HYDROGEOLOGY OF THE POWDER MOUNTAIN AREA, WEBER AND CACHE COUNTIES, UTAH

By Paul C. Inkenbrandt, Stefan M. Kirby, and Brittany Dame

SPECIAL STUDY 156
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2016

HYDROGEOLOGY OF THE POWDER MOUNTAIN AREA, WEBER AND CACHE COUNTIES, UTAH

By Paul C. Inkenbrandt, Stefan M. Kirby, and Brittany Dame

ISBN: 978-1-55791-928-1

Cover photo: View to the north of new development on the Weber County part of Powder Mountain. The Hidden Lake Well site is on the right skyline.

SPECIAL STUDY 156
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2016

STATE OF UTAH
Gary R. Herbert, Governor

DEPARTMENT OF NATURAL RESOURCES
Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY
Richard G. Allis, Director

PUBLICATIONS
contact
Natural Resources Map & Bookstore
1594 W. North Temple
Salt Lake City, UT 84116
telephone: 801-537-3320
toll-free: 1-888-UTAH MAP
website: mapstore.utah.gov
email: geostore@utah.gov

UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
telephone: 801-537-3300
website: geology.utah.gov

CONTENTS

FIGURES

TABLES

HYDROGEOLOGY OF THE POWDER MOUNTAIN AREA, WEBER AND CACHE COUNTIES, UTAH

By Paul C. Inkenbrandt, Stefan M. Kirby, and Brittany Dame

ABSTRACT

The Utah Geological Survey performed a one-year study of the hydrogeology of the Powder Mountain area to better understand the hydrologic connection between springs, streamflow, and new water wells in adjoining parts of Cache and Weber Counties. The study included measuring stream discharge during baseflow conditions, measuring water chemistry, examining geology, and analyzing data from an aquifer test.

Interconnected Paleozoic carbonate aquifers span the Cache-Weber County drainage divide in the Powder Mountain area. The Paleozoic carbonate rocks are broadly folded in an overturned syncline, underlain by low-permeability Cambrian quartzite, and mantled by semi- to unconsolidated Tertiary Wasatch Formation, colluvium, and alluvium. Within the Paleozoic carbonate rocks, the Cambrian Nounan Formation is the source of important springs and is the unit screened in the Hidden Lake Well. The extent of the carbonate aquifers is limited by folding along a broad, north-plunging syncline and their erosional extent. Most of the extent of these aquifers lies in Cache County. Groundwater elevation based on springs, gaining or losing stream sections, and water levels in existing wells generally mirrors topography and is highest along the drainage divide beneath the Cache-Weber County boundary. Carbonate-sourced springs and baseflow contribute two-thirds of the total flow to the South Fork of Wolf Creek in Weber County and nearly all the spring and baseflow to the Wellsville Creek drainage in Cache County.

Water chemistry analyses indicate all samples are dilute calcium bicarbonate ($Ca\text{-}HCO_3$) type water. Conductivity is lowest for water sourced from quartzite, Wasatch Formation, and basin fill. Water sourced from carbonate or covered carbonate rocks have higher conductivity and distinct chemistry with low dissolved silica and characteristic calcium and magnesium concentrations. Hydrogen and oxygen isotopes in water samples across the Powder Mountain area have similar isotopic concentrations likely resulting from recharge of local snow melt. Several water samples from basin fill and quartzite have distinct isotopic concentrations indicating different sources of recharge. A paired factor and hierarchical cluster analysis yielded three statistically distinct water chemistry groups with variance largely controlled by dissolved concentrations of calcium, magnesium, and silica. Analysis of the Hidden Lake Well aquifer test data indicates that the Nounan aquifer is unconfined and has a relatively low transmissivity of 228 ft^2 per day. Observations recorded by four stage-recording transducers at two weirs that measure flow from Lefty's Spring correlated poorly and included significant variability and error. Data from the upper Lefty's Weir has the longest period of record and the best correlation with measured discharge. Based on comparison of flow measured at the upper Lefty's Weir during the aquifer test and seasonal recession of flow, most change in flow at Lefty's Spring measured during the aquifer test could be produced by seasonal recession trends. Forward modeling of potential drawdown produced by the Hidden Lake Well indicates the amount of water pumped from the Cache County side of the Nounan aquifer is likely between 24 and 37% of total discharge depending on the duration and amount of pumping. Forward modeling, based on the aquifer test results and site specific assumptions, indicates hypothetical wells, completed in the Nounan aquifer on the Weber County side within 300 m of the county line, may yield drawdown on the Cache County side when pumped for a month or more. The conceptual model of the aquifer system in this report supports the potential for long term pumping in the carbonate aquifer system to impact springs and stream baseflow sourced from carbonates in the Powder Mountain area.

INTRODUCTION

Background

Groundwater from lower Paleozoic carbonate aquifers supplies springs and baseflow to streams that drain into Cache Valley and Ogden Valley. These aquifers span the Cache-Weber County line, which coincides with the Cache Valley–Ogden Valley drainage divide in the Powder Mountain area, and are the target of new culinary supply wells. Water managers from Cache and Weber Counties and the Utah Division of Water Rights seek to better understand this carbonate aquifer system, constrain sources of springs and stream baseflow, and determine potential for any changes in groundwater flow caused by new supply wells. To better understand the hydrologic connection between springs, streamflow, and new wells in adjoining parts of Cache and Weber Counties, the Utah Geological Survey performed a one-year study of the hydrogeology of the Powder Mountain area.

Hydrologic fieldwork included stream and spring gauging and water sampling during the baseflow period of late October and November 2014. Following the hydrologic fieldwork, a two week pumping test of the Hidden Lake Well was performed by Loughlin Water Associates, LLC (Loughlin Water) in December 2014. During the pump test and the recovery period, we observed spring and stream monitoring performed by both Loughlin Water and Cascade Water Resources, LLC (Cascade Water). Geologic fieldwork was completed during July 2015. This report summarizes the results of the hydrologic and geologic fieldwork and also includes an analysis of the pump test as it pertains to the regional hydrogeology in the Powder Mountain area.

Geography

The study area spans the drainage divide between Cache County to the north and Weber County to the south in the southern Bear River Range (figure 1). This part of the southern Bear River Range is bordered to the south by Ogden Valley and to

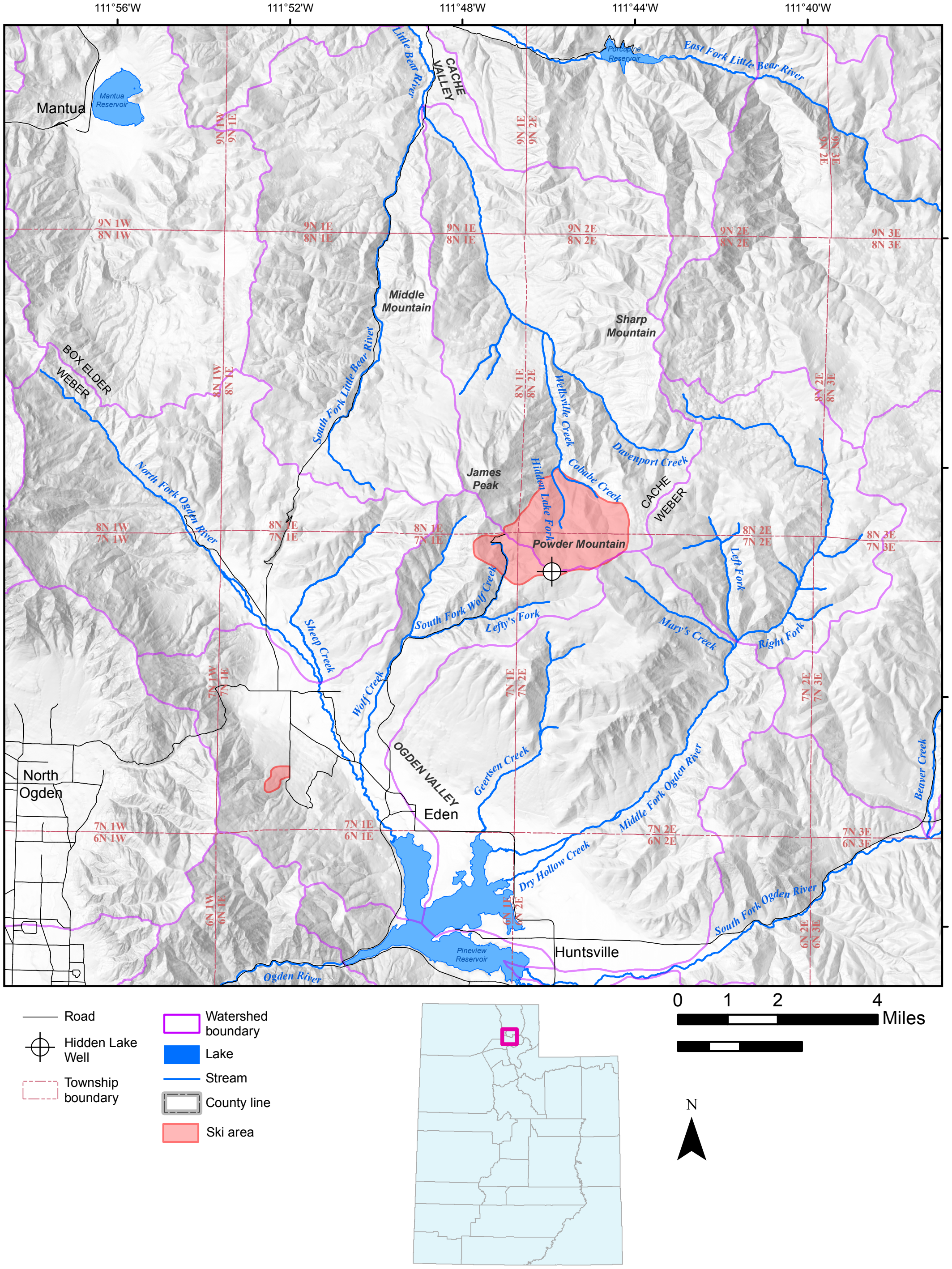


Figure 1. *The study area is located in the southern Bear River Range in Cache and Weber Counties.*

the north by Cache Valley. The area consists of a high mountain ridgeline (between 8000 and 9000 feet in elevation) along the drainage divide and an adjoining high elevation plateau in Weber County. The drainage divide delineates the headwaters of several streams that provide surface water to both Cache County and Weber County. The important streams on the Cache County side include Wellsville Creek and Davenport Creek. Both streams flow to the north and join the Little Bear River (figure 1). Wellsville Creek includes flow from several smaller tributaries that drain from the Powder Mountain area, including Cobabe Creek and the Hidden Lake Fork (figure 1). On the Weber County side, the important streams include Wolf Creek, Geertsen Creek, and Mary's Creek. Wolf Creek includes flow from South Fork Wolf Creek and Lefty's Fork, both of which drain the Powder Mountain area. Springs and seeps provide baseflow to streams on both sides on the drainage divide.

Most of the land along this part of the Cache County–Weber County line is privately owned (figure 2). A new supply well (the Hidden Lake Well) is located near the top of the Powder Mountain ski resort along the drainage divide that separates Cache County from Weber County (figure 2).

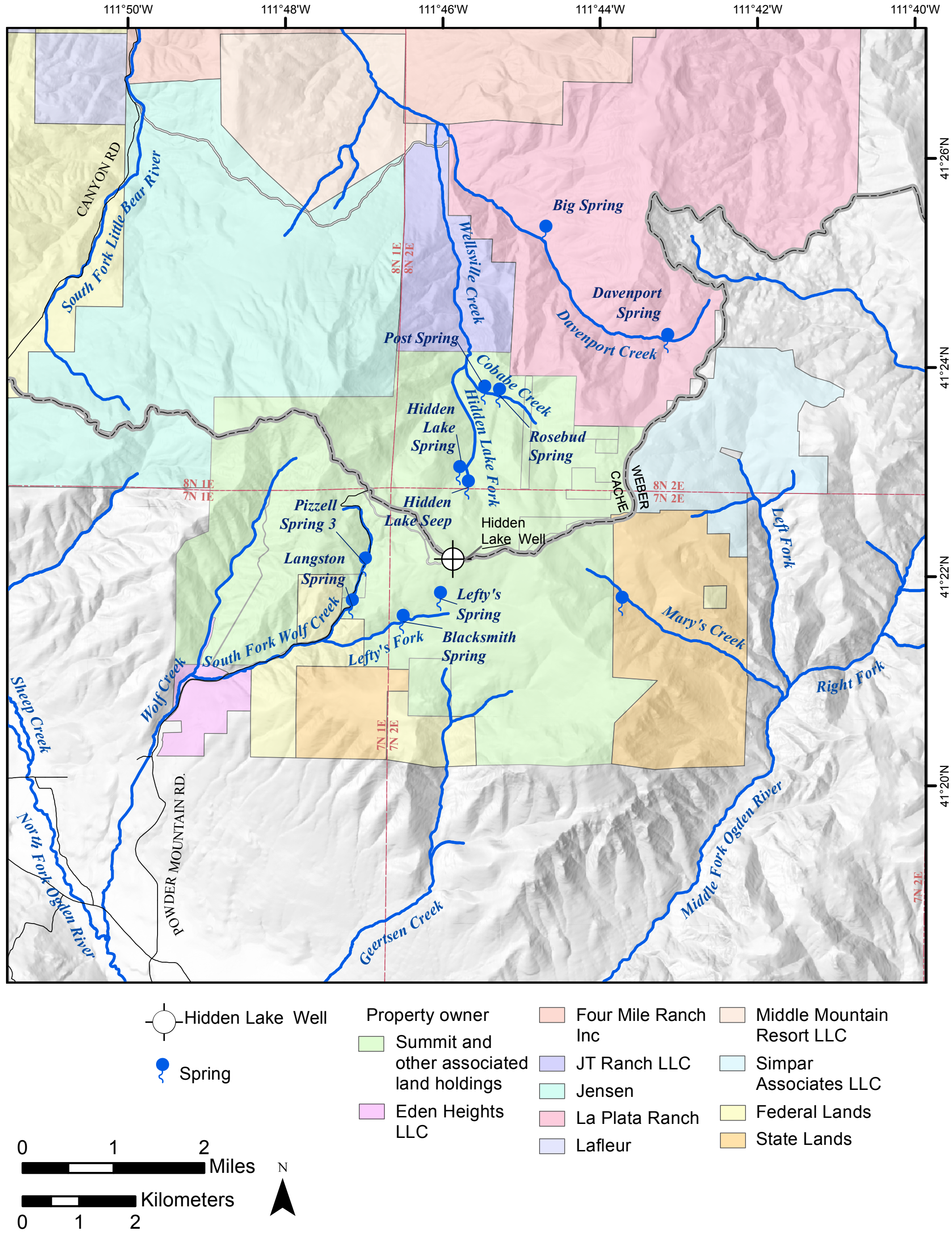


Figure 2. *Property ownership, important springs, and the Hidden Lake Well.*

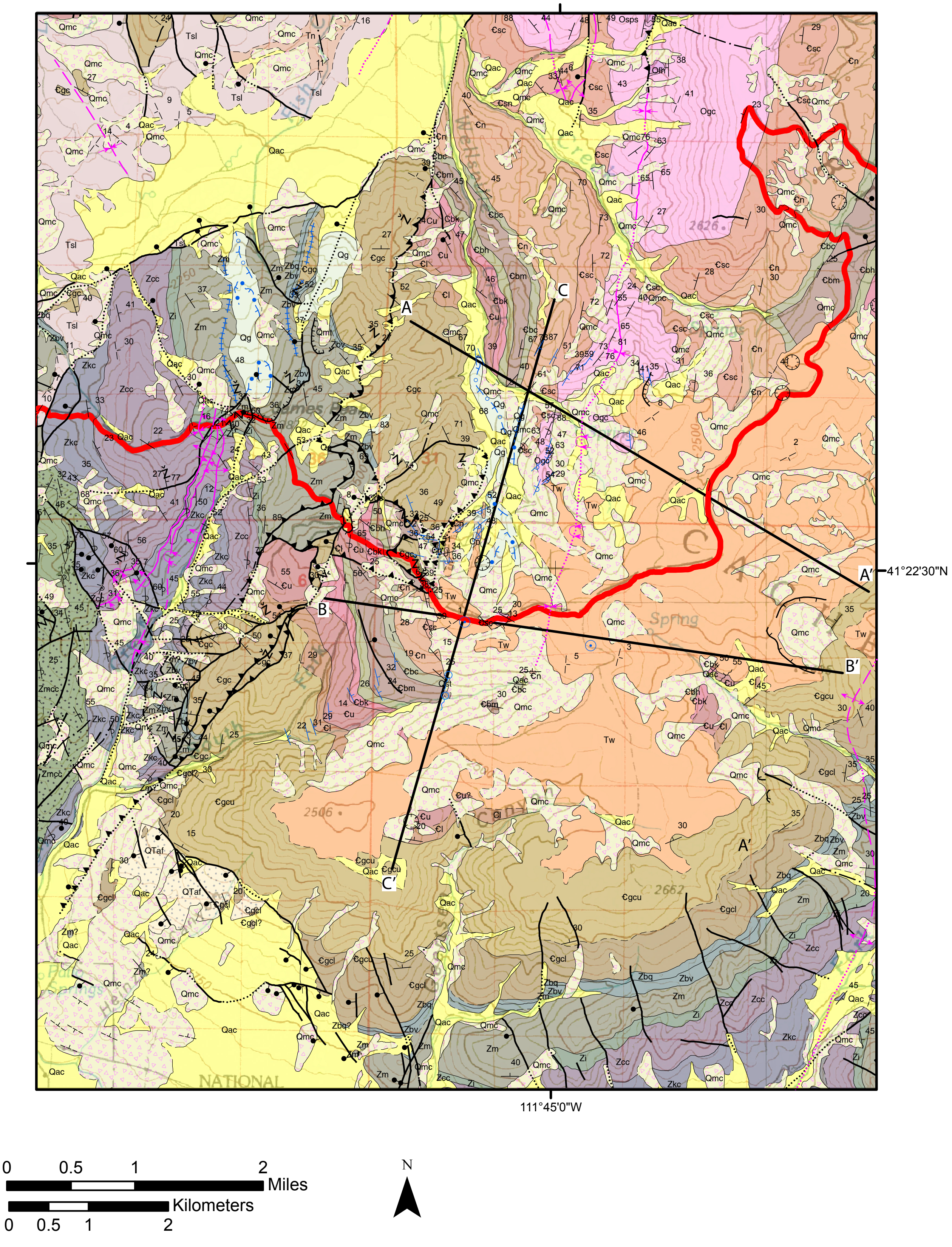


Figure 3. *Geologic map of the Powder Mountain area. Geology has been modified from Coogan and King (2001, 2016). For complete unit descriptions, see Coogan and King (2016). Cross sections shown on figure 4.*

Figure 3. *Continued.*

GEOLOGY

Introduction

The geology of the Powder Mountain area consists of Precambrian through Tertiary sedimentary rocks locally overlain by Quaternary unconsolidated deposits (Coogan and King, 2001; Coogan and King, 2012; King, 2014; King and Coogan, 2014; Coogan and King, 2016) (figure 3). The base of the geologic section includes a thick section of Precambrian through lower Cambrian quartzite and shale that outcrop along the southern mountain flank that adjoins Ogden Valley (figure 3). Overlying these rocks are a thick section of Cambrian through Ordovician limestone, dolomite, shale, and minor quartzite that outcrop in headwater areas near the drainage divide and to the north in the Bear River Range. Tertiary-age conglomerate, sandstone, and limestone unconformably overlie both the quartzite and carbonate rocks across upland parts of the study area. Quaternary, unconsolidated, surficial deposits locally cover older rock units in the Powder Mountain area and make up the uppermost part of the basin fill along the floor of Ogden Valley. A complete description of geologic units is presented in appendix A.

Rocks exposed in the study area record early deposition along a slowly subsiding continental margin, first dominated by siliclastic sediment and shale, and later by shelf carbonates. These rocks were later thrust faulted and folded during the Sevier Orogeny in the Late Jurassic through early Tertiary time (Decelles and Coogan, 2006). Subsequent basin and range extension has uplifted and exposed these rocks along the ridges on the southern Bear River Range.

Geologic Mapping and Cross Sections

Previous geologic work in the area includes two thesis investigations (Blau, 1975; Rauzi, 1979), more recent geologic mapping (Coogan and King, 2001; Coogan and King, 2012; King, 2014; King and Coogan, 2014; Coogan and King, 2016), hydrogeologic investigation (King, 2004), and several unpublished consultant reports (Cascade Water Resources, LLC, 2015; Loughlin Water Associates, LLC, 2015). The geology presented by these sources is broadly similar across most of the Powder Mountain area, and the 1:100,000 compilation by Coogan and King (2016) was used as the basis for the geology shown in figure 3. Among these authors, there are several differing interpretations of the geology immediately north of the county line in the upper Wellsville Creek drainage. To better constrain the geology in this area, a week of fieldwork was conducted in July of 2015.

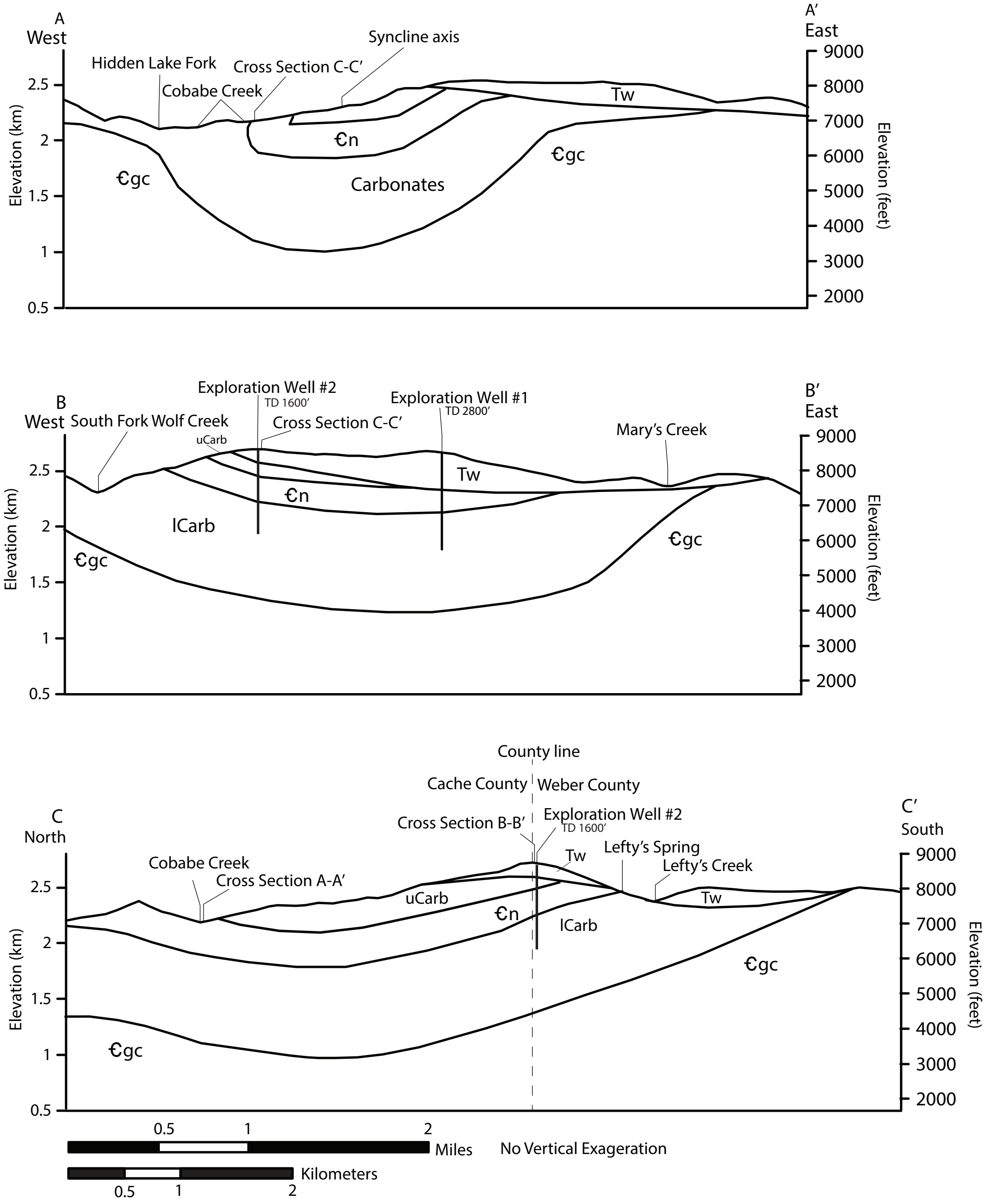
Fieldwork consisted of geologic unit description and structural measurements of bedding and fracture orientations (appendices A and B) along several transects within the upper part of the South Fork of Wolf Creek and Lefty's Fork in Weber County and the upper part of the Wellsville Creek drainage in Cache County. The upright or overturned nature of a given site was based on observable sedimentary structures, including cross-bedding cutoffs when apparent. New geologic data was used in conjunction with orthophotography to confirm and update the compiled geologic map using ArcGIS. Quaternary units were simplified and merged to reflect the scope of the study. Otherwise, geologic units and the descriptions follow those in Coogan and King (2016). Based on field observations, several minor modifications of the geology were made in the upper part of the Hidden Lake Fork of Wellsville Creek. The thrust fault trace along the west margin of the drainage was simplified, and the broad, north-south trending syncline was extended.

The rocks in the Powder Mountain area are broadly folded along an asymmetrical syncline that extends north to south across the study area (figure 3). The axis of the syncline plunges between 10 and 30 degrees to the north (King, 2004; Loughlin Water Associates, LLC, 2015; Coogan and King, 2016). This syncline varies from upright to overturned to upright from north to south along its axis. The syncline is bounded to the east by a broad, north-plunging anticline and to the west by shallowly dipping thrust faults that place Cambrian quartzite over folded lower Paleozoic carbonates (Blau, 1975; Rauzi, 1979) in the upper (southwest) part of the Hidden Lake subcatchment. East of the thrust fault, outcrops of overturned Nounan, St. Charles, and Garden City Formations have similar strike and dips that define a panel of overturned carbonate rocks. Due to limited and discontinuous bedrock exposures in this area, the correlation with upright dipping carbonate rocks immediately to the south near the Hidden Lake Well is ambiguous. However, to the north near Cobabe Creek, better exposure of these rocks shows a continuous zone of dip transition from upright to overturned. No fault is apparent in this area, and the transition from upright to overturned dip is interpreted to be the result of changes in folding along the syncline. The area of overturned bedding has a strong correlation with the location of the mapped thrust fault to the west, and it is possible that the additional east-directed slip along this thrust caused the steepening and overturning of the syncline in this area.

A slightly contrasting map interpretation of the structural geology of the north slope of Powder Mountain is presented by Coogan and King (2016). Their mapping includes the addition of concealed, queried, and steeply dipping faults of unknown slip sense that bound the panel of overturned carbonate rocks on the north and the south. As mapped, these fault segments separate areas of upright and overturned dips in the carbonate rocks on the north slope of Powder Mountain. We have not included these faults because a simple folding explanation better fits the available data. At the northern dip transition from overturned to upright, bedrock is continuously exposed and no fault is apparent. To the south, the transition from overturned to upright is not exposed. However, analysis of the aquifer test in subsequent sections did not indicate the presence of a lateral boundary or permeability contrast that could be expected for a fault located in the area of dip change near the Hidden Lake Well.

Three simplified cross sections show the extent and continuity of the important hydrogeologic units across the study area (figure 4). These cross sections are based on the geologic map in figure 3, isopach maps discussed in subsequent sections, well logs available for Exploration Wells 1 and 2 and the Hidden Lake Well (Utah Division of Water Rights, 2015a), and structural measurements. The two east-west and one north-south cross sections are meant to depict the large scale geology as it relates to the principal aquifers in the study area. Detailed, balanced, structural cross sections are beyond the scope of this study and likely not relevant to the general discussion of hydrogeology in the Powder Mountain area. The geologic units shown on the cross sections are simplified to reflect their relevance to hydrogeology of the Powder Mountain area. The units shown include (1) the Wasatch Formation (Tw), (2) a uCarb unit that includes carbonate units above the Nounan Formation, (3) the Nounan Formation (Ꞓn), (4) an lCarb that includes carbonate units below the Nounan Formation, and (5) the Geertsen Canyon Quartzite (Ꞓgc). Units below the Geertsen Canyon Quartzite are not shown. Thin unconsolidated surficial deposits are also not shown on the cross sections.

Cross section A to A′ extends west to east in Cache County. This cross section parallels the Cobabe Creek drainage along its eastern extent. The carbonate units in this cross section are directly exposed along much of the section, notably along Cobabe Creek where they directly underlie the stream and several springs (including Post and Rosebud Springs). The carbonates are steeply dipping and overturned on the west limb of the north-south trending syncline in the Powder Mountain area. Farther east across the syncline, rocks dip shallowly to the west.



	Tw	€sc	€n	€bc	€bm	€bh	Total Depth
Exploration Well #1	0	Absent	1085	1760	1990	2700	2800
Exploration Well #2	15	365	840	1580	1795		2480

Depth to the top of geologic units for wells shown on cross sections; units correlate with those on figure 3; values are in feet below land surface; well log data from Utah Division of Water RIghts (2015a).

