10	8.60	0.80	227	1.87	9.4	
	80	4/27/10	8.60	0.80	227	1.87	9.4	
	80	4/26/11	8.60	1.10	282	4.04	9.7	
	80	8/31/11	8.60	1.10	282	5.37	9.7	
	80	11/16/11	8.60	0.70	208	2.43	9.3	
Collins Rd	51	10/20/10	8.44	0.56	153	5.53	9	Local recharge, perhaps mixing with deeper upwelling waters as thermal overprint is limited
257064	51	4/20/11	8.44	0.46	135	7.2	8.9	
	51	8/18/11	8.44	0.36	117	6.57	8.8	
	51	11/14/11	8.44	0.16	80	4.81	8.6	
Howard Rd W (dp)	78	7/19/11	8.59	1.81	410	23.93	10.4	Deeper basin waters upwelling
123550	78	11/29/11	8.59	0.81	227	22.51	9.4	
Hamer W (deep)	104	7/20/11	8.73	2.27	520	17.53	11	Deeper basin waters upwelling
88213	104	11/29/11	8.73	2.07	483	17.11	10.8	

11.0 Discussion and Conclusions

The different datasets presented in this report support similar conclusions characterizing the ground water system in the Helena Valley. The Helena Valley Alluvial Aquifer as defined by Briar & Madison (1992), developed as a potable water source across the valley, represents the upper, or shallow ground water system. The deep aquifer comprises waters from depths exceeding 1,000 feet below ground surface in either major bedrock fractures or sedimentary basin fill deposits. The datasets are used to critique and refine the conceptual model of the ground water system. The focus of this assessment is the interaction of surface and ground water with respect to nutrient loading to Lake Helena as part of the Missouri River system.

Shallow Ground Water System

The water quality and temperature data indicate that primary recharge to the shallow aquifer system occurs from stream loss along valley margins, with the ground water system recharging streams towards the valley center. Shallow ground water is typically a calcium-bicarbonate type, with ground water temperature reflecting surface conditions in shallow wells, and the geothermal gradient in bedrock aquifers north and west of the Helena Valley. The shallow ground water aquifer comprises geologically recent unconsolidated alluvium and older Tertiary valley fill sediments. The shallow aquifer overlies the deeper basin fill aquifer as a separate unit. The basin fill material is generally considered to represent a thick sequence of fine-grained lakebeds interlayered with coarser lenses, with the sequence containing abundant volcaniclastic material. From the data presented in this study, the upper part of the basin fill material is interpreted to represent an effective aquitard separating the shallow ground water system from deeper basin waters, based on temperature.

Surface flowing artesian wells in the central part of the valley have been attributed to the vertical upward gradient from the deep ground water system discharging towards Lake Helena. From the data presented in this report, the vertical gradient is interpreted to be present within the shallow aquifer system. Recharge along the valley margins provides the artesian head in aquifer lenses in the central valley seal beneath lenses of fine-grained surficial deposits.

Deep Ground Water System

Hot springs and warm ground waters are present in localized areas near major faults along the boundaries of the Helena Valley. West of the valley, the Broadwater Hot Springs represents an example of a developed hot spring with a high volume of water from a deep fractured bedrock source. The deep thermal ground water is a sodium/potassium-sulfate/bicarbonate type associated with temperatures above those explained by the geothermal gradient. The thermal waters are derived from deep ground water heated by the geothermal gradient, rising to the surface along preferred conduits such as major faults between different rock types. For this assessment, geothermal water sources are present in deep bedrock fracture systems surrounding the valley as well as within the deep sedimentary basin fill sediments in the central part of the Helena Valley.

The flowpaths for warm waters towards the surface appear to be present along the margins of the Helena Valley. Major fault systems are present along the northern and southern boundaries, related to the regional Lewis & Clark Fault zone mapped across western Montana to the Helena Valley (Reynolds & Brandt, 2005). The temperature data in Table 10-1 indicate the minimum depths for recharge waters to reach measured temperatures exceed a thousand feet below ground surface from two monitoring wells, and lesser depths in other wells. The minimum depths do not reflect mixing of cool waters from local recharge with warm waters upwelling from the deep aquifer system. Since the measured temperatures above the geothermal gradient are from mixing of two water types, the actual heating depth for the warmer waters must be greater than the depth estimated by the temperature. The heating depth calculated from the ground water temperature is considered to be a minimum depth, with heated waters likely rising from a greater depth. Heated ground waters, or thermal waters, are noted in the monitoring wells installed in Tertiary sediments, and in the eastern part of the North Hills (Waren et al., 2012). Additional thermal waters are present in Tertiary wells east of the Helena Valley, with water chemistry of the deep ground water system type. This information is interpreted as rising thermal waters along major valley bounding faults. The source of the thermal waters cannot be differentiated between warm basin waters and deeper bedrock waters at higher temperatures.