Figure 4. *Simplified geologic cross sections; see figure 3 for cross section locations. The Hidden Lake Well is completed in the Nounan Formation (€n) and is located approximately at Exploration Well #2. uCarb = upper carbonate rocks, includes the St. Charles and Garden City Formations; lCarb = lower carbonate rocks, includes the Bloomington Formation, Blacksmith Dolomite, Ute Formation, and the Langston Dolomite; Tw = Tertiary Wasatch Formation; €gc = Cambrian Geertsen Canyon Quartzite.*

Cross section B to B′ extends west to east from the South Fork of Wolf Creek drainage to the Hidden Lake Well site, to the east near the location of Exploration Well 1, and through the upper part of the Mary's Creek drainage. In the west, carbonate rocks are exposed at the surface and dip to the northeast. The thickness of the Nounan Formation is between 675 and 760 feet based on well logs from the Hidden Lake Well and Exploration Well 1 (Utah Division of Water Rights, 2015a). Carbonate units lie beneath at least several hundred feet of the Wasatch Formation across much of the eastern part of this section. The carbonate units are likely near the surface beneath the upper part of the Mary's Creek drainage. The bedrock dips gently to the west across the eastern part of the cross section and defines the southern extent of the broad syncline shown on figure 3.

Cross section C to C′ extends south to north near Lefty's Spring, the Hidden Lake Well site, and Cobabe Spring to the drainage divide between Cobabe Creek and Davenport Creek. Bedrock dips gently to the north beneath the Wasatch Formation south of Lefty's Creek. Lefty's Spring issues from near the base of gently north-dipping Nounan Formation where the carbonate rocks are exposed at the surface. To the north beneath the ridge crest, several hundred feet of Wasatch Formation overlie the carbonate units. Carbonate units, including the Nounan Formation, are contiguous to the north in the upper part of the Wellsville Creek drainage and near Cobabe Spring.

As a whole, the cross sections indicate the extent and broad structural trends of the bedrock across the Powder Mountain area. Carbonate bedrock is broadly folded across a north-plunging syncline that is continuous from Weber County into Cache County and the southern Bear River Range. These rocks are locally exposed north and south of the drainage divide. The Wasatch Formation covers much of the bedrock along the drainage divide and extends to the east. Important bedrock aquifers are largely contiguous across the study area, and springs, baseflow, and supply wells are sourced from the interconnected Nounan Formation and other carbonate units.

Fractures

The movement of groundwater in bedrock aquifers is controlled by a combination of primary (matrix) and secondary (fracture) permeability. In carbonate aquifers, secondary permeability can be especially significant due to the potential for dissolution along fractures (Fetter, 2000). Fractures in the carbonate aquifer likely exert significant control on the water movement in the Powder Mountain area. Fracture orientation observable in outcrop was measured during geologic fieldwork. The longest or most continuous observable fractures were measured as primary fracture sets. At some sites, a secondary fracture orientation was measured. Secondary fractures commonly terminate against and are less continuous than primary fractures. Most fractures likely represent joints, but due to generally poor outcrop it was not possible to determine fracture type for all measurements. Figure 5 shows a geologic map of field stop locations and stereonet plots of measured fracture orientations. Field geologic stop and fracture data are presented in appendix B. Fracture measurements are subdivided into measurements taken in either Cache or Weber Counties. This separates fracture measurements into those from the upright portion of the syncline in Weber County from those measured on the overturned portion of the syncline in Cache County. Primary fractures in Weber County generally dip steeply to the northwest and secondary fractures dip moderately to the southwest. In Cache County, primary fractures dip steeply to northeast or southwest and a single secondary fracture dips steeply to the southeast. Any estimate of permeability based on these measurements is limited due to the small number of fractures measured and the spatially isolated nature of the measurements, either on the east dipping limb of the syncline in Weber County or a locally overturned section in Cache County.

Hydrogeologic Units

To better conceptualize the Powder Mountain hydrogeologic system, we simplified the geologic formations into three hydrogeologic units that represent the carbonate rocks, old siliclastic rocks, and young clastics (figure 6). The young clastic unit includes the Tertiary Wasatch Formation, basin fill including the Tertiary Salt Lake Formation and Norwood Tuff, and various Quaternary sediments. The young clastic unit is generally poorly consolidated or unconsolidated. The sand and gravel in the young clastics typically have high transmissivity due to high primary porosity. The sand and gravel sediments comprise the principal basin-fill aquifer of Ogden Valley. Tuff-rich and clay-rich strata, including the Norwood Tuff and Salt Lake Formation, typically have relatively low permeability.

The carbonate unit includes Cambrian through Ordovician limestone, dolomite, and shale, including the Langston Dolomite, Ute Formation, Blacksmith Dolomite, Bloomington Formation (including Hodges Shale, Middle Limestone, and Calls Fort Shale Members), Nounan Formation, St. Charles Formation, and Garden City Formation. The combined Paleozoic carbonate thickness is about 6000 feet (Coogan and King, 2001). Based on existing geologic mapping, these carbonates are contiguous across the drainage divide near Powder Mountain and are a source of important springs and baseflow in southern Cache County and northern Weber County.

It is possible that shaley units within the carbonate unit, especially the Calls Fort and Hodges Shale Members of Bloomington Formation, limit vertical aquifer interconnection. However, the level of interconnection has not been thoroughly investigated, and vertical, solution-enhanced fractures could permit cross-formation flow. Spring flow data presented in subsequent sections support some component of vertical interconnection across the carbonate unit. Because of this and the limited information available about the aquitards in the carbonate

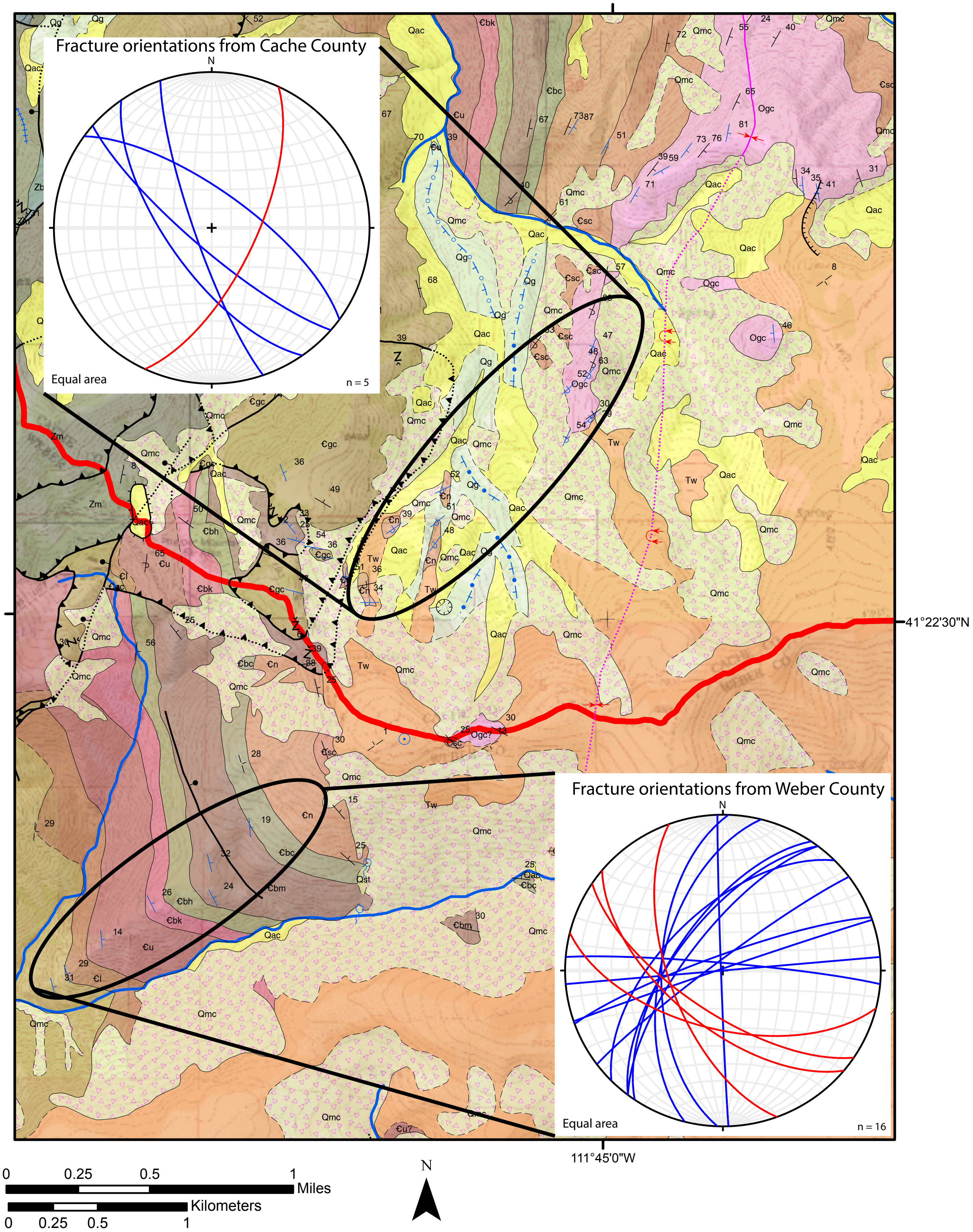
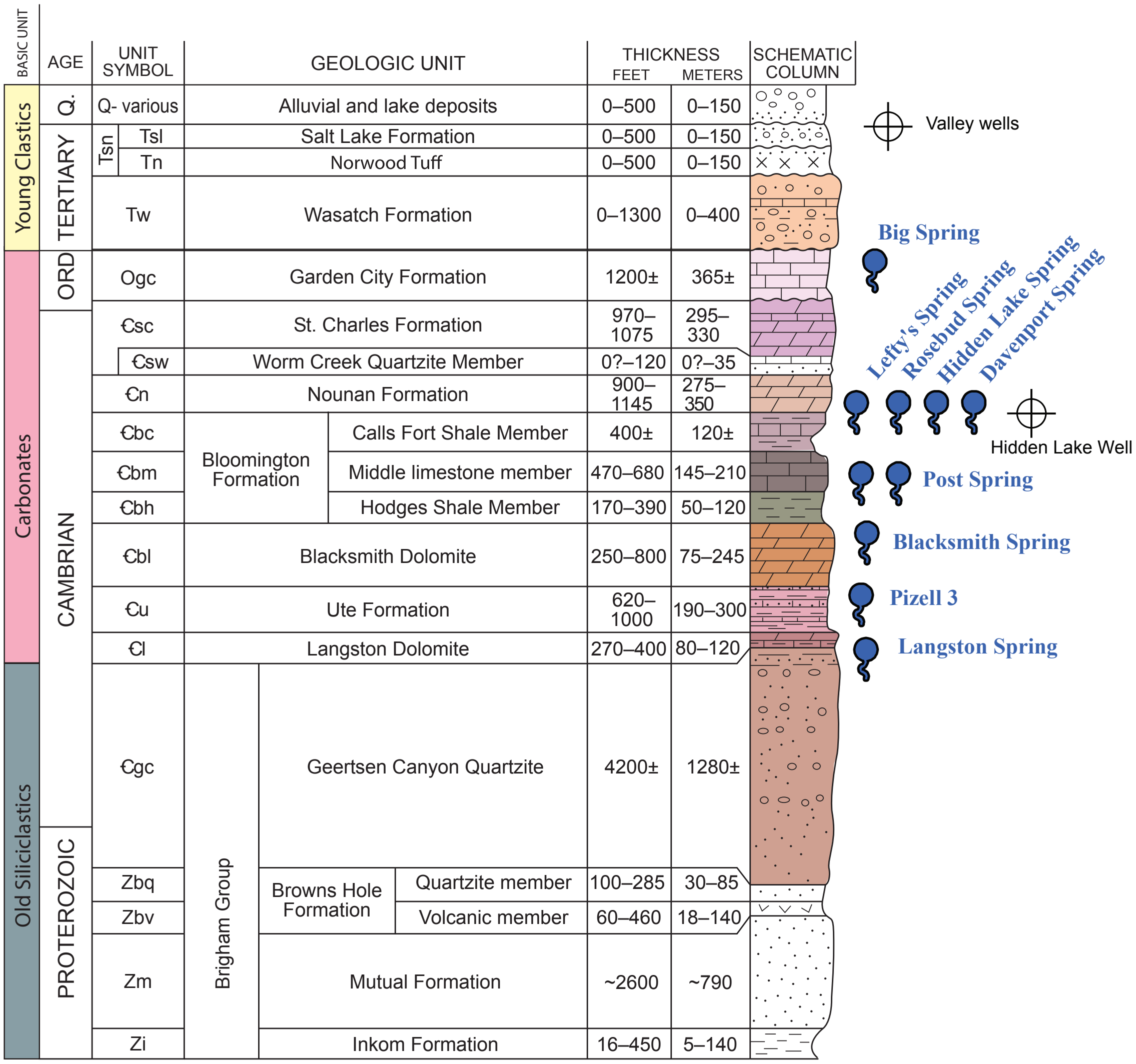


Figure 5. *Detailed geologic map and fracture orientations for the Powder Mountain area. Primary fractures shown in blue, secondary fractures shown in red. See figure 3 for description of geologic units and symbols.*



BASIC UNIT	AGE	UNIT SYMBOL	GEOLOGIC UNIT			THICKNESS FEET	THICKNESS METERS
Young Clastics	Q.	Q- various	Alluvial and lake deposits			0–500	0–150
	TERTIARY	Tsn Tsl	Salt Lake Formation			0–500	0–150
		Tsn Tn	Norwood Tuff			0–500	0–150
		Tw	Wasatch Formation			0–1300	0–400
Carbonates	ORD	Ogc	Garden City Formation			1200±	365±
	CAMBRIAN	Ꞓsc	St. Charles Formation			970–1075	295–330
		Ꞓsw	Worm Creek Quartzite Member			0?–120	0?–35
		Ꞓn	Nounan Formation			900–1145	275–350
		Ꞓbc	Bloomington Formation	Calls Fort Shale Member		400±	120±
		Ꞓbm		Middle limestone member		470–680	145–210
		Ꞓbh		Hodges Shale Member		170–390	50–120
		Ꞓbl	Blacksmith Dolomite			250–800	75–245
		Ꞓu	Ute Formation			620–1000	190–300
		Ꞓl	Langston Dolomite			270–400	80–120
Old Siliciclastics	CAMBRIAN	Ꞓgc	Brigham Group	Geertsen Canyon Quartzite		4200±	1280±
	PROTEROZOIC	Zbq		Browns Hole Formation	Quartzite member	100–285	30–85
		Zbv			Volcanic member	60–460	18–140
		Zm		Mutual Formation		~2600	~790
		Zi		Inkom Formation		16–450	5–140

Figure 6. *Hydrostratigraphy for the Powder Mountain area (modified from Coogan and King, 2106). The approximate stratigraphic position of important springs and wells is shown on the right. The Nounan Formation sources important springs and flow to the Hidden Lake Well.*

unit, we treated the carbonate unit as one aquifer with localized confining intervals. Most of the effective porosity in carbonate rocks commonly results from a combination of secondary dissolution and fracturing (Fetter, 2000).

The carbonate unit is the most important hydrogeologic unit in the Powder Mountain area. The new supply well at Powder Mountain, the Hidden Lake Well, is screened to the Nounan Formation, which is part of the carbonate unit. All of the large springs on the mountain emanate from the carbonates. Pizzell Spring 3, which flows from the Ute Formation (figure 6), is currently the primary public drinking water source on the mountain.

Below the Paleozoic carbonates is the old silicilastic unit, named for the predominance of the Geertsen Canyon Quartzite and other quartzite formations. The old siliciclastic unit consists of early Cambrian and Precambrian Brigham Group, including the Mutual Formation, Inkom Formation, Browns Hole Formation and the Geertsen Canyon Quartzite. Most of the effective porosity of quartzite is likely from fracturing. The old siliciclastic unit likely has a much lower permeability than the carbonate unit. This unit produces water to several supply wells located along the margin of Ogden Valley.

Unit Extents and Thicknesses

To constrain the extent and structural setting of the principal aquifers, we created structure contour rasters of important formations and hydrogeologic unit contacts based on existing geologic map contacts (Coogan and King, 2012; King and Coogan, 2014; Coogan and King, 2016), cross sections (King, 2004), and borehole data (Utah Division of Water Rights, 2015a). Land surface elevation data were derived from the USGS ⅓ arc-second horizontal resolution National Elevation Dataset data. We determined the approximate extent of units based on the location of structures and contacts on the geologic map (figure 3).

We constructed a unit-thickness map of the combined carbonate formations above the Geertsen Canyon Quartzite (figure 7). The extent of the carbonate unit is limited by the underlying Geertsen Canyon Quartzite and the topography. The carbonate unit forms a north to south elongated trough. The average thickness of the carbonate unit is 2500 feet. Total thickness ranges from 0 to 5300 feet. The thickest part of the carbonates generally follows the axis of the regional syncline. The elevation of the base of the carbonates (top of the quartzite) ranges from 2400 to 9700 feet. The carbonate unit is broadly folded in a north-plunging syncline and mostly covered by younger Tertiary and Quaternary units in the Powder Mountain area. The extent of the carbonate unit is limited on the Weber County side of the drainage divide. To the north, the carbonate unit is continuous into Cache County and the southern Bear River Range.

Within the upper part of carbonate unit, the Cambrian Nounan Formation is the source of water to important springs and the Hidden Lake Well. Well logs indicate the Nounan Formation is 760 to 850 ft thick. Its extent is limited by its upper contact with the St. Charles Formation and its lower contact with the Calls Fort Shale Member of the Bloomington Formation and the intersection with topography. Due to the extent of the Nounan Formation, the aquifer volume is substantially less than the carbonate unit as a whole. Most of the Nounan Formation lies on the Cache County side of the drainage divide, and the formation is continuous as it extends north into the Bear River Range.

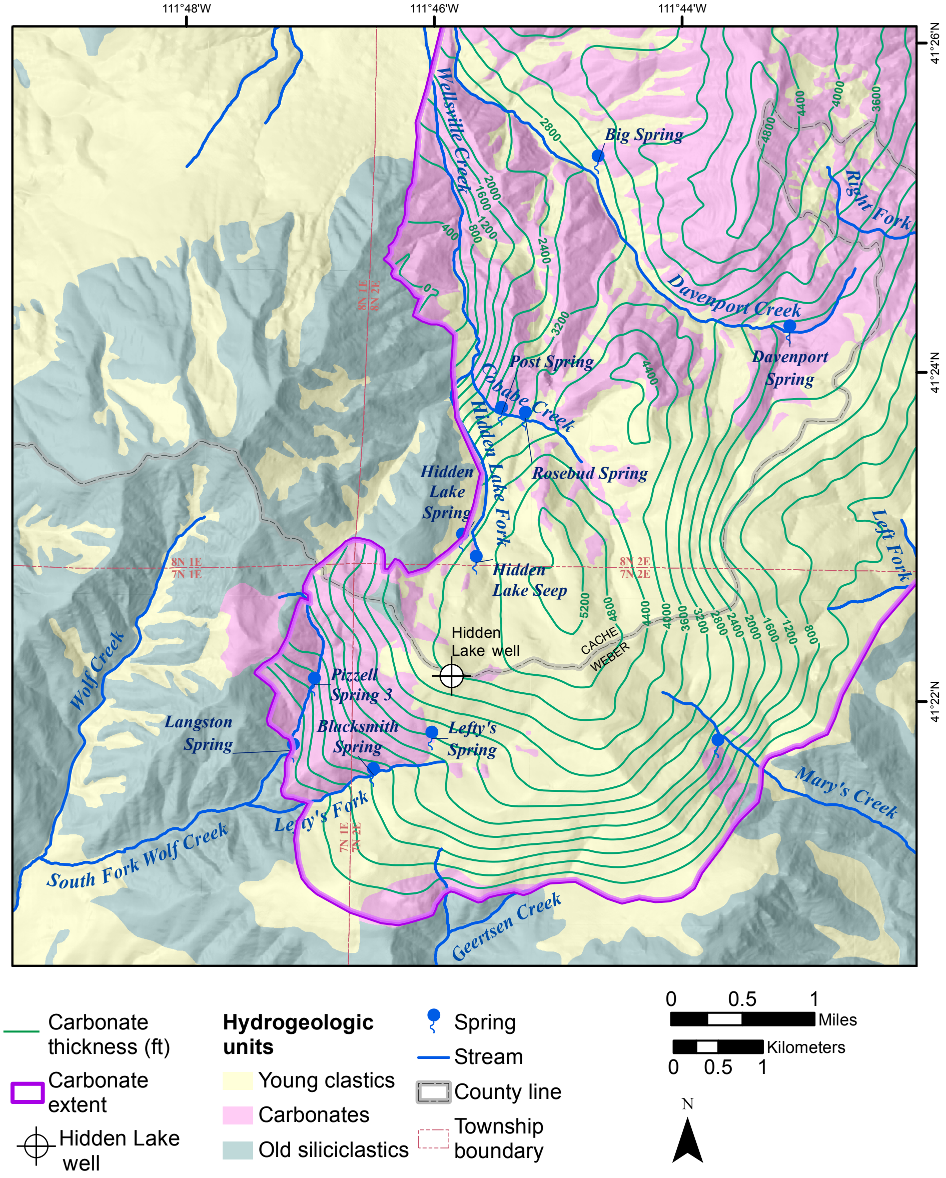


Figure 7. *Thickness of the carbonate units.*

The saturated thickness of the Nounan Formation is shown on figure 8. Saturated thickness was calculated as the difference between the potentiometric surface (presented in a subsequent section) and a contour of the base of the Nounan Formation. The structure contour of the base of the Nounan Formation is based on the spatial extent of outcrop, mapped geologic contacts, and well log data from Exploration Well 1 and the Hidden Lake Well. The mean saturated thickness of the Nounan in the study area is 550 feet. Saturated thickness increases from the southern edge of the formation and is greatest north of the Hidden Lake Well. Most of the saturated volume of the Nounan aquifer is located on the Cache County side of the study area.

In the Powder Mountain region, the Tertiary Wasatch Formation locally overlies the Paleozoic and Precambrian rocks that compose the principal aquifers. The Wasatch Formation occurs along a southwest to northeast trend across the Powder Mountain area (figure 9). Based on the isopachs, the Wasatch Formation thickness ranges from 0 to 1273 feet and has an average thickness of 320 feet. The formation is thickest along the county line, generally thinning downslope of the drainage divide. The thickness is controlled primarily by the erosional surface on which the Wasatch Formation was deposited and its current erosional extent. The base of the Wasatch Formation defines a gently east-dipping surface that cuts across older rocks at high angles.

Overall, the trend and thickness of the carbonate unit and Nounan Formation follows that of the regional syncline, which has a general north-south axis, with limbs extending to the east and west, and a gentle plunge to the north. Due to character and plunge of the syncline, most of the volume of the carbonate unit and the Nounan Formation, the key water-bearing unit of the region, is in the Cache County part of the study area. The extent of these units is limited to the south in Weber County. The Wasatch Formation overlies the older strata across much of the Powder Mountain area.

HYDROLOGY

Introduction

Groundwater supplies springs and baseflow to streams in the Powder Mountain area. To better constrain possible sources and amounts of groundwater and surface water, we conducted a hydrologic investigation of the Powder Mountain area. This investigation included measuring flows and weir stages; sampling and analyzing water chemistry of springs, streams and one well; analyzing data from an aquifer test of the Hidden Lake Well; and examining time-series data from nearby springs and streams. The resulting data are used to better constrain the relationship of groundwater to surface water and support conclusions concerning the conceptual model of groundwater in the Powder Mountain area.

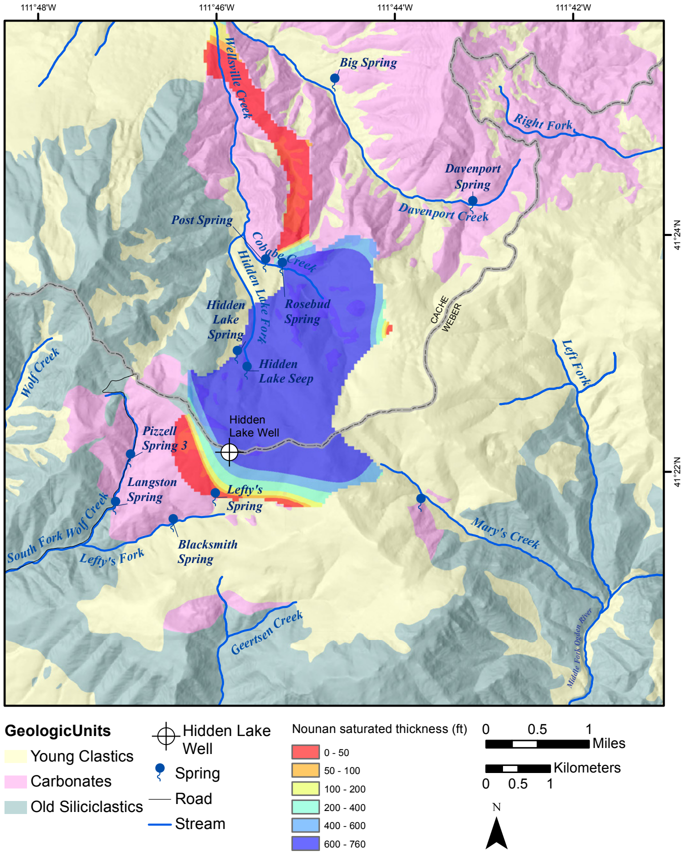


Figure 8. *Saturated thickness of the Nounan Formation in Weber County and the Wellsville catchment.*

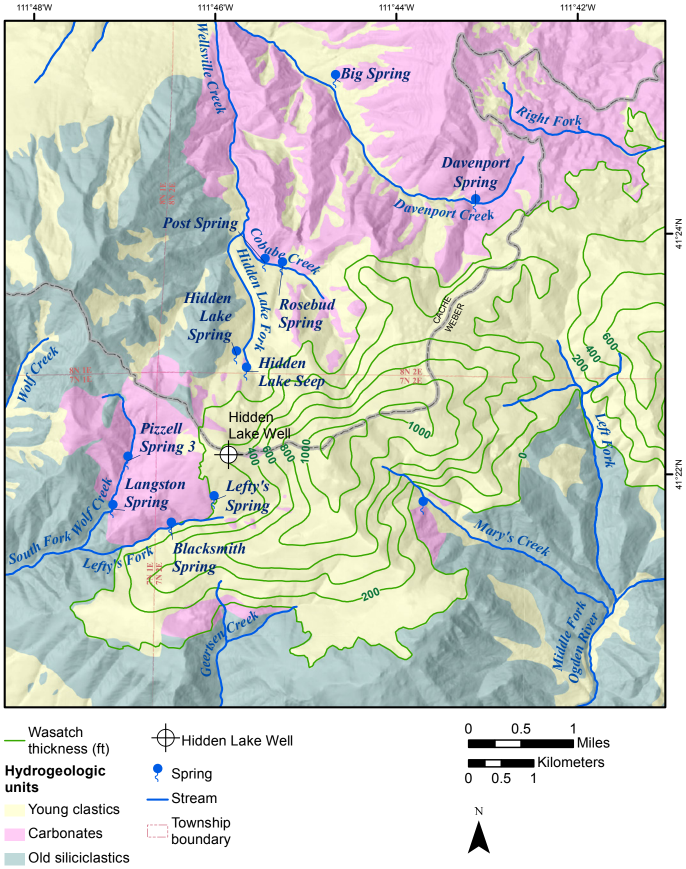


Figure 9. *Thickness of the Wasatch Formation. Contour interval is 200 feet.*

Background

King (2004) developed a hydrologic budget for the Powder Mountain area, which indicated that 143,230 acre-feet per year (ac-ft/yr) of water comes into the area, and estimated that 42%, 3%, 43%, 12%, and 0.01% leaves as stream flow, spring discharge, evapotranspiration, bedrock underflow, and groundwater use, respectively. Most of the recharge from precipitation in the study area comes in the form of snow. In his estimates, King (2004) showed a balanced hydrologic budget where outflow equals inflow of water. King (2004) estimated that 11,510 ac-ft/yr entered Ogden Valley and 5760 ac-ft/yr entered Cache Valley through bedrock underflow from Powder Mountain. King (2004) noted that pumping water from the Powder Mountain aquifer could result in reduction of groundwater in storage, bedrock underflow, evapotranspiration, and/or flow in stream channels while potentially causing recharge that is induced by groundwater pumping. Pumping-induced recharge occurs when groundwater gradient is reversed by the introduction of a cone of depression, converting discharge and transitional areas into areas of groundwater recharge. King (2004) argued that a well could capture water that wouldn't have otherwise recharged to the aquifer.

Based on existing National Hydrographic Datatset (NHD) and 1:24,000 scale topographic maps, several springs and gaining stream reaches exist downgradient of the Hidden Lake Well in Cache County (figure 2). Surface water from the study area flows to the north into Cache County via Wellsville and Davenport Creeks, which converge into greater Davenport Creek and contribute to the Little Bear River near Paradise, Utah (figure 1). In Weber County, the Wolf Creek drainage contains several springs and gaining reaches. The Hidden Lake Well is located on the north boundary of the Pineview Reservoir–North Fork Ogden River drainage (figure 1). Surface water flows to the south into Weber County via Geertsen Canyon Creek, Fish Springs Creek, the Middle Fork of the Ogden River, and Wolf Creek.

Powder Mountain Water and Sewer District currently operates three springs on the South Fork of Wolf Creek in Weber County. These springs supplied seasonal and permanent residents with 13.58 ac-ft of water in 2014 and 17.85 ac-ft in 2013 (Utah Division of Water Rights, 2015b). The three springs include Pizzel Springs 1, 2, and 3. All water sourced in 2014 was from Pizzel Springs 3 (figure 2), though previous years' records indicate that Pizzel 1 also contributes water occasionally. Wolf Creek Irrigation Company holds senior water rights on the surface streams draining the south side of the mountain that are fed by a number of springs including Lefty's Spring.

SHC Consulting, LLC (2012) created a preliminary evaluation report (PER) for five proposed wells on the Weber County side of Powder Mountain showing drinking water source protection (DWSP) areas that crossed the county line into Cache County. Loughlin Water Associates, LLC (2013) created a PER for the Hidden Lake Well showing the extent of the DWSP area for the well terminating at the county line (surface drainage divide). The DWSP plan is based on as-built and tested conditions for the Hidden Lake Well with flow rates up to 181 gpm. Loughlin Water Associates, LLC (2015) presented additional well construction and hydrogeologic data relevant to the Hidden Lake Well as part of a water right hearing.

Flow Measurements

Baseflow

We measured discharge using existing weirs, temporarily installed weir plates, in-stream flow meters, and timed volumetric measurements. Most of the measurements took place during the last week of October 2014. Conductivity, pH, and temperature measurements were measured at each flow measurement site. Site selection was based on areas of perceived hydrologic importance, including stream confluences, springs, and various locations along trunks of each stream. We collected field data at 44 sites (figure 10; table 1). Because of through-flow, incom-

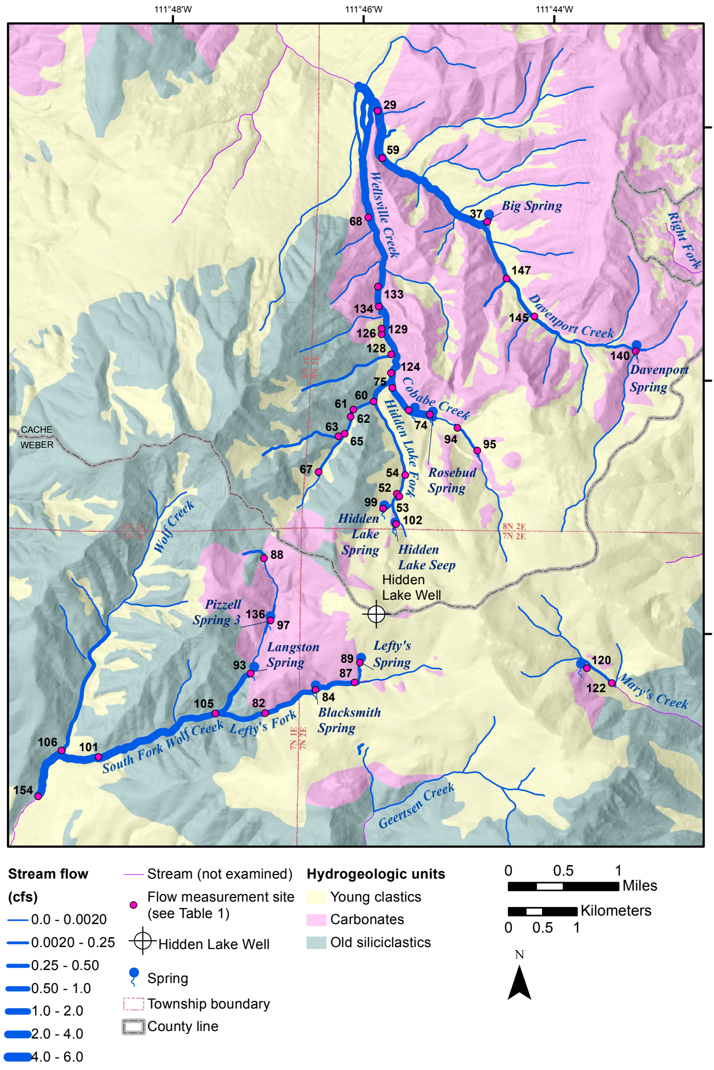


Figure 10. *Flow of streams and springs in the study area.*

Table 1. *Stream and spring flow measurements for the Powder Mountain area. View table 1 Excel file: Powdermountain_tables.xlsx*

Station ID	Name	Date-Time	T (°C)	pH	Cond (uS/cm)	Flow (gpm)	Flow (cfs)	Flow QA[1]	Measure type[2]
29	Davenport Creek elev 5961	10/23/2014 10:15	8.8	7.60	464	3004	6.7000	1	CM
37	Big Spring channel	10/23/2014 12:15	6.6	7.70	484	583	1.3000	2	CM
52	Hidden Lake Weir	10/29/2014 11:21	5.8	7.93	293	23	0.0505	1	W
53	East Hidden Lake Lift Spring	10/29/2014 11:37	6.0	7.89	315	15	0.0344	1	W
54	Culvert Spring	10/29/2014 12:51	4.9	7.81	284	16	0.0367	1	CM
59	Big Spring channel	10/29/2014 12:15	4.9	8.90	477	1363	3.0400	2	CM
60	Pour over	10/29/2014 14:03	3.8	8.01	273	42	0.0932	1	TV
61	Dual culverts	10/29/2014 14:35	4.4	7.84	101	13	0.0296	1	TV
62	Single culvert	10/29/2014 14:41	4.8	7.74	103	13	0.0293	1	TV
63	James Peak side drainage	10/29/2014 15:11	4.5	7.29	40	2	0.0047	2	TV
65	Small channel	10/29/2014 15:28	3.9	7.88	188	3	0.0070	1	W
67	Beaver Pond Spring outflow	10/29/2014 16:45	4.1	7.22	173	1	0.0022	2	W
68	Wellsville Creek elev 6278	10/29/2014 17:35	6.5	8.33	340	1233	2.7500	3	CM
74	Paradise Lift Spring in Cobabe drainage	10/30/2014 10:00	5.8	7.79	343	291	0.6491	2	W
75	Cobabe Creek elev 6888	10/30/2014 10:39	4.9	8.35	326	704	1.5700	1	CM
78	Cobabe Creek elev 7025	10/30/2014 12:10	5.4	8.25	318	976	2.1700	3	CM
82	Lefty's Fork above quartzite	10/30/2014 13:52	4.6	8.64	342	323	0.7200	1	CM
84	Unnamed Spring on Lefty's Fork	10/30/2014 14:28	5.4	7.77	316	61	0.1363	2	W
87	Lefty's channel upper	10/30/2014 15:37	7.1	8.56	411	24	0.0531	1	CM
88	South Fork of Wolf Creek elev 7899	10/30/2014 15:40	8.7	6.89	982	3	0.0067	2	TV
89	Lefty's Spring	10/30/2014 16:10	4.7	7.49	454	45	0.1001	2	TV
93	South Fork of Wolf Creek elev 7207	10/30/2014 17:46	5.6	7.94	390	333	0.7428	1	CM
94	Cobabe Creek elev 7347	10/30/2014 16:04	4.7	8.90	454	2	0.0054	3	W
95	Cobabe Creek elev 7549	10/30/2014 12:30	5.4	8.08	430	17	0.0388	2	TV
97	Pizzel Spring #3	10/30/2014 16:00	7.1	8.26	673	4	0.0084	2	TV
99	North Hidden Lake Lift Spring	10/31/2014 09:51	4.8	7.80	336	8	0.0181	2	TV
101	South Fork of Wolf Creek elev 6001	10/31/2014 10:30	5.5	8.56	281	1040	2.3200	3	CM
102	South Hidden Lake Lift Spring	10/31/2014 10:32	4.2	8.21	270	3	0.0070	2	W
105	South Fork of Wolf Creek elev 6851	10/31/2014 12:00	3.7	8.84	357	716	1.6000	2	CM
106	North Fork Wolf Creek	11/03/2014 11:12	4.7	8.06	183	193	0.4300	2	CM
120	Mary's Creek springhead flow	11/04/2014 12:49	4.5	7.50	290	2	0.0045	2	W
122	Mary's Creek Channel elev 7442	11/04/2014 13:27	1.5	8.42	289	13	0.0300	1	TV
124	North Boundary Weir (cipoletti weir)	11/05/2014 10:45	4.8	8.86	366	553	1.2329	1	W
126	Spring near Wellsville Creek	11/05/2014 12:21	5.8	8.35	325	5	0.0116	1	W
128	Tributary to Wellsville Creek elev 6742	11/05/2014 12:10	5.8	8.30	80	22	0.0495	2	W
129	Spring tributary to Wellsville Creek elev 6640	11/05/2014 13:42	6.1	8.32	376	7	0.0162	2	W
133	Wellsville Creek elev 6480	11/05/2014 15:30	5.6	8.77	311	526	1.1700	2	CM
134	Spring tributary to Lower Wellsville Creek	11/05/2014 15:00	5.4	8.48	327	138	0.3100	1	CM
140	Upper Davenport Creek elev 7390	11/06/2014 12:40	5.6	8.65	430	57	0.1300	2	CM
145	Davenport Creek elev 6819	11/06/2014 11:33	4.0	8.87	465	137	0.3000	1	CM
147	Small spring east of Davenport Creek	11/06/2014 13:00	5.9	8.70	516	84	0.1875	2	CM
154	South Fork of Wolf Creek elev 5591	11/21/2014 13:57	3.0	8.61	313	1004	2.2400	1	W

[1] Flow measurement error estimate includes percent of total flow captured and estimate of quality of flow measurement;
1 = + or - 10%, 2 = + or - 20%, 3 = + or - 30%

[2] Method used to measure flow; W = temporary or permanent weir, CM = transect within channel flow meter, TV = timed volumetric

plete capture of discharge, and inherent error of measurement devices, the resulting discharge measurements are estimated to be within 10% of actual discharge values. There was little or no significant precipitation during the flow measurements, and the flow conditions as measured were assumed to be baseflow conditions. These measurements should represent the relative contribution of groundwater sources to surface flow in the streams measured.

Using the field data we collected and the assumed hydrogeologic source for each site (table 2), we estimated the relative flow contribution of each catchment (figures 11 and 12). In Cache County, we examined relative flow contribution from Cobabe Creek, Hidden Lake Fork, and James Peak Fork to the Wellsville Creek at the North Boundary Weir (figures 11 and 12). At the time of measurement, 90% of the water flowing through the North Boundary Weir was from Cobabe Creek,

Table 2. *Summary of measurement sites in the Powder Mountain area. View table 2 Excel file: Powdermountain_tables.xlsx*

Station ID	Name	Drainage[1]	Source[2]	East[3]	North	Elev[4]	Flow (gpm)	SC[5]	Geo unit[6]	Geo Setting [7]
29	Davenport Creek elev 5961	Davenport Crk	CC	436169	4587341	5961	3004	464	Csc	Cov
31	Davenport Creek Spring 1	Davenport Crk	ST	439081	4584004	6197	--	574	Csc	Carb
33	Davenport Creek elev 6345	Davenport Crk	CC	437205	4585926	6345	--	329	Cn	Cov
34	Davenport Creek elev 6343	Davenport Crk	CC	437472	4585785	6345	--	471	Cn	Cov
35	Upper Davenport springs	Davenport Crk	ST	440025	4583858	6392	--	475	Cbc	Carb
36	Big Spring	Davenport Crk	ST	437797	4585769	6520	--	494	Csc	Carb
37	Big Spring channel	Davenport Crk	ST	437771	4585722	6479	583	484	Csc	Carb
39	Davenport Creek elev 6436	Davenport Crk	CC	438460	4584338	6436	--	465	Csc	Cov
42	Hidden Lake Spring west	Hidden Lake Fork (Wellsville Crk)	SP	436260	4581543	7760	--	335	Q	Cov
43	Hidden Lake Spring south	Hidden Lake Fork (Wellsville Crk)	SP	436394	4581242	7998	--	263	Cn	Cov
45	Rosebud Spring	Cobabe Crk	ST	436969	4582879	7162	--	362	Cn	Carb
52	Hidden Lake Weir	Hidden Lake Fork (Wellsville Crk)	CC	436451	4581747	7617	23	293	Q	Cov
53	East Hidden Lake Lift Spring	Hidden Lake Fork (Wellsville Crk)	ST	436487	4581707	7626	15	315	Q	Cov
54	Culvert Spring	Hidden Lake Fork (Wellsville Crk)	ST	436574	4582019	7487	16	284	Q	Cov
55	Spring	Davenport Crk	ST	436421	4587066	6131	--	535	Csc	Carb
56	Davenport Creek tributary	Davenport Crk	TR	438053	4584892	6052	--	516	Csc	Cov
57	Hidden Lake Fork channel	Hidden Lake Fork (Wellsville Crk)	CC	436537	4582203	7385	--	289	Q	Cov
59	Big Spring channel	Davenport Crk	CC	436237	4586650	6088	1363	484	Cn	Carb
60	Pour over	Hidden Lake Fork (Wellsville Crk)	CC	436113	4583096	6986	42	273	Q	Cov
61	Dual culverts	James Peak Fork (Wellsville Crk)	CC	435819	4582978	7128	13	101	Cgc	Qrtz
62	Single culvert	James Peak Fork (Wellsville Crk)	CC	435777	4582875	7178	13	103	Cgc	Qrtz
63	James Peak side drainage	James Peak Fork (Wellsville Crk)	CC	435600	4582588	7365	2	40	Cgc	Qrtz
65	Small channel	James Peak Fork (Wellsville Crk)	CC	435688	4582623	7298	3	188	Cgc	Qrtz
66	Beaver Pond Spring	James Peak Fork (Wellsville Crk)	ST	435300	4582019	7654	--	181	Cgc	Qrtz
67	Beaver Pond Spring outflow	James Peak Fork (Wellsville Crk)	ST	435309	4582065	7637	1	173	Cgc	Qrtz
68	Wellsville Creek	Wellsville Crk	CC	436037	4585785	6278	1233	340	Cbc	Cov
70	Hidden Lake Fork channel	Hidden Lake Fork (Wellsville Crk)	CC	436425	4582522	7257	--	292	Q	Cov
74	Paradise Lift Spring in Cobabe Creek	Cobabe Crk	ST	436933	4582904	7159	291	343	Cn	Carb
75	Cobabe Creek elev 6888	Cobabe Crk	CC	436386	4583294	6888	704	326	Cu	Cov
77	N Hidden Lake Lift Spring	Hidden Lake Fork (Wellsville Crk)	ST	436261	4581532	7782	--	336	Q	Cov
78	Cobabe Creek elev 7025	Cobabe Crk	CC	436626	4582968	7025	976	318	Cbh	Carb
80	Cobabe Creek elev 7347	Cobabe Crk	ST	437630	4582381	7347	--	420	Ogc	Cov
81	Spring North of Cobabe Creek	Cobabe Crk	SP	437647	4582384	7347	--	420	Ogc	Cov
82	Lefty's Fork above quartzite	Lefty's Fork	CC	434531	4578543	7300	323	342	Cl	Carb
84	Unnamed Spring on Lefty's Fork	Lefty's Fork	ST	435266	4578880	7569	61	316	Cbk	Carb
87	Lefty's channel upper	Lefty's Fork	CC	435836	4578993	7765	24	411	Cbm	Carb
88	South Fork of Wolf Creek elev 7899	South Fork Wolf Crk	CC	434512	4580804	7899	3	982	Cbk	Carb
89	Lefty's Spring	Lefty's Fork	SP	435912	4579280	8077	45	454	Cn	Carb
92	Spring on South Fork of Wolf Creek	South Fork Wolf Crk	SP	434351	4579140	7224	--	390	Cl	Carb
93	South Fork of Wolf Creek elev 7207	South Fork Wolf Crk	CC	434315	4579121	7207	333	390	Cl	Carb

***Table 2.** Continued.*

Station ID	Name	Drainage[1]	Source[2]	East[3]	North	Elev[4]	Flow (gpm)	SC[5]	Geo unit[6]	Geo Setting [7]
94	Cobabe Creek elev 7347	Cobabe Crk	CC	437335	4582709	7347	2	454	Ogc	Cov
95	Cobabe Creek elev 7549	Cobabe Crk	CC	437629	4582381	7549	17	430	Ogc	Cov
97	Pizell Spring #3	South Fork Wolf Crk	ST	434606	4579896	7495	4	673	Cu	Carb
99	N Hidden Lake Lift Spring	Hidden Lake Fork (Wellsville Crk)	CC	436253	4581532	7791	8	--	Q	Cov
100	S Hidden Lake Lift Spring	Hidden Lake Fork (Wellsville Crk)	ST	436400	4581241	7958	--	271	Cn	Carb
101	South fork of Wolf Creek elev 6001	South Fork Wolf Crk	CC	432093	4577901	6001	1040	281	Cgc	Qrtz
102	South Hidden Lake Lift Spring	Hidden Lake Fork (Wellsville Crk)	ST	436440	4581306	7877	3	270	Cn	Cov
103	Small springhead A	Hidden Lake Fork (Wellsville Crk)	ST	436482	4581329	7840	--	349	Q	Cov
104	Small springhead B	Hidden Lake Fork (Wellsville Crk)	ST	436476	4581386	7836	--	308	Q	Cov
105	South fork of Wolf Creek elev 6851	South Fork Wolf Crk	CC	433804	4578538	6851	716	357	Cgc	Qrtz
106	North Fork Wolf Creek	North Fork Wolf Crk	CC	431553	4577996	5804	193	183	Zkc	Qrtz
107	Spring in Geertsen Creek	Geertsen Creek	SP	437446	4577675	8005	--	92	Tw	Oth
108	Geertsen Hilton	Geertsen Creek	ST	435952	4578090	7978	--	291	Tw	Oth
109	Upper Geertsen Creek elev 8241	Geertsen Creek	CC	438249	4577492	8241	--	61	Tw	Oth
111	Upper Geertsen Creek elev 8110	Geertsen Creek	CC	437745	4577579	8110	--	72	Tw	Oth
118	Mary's Creek Spring	Mary's Creek	SP	438836	4579664	7740	--	290	Tw	Oth
119	Mary's Creek Channel elev 7706	Mary's Creek	CC	439175	4579304	7706	--	243	Cbk	Cov
120	Mary's Creek springhead flow	Mary's Creek	ST	439226	4579198	7686	2	290	Cbk	Carb
122	Mary's Creek Channel elev 7442	Mary's Creek	CC	439589	4578982	7442	13	289	Cl	Cov
124	North Boundary Weir (cipoletti weir)	Wellsville Crk	CC	436368	4583515	6809	553	366	Cu	Cov
125	Tributary to Wellsville Creek elev 6882	Wellsville Crk	TR	436192	4583751	6882	--	80	Cgc	Qrtz
126	Spring near Wellsville Creek	Wellsville Crk	CC	436231	4584081	6653	5	325	Cu	Cov
128	Wellsville Creek tributary elev 6742	Wellsville Crk	TR	436372	4583784	6743	22	80	Cu	Cov
129	Spring tributary to Wellsville Creek elev 6640	Wellsville Crk	ST	436229	4584161	6640	7	376	Cu	Cov
131	Wellsville Creek Spring elev 6508	Wellsville Crk	ST	436177	4584841	6508	--	280	Cbk	Carb
132	Wellsville Creek elev 6391	Wellsville Crk	CC	436260	4585187	6391	--	316	Cbm	Cov
133	Wellsville Creek elev 6480	Wellsville Crk	CC	436174	4584773	6480	526	311	Cbk	Cov
134	Spring tributary to Lower Wellsville Creek	Wellsville Crk	ST	436189	4584486	6547	138	327	Cu	Carb
135	Lower Wellsville Spring	Wellsville Crk	SP	436202	4584397	6547	--	327	Cu	Carb
139	Davenport Creek	Davenport Crk	CC	436237	4586650	7456	--	475	Cbc	Carb
140	Upper Davenport Creek elev 7390	Davenport Crk	CC	439940	4583829	7390	57	430	Cbc	Carb
143	South Fork of Wolf Creek elev 7074	South Fork Wolf Crk	CC	434608	4579897	7074	--	650	Cu	Carb
144	Cliff Spring in Davenport	Davenport Crk	ST	436252	4587000	6974	--	504	Csc	Carb
145	Davenport Creek elev 6819	Davenport Crk	CC	438460	4584338	6819	137	466	Csc	Cov
147	Small spring E of Davenport Creek	Davenport Crk	CC	438053	4584892	6615	84	516	Csc	Cov
148	Davenport Creek Spring 2	Davenport Crk	ST	438859	4584018	6519	--	503	Csc	Cov
154	South Fork of Wolf Creek elev 5591	South Fork Wolf Crk	CC	431213	4577327	5591	1004	313	Cgc	Qrtz
155	Bar B Geersten Upper Flume	Geertsen Creek	CC	434843	4572820	5157	--	42	Q/Cgc	Oth
160	Hidden Lake Well	Lefty's Fork	WL	436188	4579961	8876	--	412	Cn	Cov
171	Warm Springs	Ogden Valley	SP	430791	4575361	5234	--	172	Tn	Oth
172	Burnett Spring	Ogden Valley	SP	431612	4575333	5348	--	122	Q/Tn	Oth
173	Bad Spring	Ogden Valley	SP	431600	4575313	5327	--	112	Q/Tn	Oth

[1] Subdrainage of measurement

[2] Source of measurement; ST = Spring Tributary, CC = Creek Channel, SP = Spring, TR = Tributary, WL = Well

[3] Location in UTM NAD 83 Zone 12N

[4] Elevation taken from the 10 meter National Elevation Dataset

[5] Specific Conductance in µS/cm

[6] Geologic unit near or at measurement location most relevant to the hydrology

[7] Geologic Setting; Carb = carbonate, Cov = covered carbonate, Oth = other, Qrtz = quartzite

Source at:	Quantity location description	Flow (cfs)	Flow (%)	Station ID (#)
N. Boundary Weir on Wellsville Creek	N. Boundary Weir on Wellsville Creek	1.23	100%	124
	Hidden Lake Fork (Wellsville Creek)	0.09	8%	60
	James Peak Fork (Wellsville Creek)	0.03	2%	61
	Cobabe Creek[1]	1.11	90%	
Cobabe Creek	Cobabe Creek[1]	1.11	100%	
	Nounan Formation	0.65	58%	74
	Other Carbonates[2]	0.46	42%	
Wolf Creek	Total Wolf Creek	2.24	100%	154
	Lefty's Fork	0.72	32%	82
	South Fork Wolf Creek base of carbonates	0.74	33%	93
	North Fork of Wolf Creek quartzite	0.43	19%	106
	Other quartzite[3]	0.35	16%	
Lefty's Fork	Lefty's Fork	0.72	100%	82
	Lefty's Spring	0.10	14%	89
	Spring from Blacksmith Formation	0.14	19%	84
	Other Carbonates[4]	0.48	67%	

[1] Cobabe Creek = #124 - (#60 + #61)

[2] Other Carbonates = Cobabe Creek - #74

[3] Other Quartzite = #154 - (#82 + #93 + #106)

[4] Other Carbonates = #84 - (#82 + #89)

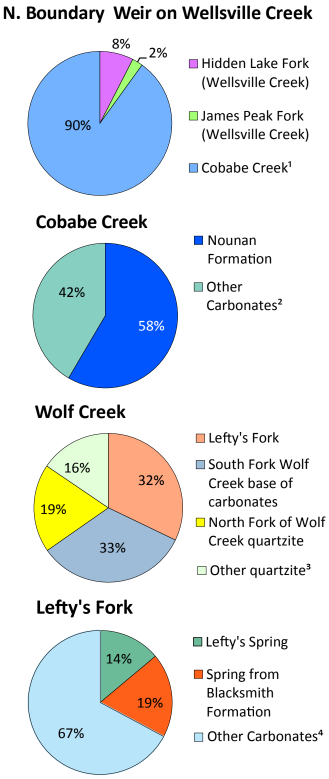


Figure 11. *Relative sources of baseflow for select drainages in the Powder Mountain area.*

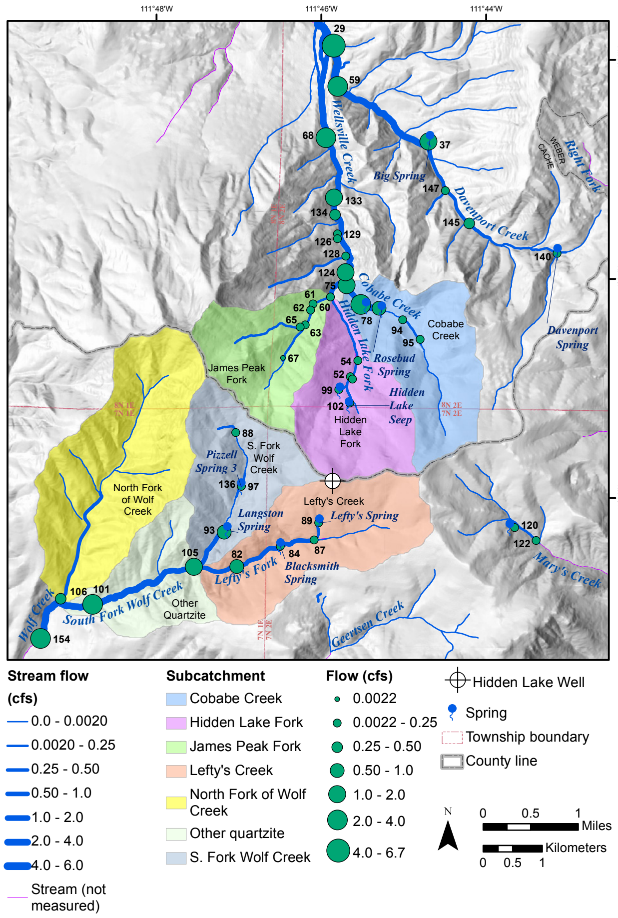


Figure 12. *Subcatchments and measured flow. Numbers are station IDs that correlate with table 2.*

8% was from the Hidden Lake Fork, and 2% was from the James Peak Fork. Cobabe Creek receives all its water from springs and gaining streams sourced from carbonates; 58% was from the Nounan Formation and 42% from other carbonates. While we did not examine Davenport Creek in great detail, more than half of its flow at the time of measurement was from Big Spring, and all of the flow measured appeared to come from carbonate rocks.

In Weber County, we estimated the contributions of flow to Wolf Creek and its tributary, Lefty's Creek (figures 11 and 12). Wolf Creek gets 65% of its flow from springs and gaining streams sourced from carbonates, and the other 35% comes from catchments underlain by quartzite formations. For Lefty's Creek, 66% of the flow comes from carbonate units other than the Blacksmith and Nounan Formations, which makeup the other 33% of the contributions to the flow. Four percent of the total flow of Wolf Creek is Lefty's Spring, and 6% comes from a spring in the Blacksmith Formation.

Stream gaging measurements indicated that the majority of stream baseflow comes from the carbonate aquifers. Over two-thirds of Wolf Creek's flow is derived from carbonate-sourced springs, the most important of which emanates from the base of the carbonates just above site 93 on the South Fork of Wolf Creek (labeled Langston Spring on figure 11). This spring issues from the Langston Dolomite and contributes 33% of Wolf Creek's total flow, while Lefty's Spring (site 89) and a spring from the Blacksmith Formation (site 84) contribute 4 and 6% of the total flow, respectively.

Every drainage underlain by carbonate rocks has a major spring that contributes between one-third and one-half of the total baseflow. In the Wellsville drainage, Rosebud Spring issues from the Nounan Formation along Cobabe Creek (site 45) and contributes 53% of the total discharge of this part of Wellsville Creek. The largest spring along the Davenport drainage is Big Spring (site 37) which contributes 47% of the baseflow of Davenport Creek above the confluence with Wellsville Creek (site 29). Langston Spring is the largest spring in the South Fork of Wolf Creek drainage and contributes 33% of the total flow.