Deep warm ground water from the Helena Valley sedimentary basin are interpreted as rising from the deep part of the valley along the eastern, northern and southern major fault systems which define the basin. The upwelling waters flow into and mix with water in the Helena Valley aquifer and/or connected Tertiary aquifers. The deeper ground water system seen in bedrock faults is interpreted to be present under the high permeability shallow surficial aquifers, and potentially the very deep bedrock aquifers in the area. The general gradient in the deep bedrock aquifer system is interpreted as generally to the north towards the Missouri River. The deep aquifer gradient is controlled by the Missouri River and lakes as base levels for all surface and ground water flows, coming from the higher elevation mountainous areas towards the continental divide west of the river. The dammed lakes on the Missouri River represent successively lower elevation systems, such that the associated ground water gradient will have a northern trend following the river gradient.

Mixing Ground Waters

Ground water temperatures from potable wells in the northeastern and southeastern parts of the Helena Valley are consistently greater than temperatures predicted by a normal geothermal gradient. This thermal overprint monitored within the Helena Valley Alluvial Aquifer is interpreted to result from mixing of deep upwelling heated ground water from the deeper aquifer in the area with the shallow ground water derived from local recharge. The aquifer developed as a potable source in both areas, considered the Helena Valley Alluvial Aquifer, comprises several hundred feet or more of unconsolidated alluvial fill. In the North Hills area, water chemistry reflects the sodium/potassium-bicarbonate/sulfate waters representative of deep basin waters. In the southeast Helena Valley area, the regional water chemistry is distinctly different from calcium-bicarbonate waters derived from recharge from Prickly Pear Creek, inferring mixing of deep waters as a second recharge source to the aquifer. The shallow and deep ground water results in a mixed cation-bicarbonate/sulfate water type which reflects both deep and shallow water recharge sources. The combination of water from two recharge sources is consistent with the water balance from Briar & Madison (1992) which concludes that a significant component of recharge to the Helena Valley Alluvial Aquifer system occurs from subsurface flow from the bedrock system directly into the alluvial system.

The detailed hydrogeology and geochemistry of the aquifer system in the East Helena area can be refined with datasets generated for the site characterization of the former Asarco Smelter site. This data will be incorporated into this assessment after they are made available to the public.

Nutrients in Ground Water and Loading to Lake Helena

Across the Helena Valley, septic system effluent discharges to the top of the Helena Valley Alluvial Aquifer. The effluent discharge percolates through unsaturated soils until it reaches the ground water surface. Near the center of the valley, nutrient concentrations are generally near background levels. However, along the valley margins where coarse grained materials are present (evidenced by gravel pit locations), nutrient concentrations vary and are locally elevated to points near or exceeding drinking water standards based on nitrate concentrations. In high permeability aquifer systems, plumes from septic system infiltration galleries generally are long and linear away from the source (DeBorde et al., 1998). As a result, monitoring wells for characterization of water quality impacts from surface sources need to be located in specific locations relative to sources with screened intervals across the top of the water table. The wells utilized as monitoring points for this study were not placed in locations to assess any specific nutrient sources, and are typically have intakes below the top of the water table. This limits the usefulness of the results to fully characterize water quality impacts from nutrients.

Recent studies in the bedrock areas to the north and west of Helena conclude that septic system effluent can migrate within the fractured bedrock system with limited attenuation (Waren et al., 2012; Bobst et al., 2013). In the coarse grained parts of the Helena Valley Alluvial Aquifer, attenuation of nutrients appears limited, with problem areas present where Tenmile Creek, Silver Creek and Prickly Pear Creek enter the valley. Data for the central part of the valley indicates localized levels of elevated nutrients; however, in general, the data show nutrient levels near background. The nutrient data from the piezometer network shows nitrate plus nitrite concentrations at background, less than 1 mg/L, with the exception of near the D-2 drain, with concentrations slightly above background ranging from 2 to 3 mg/L.

In order to properly evaluate nutrient loading rates to Lake Helena from non-point pollution source, a mass balance is required to account for all potential sources from both ground and surface water. Shallow ground water loading to Lake Helena occurs from direct recharge and upwelling, which is difficult to quantify, and discharges to a drain network installed to lower the water table in the central part of the valley. The drain network includes both tile drains installed into the subsurface, and an open ditch system, which receives the drain waters and then discharge into major valley streams or directly into Lake Helena. Data is available characterizing surface water quality from the major streams collected by EPA and LCWQPD as part of the implementation of the Framework Restoration Plan. However, the complete mass balance for nutrient loading to Lake Helena requires additional information characterizing the loading from the drain system. This data gap will be evaluated with a current LCWQPD study.

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