Long Term Hydrographs

While the field measurements give some indication of flow conditions during base flow, they may not be representative of peak flow. To gain a better understanding of seasonal flow rates and groundwater levels, we examined time-series data collected by Loughlin Water and Cascade Water from various sites (figure 13) over extended time periods (figure 14) (Loughlin Water Associates, LLC, 2015; Cascade Water Resources, LLC, 2015). The sites with the longest period of record were Exploration Well 2 (observation well near the Hidden Lake Well) and upper Lefty's Spring (figure 13). Stage and discharge data were

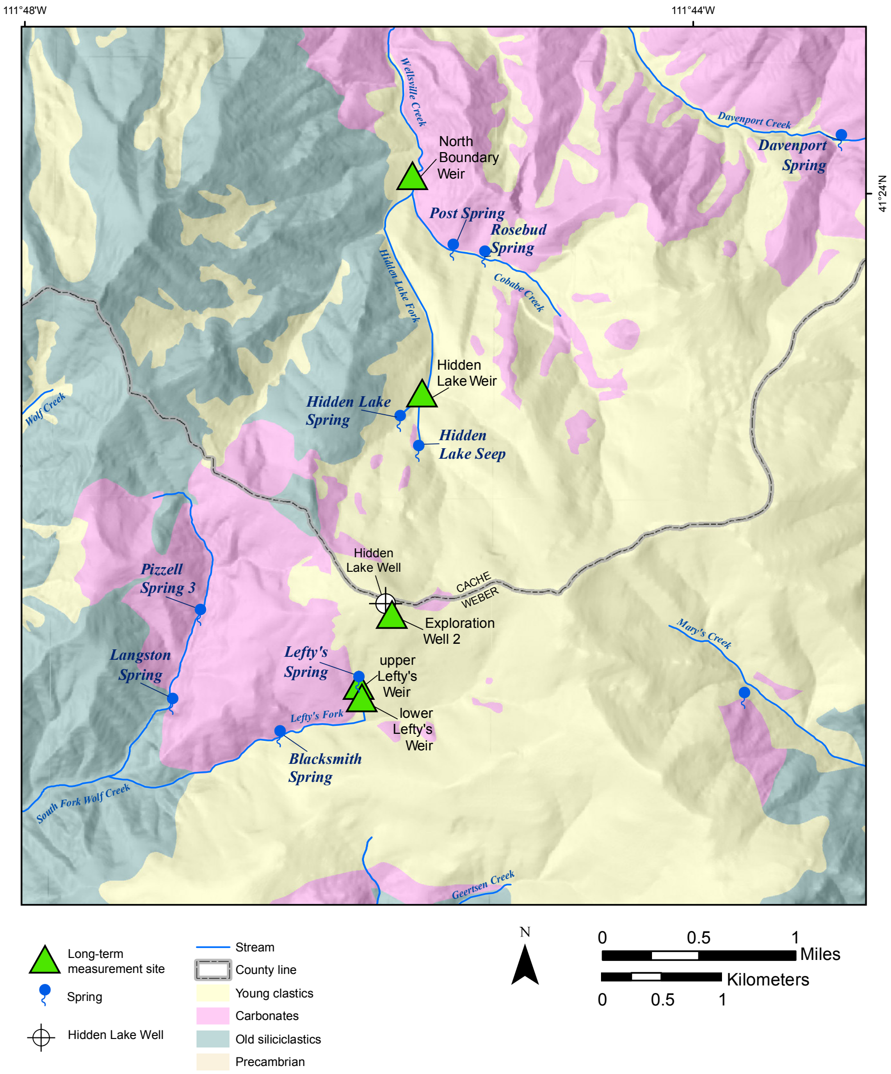


Figure 13. *Locations of long-term measurement.*

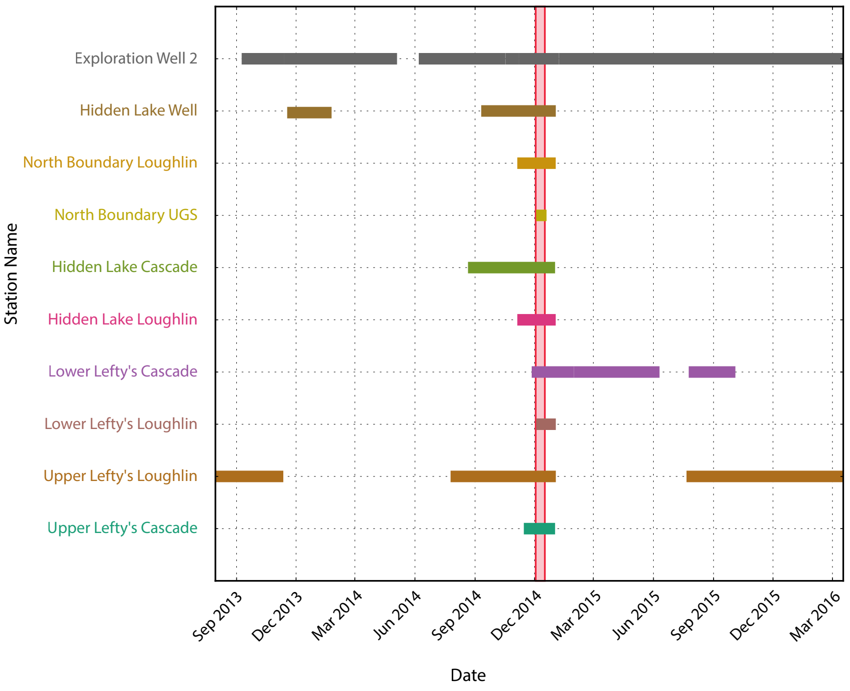


Figure 14. *Periods of flow and water-level monitoring used for this study. Vertical red bar highlights the aquifer test period.*

recorded, by Loughlin Water and Cascade Water, for two sites at Lefty's Spring, a weir in the upper part of the Hidden Lake drainage, and at a cipoletti weir on Wellsville Creek.

All of the time-series data presented in this report, with the exception of a small amount of data from the North Boundary Weir (site 124), were collected by Loughlin Water Associates, LLC or affiliates of Cascade Water Resources, LLC. These parties provided the UGS with raw data files and manual measurements, which we combined with our own manual measurements and processed. Most of the spring and stream time-series data was recorded using pressure transducers. We used the raw data and manual measurements to convert those data into estimates of discharge over time. The transducers recorded pressure behind the weir plates which was converted to stage. Using weir flow equations and by fitting to manual measurements, we converted the continuously measured stage values to discharge. These methods are summarized as Python scripts available from the authors upon request.

Loughlin Water collected water levels from Exploration Well 2 from mid-September 2013 to the present (figure 15). This well is located ~50 feet southeast of the Hidden Lake Well. Based on the available data, Exploration Well 2 shows a linear declining trend of about -0.2 feet per day from mid-July to late April punctuated by drawdown induced by pumping the Hidden Lake Well during the December 2014 aquifer test. Seasonal variation in water levels is approximately 65 feet, ranging in elevation from about 8115 feet in late April 2014 to about 8180 feet in late July 2014. The seasonal peak and trough of the trend is likely correlative with the timing of snow accumulation and melt cycles, and the rate of decline could be dictated by annual snowmelt availability.

Continuous discharge monitoring at Lefty's Spring consists of a v-notch weir at the spring head (upper Lefty's Weir) and lower v-notch weir located approximately 100 feet downstream along the outflow channel from Lefty's Spring (lower Lefty's Weir). A total of four transducers were deployed, and Cascade Water and Loughlin Water each had a transducer at both the upper and lower locations. Cascade Water collected discharge data from lower Lefty's Weir from December 2014 to October 2015 (figure 15). This weir was constructed downstream of the upper Lefty's Weir to capture spring discharge occurring below the upper weir. Cascade Water's data captures the timing of the approximate peak discharge in late May 2015 coincident with modeled snowmelt (National Operational Hydrologic Remote Sensing Center, 2015) near Lefty's Spring. The lowest discharge measured at this site was about 44 gallons per minute (gpm) in early March 2015. Based on these measurements, discharge at this site ranged from about 44 to 222 gpm. Unfortunately, the longer term records available do not have significant overlap and are difficult to compare. Median discharge from the weir is 71 gpm and discharge ranges from 35 to 222 gpm (table 3).

Upper Lefty's Weir captures spring flow that emits directly from bedrock of the Nounan Formation (site 89; table 1 and figure 10). The upper Lefty's Weir was installed by the Powder Mountain Water and Sewer District. The weir has the longest record of monitoring for any of the non-developed sites in the study area, having flow data from late 2013 to the present. The weir is directly downstream of where the main Lefty's Spring head emerges and contribution from overland flow is negligible. The median of discharge measurements from upper Lefty's Spring is 32 gpm, having values ranging from 4 to 129 gpm (table 3).

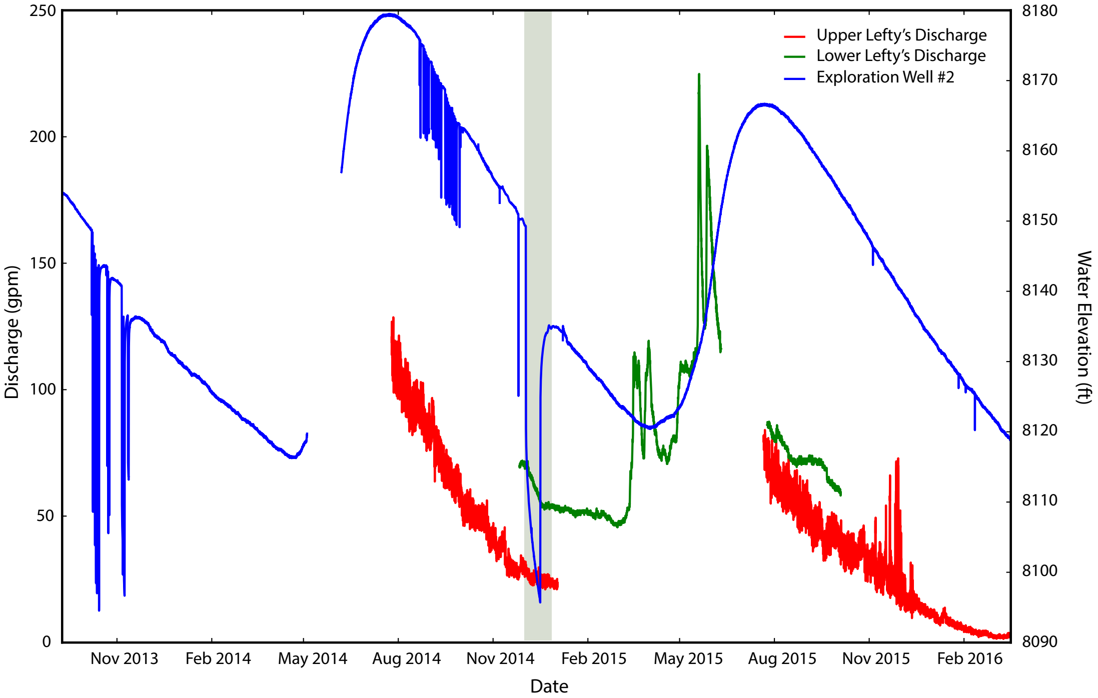


Figure 15. *Long-term water levels for Exploration Well #2 and discharge for upper and lower Lefty's Fork Weir flow measurement sites. Gray highlight is the period of the Hidden Lake Well aquifer test.*

Table 3. *Summary statistics of time-series data collected during the study. View table 3 Excel file: Powdermountain_tables.xlsx*

Site	Station ID	Measured By	Measure Start Date	Measure End Date	Measure Int. (days)	Min (gpm)	Max (gpm)	Quartiles (gpm)		
								25%	50%	75%
Hidden Lake	52	Cascade Water	8/21/14	1/1/15	133	4	315	79	87	104
		Loughlin Water	11/4/14	1/2/15	59	48	177	71	78	87
North Boundary	124	Loughlin Water	11/4/14	1/2/15	59	356	3054	465	498	550
		UGS	12/3/14	12/19/14	16	365	1011	459	486	508
Lower Lefty's	NA	Cascade Water	11/26/14	10/4/15	312	44	222	53	71	97
		Loughlin Water	12/3/14	1/2/15	30	35	98	57	64	71
Upper Lefty's	89	Cascade Water	11/14/14	12/16/14	32	16	23	19	20	21
		Loughlin Water	7/25/14	3/17/16	601	4	129	14	32	51

We created scatter plots comparing discharge measurements by Loughlin Water and Cascade Water and measurements between the upper and lower weirs. The lower Lefty's Weir discharge data have the highest correlation with an r-squared value of 0.57. The Loughlin Water data for upper and lower Lefty's Weirs have an r-squared value of 0.36. The various discharge measurements from Lefty's Spring have poor correlation indicating potentially large error in the measurements (figure 16).

Several factors can contribute to the observed variation and lack of correlation among the measurements. The upper Lefty's Weir had notable seepage and underflow, and the weir

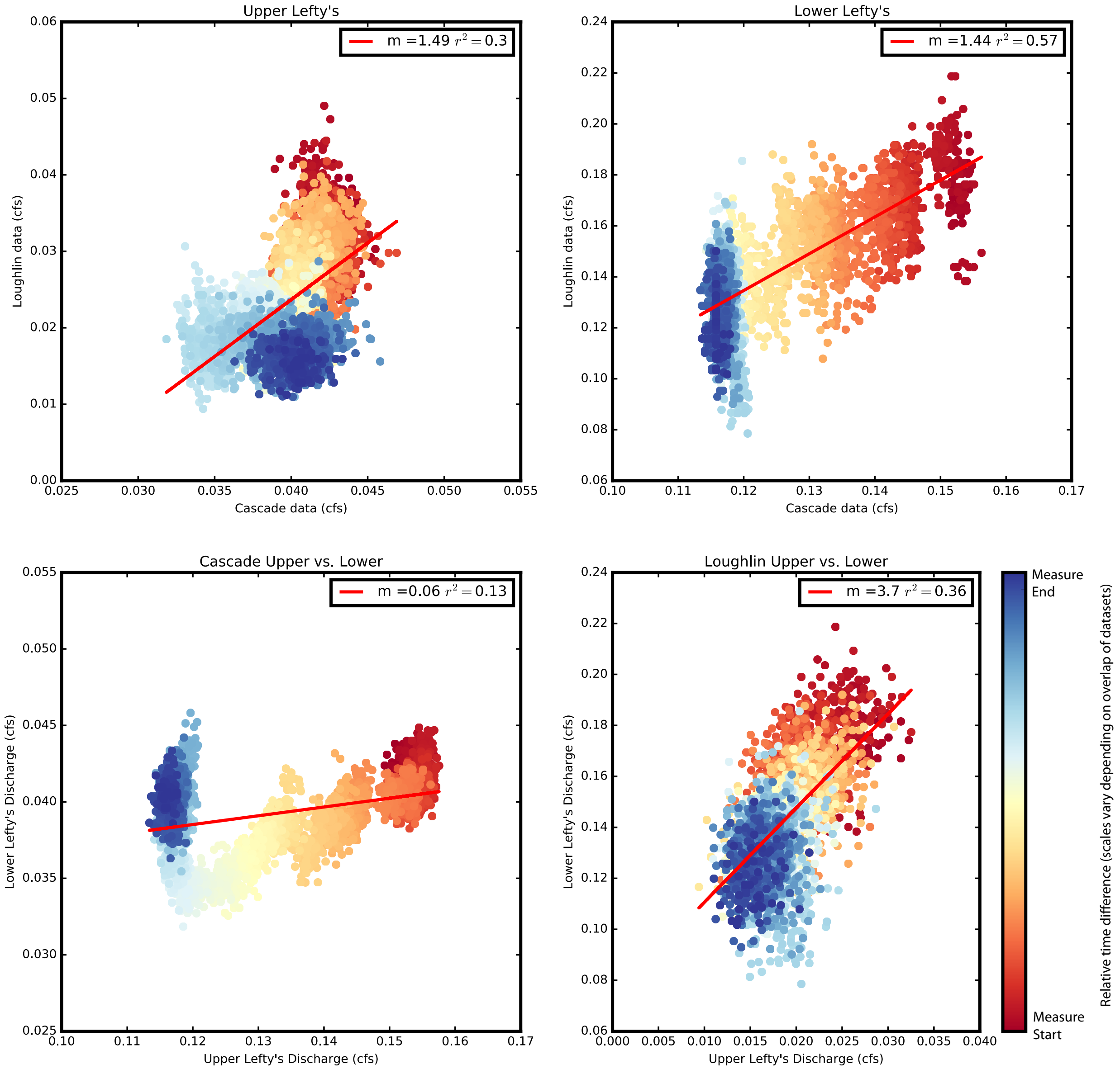


Figure 16. *Correlation of flow measurements recorded at upper and lower Lefty's Fork Weirs.*

was constructed from plywood and other non-traditional materials instead of a calibrated, sharp-crested steel weir. Several adjustments were made throughout the study period to both weirs. Lucy Jordan, Utah Geological Survey, noted that neither of the weirs were level or plumb in the longitudinal and transverse directions which could cause errors in discharge measurements as high as 8% (Adkins, 2006). The unvented transducers used by Loughlin Water had considerably more variability (noise) in the data than did the vented transducers used by Cascade Water (Cascade Water Resources, LLC, 2015), although the accuracy seemed comparable. Cascade Water noted that the transducer vent was blocked at one interval disturbing data over that period.

Discharge estimates for lower Lefty's Weir are based solely on the Thomson weir equation, and because of relative lack of manual flow measurements this site has no discharge-stage relationship. Bucket and stopwatch discharge measurements are only available for upper Lefty's Weir. Based on these manual measurements, the average root-mean-squared error from discharge based on the standard Thomson weir equation (U.S. Bureau of Reclamation, 2001) was 8 gpm.

Both water levels in the aquifer and flows from the springs have a seasonal decline related to recharge and discharge of the carbonate aquifers that is not associated with anthropogenic activities. We noted seasonal recession in four of the time-series sites. Using ordinary least squared regression, we determined the recession of the time series to see how quickly flow is reduced and water level drops. Exploration Well 2 and the Hidden Lake Well showed seasonal decline in water levels between 0.14 and 0.3 feet per day over the baseflow period of August to December. The Hidden Lake Weir (site 52) and upper Lefty's Spring (site 89) showed seasonal declines in 2014 between 0.2 and 0.68 gpm per day depending on measurement style. Documenting seasonal decline can allow for differentiation from pumping-based decline in the future. We discuss declines in terms of spring flow recession in our analysis of the aquifer test data.

The measured record of the North Boundary Weir (site 124) did not show a seasonal decline in the hydrograph. This is likely because the measurement period was not long enough to capture a decline in flow. Declines in water level may have been buffered by other variations in the flow at this site. This site had a periodic doubling of discharge that recurred about every 36 hours (figure 17). Video was captured to verify the doubling of flow (Loughlin Water, unpublished data, 2015). We attributed this periodicity to vacuum draining of a subterranean karst chamber, as observed at Periodic Spring near Afton, Wyoming (Blanchard, 1990).

Potentiometric Surface

We constructed a potentiometric surface using field observations of dry and wet stream reaches (figure 10), well water level data, and spring locations. We assumed that points of spring or stream emergence indicated contact of the water table with the ground surface. We then interpolated these locations with water-level elevations from test wells to create a potentiometric surface for the aquifer system, assuming that the spring/stream emergence does not represent discrete perched zones in the aquifer system. Depth to water information is sparse, and springs and gaining segments of creeks are likely the best available constraints for the potentiometric surface where well data are unavailable. Due to a relative lack of water-level data for discrete geologic units, the contours represent water levels from the entire carbonate aquifer system at the time of measurement (figure 18). Groundwater elevation is assumed to be equal to the land surface at major springs, including Lefty's Spring, Hidden Lake Spring, and Cobabe Spring, and along gaining stream reaches, including Lefty's Fork, Cobabe Creek, and Wellsville Creek.

Groundwater elevations decrease away from the Hidden Lake Well site into Weber and Cache Counties. The potentiometric slope increases below approximately 7840 feet in areas of spring discharge and gaining streams in the upper parts of the Wellsville Creek and South Fork of Wolf Creek drainages. The potentiometric divide likely follows the topographic divide, and the potentiometric surface is gently east sloping to the east of the Hidden Lake Well. A saddle or high in the potentiometric surface is shown for the area between Lefty's Fork and the upper part of Geertsen Creek.

The potentiometric surface and the structure contours can be used to estimate saturated volume of the principal aquifers. Saturated volume of the Nounan aquifer was calculated as the difference between the potentiometric surface and the base of the Nounan Formation. The resulting grid was split along the county boundary and used to calculate the total saturated volume and volume of groundwater in the Nounan aquifer in Cache and Weber Counties (table 4). The Nounan aquifer is continuous north of the study area in Cache County, and the

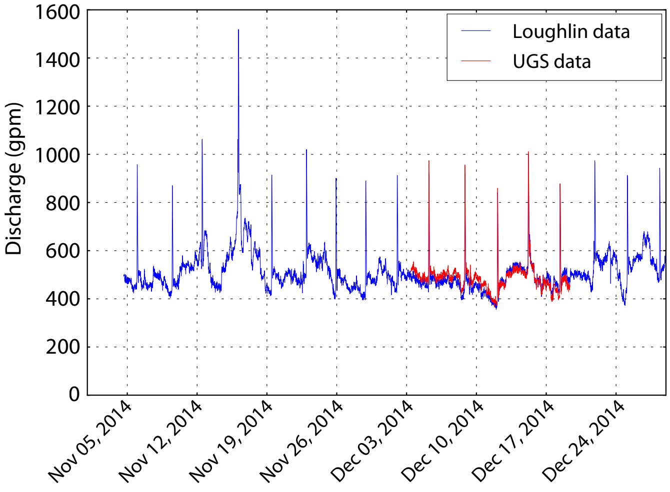


Figure 17. *Hydrograph measured at the North Boundary Weir (site 124) showing periodic doubling of discharge occurring every 36 hours.*

estimate of the groundwater volume in Cache County is limited to the Wellsville drainage. Total volume of groundwater in the Nounan aquifer in Weber County and the Wellsville drainage of Cache County is just under 100,000 acre-feet. Just over 80,000 acre-feet of the total is located in Cache County, and just under 20,000 acre-feet are located in Weber County.

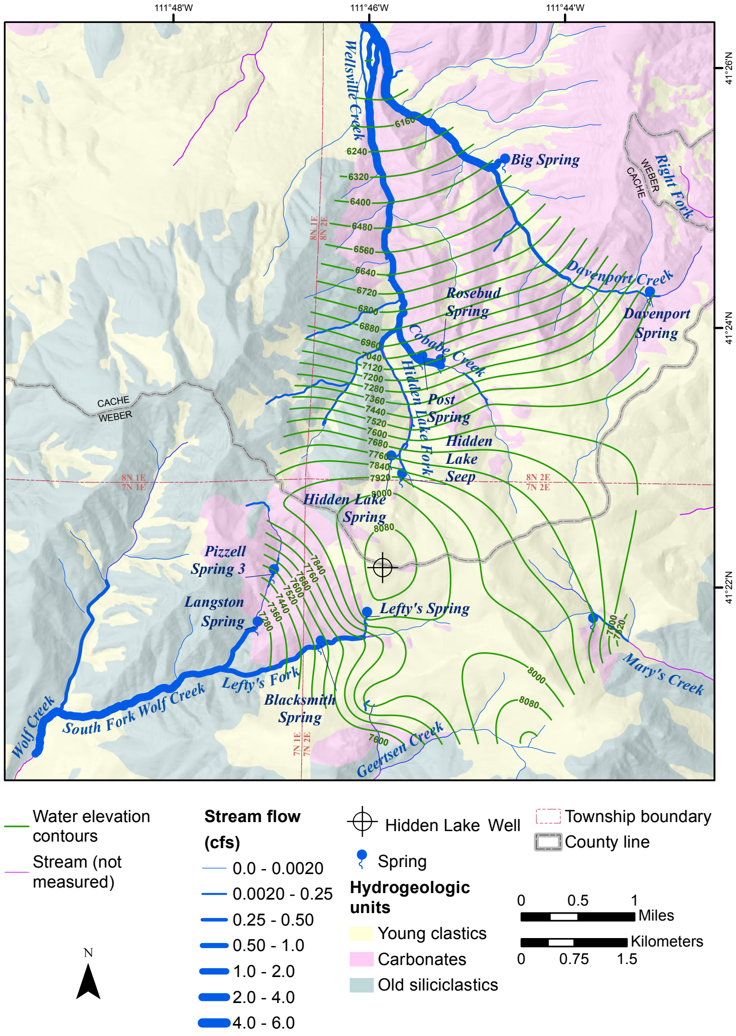


Figure 18. Potentiometric surface of the carbonate units.

Water Chemistry

Introduction

We collected basic field parameter measurements from a total of 70 sites between October 23, 2014, and December 9, 2014 (figure 19; table 5). Field parameters of temperature, pH, and conductivity, were collected at all flow measurement and water sampling sites and at a variety of other sites. Most site visits (47) were conducted from October 28, 2014, to October 30, 2014.

All field measurement sites were assigned a hydrostratigraphic unit and hydrochemical group based the mapped geology near the measurement site and the hydrochemical characteristics of the samples, respectively (table 2). Hydrochemical groups are based on assumed groundwater flow paths derived from water chemistry and include (1) carbonate, where carbonate rocks are exposed or are the obvious source of water sampled or measured; (2) covered carbonate, where carbonate rocks likely lie in the near subsurface beneath either unconsolidated deposits or Wasatch Formation; (3) quartzite, where quartzite rocks are exposed or are the source of water sampled or measured; and (4) other, that includes sample sites from the Wasatch Formation, basin fill including the Norwood Tuff, and other unconsolidated deposits.

The conductivity of a fluid is a basic measurement of the resistive character of a fluid and is correlative with solute concentrations, particularly sodium and chloride. Conductivity provides a simple measurement of total chemistry and potential correlation of waters. A map of conductivity measurements shows systematic changes in conductivity across the Powder Mountain area (figure 19). Measurement sites at sources in quartzite or clastics have lower conductivity than water issuing from carbonate aquifers (figure 19). The conductivity in Ogden Valley (sites 171–173, 155), areas draining quartzite (sites 60–65, 106), and in the Wasatch Formation (sites 107,109, and 111) is noticeably lower (less than 188 µS/cm) than all other sites. The conductivity measured at the Hidden Lake Well (site 160) and the outflow from Lefty's Spring (sites 87, 89, and 94) is higher

Table 4. Volume of groundwater in the Nounan aquifer. View table 4 Excel file: Powdermountain_tables.xlsx

County	Total Saturated Volume[1] (ac-ft)	Effective Porosity	Volume of Groundwater[2] (ac-ft)	Percent of Total
Weber	273,180	0.07	19,123	19%
Cache (Wellsville drainage)	1,150,092	0.07	80,506	81%
Total	1,423,272		99,629	100%

[1] Total saturated volume calculated as the difference between the potentiometric surface and the base of the Nounan Formation (figure 7)

[2] Volume of groundwater calculated as total saturated volume times preferred effective porosity of 7%

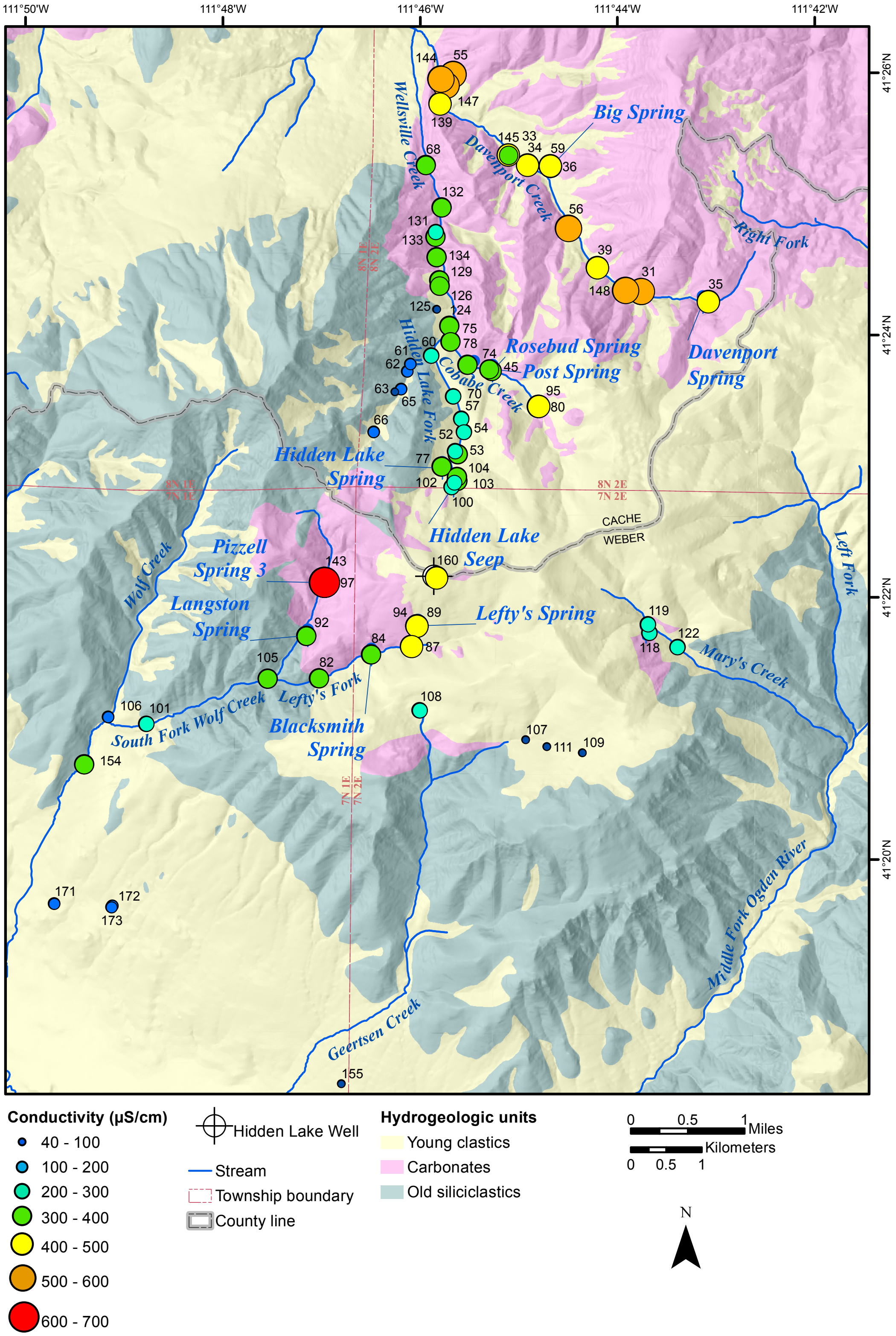


Figure 19. *Map of fluid conductivity. Numbers on map are the station IDs (see table 2).*

Table 5. *Field parameter measurements for the Powder Mountain area. View table 5 Excel file: Powdermountain_tables.xlsx*

Station ID	Name	Date	Time	T (°C)	pH	Cond (uS/cm)
31	Davenport Creek Spring 1	11/6/14	13:00	6.9	7.77	574
33	Davenport Creek elev 6345	10/23/14	11:27	7.0	8.93	329
34	Davenport Creek elev 6343	10/23/14	11:45	7.2	8.76	471
35	Upper Davenport Springs	11/6/14	11:45	5.5	8.48	475
36	Big Spring	11/6/14	13:30	6.6	7.78	494
39	Davenport Creek elev 6436	11/6/14	13:30	4.0	8.87	465
45	Rosebud Spring	10/28/14	15:23	5.9	8.13	362
52	Hidden Lake Weir v-notch	10/29/14	11:21	5.8	7.93	293
53	East Hidden Lake Lift Spring	10/29/14	11:37	6.0	7.89	315
54	Culvert Spring	10/29/14	12:51	4.9	7.81	284
55	Spring	10/23/14	10:50	8.8	7.72	535
56	Tributary to Davenport Creek	11/6/14	14:00	5.9	8.70	516
57	Hidden Lake Fork channel	10/29/14	13:14	3.7	8.28	289
59	Channel near Big Spring	10/23/14	12:15	6.6	7.79	484
60	Pour over	10/29/14	14:03	3.8	8.01	273
61	Dual culverts	10/29/14	14:35	4.4	7.84	101
62	Single culvert	10/29/14	14:41	4.8	7.74	103
63	James Peak side drainage	10/29/14	15:11	4.5	7.29	40
65	Small channel	10/29/14	15:28	3.9	7.88	188
66	Beaver Pond Spring	10/29/14	16:37	6.8	6.95	181
68	Wellsville Creek elev 6278	10/29/14	17:35	6.5	8.33	340
70	Hidden Lake Fork channel	10/29/14	13:31	3.0	7.97	292
74	Paradise Lift Spring in Cobabe drainage	10/30/14	10:00	5.8	7.79	343
75	Cobabe Creek elev 6888	10/30/14	10:39	4.9	8.35	326
77	North Hidden Lake Lift Spring	10/30/14	11:21	4.8	7.86	336
78	Cobabe Creek elev 7025	10/30/14	12:10	5.4	8.25	318
80	Cobabe Creek elev 7347	10/30/14	14:55	5.4	8.08	420
82	Lefty's Fork above quartzite	10/30/14	13:52	4.6	8.64	342
84	Unnamed spring on Lefty's Fork	10/30/14	14:28	5.4	7.77	316
87	Lefty's channel upper	10/30/14	15:37	7.1	8.56	411
89	Lefty's Spring	10/30/14	14:10	4.7	7.49	454
92	Spring on South Fork of Wolf Creek	10/30/14	17:15	5.6	7.94	390
94	Cobabe Creek elev 7348	10/30/14	16:04	4.7	7.49	454
95	Cobabe Creek elev 7549	11/6/14	12:30	5.6	8.65	430
97	Pizzel Spring #3	11/5/14	16:00	5.8	7.90	673
100	South Hidden Lake Lift Spring	10/31/14	10:22	3.8	7.96	271
101	South Fork of Wolf Creek elev 6001	10/31/14	10:30	5.5	8.56	281
102	South Hidden Lake Lift Spring	10/31/14	10:32	4.2	8.21	270
103	Small springhead A	10/31/14	10:48	5.5	7.24	349
104	Small springhead B	10/31/14	11:29	6.2	7.26	308
105	South Fork of Wolf Creek elev 6851	10/31/14	12:00	3.7	8.84	357
106	North Fork Wolf Creek	11/3/14	11:12	4.7	8.06	183
107	Spring in Geertsen Creek	11/3/14	13:27	6.0	6.37	92
108	Geertsen Hilton	11/3/14	15:45	6.1	7.48	291
109	Upper Geertsen Creek elev 8241	11/3/14	16:51	2.0	6.89	61
111	Upper Geertsen Creek elev 8110	11/3/14	12:43	6.1	6.37	72
118	Mary's Creek springhead	11/4/14	12:43	4.5	7.51	290
119	Mary's Creek Channel elev 7706	11/4/14	12:57	1.8	7.62	243
122	Mary's Creek Channel elev 7442	11/4/14	13:27	1.5	8.42	289
124	North Boundary Weir (cipoletti weir)	11/5/14	10:45	4.8	8.86	366
125	Tributary to Wellsville Creek elev 6882	11/5/14	11:40	5.8	8.30	80
126	Spring near Wellsville Creek	11/5/14	12:21	5.8	8.35	325
129	Spring tributary to Wellsville Creek elev 6640	11/5/14	13:42	6.1	8.32	376
131	Spring tributary to Wellsville Creek elev 6508	11/5/14	13:34	7.8	7.97	280
132	Wellsville Creek elev 6391	11/5/14	14:51	5.8	8.82	316
133	Wellsville Creek elev 6480	11/5/14	15:30	5.6	8.77	311
134	Spring tributary to Lower Wellsville Creek	11/5/14	15:00	5.4	8.48	327
139	Davenport Creek elev 7456	10/29/14	14:00	4.9	8.90	477
143	South Fork of Wolf Creek elev 7074	10/30/14	16:15	7.1	8.26	650
144	Cliff Spring in Davenport drainage	10/29/14	13:10	8.3	8.69	504
145	Davenport Creek elev 6819	10/23/14	11:33	6.9	9.10	466
147	Small spring east of Davenport Creek	10/29/14	13:00	8.5	7.71	521
148	Davenport Creek Spring 2	11/6/14	12:03	6.8	7.70	503
154	South Fork of Wolf Creek elev 5591	11/21/14	13:57	3.0	8.61	313
155	Bar B Upper Flume on Geertsen Creek	11/21/14	14:42	2.5	8.20	42
160	Hidden Lake Well	12/9/14	9:29	5.7	7.87	412
171	Warm Springs	12/9/14	13:55	24.3	7.15	172
172	Burnett Spring	12/9/14	14:16	12.9	6.96	122
173	Bad Spring	12/9/14	14:20	10.9	7.43	112

Field descriptions

[1] Subdrainage of measurement

[2] Source of measurement

[3] Location in UTM NAD 83 Zone 12N

[4] Elevation taken from the 10 meter National Elevation Dataset

(greater than 400 µS/cm) than conductivity measured to the north in the Hidden Lake drainage and along Wellsville Creek. Measurements of conductivity from areas where Wasatch Formation or unconsolidated material likely cover the carbonate aquifers, including Mary's Creek (sites 118, 119, and 122), the Hidden Lake drainage, and a single site in upper Geertsen Creek (site 108), have conductivities that range between 200 and 300 µS/cm. Pizell Spring 3 had the highest measured conductivity of 673 µS/cm. High conductivity at the Pizell Spring 3 may result from high concentrations of sodium and chloride at this site, potentially related to dissolution of road salt along the Powder Mountain access road. Conductivity of carbonate source water at Wellsville Creek and Mary's Creek is lower than those from Hidden Lake Well and Davenport Canyon, which could indicate mixing of water.

Simple box plots of the conductivity data symbolized by generalized geologic units are shown in figure 20. The left and right edges of the box plots indicate the 25th and 75th percentile and the center line indicates the 50th percentile or median of a given conductivity plot. The conductivity of both the carbonate and covered carbonate groups largely overlap one another, and the carbonate group has a higher median conductivity than those of the covered carbonate group. Quartzite and the other geologic groups have markedly lower conductivity with median values below 200 µS/cm. The "other" group has the lowest median conductivity and consists of samples from basin fill and Wasatch Formation. These box plots indicate conductivity and hence basic chemistry has a strong correlation with the simplified hydrogeologic units. Samples from similar geologic settings have similar chemistry, and basic chemistry is controlled primarily by the geologic setting of a water source.

Major Ion Chemistry

Water samples were collected from important sites to constrain chemical and isotopic character of springs and stream flow across the Powder Mountain area. The Utah State Health Laboratory analyzed water sampled from 26 select streams, springs, and wells for calcium, carbonate, bicarbonate, potassium, magnesium, sodium, silicate, alkalinity, and total dissolved solids. The Utah State University stable isotope laboratory analyzed for ratios of oxygen and hydrogen isotopes (table 6). Most of the samples we collected were sourced from carbonate aquifers in the headwater regions of the study area, and a few samples were from basin fill or quartzite aquifers in Ogden Valley.

The charge balance for most of the samples was below 5%, with the exception of Burnett Spring (site 172), a spring in Geersten Creek (site 107), and the upper flume at Bar B Ranch (#155). All of the water had relatively low specific conductivities (below 1000 µS/cm), and samples from upland areas are quite dilute with low total dissolved solids (TDS). The samples with lower specific conductance also have low TDS. The quartzite samples have TDS concentrations between 36 and 104 mg/l, and the carbonate samples have concentrations between 132 and 328 mg/l.

All of the samples analyzed were calcium-bicarbonate-type water, and the chemistry of the samples is dominated by these solutes. We constructed a trilinear diagram (figure 21) that divides samples based on their relative meq/L concentrations of calcium, magnesium, and silica (as SiO_2). Covered carbonate and carbonate samples overlap in part and cluster near the lower right corner of the diagram. The covered carbon-

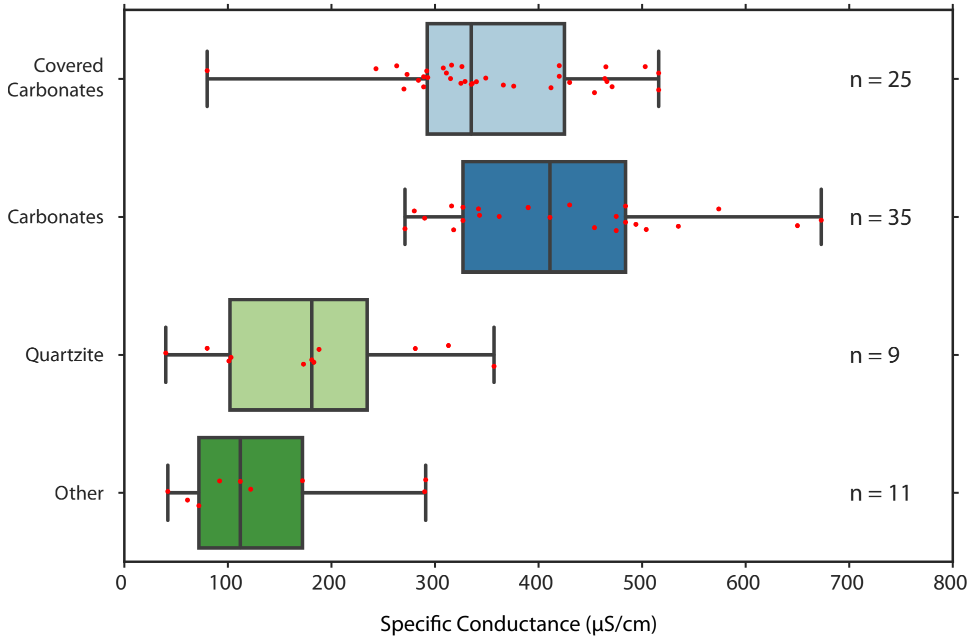


Figure 20. *Box plots of conductivity.*

Table 6. *Chemistry and stable isotope data for the Powder Mountain area. View table 6 Excel file: Powdermountain_tables.xlsx*

Station ID	Name	Date-Time	T (°C)	pH	Cond (uS/cm)	δ^2H[4] (‰)	$\delta^{18}O$[5] (‰)	Mg[6] (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)	CO_2 (mg/L)	SiO_2 (mg/L)	TDS[7] (mg/L)	CO_3 solid[8] (mg/L)	Tot Alk[9] (mg/L)	Charge Balance (%)	Cluster Group
35	Upper Davenport Springs	11/06/2014 11:00	7.2	8.76	471	-129.9	-18.04	19.90	64.5	2.3	<1	3.21	10.40	286	3.00	6.74	244	141	235	-0.4%	B1
36	Big Springs	11/06/2014 13:30	6.6	7.79	494	-129.4	-17.45	22.90	64.1	2.4	<1	2.85	10.10	302	7.00	6.00	252	149	248	-0.5%	B1
42	Hidden Lake Spring west	10/28/2014 10:00	5.0	8.77	335	-127.6	-17.74	18.70	36.0	1.9	<1	2.85	10.80	202	4.00	5.39	168	99	166	-2.8%	B2
43	Hidden Lake Spring south	10/28/2014 11:00	3.9	8.35	263	-128.8	-17.64	14.50	29.1	1.7	<1	3.20	16.60	156	3.00	5.37	132	77	128	-4.8%	B2
45	Rosebud Spring	10/28/2014 15:30	5.9	8.13	362	-128.7	-18.21	19.40	38.7	2.2	1.02	3.57	10.10	216	3.00	6.44	174	106	177	-2.7%	B2
52	Hidden Lake Weir	10/29/2014 14:07	5.8	7.93	293	-125.0	-17.32	14.50	28.8	2.0	<1	2.75	5.76	157	3.00	4.45	136	77	129	-0.9%	B2
66	Beaver Pond Spring	10/29/2014 16:44	6.8	6.95	181	-121.8	-16.69	8.37	17.9	2.8	<1	4.76	10.00	90	51.00	5.54	96	44	73	-3.3%	A
68	Wellsville Creek	10/29/2014 17:35	6.5	8.33	340	-126.9	-17.63	16.00	37.7	2.3	22.0	3.45	14.20	198	3.00	6.54	188	98	163	3.0%	B2
75	Cobabe Creek elev 6888	10/30/2014 10:50	4.9	8.35	326	-129.4	-17.98	16.90	36.0	2.2	<1	2.94	1.17	192	1.00	6.67	188	98	163	0.8%	B2
81	Spring north of Cobabe Creek	10/30/2014 14:40	5.4	8.00	420	-126.7	-17.53	24.30	46.1	1.7	<1	3.02	12.20	270	7.00	5.40	244	133	221	-2.9%	B2
82	Lefty's Fork above quartzite	10/30/2014 13:45	4.6	8.64	342	-129.1	-17.81	14.30	44.8	3.2	<1	3.67	21.30	206	2.00	6.62	178	101	169	-5.0%	B2
84	Unnamed Spring on Lower Lefty's	10/30/2014 14:40	5.4	7.77	316	-128.9	-17.76	12.10	41.7	2.4	<1	3.02	12.20	187	6.00	6.92	190	92	154	-3.4%	B2
87	Lefty's channel upper	10/30/2014 15:30	7.1	8.56	411	-129.0	-17.74	24.10	46.7	2.1	<1	3.55	9.52	250	1.00	5.21	210	130	216	0.1%	B1
89	Lefty's Spring	10/30/2014 16:10	4.7	7.49	454	-128.7	-18.06	24.40	51.1	2.1	<1	3.56	13.80	278	8.00	5.14	230	137	228	-3.1%	B1
92	Spring on south fork of Wolf Creek	10/30/2014 17:10	5.6	7.94	390	-130.6	-17.85	11.80	43.2	13.7	<1	21.00	5.44	183	4.00	6.83	222	90	150	0.2%	B1
97	Pizell Spring #3	11/05/2014 16:00	7.1	8.26	673	-128.1	-17.56	22.10	56.0	38.1	<1	68.10	12.90	252	7.00	5.60	328	124	207	-0.4%	B1
101	South fork of Wolf Creek elev 6001	10/31/2014 10:55	5.5	8.56	281	-128.6	-17.67	9.67	31.6	8.7	<1	11.00	10.40	143	2.00	7.35	176	70	117	-2.2%	B2
107	Spring in Geertsen Creek	11/03/2014 13:27	6.0	6.37	92	-116.8	-16.14	1.74	11.0	2.3	<1	4.85	7.15	38	51.00	7.41	46	18	31	-7.0%	A
118	Mary's Creek Spring	11/04/2014 10:11	4.5	7.51	290	-130.5	-18.25	4.13	46.0	2.1	<1	2.62	7.01	163	25.00	6.73	150	80	134	-2.9%	B2
124	North Boundary Weir (cipoletti weir)	10/30/2014 09:45	4.8	8.86	366	-129.3	-17.45	16.00	34.1	2.2	<1	2.84	1.17	189	2.00	6.56	178	93	155	-1.0%	B2
135	Lower Wellsville Spring	11/05/2014 15:00	5.4	8.40	327	-128.8	-17.57	15.40	37.9	2.4	<1	3.36	5.85	186	9.00	6.56	162	91	152	-0.1%	B2
139	Davenport Creek	10/29/2014 15:05	5.5	8.48	475	-129.5	-17.86	25.00	55.8	2.7	<1	3.23	10.70	276	2.00	6.28	240	138	230	1.2%	B1
155	Bar B Geersten Upper Flume	11/21/2014 14:45	2.5	8.20	42	-122.8	-16.83	<1	3.7	1.9	<1	3.05	5.18	15	26.00	5.45	36	7	12	-23.8%	A
160	Hidden Lake Well	12/09/2014 09:29	5.7	7.87	412	-128.5	-17.69	18.10	46.7	4.0	<1	4.38	12.50	236	5.00	6.77	214	116	194	-2.0%	B1
171	Warm Springs	12/09/2014 13:55	24.3	7.15	172	-134.6	-18.49	4.99	13.1	10.8	1.91	6.85	12.50	69	34.00	13.60	104	34	57	0.0%	A
172	Burnett Spring	12/09/2014 14:16	12.9	6.96	122	-130.8	-17.63	2.68	11.5	5.4	1.07	6.61	7.55	43	49.00	12.10	76	21	35	8.4%	A

Field descriptions

[1] Subdrainage of measurement

[2] Source of measurement

[3] Location in UTM NAD 83 Zone 12N

[4] Stable isotope of ^2H measured at Utah State University stable isotope lab; standard error is ± 2‰

[5] Stable isotope of ^{18}O measured at Utah State University stable isotope lab; standard error is ± 0.2‰

[6] All chemistry analyses preformed at the Utah State Lab; for analytical methods see <http://health.utah.gov/lab/chemistry/index.html>; < indicates value was below detection

[7] Total dissolved solids; for analytical methods see <http://health.utah.gov/lab/chemistry/index.html>

[8] Total carbonate solids: for analytical methods see <http://health.utah.gov/lab/chemistry/index.html>

[9] Total alkalinty as mg/L $CaCO_3$; for analytical methods see <http://health.utah.gov/lab/chemistry/index.html>

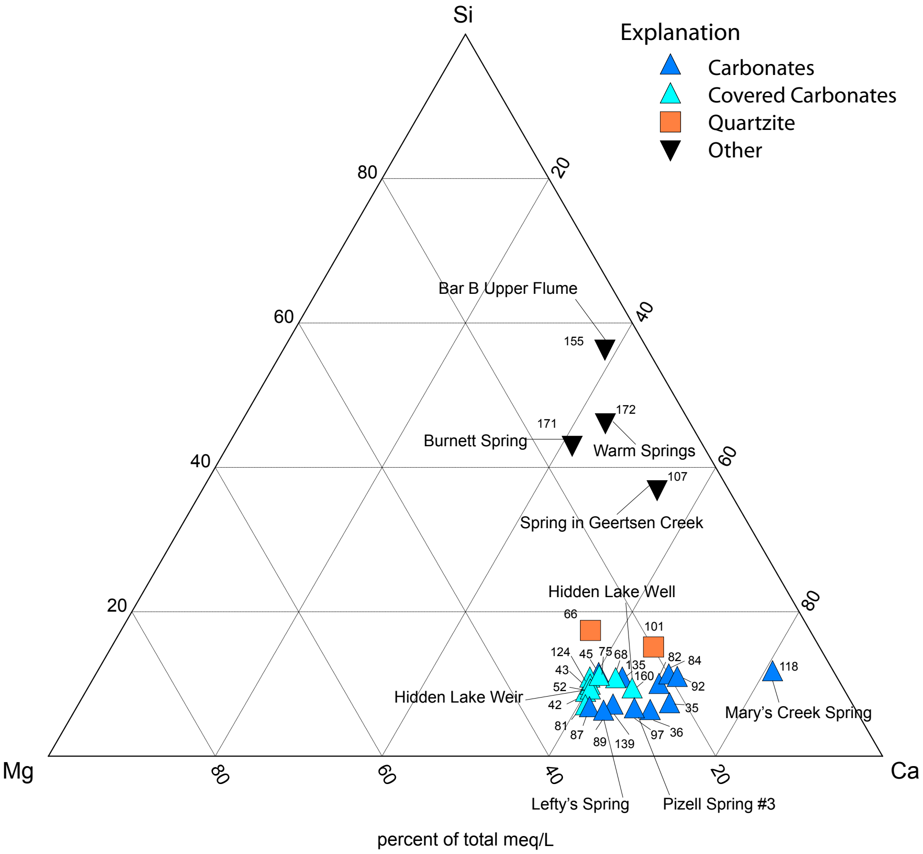


Figure 21. *Trilinear diagram of Si, Ca, and Mg concentrations as percentage of the total meq/L of these three components. Sample symbolization and numbers correlate with the general geology and station ID fields in table 1.*

ate samples all cluster near the bottom left of the group of samples, near the 60 to 65% calcium, 35 to 40% magnesium, and near 5 to 15% silica area of the plot. Most of the carbonate samples cluster in the 65 to 80% calcium, 20 to 35% magnesium, and 5 to 15% silica area of the plot. This plot shows that water from the carbonates and covered carbonates have similar relative concentrations of silica and are best differentiated based on calcium and magnesium ratios. However, relative silica concentration is better for differentiating between the quartzite, other (alluvium and Tertiary), and carbonate types. The "other" samples have the highest relative silica values, and the relative silica content of the quartzite samples is just slightly above that of the various carbonate samples.

Table 7. *Results of factor analysis of major ions in water samples. View table 7 Excel file: Powdermountain_tables.xlsx*

	Loadings			Uniqueness
	Factor 1	Factor 2	Factor 3	
Calcium	0.904		0.42	0.005
Chloride		0.98	0.162	0.005
Bicarbonate	0.985		0.161	0.005
Potassium				0.993
Magnesium	0.979		-0.179	0.005
Sodium		0.968	0.179	0.03
Silica (SiO_2)	-0.496			0.744
Sulfate	0.252			0.919
Eigenvalue	3.063	1.915	0.317	
Total Variance (%)	0.383	0.239	0.04	
Cumulative Variance (%)	0.383	0.622	0.662	

Test of the hypothesis that 3 factors are sufficient.

The chi square statistic is 27.24 on 7 degrees of freedom.

The p-value is 0.000302.

Statistical Analysis

We input the results of the water-sample analysis into R statistical software (R Development Core Team, 2015) to conduct a factor analysis and a hierarchical cluster analysis. First we conducted a factor analysis to determine the solutes that are responsible for the chemical variation amongst the samples (table 7). Then we conducted a hierarchical cluster analysis to objectively group samples based on major solute chemistry.

Factor analysis: The correlation between the major dissolved constituents and their control on the total variability of dissolved chemistry can be objectively analyzed via a statistical factor analysis of the dataset (Dawdy and Feth, 1967). Factor analysis is a scale-independent mathematical reduction that calculates synthetic variables and retains the inherent variability in given samples and across a data array. This variability is represented in a number of simplified factors calculated for each sample. These objective factors may then be interpreted in the context of the original variables and samples to constrain numeric variability and correlation across a data array (Everitt and Torsten, 2006). Factor analysis can therefore provide a robust mathematical basis for understanding the relationship of various aqueous species and their interrelation in a hydrogeologic system (Dawdy and Feth, 1967; Dalton and Upchurch, 1978; Usunoff and Guzmán-Guzmán, 1989; Suk and Lee, 1999).

For this study, R-Mode factor analysis was completed to assess the correlation and similarities between the major solute concentrations in the dataset. The factor analysis of the dataset was performed on a data matrix that included the concentrations of eight principal solute compounds (Ca, Mg, Na, K, Cl, SO_4, HCO_3, and SiO_2) using the open-source R statistical software (Everitt and Torsten, 2006; R Development Core Team, 2015). The statistical routine included a standard factor analysis with varimax rotation and calculation of Bartlett scores for each factor and each sample. This method calculated three unique factors, of which the first two factors describe 62% of the variance across the dataset.

Factor 1 accounts for 38% of the total variance and is driven primarily by changes in calcium, magnesium, bicarbonate, and silica. Variability in the concentration of calcium, magnesium, and bicarbonate is likely driven by water-rock interaction in carbonate aquifers. Calcium and magnesium may also be involved in ion exchange reactions that may occur with clay minerals and, to a lesser degree, with carbonate minerals (Kehew, 2000). Silica concentrations are also likely driven by water-rock interaction with siliciclastics. This factor suggests chemical variability is controlled by relative amounts of water-rock interaction within either carbonate or siliciclastic units.

Factor 2 accounts for 24% of the total variance. This factor is controlled by concentrations of chloride and sodium, which are likely driven by variable amounts of dissolution of halite. Dissolution of halite may occur locally within the marine carbonates and shales that characterize the carbonate aquifers. Contributions of sodium and chloride may also result from infiltration of water containing road de-icing salts for sites along Wolf Creek drainage.

The factor analysis results suggest water-rock (aquifer) interaction in the form of mineral dissolution or precipitation and ion exchange account for much of the observed variability in solute concentration across the dataset. The changes in solute concentration may result either from residence-time-dependent sequential water-rock interactions or localized geologic conditions along a given flow path.

Cluster analysis: Groundwater samples are statistically grouped via cluster analysis into hydrochemical facies based on concentrations of the seven principal dissolved anions and cations. Cluster analysis is a multivariate statistical technique used to delineate statistically distinct groups from a given data set. During cluster analysis, samples are intercorrelated based on multiple parameters and grouped with one another based on the relative variability among the parameters of a given sample (Everitt and Torsten, 2006; Templ and others, 2008). The geochemical dataset, including the concentrations of the major solutes, was entered into the R software package, and all data transformation and statistical analyses were calculated using standard R routines and functions (Everitt and Torsten, 2006; R Development Core Team, 2015). A hierarchical cluster analysis, using the Ward method and standard Euclidean scores, was performed to group the data. From these data, a given number of clusters are extracted and the cluster labels applied to a given sample.

Numerous techniques exist for determining the appropriate number of clusters to extract from a dataset, all of which rely to varying degrees on subjective decisions (Templ and others, 2008). For this analysis, the sum-of-squares technique was chosen to give a range of possible numbers of clusters that were statistically valid based on the dataset (Suk and Lee, 1999; Everitt and Torsten, 2006; Guler and Thyne, 2006). The sum-of-squares method yields either three or four clusters that may reasonably group the data set. Both of these options were run and the results examined for both spatial coherence and cluster coherence based on plots of the previously calculated factor scores and spatial distribution of the groups. A total of three groups were extracted from the dataset based on this analysis.

Clustering statistical analysis resulted in three statistically distinct groups of samples (figure 22; table 6). Water collected from quartzite aquifers in Geertsen Canyon and the basin-fill aquifer compose Group A; water from Hidden Lake Well, Lefty's Spring, and Davenport Canyon make up group B1; and water from Wellsville Creek, lower Wolf Creek, and Mary's Creek make up group B2.

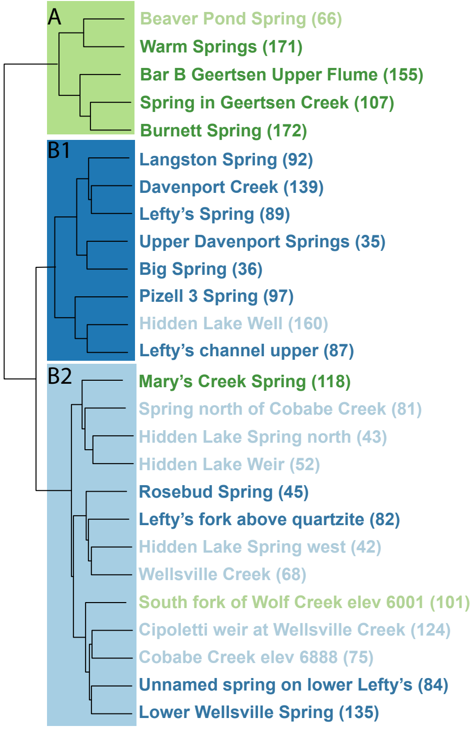


Figure 22. *Dendrogram from cluster analysis of water chemistry data. Numbers are the station ID and text color indicates geologic setting from table 2; light blue = covered carbonates, dark blue = carbonates, light green = quartzite, and dark green = other.*

Groups B1 and B2 are significantly related (mostly Ca-Mg-HCO_3 water) and consist mostly of water issuing from carbonate aquifers. Groups B1 and B2 have a similar chemical fingerprint, and samples in group B2 (Wellsville Creek, Mary's Creek, and lower Wolf Creek) have slightly lower chemical concentrations (HCO_3, Mg, Ca, Na) than those in group B1 (Hidden Lake Well, Lefty's Spring, and Davenport Canyon water) (figure 23). Waters from B2 group may be a mixture of water from carbonate aquifers and more dilute water from the overlying Wasatch Formation. Group B1 likely represents water directly recharged to the carbonate sources without interaction with young clastics.

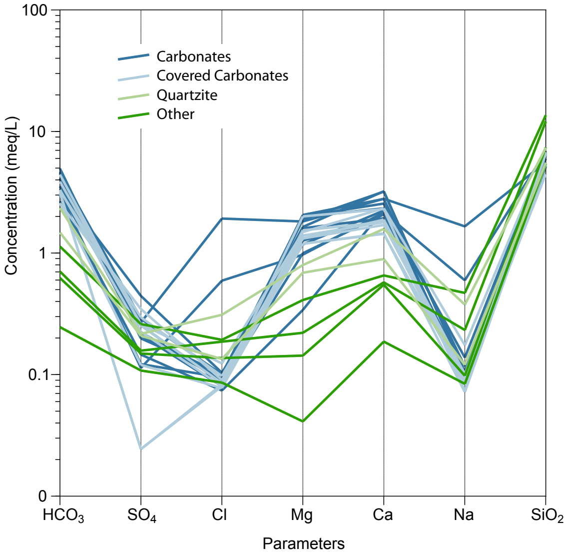


Figure 23. *Schoeller plot of major solutes. Samples are colored based on the geologic setting in table 1.*

Stable Isotopes

The isotopic ratios of oxygen (^{16}O to ^{18}O) and hydrogen (^{1}H to ^{2}H) in precipitation vary systematically with topography, temperature, and distance from the ocean (Craig, 1961; Clark and Fritz, 1997). These isotopic ratios may be altered by evaporation following precipitation but generally remain unchanged in groundwater and stream baseflow if no mixing occurs. Hydrogen and oxygen isotopes therefore record the isotopic signature of meteoric waters at the time of recharge and sources of water to an aquifer or stream baseflow (Clark and Fritz, 1997).

Hydrogen and oxygen isotopes were analyzed for all water samples at the Utah State University stable isotope laboratory using a cavity ring down spectrometer (de Groot, 2004). A standard plot of deuterium (δ^2H) versus oxygen-18 ($\delta^{18}O$) is shown in figure 24. Samples are differentiated based on geochemical cluster results and sample type. The Global Meteoric Water Line (GMWL) of Craig (1961) is shown as a reference for the isotopic concentrations of precipitation. Cooler or higher elevation recharge is generally characterized by depleted stable isotopic concentrations that plot on the lower left corner of figure 24. Warmer or lower elevation recharge is characterized by enriched stable isotopic concentrations that plot in the upper right corner of figure 24. Most samples plot in a zone between sites 52 and 118, including all samples from cluster groups B1 and B2, which include Lefty's Springs, Hidden Lake Well, Hidden Lake Weir, Pizell Spring 3 and the Cobabe Springs. Groups B1 and B2 have broadly similar recharge conditions likely from upper elevation snowmelt in the Powder Mountain area. On the stable

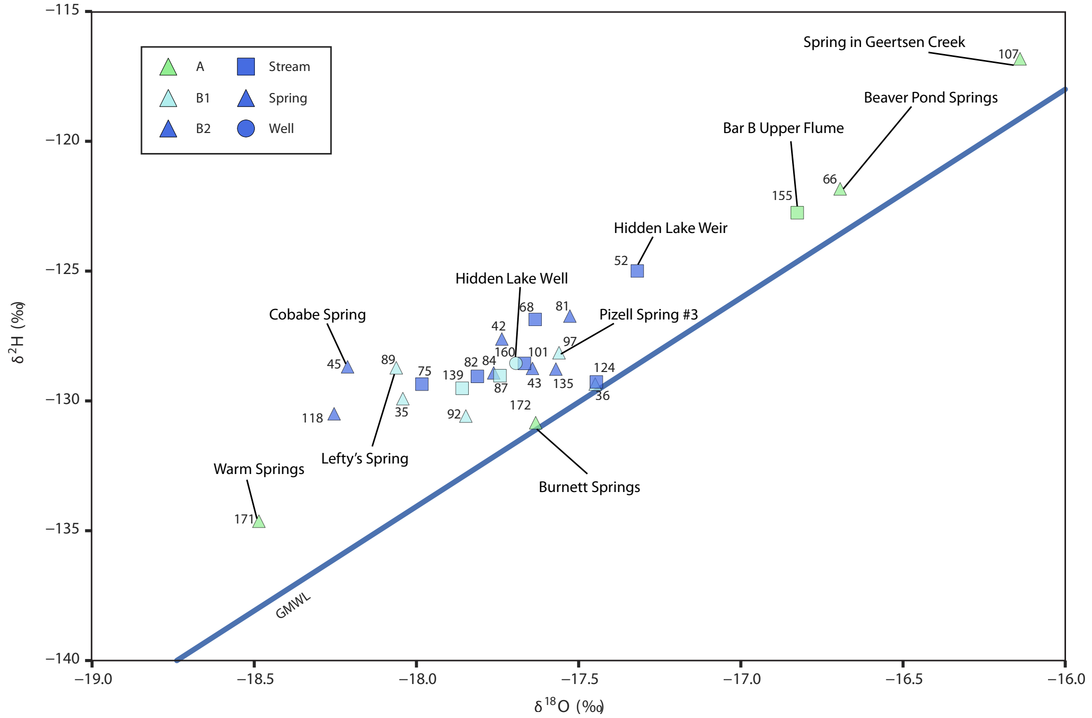


Figure 24. *Stable isotopes of samples collected for this study. GMWL is the global meteoric water line (Craig, 1961). Numbers represent station IDs presented in tables 1 and 6. Samples are colored based on statistical grouping.*

isotope plot, samples from cluster group A lie to the right and left of those from cluster group B1 and B2 and likely represent water with different recharge conditions (elevation or temperature). Burnett Springs plots near those from group B1 and B2 and likely results from isotopically similar precipitation despite their chemical differences (figure 24). Samples from the Bar B Upper Flume, Beaver Pond Springs, and spring in Geertsen Creek plot to the right of the other samples suggesting a greater component of warm season recharge in these sites.

Aquifer Test

Loughlin Water conducted a two week, constant-rate aquifer test using the Hidden Lake Well. The UGS observed the test and compiled and analyzed measurements made by Cascade Water and Loughlin Water. We also recorded some measurements ourselves to verify those recorded by others. Pumping lasted for exactly two weeks (20,160 minutes) starting December 2, 2014, at 19:00 hours. A total of 3,033,700 gallons (9.31 ac-ft) was pumped during test pumping at a near constant rate of 151 gpm (9.5 l/s).

The Hidden Lake Well is completed in the Cambrian Nounan aquifer screened from 980 to 1580 feet below land surface. Based on well logs, the Nounan aquifer extends between 830 and 1590 feet below land surface. The Nounan aquifer at the well site is overlain by the Wasatch Formation from 15 to 390 feet depth, an incomplete section of the St. Charles Formation between 390 and 690 feet, and the Worm Creek Quartzite member of the Nounan between 690 and 830 feet below the land surface.

Four surface water sites and one observation well (Exploration Well 2) were monitored during the aquifer test to determine if pumping the Hidden Lake Well influences local springs and streams (figure 13). Loughlin Water also recorded drawdown in the Hidden Lake Well. Some of the sites have data that extend beyond the testing period to record antecedent and seasonal trends (figure 14). Antecedent data are discussed briefly in the "Long Term Hydrographs" subsection of the "Flow Measurements" section above.

We analyzed drawdown data collected by Loughlin Water from Exploration Well 2 and the Hidden Lake Well using traditional analytical (curve-matching) pumping test analysis (appendix C). Using AQTESOLV software (Duffield, 2007), we attempted to match several theoretical type curves to the drawdown data (figure 25). AQTESOLV (Duffield, 2007) allows for the consideration of aquifer boundaries, multiple wells, and forward modeling.

Based on the shape of the derivatives of the drawdown curves and our conceptual understanding of the aquifer, we determined that the Moench (1997) unconfined aquifer type curve was the most appropriate match for the drawdown data. The type curve assumes a late-time, delayed gravity yield response of an unconfined system, which is represented by an inflection in the drawdown curve (Moench, 1997). A late-time inflection in the drawdown data could also indicate the presence of a barrier boundary in the aquifer. However, the shape of the drawdown curve derivative is more typical of delayed gravity yield than boundary effects (Renard and others, 2008). We do not think that the inflection in the late-time drawdown data represents a boundary. To account for potential boundary effect in the analysis, we incorporated modeled boundaries based on the horizontal and vertical extent of the Nounan aquifer (figure 8). A hypothetical cone of depression plotted for the total duration of the aquifer test extrapolated from well-water level observations nears the edge of the aquifer extent but may have not reached it by the end of pumping. There is no information in the well driller's log or from nearby geologic outcrops to indicate the presence of an overlying confining layer.

Transmissivity, hydraulic conductivity, and specific yield of the aquifer were calculated from the aquifer test. Transmissivity and hydraulic conductivity indicate how readily fluids move through rock or sediment, as controlled by the properties of the fluid and the aquifer material. Specific yield is the amount of effective pore space of the aquifer, which is the fraction of the aquifer that contains a drainable volume of water. The specific yield estimate is 0.07 (figure 25) and the storativity is 0.006. We determined transmissivity of the Nounan aquifer to be 200 ft^2/day. Based on a saturated aquifer thickness of 700 feet (figure 8), the horizontal hydraulic conductivity of the Nounan aquifer is 0.3 ft/day. This value is reasonable for carbonate rocks but low relative to unconsolidated deposits (Heath, 1983). Based on the calculated vertical to horizontal hydraulic conductivity ratio of 37, the vertical hydraulic conductivity is 12 ft/day.

A ratio of vertical hydraulic conductivity relative to horizontal hydraulic conductivity of 37 is relatively high. This may indicate that a component of the water pumped was derived from overlying storage in the Wasatch Formation or melting snow. Another possible explanation for the high ratio is that

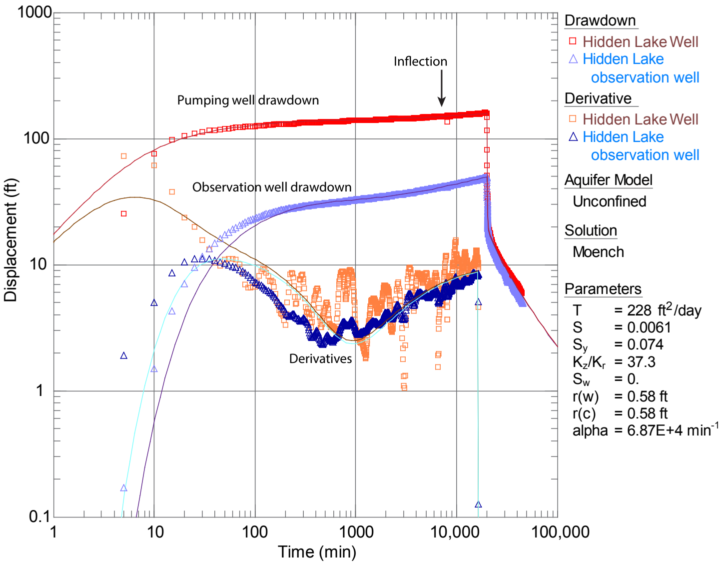


Figure 25. *Drawdown measured during the Nounan aquifer test using the Hidden Lake Well.*

the dominant porosity and permeability of the aquifer is produced by steeply dipping fractures in the carbonates.

Recession Analysis

Analysis of the recession of spring discharge data can provide information about the aquifer system contributing to the spring, including indications of the dominant form of porosity present (fracture versus primary porosity) and changes in storage geometry (Bonacci, 1993; Adkins, 2006; Azeez and others, 2015). We matched exponential decay curves to the spring discharge recession data from upper Lefty's Weir (figure 26), using only baseflow data, and removing data during the period of the aquifer test in 2014 and a period of recharge during 2015. The exponential decay curves follow the equation (Bonacci, 1993):

$$Q_t = Q_0 \, e^{-at} \qquad (1)$$

where:

Q_t = discharge at time t (in gallons per minute)

Q_0 = discharge at beginning of recession period (in gallons per minute)

a = recession coefficient (in 1/time)

Based on the analysis of Loughlin's upper Lefty's data, we determined the recession coefficient is 0.01 for 2014 and 2015. Data from Cascade Water for upper Lefty's was only available starting in November 2014, limiting the recession analysis to smaller duration of the baseflow recession. The Cascade Water recession coefficient is 0.0001, which is two orders of magnitude lower than the Loughlin Water data recession values.

We visually compared the exponential recession trends to the period of the aquifer test to see if there was significant deviation from the recession. Spring discharge measurements did not deviate significantly from the recession trend during the period of the aquifer test. Decline in discharge from pumping may not be apparent because the magnitude of seasonal recession is greater than decline caused by pumping. Another potential explanation is that drawdown from pumping during the test was not long enough in duration or widespread enough to impact the discharge of the spring.

We determined that data from lower Lefty's Weir was not adequate for analysis of influences from the aquifer test. Lower Lefty's Weir data do not have sufficient antecedent measurements to determine a recession trend. This weir also lacks sufficient manual measurements to establish a stage-discharge relationship. Lower Lefty's Weir has the potential to capture overland flow, especially during times of snowmelt, whereas upper Lefty's records discharge primarily at the springhead.

Forward Modeling

A forward model was constructed to determine the spatial extent of potential drawdown under future pumping scenar-

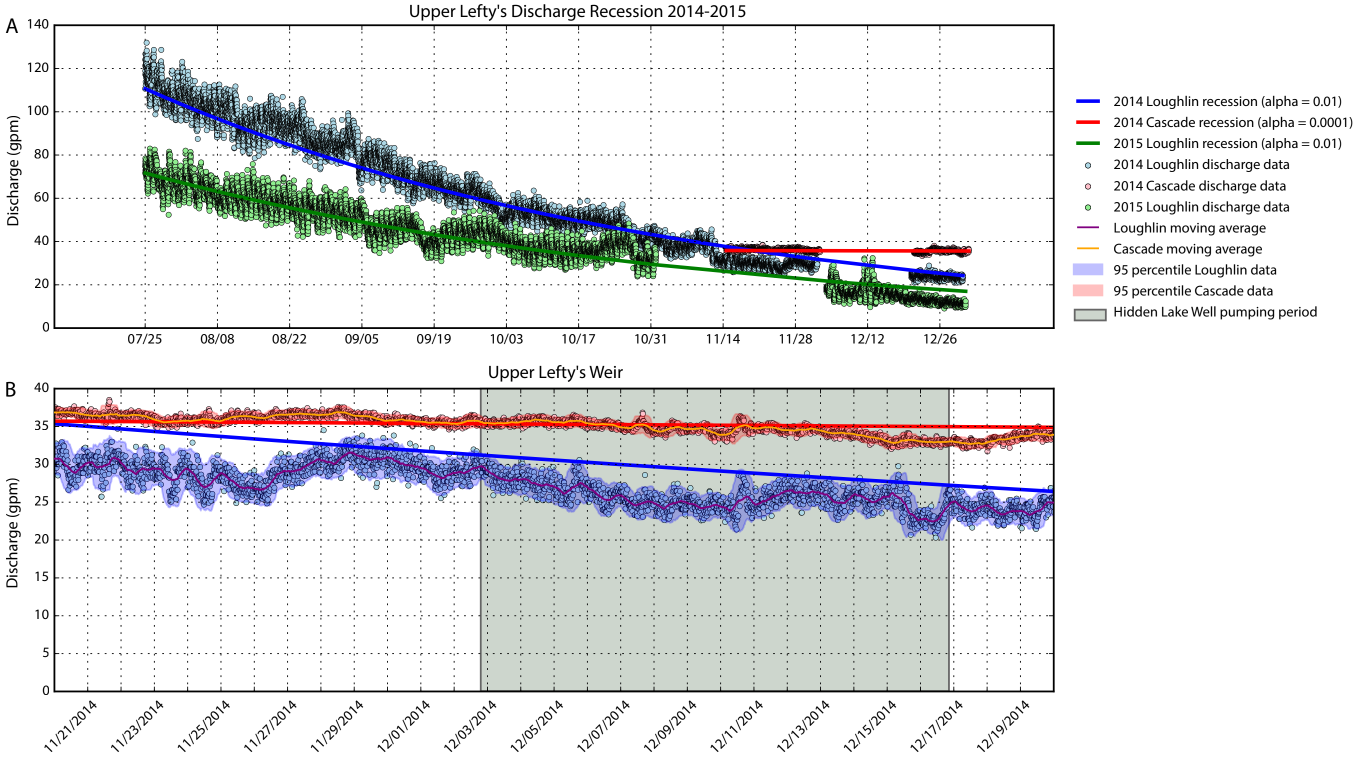


Figure 26. *Discharge recession for upper Lefty's Weir (A) and discharge and recession during the Hidden Lake Well aquifer test (B). Gray highlight is the Hidden Lake Well aquifer test period.*

ios. The two-dimensional model created in AQTESOLV (Duffield, 2007) assumes the aquifer is isotropic and homogeneous with aquifer properties equal to those calculated from the aquifer test. In reality, the aquifer is likely anisotropic and primary permeability may result from heterogeneous fracturing. Heterogeneity may also exist in the form of karst or stratigraphic discontinuities in the carbonate units (e.g., lenses of shale). The forward modeling, like the aquifer test analysis, was limited to the horizontal and vertical extent of the Nounan aquifer. AQTESOLV (Duffield, 2007) also limits the boundary geometry to four-sided polygons and does not account for the three-dimensional geometry of the potentiometric surface. The model uses a constant 150 gpm pump rate and aquifer parameters calculated from the aquifer test. The conceptual model was of an unconfined aquifer of limited extent, and the modeling software is limited to conditions with no recharge. Based on hydrographs from Exploration Well 2 and upper Lefty's, recharge to the Nounan aquifer is generally limited to spring snowmelt and runoff, and time without recharge is commonly up to six months. In an attempt to illustrate maximum potential drawdown due to long term pumping, a plot of forward model drawdown for a pumping period of 1 year is shown in figure 27. Based on this model, drawdown between 0 and 1 ft extends north of the Hidden Lake Weir in Cache County. Drawdown on the Weber County side is nearly 2 ft at Lefty's Spring. This period of pumping is much greater than the typical 6 month recession, or no recharge period, shown by long term water level trends and could be assumed to represent maximum possible drawdown related to pumping of the Hidden Lake Well over an extended drought period.

The relative amount of forward model drawdown encountered in Cache or Weber Counties varies depending on the time span of pumping. Forward model results were plotted as grids of drawdown for time intervals of one week, two months, four months, and one year of pumping. Each grid was then cut along the county boundary, and an average drawdown was calculated using ArcGIS statistics to yield the relative percentage of drawdown by county. As average areal drawdown in the Nounan aquifer increases, the relative volume of water taken from Cache County increases (figure 28). Forward modeling of the aquifer test shows that 24 to 44% of the water extracted from the aquifer comes from Cache County for time intervals between two weeks to one year (table 8). Within a single baseflow season (<six months), up to 37% of the water extracted comes from Cache County. More than six months without recharge while pumping at 150 gpm is an unlikely condition. To reproduce these conditions, large amounts of pumping or very little precipitation would have to occur for an extended duration. A long term imbalance between groundwater recharge and pumping could result in the conditions similar to those produced by the long term cases of the forward model.

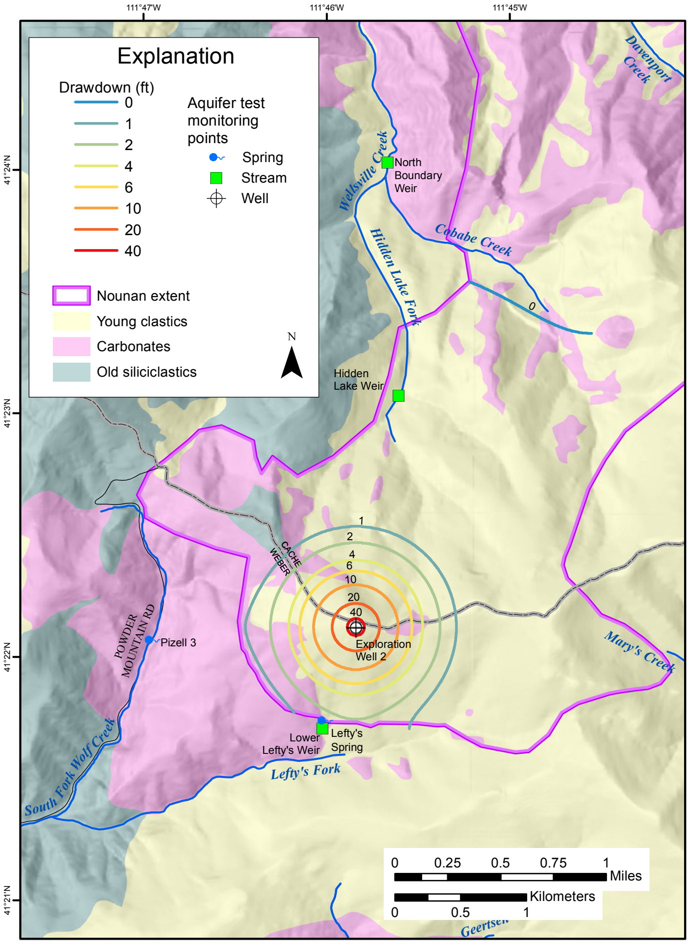


Figure 27. Cone of depression resulting from forward model of pumping 150 gpm from the Hidden Lake Well continuously for one year without recharge.

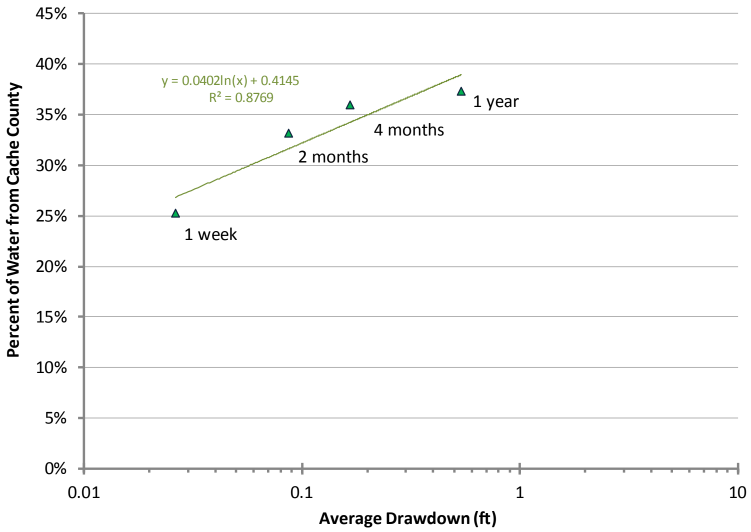


Figure 28. Modeled percent volume extracted by average drawdown in the Nounan aquifer. Model assumes no recharge. See text for details.

Table 8. *Modeled estimates of volume of water extracted by county, assuming Hidden Lake Well pumping at 150 gallons per minute. View table 8 Excel file: Powdermountain_tables.xlsx*

Pumping Duration (min)	County	Area Examined (m^2)	Area of Drawdown[1] (m^2)	Maximum Drawdown (m)	Mean Drawdown[2] (m)	Saturated Volume Change[3] (m^3)	Extracted Water Volume (ac-ft)[4]	Relative Volume Drained
20000	Cache	7.3E+06	4.6E+05	5.2	0.005	3.9E+04	2.2	24%
20000	Weber	2.7E+06	7.2E+05	25.5	0.05	1.2E+05	7.1	76%
40000	Cache	7.3E+06	8.2E+05	7.0	0.01	8.8E+04	5.0	29%
40000	Weber	2.7E+06	1.3E+06	27.6	0.08	2.2E+05	12	71%
80000	Cache	7.3E+06	1.5E+06	9.1	0.03	1.9E+05	11	33%
80000	Weber	2.7E+06	2.0E+06	29.7	0.15	3.9E+05	22	67%
160000	Cache	7.3E+06	2.9E+06	11.1	0.06	4.1E+05	23	36%
160000	Weber	2.7E+06	2.4E+06	31.8	0.28	7.4E+05	42	64%
526000	Cache	7.3E+06	6.5E+06	14.8	0.19	1.4E+06	80	38%
526000	Weber	2.7E+06	2.7E+06	35.5	0.87	2.3E+06	130	62%
5260000	Cache	7.3E+06	7.3E+06	24.4	2.2	1.6E+07	940	44%
5260000	Weber	2.7E+06	2.7E+06	45.2	7.8	2.1E+07	1200	56%

[1] Area of drawdown greater than 0 calcuated using ArcGIS

[2] Mean drawdown was calculated in ArcGIS using zonal statistics on modeled drawdown grids

[3] Saturated volume change is area of examination times mean drawdown

[4] Extracted water volume is saturated volume change times preferred effective porosity of 7%

We conducted additional forward modeling to estimate the radius of drawdown associated with hypothetical wells completed in the Nounan aquifer, south of the Weber-Cache County line. The goal of this modeling is to estimate the distance from the county line that hypothetical wells on the Weber County side could cause drawdown on the Cache County side of the divide. The model results are strongly dependent on the assumed location of the pumping well and are therefore unique to a given model scenario. These results therefore cannot predict actual drawdown associated with any new well and are instead intended to show a range of possible drawdown based on reasonable aquifer properties and extents. Actual estimates of drawdown from any new wells will require additional site specific analysis.

For this model, the hypothetical well is located 300 m south of the Hidden Lake Well, approximately halfway between the Hidden Lake Well and the southern extent of the Nounan aquifer. We used the aquifer parameters determined from the Hidden Lake aquifer test and projected the amount of drawdown over distance caused by pumping 150 gallons per minute without recharge for durations that include one month, two months, four months, and one year (figure 29). Modeling produced a distance-drawdown plot, showing how pumping duration influences the radius of the cone of depression produced by the well. Pumping at 150 gpm for one month without recharge will produce a cone of depression with a radius of just less than 300 meters, which does not intersect the county line. Pumping for periods greater than one month, without recharge, produces drawdown at the county line. As well locations and drawdown approach the southern extent of the aquifer, image well effects created by the no-flow boundary intensify the effects of drawdown, effectively increasing the radius of the cone of depression. These results are specific to the Nounan aquifer. Hypothetical wells completed in other units in the larger carbonate aquifer system would necessarily yield different results. Based on this modeling and the assumptions therein, new wells completed in the Nounan aquifer in Weber County, within 300 m of the county line, may produce drawdown in Cache County when pumped for less than one month. New wells located more 300 m from the county line may yield drawdown in Cache County when pumped for time periods greater than one month.

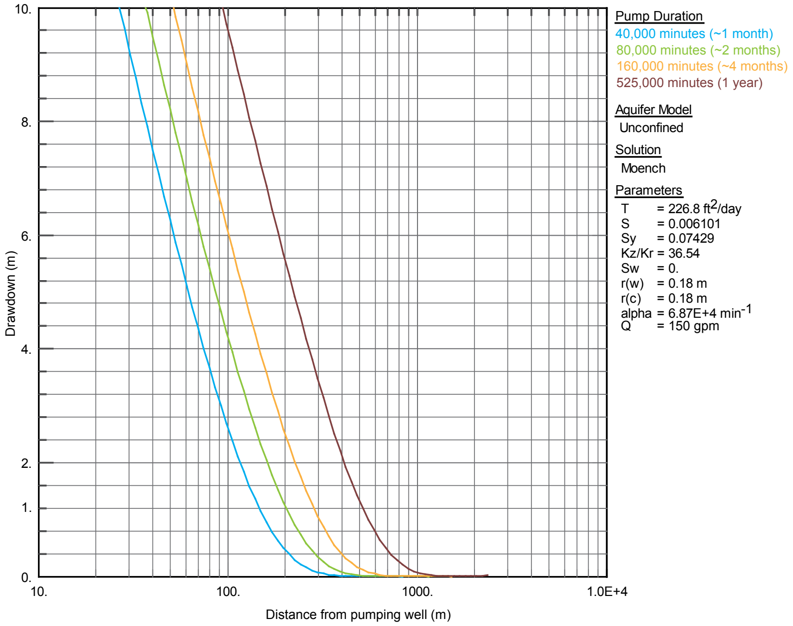


Figure 29. *Modeled distance-drawdown plot of pumping in the Nounan aquifer.*

CONCLUSIONS

Interconnected carbonate aquifers span the Cache-Weber County drainage divide in the Powder Mountain area. These aquifers include a section of Cambrian through Ordovician limestone, dolomite, and shale that overlie relatively impermeable quartzite. Within this section, the Nounan Formation is the source of important springs and is the unit screened by the Hidden Lake Well. Aquifer extent is limited by folding along a broad, north-plunging syncline and erosional extent. Most of the volume of these aquifers lie in Cache County.

The Calls Fort and Hodges Shale Members of the Bloomington Formation have been assumed to be lower permeability than adjoining units, potentially forming local hydrologic boundaries for the Nounan and Bloomington Formations. Baseflow and several of the springs issuing from the units below the Nounan and Bloomington Formations (e.g., Langston Spring) have flows that likely require recharge areas larger than the outcrop of the formations from which they issue. This implies a component of downward inter-formation flow from the Nounan Formation and other overlying units would be necessary to supply high discharge springs and baseflow. Based on a limited recharge area and the large observed base flows from the lower carbonate units, the various carbonate units are likely vertically hydraulically connected.

Groundwater elevation based on springs, gaining or losing stream sections, and water levels in existing wells generally mirrors topography, and groundwater elevation is highest along the drainage divide beneath the Cache-Weber County line. Groundwater elevation decreases to the north and south away from the Hidden Lake Well site.

Big Spring along Davenport Creek, Rosebud Spring along Cobabe Creek, and Langston Spring at the base of the carbonates in South Fork of Wolf Creek (sites 37, 74, and 93) contribute one-third or more of the flow to their respective drainages. These springs all discharge from the carbonate units, and evidence to support karst aquifers in the area includes the periodic nature of the spring along Cobabe Creek and observed karst in equivalent geologic units to the North in the Bear River Range (Wilson, 1976). Most of the stream baseflow in the Powder Mountain area is supplied by these karst aquifers.

Water chemistry and field conductivity were used to discriminate the source and history of surface water and groundwater. All samples were dilute, calcium-bicarbonate-type water. Conductivity was lowest for water sourced from quartzite, Wasatch Formation, and basin fill. Water sourced from carbonates or covered carbonates had higher conductivity and distinct chemistry with a low dissolved silica and characteristic calcium and magnesium concentration. Hydrogen and oxygen isotopes indicate most groundwater is local, snowmelt recharge. Samples located in the basin fill and quartzite have different isotopic ratios which may indicate a different recharge source. The chemistry of the water samples from the different settings were distinct based on simple statistical methods. A paired factor analysis and hierarchical cluster analysis technique yielded three statistically distinct groups with variance largely controlled by dissolved concentrations of calcium, magnesium, and silica. The statistically defined groups broadly correlate with geologic setting and it is likely that measured chemistry is controlled by local water-rock interaction.

The aquifer test of the Hidden Lake Well indicated that the Nounan aquifer is unconfined and has a relatively low transmissivity in this area. The transmissivity is potentially higher where the aquifer is fractured and karstic, areas of which are likely demarcated by springs. Observations recorded by the four stage-recording transducers at upper and lower Lefty's Weirs (Loughlin Water Associates, LLC, 2015; Cascade Water Resources, LLC, 2015) correlated poorly and included significant variations and potential for error. Discharge data of Lefty's Spring and the Hidden Lake Weir collected during the aquifer test can be closely approximated using natural seasonal recession. If the pumping during the test did influence the discharge at those points, then that influence was less significant typical seasonal fluctuations. Although a significant effect was not discernable during the aquifer test, the test results and our understanding of the aquifer system do not preclude the potential of pumping impact on springs and streams in the area.

The amount of potential drawdown observed on the Weber County side of the Nounan aquifer is amplified by the topographic and geologic extent of the aquifer to the south, east, and west. Based on the aquifer properties determined using the Hidden Lake Well aquifer test, the amount of water pumped from the Cache County side of the Nounan aquifer is likely between 24 and 37% of total water pumped, depending on the duration and amount of pumping and the available recharge. If a well is drilled far enough south of the county line on Powder Mountain, it could pump for one month at 300 gpm before significantly impinging on Cache County water.

ACKNOWLEDGMENTS

We thank George Condrat of Loughlin Water Associates, LLC and John Files with Cascade Water Resources, LLC for thoughtful and thorough reviews of this manuscript. Thanks to Powder Mountain employees for mountain access and over-snow transport, especially Roger Arave and Kalem Minor. Don Barnett and Scott Clark provided background information on hydrogeology of the area; George Condrat, Bill Loughlin, and Neil Burk with Loughlin Water Associates, LLC provided data and assistance in the field; John Files also provided important data. We would like to thank Miranda Menzies for her assistance collecting and providing data and her thoughtful input on our analytical techniques.

We are grateful to David L. Nielsen for providing land access in Cache County. We are especially grateful to the Utah Division of Water Rights for their support, impetus, and interest in this project. Thanks to Cache County, especially Bob Fotheringham, for their support, involvement, and assistance with land access. Bar B Ranch provided important support, land access, and data.

REFERENCES

Adkins, G.B., 2006, Flow measurement devices: Utah Division of Water Rights: Online, http://waterrights.utah.gov/distinfo/measurement_devices.pdf, 34 p.

Azeez, N., West, L., and Bottrell, S., 2015, Numerical simulation of spring hydrograph recession curves for East Yorkshire Chalk Aquifer, UK: Sinkholes and the engineering and environmental impacts of karst, *in* Proceedings of the Fourteenth Multidisciplinary Conference, October 5–9, 2015, Rochester, MN: Online, http://scholarcommons.usf.edu/sinkhole_2015/ProceedingswithProgram/Modeling/3/.

Blanchard, M.R., 1990, Discrimination between flow-through and pulse-through components of an alpine carbonate aquifer, Salt River Range, Wyoming: Laramie, University of Wyoming, M.S. thesis, 77 p.

Blau, J.G., 1975, Geology of southern part of the James Peak quadrangle, Utah: Logan, Utah, Utah State University, M.S. thesis, 55 p., scale 1:12,000.

Bonacci, O., 1993, Karst springs hydrographs as indicators of karst aquifers: Hydrological Sciences Journal, v. 38, no. 1, p. 51–62.

Cascade Water Resources, LLC, 2015, Aquifer test report on the summit Hidden Lake Well and potential for interference with nearby springs, submitted on exchange application E5382 Powder Mountain, Utah: Salt Lake City, Utah, unpublished consultant's report prepared for Wolf Creek Irrigation, Eden Water Works, Bar B Ranch, Middle Fork Irrigation, and Wolf Creek Water and Sewer Improvement District: Online, http://waterrights.utah.gov/docImport/0571/05716166.pdf, 89 p.

Coogan, J.C., and King, J.K., 2001, Progress report geologic map of the Ogden 30' x 60' quadrangle, Utah and Wyoming, year 3 of 3: Utah Geological Survey Open-File Report 380, 1 plate, 34 p., scale 1:100,000.

Coogan, J.C., and King, J.K., 2012, Progress report geologic map of the Sharp Mountain quadrangle, Cache and Weber Counties, Utah: Utah Geological Survey, unpublished geologic map, 1 plate, scale 1:24,000.

Coogan, J.C., and King, J.K., 2016, Interim geologic map of the Ogden 30' x 60' quadrangle, Box Elder, Cache, Davis, Morgan, Rich, and Summit Counties, Utah, and Uinta County, Wyoming: Utah Geological Survey Open-File Report 653DM, 3 plates, 147 p., scale 1:62,500.

Clark, I., and Fritz, P., 1997, Environmental isotopes in hydrogeology: New York, Lewis Publishers, 328 p.

Craig, H., 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1833–1834.

Dalton, M.G., and Upchurch, S.B., 1978, Interpretation of hydrochemical facies by factor analysis: Ground Water, v. 16, no. 4, p. 228–233.

Dawdy, D.R., and Feth, J.H., 1967, Applications of factor analysis in study of chemistry of groundwater quality, Mojave River Valley, California: Water Resources Research, v. 3, no. 2, p. 505–510.

DeCelles, P.G., and Coogan, J.C., 2006, Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: Geological Society of America Bulletin, v. 118, p. 841–864.

de Groot, P.A., editor, 2004, Handbook of stable isotope analytical techniques, v. 1: Elsevier, 1234 p.

Duffield, G.M., 2007, AQTESOLV: HydroSOLVE, Inc., Reston, Virginia.

Everitt, B.S., and Torsten, H., 2006, A handbook of statistical analyses using R: Boca Raton, Florida, Chapman and Hall/CRC, 304 p.

Fetter, C.W., Jr., 2000, Applied Hydrogeology (4th edition): Prentice Hall, New Jersey, 488 p.

Guler, C., and Thyne, G.D., 2006, Statistical clustering of major solutes—use as a tracer for evaluating interbasin groundwater flow into Indian Wells Valley, California: Environmental and Engineering Geoscience, v. 12, no. 1, p. 53–65.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 83 p.

Kehew, A.E., 2000, Applied chemical hydrogeology: Upper Saddle River, New Jersey, Prentice Hall, 368 p.

King, J.K., 2014, Progress report geologic map of the Huntsville quadrangle, Weber County, Utah: unpublished geologic map, Utah Geological Survey, 1 plate, scale 1:24,000.

King, J.K., and Coogan, J.C., 2014, Progress report geologic map of the James Peak quadrangle, Cache and Weber Counties, Utah: Utah Geological Survey, unpublished geologic map, 1 plate, scale 1:24,000.

King, V.F., 2004, Water budget estimates for the Powder Mountain region, Cache and Weber Counties, Utah—Methods and proper use of ground-water recharge estimations, *in* Spangler, L.E., editor, Groundwater in Utah—Resource protection and remediation: Utah Geological Association Publication 31, p. 219–234.

Loughlin Water Associates, LLC, 2013, Well drilling, construction and testing report Hidden Lake Well (WS008) Powder Mountain Water & Sewer Improvement District (PMWSID) Public Water Supply System No. 29028

Weber County, Utah: Park City, Utah, unpublished consultant report prepared for Summit Mountain Holding Group, 126 p.

Loughlin Water Associates, LLC, 2015, Exchange application E5382 (35-12848) Powder Mountain aquifer test and monitoring report for Summit Mountain Holding Group, LLC: Park City, Utah, unpublished consultant's report prepared: Online, http://waterrights.utah.gov/docImport/0571/05716157.pdf, 244 p.

Moench, A.F., 1997, Flow to a well of finite diameter in a homogeneous, anisotropic water table aquifer: Water resources research, v. 33, no. 6, p. 1397–1407.

National Operational Hydrologic Remote Sensing Center, 2004, Snow data assimilation system (SNODAS) data products at NSIDC, Boulder, Colorado: National Snow and Ice Data Center: Online, http://dx.doi.org/10.7265/N5TB14TC, accessed July 2014.

R Development Core Team, 2015, R—a language and environment for statistical computing: R Foundation for Statistical Computing, Vienna, Austria: Online, http://www.R-project.org, accessed January 2015.

Rauzi, S.L., 1979, Structural geology of eastern part of James Peak quadrangle and western part of Sharp Mountain quadrangle, Utah: Logan, Utah, Utah State University, M.S. thesis, 73 p.

Renard, P., Glenz, D., and Mejias, M., 2008, Understanding diagnostic plots for well-test interpretation: Hydrogeology Journal, v. 17, no. 3, p. 589–600.

SHC Consulting, LLC, 2012, Drinking water source protection preliminary evaluation report—Powder Mountain Water and Sewer Improvement District, Cache and Weber Counties, Utah, proposed drinking water source: Logan, Utah, unpublished consultant's report prepared for Powder Mountain Water and Sewer Improvement District, 39 p.

Suk, H., and Lee, K.K., 1999, Characterization of a ground water hydrochemical system through multivariate analysis—clustering into ground water zones: Ground Water, v. 37, no. 3, p. 358–366.

Templ, M., Filzmoser, P., and Reimann, C., 2008, Cluster analysis applied to regional geochemical data—problems and possibilities: Applied Geochemistry, v. 23, p. 2198–2213.

U.S. Bureau of Reclamation, 2001, Water measurement manual: Online, http://www.usbr.gov/tsc/techreferences/mands/wmm/index.htm, accessed June 2016.

Usunoff, E.J., and Guzmán-Guzmán, A., 1989, Multivariate analysis in hydrochemistry—an example of the use of factor and correspondence analyses: Ground Water, v. 27, no. 1, p. 27–34.

Utah Division of Water Rights, 2015a, Well-drilling database: Online, http://maps.waterrights.utah.gov/EsriMap/map.asp?layersToAdd=WellLogs, accessed January 2015.

Utah Division of Water Rights, 2015b, Document listing for folder—35-12099: Online, http://waterrights.utah.gov/cgi-bin/docview.exe?Folder=35-12099, accessed September 2015.

Wilson, J.R., 1976, Glaciated dolomite karst in the Bear River Range, Utah: Salt Lake City, University of Utah, M.S. thesis, 120 p.

APPENDICES

APPENDIX A
GEOLOGIC MAP UNIT DESCRIPTIONS

APPENDIX A

Geologic map unit descriptions (modified from Coogan and King, 2016)

QUATERNARY

Qac Alluvial and colluvial deposits, undivided (Holocene and Pleistocene) – Deposits include various ages of alluvial fan, stream alluvium; and colluvial deposits; unit consists of sand, gravel, silt, clay, and boulders; 20 to 180 feet (6-55 m) thick.

Qmc Mass movement and colluvial deposits, undivided (Holocene and Pleistocene) – Deposits include various ages of mass movement, talus, and associated colluvial deposits; unit consists of sand, gravel, boulders, silt, and clay, also includes angular talus derived from adjoining bedrock; 0 to 40 feet (12 m) thick.

Qst Spring and travertine deposits (Holocene) – Travertine and associated calcium carbonate cemented gravels and colluvium; mapped along the Lefty's Spring outflow channel; 0 to 10 feet (3 m) thick.

Qg Glacial deposits, undivided (middle and lower Pleistocene) – Glacial deposits including moraines, till, and outwash of various ages; includes moraines that are mapped where distinct shapes of end, recessional and lateral moraines are apparent; unit consists of poorly sorted clay, silt, sand, gravel, and boulder size material; 6 to 150 feet (2-45 m) thick.

QUATERNARY AND TERTIARY

QTaf Older alluvial fan deposits (middle and lower Pleistocene) – High level alluvial fan deposits; unit consists of sand, gravel, boulders, silt, and clay; mapped in Ogden Valley across prominent, dissected, high standing fan surface; 30 to 150 feet (9-45 m) thick.

TERTIARY

Tsl Salt Lake Formation (Pliocene and Miocene) - Grayish-white tuff, tuffaceous siltstone and sandstone, altered tuff/claystone, and conglomerate, with local limestone; about 450 feet (140 m) exposed in James Peak quadrangle east of Davenport Creek.

Tn Norwood Tuff (Eocene and Oligocene?) - Light-colored, altered tuffaceous claystone and mudstone with local conglomerate, limestone, and sandstone; about 500 feet (150 m) exposed below angular unconformity in James Peak quadrangle east of Davenport Creek.

Tw Wasatch Formation (Eocene and upper Paleocene?) - Red to brownish-red sandstone, siltstone, mudstone, and conglomerate with minor gray limestone; mapped along the drainage divide primarily east of the Hidden Lake Well; up to 1200 feet (365 m) thick based on structure contour in figure 9.

ORDOVICIAN

Ogc Garden City Formation (Lower Ordovician) - Gray to tan weathering, dark-gray to gray, thin- to medium-bedded, silty limestone; contains tan to yellowish-weathering, less resistant, wavy, silty to argillaceous laminae to inch-scale layers that are more abundant in lower part; intraformational, flat-pebble conglomerate present in lower half; ledge forming; black chert nodules and stringers near the top of unit and in lowermost part; locally fossiliferous; 500 to 1200 feet (150-365 m) thick.

CAMBRIAN

Ꞓsc St. Charles Formation (Upper Cambrian) - Dark-gray, medium- to thick-bedded dolomite; contains subordinate medium-gray dolomite and limestone; occasional tan mottling and laminae of sandstone and siltstone; overall gray to tan weathering and ledge forming; uppermost part contains light-colored, chert; lower part is less resistant, light-gray, tannish-gray weathering, thin-bedded, silty and sandy limestone and dolomite, and silty shale, with tannish-gray, medium-bedded, cross-bedded Worm Creek Quartzite Member; it is 970 feet (295 m) thick, including Worm Creek, in the Sharp Mountain quadrangle.

Ꞓn Nounan Formation (Upper Cambrian) - Medium-gray to dark-gray, very thick to thick-bedded, light to medium gray and tan-weathering, typically cliff forming, variably sandy and silty dolomite and lesser limestone, with crude laminae to partings and mottling of sandstone and siltstone that weather tan or reddish; little sandstone and siltstone in more resistant lower part; 800 to 1145 feet (245-350 m) in the Powder Mountain area.

Ꞓbc Calls Fort Shale Member of the Bloomington Formation (Middle Cambrian) - Brown-weathering, slope-forming, olive-gray to tan-gray, thin bedded, shale and micaceous argillite with minor, thin-bedded, dark-gray, silty limestone; about 400 feet (120 m) thick.

Cbm Middle limestone member of the Bloomington Formation (Middle Cambrian) - Dark to medium-gray, thick- to thin-bedded, argillaceous limestone with tan-, yellow-, and red-weathering, wavy, silty layers and partings; contains subordinate olive-gray and tan-gray, thin-bedded, shale and micaceous argillite; typically forms cliff or prominent outcrop between less resistant shale members; 680 feet (200 m) thick.

Ꞓbh Hodges Shale Member of the Bloomington Formation (Middle Cambrian) - Brown-weathering, slope-forming, olive-gray to tan-gray, thin-bedded, shale and micaceous argillite, and thin- to thick-bedded, dark- to medium-gray limestone with tan-, yellow-, and red-weathering, wavy, silty layers and partings; typically forms vegetated slopes; 300 feet (90 m) thick.

Ꞓbk Blacksmith Formation (Middle Cambrian) - Medium-gray, very thick to thick-bedded, dolomite and dolomitic limestone that contains tan-weathering, irregular silty partings to layers; weathers to light gray cliffs and ridges; about 250 feet (75 m) thick.

Ꞓu Ute Formation (Middle Cambrian) - Interbedded gray thin- to thick-bedded limestone with tan-, yellowish-tan-, and reddish-tan-weathering, wavy, silty layers and partings, and olive-gray to tan-gray, thin-bedded shale and micaceous argillite; and minor, medium-bedded, gray to light-gray dolomite; forms slopes and ledges; 1000 feet (300 m) thick.

Ꞓl Langston Formation (Middle Cambrian) - Upper part is gray, sandy dolomite and limestone that weathers to ledges and cliffs; middle part is yellowish- to reddish-brown to gray weathering, greenish-gray, fossiliferous shale and lesser interbedded gray, laminated to very thin-bedded; basal part is light-brown-weathering, ledge forming gray limestone and dolomite with local poorly indurated tan, dolomitic sandstone at bottom; basal part that is less resistant; up to 270 feet (80 m) thick.

Ꞓgc Geertsen Canyon Quartzite, undivided (Middle and Lower Cambrian) - White and tan quartzite, with pebble conglomerate beds; pebbles are mostly rounded light-colored quartzite; contains cross-bedding, and pebble layers and lenses; colors vary from tan and light to medium gray, with pinkish, orangish, reddish, and purplish hues; cliff forming; thickness about 4200 feet (1280 m).

Ꞓgcu Geertsen Canyon Quartzite, upper (Middle and Lower Cambrian) - Tan, white, and light-gray, medium- to coarse-grained, cross-bedded, thick-bedded quartzite; base of upper part is marked by a resistant, light-colored quartzite with quartz-pebble conglomerate containing white and pink quartz and rare jasper clasts, up to 2500 to 3000 feet (760-910 m).

Ꞓgcl Geertsen Canyon Quartzite, lower (Lower Cambrian) - Typically conglomeratic and feldspathic; contains a purplish-gray upper part and a light-colored lower part; 1175 to 1700 feet (360-520 m) thick.

NEOPROTEROZOIC

Zbq Quartzite Member of the Browns Hole Formation (Neoproterozoic) – Reddish-orange to light colored quartzite; locally more resistant than overlying Geertsen Canyon Quartzite; 0 to 285 feet (0-85 m) thick.

Zbv Volcanic Member of the Browns Hole Formation (Neoproterozoic) - Gray to reddish-gray weathering, brownish- to purplish-red volcanic-clastic sedimentary strata; 180 to 460 feet (55-140 m) thick.

Zm Mutual Formation (Neoproterozoic) - Grayish-red to purplish-gray, medium to thick-bedded quartzite with pebble conglomerate lenses; also reddish-gray, pink, tan, and light-gray in color; up to 2600 feet (800 m) thick.

Zi Inkom Formation (Neoproterozoic) - Gray to reddish-gray or greenish-gray shale and argillite, locally contains very-fine grained thin-bedded quartzite; 300 feet (90 m) thick.

Zcc Caddy Canyon Quartzite (Neoproterozoic) – Tan, light-gray, pinkish-gray, greenish-gray, and purplish-gray, or white, locally vitreous, cliff-forming, quartzite; typically lighter colored than the Geertsen Canyon Quartzite; up to 2500 feet (760 m) thick.

Zpc Papoose Creek Formation (Neoproterozoic) - Gray to brownish-gray to olive-gray argillite and interbedded quartzose metasandstone and quartzite, up to 750 feet (230 m) thick.

Zkc Kelley Canyon Formation (Neoproterozoic) - Dark-gray to black, gray to olive-gray-weathering argillite to phyllite; gradational with the Papoose Creek Formation (Zpc); about 1600 feet (500 m) thick.

Zmcc Quartzite member of the Maple Canyon Formation (Neoproterozoic) - Light-gray coarse-grained, quartzite to pebble and small cobble meta-conglomerate with local tan-weathering, dark-gray, meta-graywacke matrix; 60 to 500 feet (20-150m) thick.

Zmcg Arkose member of the Maple Canyon Formation (Neoproterozoic) - Grayish-green, greenish-brown, fine-grained arkosic meta-sandstone and sandy argillite, with local quartzite lenses; 500 to 1000 feet (150-305 m) thick.

APPENDIX B
GEOLOGIC FIELD STOP DATA

PowderMt_AppendixB.xlsx

Appendix B. *Geologic field stop data.*

SiteID	Date	Easting[1]	Northing	Type[2]	Unit[3]	S[4]	D	S1[5]	D1	S2	D2	Frctr Grp[6]	Notes
209	7/27/15	433938	4578552	upright	pCgc	340	22	217	65	124	68	SC	
210	7/27/15	434097	4578604	upright	pCgc	326	27	250	82	160	62	SC	
211	7/27/15	434184	4578598	upright	pCgc	346	31	214	64			SC	joint zone here is 1 ft wide
212	7/27/15	434237	4578724	upright	pCgc	354	28	251	89	130	61	SC	joints sets equally developed
213	7/27/15	434264	4578674	upright	Cl	341	29	265	90			SC	silty limestone with joints spaced ~ 1ft
214	7/27/15	434324	4578732	upright	Cl/Cu?	356	29	217	71			SC	primary joint is open oolitic limestone
215	7/27/15	434456	4578862	upright	Cu	355	14	275	86			SC	pisolitic limestone
216	7/27/15	434588	4578983	upright	Cu	342	26	225	59			SC	silty interbedded limestone
217	7/27/15	434732	4579067	upright	Cbk	334	26	233	85			SC	prominent open joint
218	7/27/15	435061	4579294	upright	Cb	346	32	182	58			SC	oolitic middle limestone
219	7/27/15	435182	4579537	upright	Cb	351	29	194	58			SC	laminated pale limestone
220	7/27/15	435287	4579491	upright	Cb	356	19						poorly defined jointing
221	7/27/15	435079	4579101	upright	Cb	332	24	178	89			SC	silty blebs in limestone
222	7/28/15	435528	4580806	upright	pCgc	105	47						shattered qrtzt… jointing very complex could be cleavage as well
223	7/28/15	435508	4581186	upright	Cb	321	33						oolitic limestone, middle limestone, small outcrop otherwise regraded near here
224	7/28/15	435475	4581486	upright	pCgc	339	36						shattered qrtzt, outcrop
225	7/28/15	435537	4581109	upright	Cb	285	25	355	75	104	59		outcrop of middle limestone no topping indicators here
226	7/28/15	435630	4581052	upright	pCgc	99	54						Seems upright but topping indicators are poor here… shattered outcrop
227	7/28/15	435656	4581009	upright	pCgc	112	59						upright, from xbed cutoffs
228	7/28/15	435697	4580997	upright	pCgc	95	36						another shattered qrtzt swaddled in Q
229	7/28/15	435802	4580878	other	Cn								pale dolomite float
230	7/28/15	435811	4580899	overturned	Cn	186	51						pale finely bedded dolomite overturned based on fine bedding truncations
231	7/28/15	435815	4580981	other	Cn								north edge of poorly exposed Nounan
232	7/28/15	435951	4580755	overturned	Cn	270	34						no real topping indicators here, gray sparry dolomite
233	7/28/15	436085	4581168	overturned	Cn	235	39						finely bedded medium gray dolomite
234	7/28/15	436366	4581603	other	Tw								western hidden lake spring head
235	7/28/15	436360	4581390	overturned	Cn	245	52	161	81			NC	no topping indicators here, assume overturned
236	7/28/15	436330	4581211	overturned	Cn	231	51	145	67			NC	overturned based on bedding truncations, joints are tight here
237	7/28/15	436316	4581084	overturned	Cn	216	48						poor outcrop dolomite assume overturned
238	7/28/15	436294	4581021	other									contact with Tw just uphill of here
239	7/28/15	436127	4580863	other									sinkhole? Strange depression in Tw or Q
240	7/29/15	436639	4580464	other	Tw								sinkholes near here strange depression
241	7/29/15	437097	4580269	other	Tw								
242	7/29/15	437692	4580292	other	Tw								
243	7/29/15	437513	4581161	other	Tw								
244	7/29/15	437190	4581757	other									contact of Tw and carbs here
245	7/29/15	437189	4581790	overturned	Csc	300	89					NC	granular dolomite
246	7/29/15	437185	4581830	overturned	Csc	213	39	131	79	25	67	NC	silty dolomitic grainstone
247	7/29/15	437179	4582034	overturned	Ogc	216	63						intraclastic limestone
248	7/29/15	437201	4582189	overturned	Ogc	200	47	306	71			NC	fossiliferous limestone
249	7/29/15	437064	4581956	overturned	Ogc	228	52						silty intraclastic limestone
250	7/29/15	437058	4581689	other	Qc								Slope colluvium
251	7/29/15	437052	4581680	overturned	Ogc	204	54						
252	7/29/15	436862	4581778	other	Qtill?								quaternary deposits of glacial origin… Tw cobbles and boulders
253	7/29/15	436700	4581528	other	Q/Tw								quaternary deposits of glacial origin… Tw cobbles and boulders
254	7/29/15	436781	4581267	other	Q/Tw								
255	7/30/15	436307	4583319	upright	Cu?	354	70						brownish shale seems like Ute
256	7/30/15	436334	4583306	upright	Cu?	159	39						shales overlain by lateral moraine?
257	7/30/15	437862	4581762	other	Qc/Tw								
258	7/30/15	437795	4581407	other	Tw								nothing but Tw no carbonates near here…
259	7/30/15	438132	4581530	other	Tw								
260	7/30/15	438208	4582264	upright	Csc	175	46						bioclastic dolomite
261	7/30/15	438338	4582291	other	Cwc?								quartzite float… could be worm creek?!?
262	7/30/15	438386	4582299	other	Tw								contact with Tw here
263	7/30/15	438426	4582669	other	Tw								
264	7/30/15	438454	4583049	upright	Ogc	169	41						blocky medium bedded limestone
265	7/30/15	438369	4583091	upright	Ogc	175	35						intraclastic limestone
266	7/30/15	438164	4583362	other	sinter								beat up silicified limestone? Or dolomite? Hard to tell the unit extends along ridge near here
267	7/30/15	438073	4583379	other	Tw								small patch of Tw cobbles along ridgeline here
268	7/30/15	437967	4583387	upright	Ogc	11	81						
269	7/30/15	437880	4583348	upright	Ogc	35	65						silty limestone poor truncations indicate upright…
270	7/30/15	437805	4583302	upright	Ogc	36	55						
271	7/30/15	437734	4583284	upright	Ogc	37	73						
272	7/30/15	437590	4583169	upright	Ogc	61	59						
273	7/30/15	437517	4583117	upright	Ogc	80	50						
274	7/30/15	437418	4583062	upright	Csc	30	52						dolomite in road cut
275	7/30/15	437444	4583035	upright	Ogc	30	71						thin bedded limestone… cherts downsection between here and 274
276	7/30/15	437338	4583255	other	Cn?								poor exposure since 275
277	7/30/15	437282	4583310	upright	Cn	29	51						pervasively disrupted dolomite
278	7/30/15	437234	4583402	upright	Cn	42	80						
279	7/30/15	437101	4583415	upright	Cn	31	87						bioturbated pale dolostone
280	7/30/15	436928	4583498	upright	Cb	356	90						oolitic middle limestone
281	7/30/15	436980	4583469	other	Cb								top of the Nounan, Calls Fort above here
282	7/30/15	436972	4582890	other	Cn								springhead in Cobabe
283	7/30/15	437649	4582378	other	Tw/Q								upper springhead
284	7/30/15	437661	4582369	other	Tw/Q								periodic springhead? Anomalous dry algal here in this otherwise dry springhead?

[1] All location data is in NAD 83 UTM zone 12 N

[2] Measurement type; upright indicates upright bedding; overturned indicates overturned; other indicates no bedding measurement

[3] Geologic unit at field stop; correlates with geologic map units of figure 4

[4] Strike and dip of bedding

[5] Strike and dip of fracture; S1 is primary fracture and S2 is secondary fracture

[6] Fracture group; SC is carbonates in Weber County; NC is carbonates in Cache County

APPENDIX C
OUTPUT DATA FROM ANALYSES

PowderMt_AppendixC_v2.xlsx

Appendix C. *Output data from analyses. [1] Denotes data from Loughlin Water and [2] denotes data from Cascade Water, both of which have been resampled.*

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
9/8/13				13													8153.66
9/9/13				10													8153.97
9/10/13				14													8153.89
9/11/13				24													8153.80
9/12/13				25													8153.68
9/13/13				8													8153.56
9/14/13				1													8153.34
9/15/13				13													8153.13
9/16/13				16													8152.90
9/17/13				-10													8152.71
9/18/13				-9													8152.54
9/19/13				14													8152.36
9/20/13				9													8152.18
9/21/13				-13													8151.87
9/22/13				-33													8151.66
9/23/13				2													8151.46
9/24/13				-4													8151.26
9/25/13				-44													8151.04
9/26/13				-40													8150.80
9/27/13				-14													8150.59
9/28/13				15													8150.41
9/29/13				5													8150.23
9/30/13				-7													8150.04
10/1/13				-2													8149.81
10/2/13				-10													8149.61
10/3/13				-25													8149.44
10/4/13				12													8149.23
10/5/13				40													8149.05
10/6/13				40													8148.85
10/7/13				12													8147.39
10/8/13				0													8135.50
10/9/13				0													8133.81
10/10/13				0													8135.14
10/11/13				0													8129.48
10/12/13				0													8129.78
10/13/13				0													8142.86
10/14/13				5													8129.91
10/15/13				10													8142.42
10/16/13				8													8143.28
10/17/13				1													8143.44
10/18/13				13													8143.58
10/19/13				13													8143.61
10/20/13				1													8143.56
10/21/13				15													8143.42
10/22/13				27													8139.00
10/23/13				36													8133.80
10/24/13				37													8133.36
10/25/13				28													8141.24
10/26/13				20													8141.79
10/27/13				67													8141.86
10/28/13				114													8141.77
10/29/13				94													8141.67
10/30/13				77													8141.56
10/31/13				57													8141.48
11/1/13				36													8141.41
11/2/13				60													8141.23
11/3/13				90													8141.10
11/4/13				81													8140.91
11/5/13				55													8130.56
11/6/13				26													8110.21
11/7/13				32													8116.19
11/8/13				60													8115.29
11/9/13				46													8134.70
11/10/13				31													8135.98
11/11/13				24													8127.50
11/12/13																	8124.42
11/13/13																	8135.09
11/14/13																	8135.73
11/15/13																	8135.95
11/16/13																	8136.03
11/17/13																	8136.09
11/18/13																	8136.23
11/19/13																	8136.29
11/20/13																	8136.26
11/21/13																	8136.23

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
11/22/13																	8136.22
11/23/13																	8136.18
11/24/13																	8136.10
11/25/13																	8136.02
11/26/13																	8135.90
11/27/13																	8135.84
11/28/13																	8135.64
11/29/13																	8135.55
11/30/13																	8135.43
12/1/13																	8135.29
12/2/13																	8134.99
12/3/13																	8134.64
12/4/13																	8134.45
12/5/13																	8134.19
12/6/13																	8134.05
12/7/13																	8133.77
12/8/13																	8133.65
12/9/13																	8133.54
12/10/13																	8133.41
12/11/13																	8133.37
12/12/13																	8133.23
12/13/13																	8133.05
12/14/13																	8132.94
12/15/13																	8132.89
12/16/13																	8132.77
12/17/13																	8132.57
12/18/13																	8132.29
12/19/13																	8131.95
12/20/13																	8131.62
12/21/13																	8131.35
12/22/13																	8131.20
12/23/13																	8131.08
12/24/13																	8131.01
12/25/13																	8130.86
12/26/13																	8130.79
12/27/13																	8130.68
12/28/13																	8130.46
12/29/13																	8130.25
12/30/13																	8130.11
12/31/13																	8129.93
1/1/14																	8129.82
1/2/14																	8129.75
1/3/14																	8129.55
1/4/14																	8129.36
1/5/14																	8129.20
1/6/14																	8129.13
1/7/14																	8129.10
1/8/14																	8128.93
1/9/14																	8128.74
1/10/14																	8128.54
1/11/14																	8128.35
1/12/14																	8128.18
1/13/14																	8128.11
1/14/14																	8128.13
1/15/14																	8128.12
1/16/14																	8128.05
1/17/14																	8127.87
1/18/14																	8127.79
1/19/14																	8127.70
1/20/14																	8127.58
1/21/14																	8127.41
1/22/14																	8127.19
1/23/14																	8127.05
1/24/14																	8126.95
1/25/14																	8126.90
1/26/14																	8126.76
1/27/14																	8126.58
1/28/14																	8126.41
1/29/14																	8126.20
1/30/14																	8125.92
1/31/14																	8125.71
2/1/14																	8125.52
2/2/14																	8125.42
2/3/14																	8125.26
2/4/14																	8125.09

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
2/5/14																	8124.97
2/6/14																	8124.80
2/7/14																	8124.69
2/8/14																	8124.56
2/9/14																	8124.50
2/10/14																	8124.39
2/11/14																	8124.36
2/12/14																	8124.25
2/13/14																	8124.15
2/14/14																	8123.98
2/15/14																	8123.88
2/16/14																	8123.78
2/17/14																	8123.63
2/18/14																	8123.62
2/19/14																	8123.44
2/20/14																	8123.25
2/21/14																	8123.09
2/22/14																	8123.02
2/23/14																	8122.87
2/24/14																	8122.73
2/25/14																	8122.67
2/26/14																	8122.64
2/27/14																	8122.41
2/28/14																	8122.26
3/1/14																	8122.04
3/2/14																	8121.82
3/3/14																	8121.78
3/4/14																	8121.74
3/5/14																	8121.69
3/6/14																	8121.51
3/7/14																	8121.45
3/8/14																	8121.38
3/9/14																	8121.32
3/10/14																	8121.11
3/11/14																	8121.02
3/12/14																	8120.95
3/13/14																	8120.85
3/14/14																	8120.64
3/15/14																	8120.48
3/16/14																	8120.42
3/17/14																	8120.23
3/18/14																	8120.03
3/19/14																	8119.90
3/20/14																	8119.75
3/21/14																	8119.67
3/22/14																	8119.54
3/23/14																	8119.41
3/24/14																	8119.30
3/25/14																	8119.21
3/26/14																	8119.02
3/27/14																	8118.76
3/28/14																	8118.65
3/29/14																	8118.55
3/30/14																	8118.46
3/31/14																	8118.30
4/1/14																	8118.12
4/2/14																	8117.96
4/3/14																	8117.86
4/4/14																	8117.70
4/5/14																	8117.59
4/6/14																	8117.51
4/7/14																	8117.48
4/8/14																	8117.48
4/9/14																	8117.41
4/10/14																	8117.22
4/11/14																	8117.16
4/12/14																	8117.01
4/13/14																	8116.78
4/14/14																	8116.77
4/15/14																	8116.66
4/16/14																	8116.53
4/17/14																	8116.45
4/18/14																	8116.41
4/19/14																	8116.41
4/20/14																	8116.40

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
4/21/14																	8116.39
4/22/14																	8116.40
4/23/14																	8116.39
4/24/14																	8116.58
4/25/14																	8116.82
4/26/14																	8116.84
4/27/14																	8117.06
4/28/14																	8117.25
4/29/14																	8117.58
4/30/14																	8117.94
5/1/14																	8118.23
5/2/14																	8118.47
5/3/14																	8118.65
5/4/14																	8119.36
5/5/14																	
5/6/14																	
5/7/14																	
5/8/14																	
5/9/14																	
5/10/14																	
5/11/14																	
5/12/14																	
5/13/14																	
5/14/14																	
5/15/14																	
5/16/14																	
5/17/14																	
5/18/14																	
5/19/14																	
5/20/14																	
5/21/14																	
5/22/14																	
5/23/14																	
5/24/14																	
5/25/14																	
5/26/14																	
5/27/14																	
5/28/14																	
5/29/14																	
5/30/14																	
5/31/14																	
6/1/14																	
6/2/14																	
6/3/14																	
6/4/14																	
6/5/14																	
6/6/14																	8157.06
6/7/14																	8157.88
6/8/14																	8159.32
6/9/14																	8160.68
6/10/14																	8161.92
6/11/14																	8163.12
6/12/14																	8164.31
6/13/14																	8165.46
6/14/14																	8166.54
6/15/14																	8167.53
6/16/14																	8168.38
6/17/14																	8169.21
6/18/14																	8170.15
6/19/14																	8170.89
6/20/14																	8171.61
6/21/14																	8172.22
6/22/14																	8172.79
6/23/14																	8173.36
6/24/14																	8173.82
6/25/14																	8174.27
6/26/14																	8174.71
6/27/14																	8175.11
6/28/14																	8175.49
6/29/14																	8175.88
6/30/14																	8176.17
7/1/14																	8176.56
7/2/14																	8176.87
7/3/14																	8177.12
7/4/14																	8177.40

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
7/5/14																	8177.63
7/6/14																	8177.77
7/7/14																	8177.93
7/8/14																	8178.13
7/9/14																	8178.30
7/10/14																	8178.42
7/11/14																	8178.54
7/12/14																	8178.74
7/13/14																	8178.89
7/14/14																	8179.01
7/15/14																	8179.08
7/16/14																	8179.16
7/17/14																	8179.25
7/18/14																	8179.26
7/19/14																	8179.27
7/20/14																	8179.31
7/21/14																	8179.31
7/22/14																	8179.33
7/23/14																	8179.33
7/24/14																	8179.33
7/25/14	20.8	25.4	5.2	119													8179.28
7/26/14	17.0	25.5	5.2	112													8179.27
7/27/14	18.2	25.5	5.2	114													8179.26
7/28/14	15.9	25.6	5.2	112													8179.26
7/29/14	12.3	25.5	5.2	108													8179.17
7/30/14	12.5	25.5	5.2	107													8179.11
7/31/14	13.5	25.5	5.2	106													8179.03
8/1/14	14.8	25.5	5.2	108													8178.92
8/2/14	16.3	25.5	5.2	107													8178.83
8/3/14	15.8	25.5	5.2	106													8178.68
8/4/14	14.1	25.4	5.2	102													8178.51
8/5/14	11.8	25.4	5.2	102													8178.43
8/6/14	14.5	25.4	5.2	101													8178.37
8/7/14	13.1	25.4	5.2	102													8178.23
8/8/14	15.1	25.4	5.2	100													8178.04
8/9/14	15.6	25.5	5.2	101													8177.92
8/10/14	17.0	25.5	5.2	100													8177.84
8/11/14	19.0	25.5	5.2	99													8177.73
8/12/14	16.5	25.5	5.2	96													8177.68
8/13/14	13.1	25.4	5.2	92													8177.48
8/14/14	14.8	25.4	5.2	92													8177.32
8/15/14	15.6	25.4	5.2	93													8177.13
8/16/14	16.3	25.5	5.2	94													8177.04
8/17/14	17.6	25.5	5.2	94													8176.84
8/18/14	18.4	25.4	5.6	97													8176.56
8/19/14	13.7	25.3	5.2	95													8176.31
8/20/14	13.5	25.3	5.2	94													8176.13
8/21/14	10.7	25.4	5.2	92									125				8175.41
8/22/14	10.4	25.3	5.2	93									152				8172.21
8/23/14	7.5	25.3	5.2	92									156				8175.06
8/24/14	9.9	25.3	5.2	95									123				8175.01
8/25/14	11.1	25.3	5.2	91									122				8172.80
8/26/14	10.9	25.4	5.2	87									136				8171.15
8/27/14	10.7	25.5	5.2	85									123				8170.32
8/28/14	12.7	25.5	5.2	84									118				8169.80
8/29/14	14.7	25.4	5.2	85									119				8171.40
8/30/14	13.8	25.3	5.2	84									120				8169.57
8/31/14	11.3	25.3	5.2	85									120				8172.63
9/1/14	11.1	25.3	5.2	83									117				8172.64
9/2/14	13.6	25.3	5.2	86									115				8169.98
9/3/14	16.2	25.2	5.2	88									113				8168.90
9/4/14	11.3	25.3	5.6	85									113				8168.36
9/5/14	13.2	25.4	5.2	73									111				8168.22
9/6/14	15.0	25.5	5.2	78									109				8167.68
9/7/14	16.0	25.4	5.2	78									105				8170.58
9/8/14	13.1	25.3	5.2	79									103				8167.28
9/9/14	10.3	25.3	5.2	76									103				8167.32
9/10/14	10.3	25.3	5.2	75									99				8169.04
9/11/14	9.5	25.4	5.2	76									95				8166.13
9/12/14	7.0	25.4	5.2	71									97				8169.06
9/13/14	12.4	25.4	5.2	71									98				8169.08
9/14/14	15.2	25.4	5.2	70									98				8168.90
9/15/14	16.5	25.4	5.3	66									94				8163.84
9/16/14	16.7	25.4	5.3	67									94				8163.07
9/17/14	18.2	25.3	5.3	70									93				8162.73

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
9/18/14	17.7	25.3	5.3	67									94				8162.23
9/19/14	14.8	25.4	5.3	66									93				8162.04
9/20/14	15.7	25.5	5.2	67									90				8162.98
9/21/14	10.4	25.4	5.2	66									122				8165.91
9/22/14	11.1	25.4	5.2	62									93				8161.27
9/23/14	14.2	25.5	5.3	64									88				8160.89
9/24/14	16.2	25.5	5.3	63									88				8160.89
9/25/14	18.5	25.4	5.3	62									86				8160.12
9/26/14	16.7	25.3	5.3	63									86				8160.04
9/27/14	7.6	25.2	5.2	65									155				8163.73
9/28/14	6.5	25.2	5.2	62									68				8163.87
9/29/14	5.0	25.2	5.2	60									111				8160.76
9/30/14	3.4	25.2	5.2	59									168				8163.10
10/1/14	1.1	25.2	5.2	56									139				8163.28
10/2/14	3.8	25.4	5.2	53									127				8163.08
10/3/14	7.2	25.6	5.3	50									123				8163.15
10/4/14	8.8	25.5	5.3	53									119				8163.01
10/5/14	10.1	25.4	5.3	53									118				8162.82
10/6/14	11.5	25.4	5.3	54									117				8162.66
10/7/14	12.1	25.4	5.3	53									113				8162.44
10/8/14	12.4	25.3	5.3	54									111				8162.23
10/9/14	12.8	25.3	5.3	54									109				8161.95
10/10/14	11.7	25.3	5.3	54									102				8161.69
10/11/14	8.7	25.3	5.3	51									104				8161.50
10/12/14	3.2	25.3	5.3	51									111				8161.34
10/13/14	4.4	25.4	5.3	48									101				8161.14
10/14/14	10.4	25.4	5.3	49									104				8160.87
10/15/14	11.3	25.2	5.3	51									103				8160.62
10/16/14	6.2	25.3	5.3	50									102				8160.29
10/17/14	9.3	25.3	5.3	49									96				8160.24
10/18/14	11.5	25.3	5.3	49									91				8159.86
10/19/14	11.4	25.3	5.3	50									97				8159.56
10/20/14	12.3	25.3	5.3	49									96				8159.25
10/21/14	6.9	25.2	5.3	50									96				8158.91
10/22/14	4.3	25.3	5.3	50									95				8158.65
10/23/14	9.9	25.4	5.3	48									91				8158.40
10/24/14	13.0	25.4	5.3	48									95				8158.13
10/25/14	13.5	25.3	5.3	49									87				8157.86
10/26/14	5.1	25.2	5.3	47									89				8157.60
10/27/14	-0.9	25.3	5.3	44									86				8157.41
10/28/14	2.1	25.4	5.3	41									86				8157.08
10/29/14	6.7	25.5	5.3	40									87				8156.93
10/30/14	9.9	25.5	5.3	41									86				8156.66
10/31/14	10.6	25.3	5.3	42									81				8156.29
11/1/14	6.1	25.0	5.3	42									82				8156.01
11/2/14	-1.3	25.1	5.3	41									86				8155.80
11/3/14	-2.1	25.3	5.3	40									84				8155.59
11/4/14	-0.4	25.5	5.3	36					3.1	0.3	25.9	90	85	4.0	485		8155.36
11/5/14	2.9	25.6	5.3	37					3.8	1.3	26.0	86	89	4.5	461		8155.16
11/6/14	6.8	25.6	5.3	37					4.0	5.5	25.9	85	86	4.5	505		8154.94
11/7/14	6.4	25.5	5.3	38					4.5	4.6	25.9	89	88	5.0	474		8154.70
11/8/14	4.2	25.5	5.3	38					3.7	2.6	25.9	88	85	4.2	479		8154.75
11/9/14	7.5	25.2	5.3	40					4.2	6.9	25.6	86	83	4.8	466		8154.78
11/10/14	-0.6	25.0	5.3	40					3.0	-2.0	25.4	96	84	4.0	516		8154.72
11/11/14	-5.1	25.1	5.3	39					1.2	-8.8	25.5	98	84	2.5	543		8154.38
11/12/14	-9.7	25.2	5.3	37					0.3	-14.4	25.5	115	80	1.1	637		8154.06
11/13/14	-7.2	25.1	5.3	33					0.4	-6.6	25.5	84	79	1.8	497		8153.83
11/14/14	-1.7	25.1	5.3	31	37				1.2	-1.2	25.5	93	84	3.1	491		8153.69
11/15/14	-7.1	25.1	5.3	31	37				0.8	-11.4	25.5	119	78	1.6	609		8153.42
11/16/14	-11.5	25.4	5.3	32	36				0.3	-17.1	25.7	129	70	0.8	776		8152.95
11/17/14	-7.8	25.4	5.3	31	37				0.3	-13.8	25.8	92	68	1.1	625		8152.67
11/18/14	-4.8	25.4	5.3	30	36				0.3	-7.7	25.8	67	60	1.8	516		8152.55
11/19/14	-1.0	25.3	5.3	30	37				0.5	-1.8	25.7	55	63	2.7	490		8152.41
11/20/14	-0.2	25.2	5.3	30	37				0.9	-1.6	25.6	60	66	3.4	482		8152.25
11/21/14	0.8	25.2	5.3	30	36				0.7	-2.3	25.6	65	68	2.9	495		8152.06
11/22/14	-1.3	25.1	5.3	29	36				0.5	-1.1	25.4	66	75	2.6	502		8151.95
11/23/14	-5.2	25.2	5.3	29	36				0.6	-6.8	25.6	82	75	2.6	594		8151.59
11/24/14	-5.1	25.4	5.3	28	36				0.8	-8.0	25.8	83	76	2.4	563		8151.24
11/25/14	-4.2	25.4	5.3	28	36				0.9	-3.0	25.8	67	79	3.0	500	8062.71	8147.87
11/26/14	2.2	25.5	5.3	28	36			70	1.5	1.1	25.9	65	80	3.9	487	8154.37	8150.28
11/27/14	4.1	25.5	5.3	30	37			70	1.8	4.6	25.9	64	79	4.1	446		8150.25
11/28/14	5.1	25.2	5.3	31	37			71	1.9	5.2	25.6	71	80	4.1	457	8154.27	8150.29
11/29/14	2.5	25.0	5.3	31	36			71	1.9	3.7	25.4	75	81	4.2	479	8154.16	8150.29
11/30/14	-1.1	25.1	5.3	30	36			71	1.2	-2.7	25.5	81	83	3.1	528	8154.08	8149.90
12/1/14	-1.4	25.3	5.3	29	35			70	1.6	-0.9	25.7	74	82	3.7	477	8153.82	8149.48

Date	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
12/2/14	1.2	25.3	5.3	29	36			70	1.6	-0.9	25.7	74	82	3.7	523	8129.00	8144.50
12/3/14	-0.3	25.2	5.3	28	35	5.1	105	70	1.8	0.2	25.6	75	82	4.1	493	8015.21	8116.61
12/4/14	1.7	25.2	5.3	28	36	5.1	108	70	2.1	1.3	25.6	74	83	4.3	467	8010.31	8113.00
12/5/14	2.6	25.4	5.3	27	36	5.2	109	68	1.7	0.2	25.8	74	80	3.9	499	8007.50	8110.50
12/6/14	1.7	25.4	5.3	26	35	5.1	103	67	2.0	1.7	25.8	70	79	4.2	470	8004.82	8108.40
12/7/14	2.1	25.5	5.3	25	35	5.1	101	66	1.5	-0.9	25.9	73	78	3.7	471	8002.86	8106.64
12/8/14	3.0	25.5	5.3	25	35	5.1	101	65	1.3	-1.1	25.9	73	78	3.4	470	8001.31	8105.28
12/9/14	4.1	25.4	5.3	24	34	5.1	99	64	1.4	0.0	25.8	72	77	3.5	458	7999.50	8103.81
12/10/14	4.6	25.3	5.3	25	35	5.1	95	62	1.0	-0.1	25.7	71	75	3.0	437	7997.70	8102.52
12/11/14	4.1	25.2	5.3	26	35	5.1	96	61	1.6	4.3	25.6	69	75	3.8	397	7996.28	8101.37
12/12/14	4.8	25.2	5.5	26	35	5.1	94	61	2.1	4.5	25.5	74	77	4.4	472	7994.85	8100.19
12/13/14	-2.0	25.1	5.3	25	34	5.0	96	60	1.1	-2.3	25.5	79	82	3.4	526	7993.67	8099.13
12/14/14	-5.5	25.2	5.3	26	34	5.0	94	59	0.7	-6.6	25.6	80	79	2.6	530	7992.49	8098.03
12/15/14	-4.5	25.2	5.3	25	33	5.0	91	58	0.3	-9.9	25.6	84	77	2.0	571	7991.21	8096.99
12/16/14	-2.4	25.2	5.3	23	33	5.1	87	56	0.5	-3.5	25.5	71	78	2.7	469	8014.72	8100.79
12/17/14	-3.1	25.1	5.3	24	33	5.0	89	55	0.5	-6.1	25.5	76	77	2.5	468	8130.79	8127.77
12/18/14	-4.3	25.2	5.3	24	33	5.0	87	54	0.3	-6.6	25.6	73	77	2.3	502	8134.10	8130.50
12/19/14	-2.8	25.3	5.3	24	34	5.1	84	54	0.4	-3.8	25.7	73	77	2.8	496	8135.56	8131.90
12/20/14	-2.9	25.2	5.3	24	34	5.0	83	54	0.7	-2.6	25.6	76	78	3.2	497	8136.42	8132.87
12/21/14	-1.4	25.1	5.3	24	35	4.9	81	54	0.4	-1.2	25.5	77	82	2.6	527	8137.10	8133.59
12/22/14	-2.1	25.1	5.3	24	35	5.0	84	54	0.7	-3.9	25.5	83	82	2.5	565	8137.57	8133.99
12/23/14	-3.3	25.4	5.3	24	35	5.0	82	54	0.7	-11.5	25.8	96	80	1.4	578	8137.97	8134.13
12/24/14	-4.0	25.1	5.3	24	36	5.0	68	55	0.9	-4.4	25.4	74	79	2.2	460	8138.14	8134.65
12/25/14	-2.5	24.7	5.3	24	36	5.0	86	54	0.9	-7.9	25.1	82	80	2.0	549	8138.30	8135.06
12/26/14	-2.2	25.0	5.3	23	36	5.0	85	54	0.9	-14.1	25.4	100	79	1.4	600	8138.39	8134.85
12/27/14	-2.4	25.3	5.3	24	36	5.0	80	54	0.7	-14.8	25.6	100	78	0.9	595	8138.53	8134.72
12/28/14	-2.8	25.1	5.3	24	36	5.0	75	54	0.8	-10.4	25.5	77	79	1.7	545	8138.56	8134.96
12/29/14	-2.7	25.1	5.3	23	36	5.0	82	54	0.9	-14.0	25.5	93	78	1.5	573	8138.54	8135.03
12/30/14	-2.7	25.2	5.3	23	35	4.9	83	54	0.5	-20.0	25.6	135	77	0.3	1340	8138.43	8134.93
12/31/14	-3.3	25.2	5.3	23	36	4.9	77	53	0.5	-14.7	25.6	93	76	0.5	1565	8138.50	8134.89
1/1/15	-3.3	25.1	5.3	23	36	5.0	79	53	0.6	-12.4	25.5	78	75	1.0	586	8138.53	8134.92
1/2/15	-2.8	25.2	5.3	23		5.0	76	53	0.7	-11.3	25.6	70		1.2	512	8138.54	8134.84
1/3/15								53								8138.07	8134.75
1/4/15								53									8134.52
1/5/15								52									8134.40
1/6/15								53									8134.25
1/7/15								53								8138.07	8134.39
1/8/15								53									8134.45
1/9/15								53									8133.96
1/10/15								53									8133.66
1/11/15								53									8133.17
1/12/15								53									8132.65
1/13/15								53									8132.60
1/14/15								52									8132.46
1/15/15								52								8136.97	8132.31
1/16/15								52									8132.05
1/17/15								51									8131.83
1/18/15								51									8131.67
1/19/15								51									8131.52
1/20/15								51									8131.30
1/21/15								51									8131.18
1/22/15								51									8131.03
1/23/15								51								8135.97	8130.90
1/24/15								51									8130.72
1/25/15								51									8130.59
1/26/15								52									8130.39
1/27/15								52								8135.37	8130.16
1/28/15								52									8130.04
1/29/15								52									8129.93
1/30/15								52								8134.87	8129.75
1/31/15								52									8129.38
2/1/15								51									8129.19
2/2/15								51									8128.95
2/3/15								51									8128.82
2/4/15								51									8128.71
2/5/15								51									8128.50
2/6/15								50									8128.34
2/7/15								50									8128.17
2/8/15								50									8128.06
2/9/15								52									8127.74
2/10/15								51									8127.58
2/11/15								50									8127.48
2/12/15								50									8127.40
2/13/15								50									8127.28
2/14/15								51									8127.11

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
2/15/15								51									8126.87
2/16/15								51									8126.63
2/17/15								50									8126.43
2/18/15								50									8126.25
2/19/15								49									8126.06
2/20/15								50									8125.90
2/21/15								50									8125.65
2/22/15								49									8125.46
2/23/15								48								8130.97	8125.24
2/24/15								48									8125.09
2/25/15								47									8124.91
2/26/15								47									8124.70
2/27/15								47									8124.56
2/28/15								47									8124.29
3/1/15								47									8124.13
3/2/15								47								8129.77	8123.93
3/3/15								47									8123.78
3/4/15								47									8123.61
3/5/15								48									8123.51
3/6/15								48									8123.47
3/7/15								48									8123.46
3/8/15								48									8123.31
3/9/15								49									8123.15
3/10/15								51								8128.77	8122.97
3/11/15								53									8122.81
3/12/15								53									8122.67
3/13/15								55									8122.56
3/14/15								66									8122.35
3/15/15								70									8122.27
3/16/15								82									8122.08
3/17/15								108									8121.95
3/18/15								111									8121.71
3/19/15								109									8121.52
3/20/15								104									8121.47
3/21/15								108									8121.34
3/22/15								108									8121.25
3/23/15								99									8121.11
3/24/15								89									8121.01
3/25/15								81									8120.96
3/26/15								75									8120.91
3/27/15								75									8120.92
3/28/15								92									8120.81
3/29/15								105									8120.72
3/30/15								107									8120.71
3/31/15								115									8120.61
4/1/15								116									8120.55
4/2/15								109								8126.87	8120.52
4/3/15								98									8120.62
4/4/15								92									8120.68
4/5/15								89									8120.70
4/6/15								85									8120.74
4/7/15								83									8120.79
4/8/15								81									8120.87
4/9/15								77									8121.05
4/10/15								75									8121.16
4/11/15								74									8121.29
4/12/15								74									8121.41
4/13/15								74									8121.50
4/14/15								76									8121.54
4/15/15								76									8121.63
4/16/15								75									8121.73
4/17/15								74									8121.89
4/18/15								72									8122.00
4/19/15								72									8122.04
4/20/15								73									8122.09
4/21/15								75									8122.13
4/22/15								78									8122.22
4/23/15								80									8122.26
4/24/15								80									8122.30
4/25/15								81									8122.32
4/26/15								80									8122.62
4/27/15								80									8122.79
4/28/15								85									8123.04
4/29/15								95									8123.25
4/30/15								102									8123.44

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
5/1/15								107								8130.29	8123.62
5/2/15								109									8123.87
5/3/15								109									8124.16
5/4/15								109									8124.49
5/5/15								108									8124.82
5/6/15								109									8125.26
5/7/15								109									8125.64
5/8/15								108									8126.05
5/9/15								108									8126.47
5/10/15								107									8127.03
5/11/15								107									8127.51
5/12/15								109									8128.03
5/13/15								110									8128.51
5/14/15								112									8128.90
5/15/15								113									8129.47
5/16/15								114									8129.97
5/17/15								114									8130.50
5/18/15								129									8131.08
5/19/15								198									8131.50
5/20/15								208									8132.08
5/21/15								172									8132.64
5/22/15								152									8133.28
5/23/15								138									8134.06
5/24/15								129									8134.79
5/25/15								127									8135.53
5/26/15								130									8136.36
5/27/15								184									8137.32
5/28/15								191									8138.29
5/29/15								183									8139.28
5/30/15								174									8140.34
5/31/15								166									8141.40
6/1/15								157									8142.41
6/2/15								149									8143.48
6/3/15								144									8144.51
6/4/15								139									8145.58
6/5/15								134									8146.71
6/6/15								129									8147.83
6/7/15								125									8148.88
6/8/15								122									8149.88
6/9/15								118									8150.85
6/10/15								116								8158.71	8151.82
6/11/15																	8152.64
6/12/15																	8153.51
6/13/15																	8154.36
6/14/15																	8155.17
6/15/15																	8155.95
6/16/15																8163.69	8156.66
6/17/15																	8157.33
6/18/15																	8157.95
6/19/15																	8158.53
6/20/15																	8159.11
6/21/15																	8159.69
6/22/15																	8160.23
6/23/15																8167.99	8160.80
6/24/15																	8161.24
6/25/15																	8161.72
6/26/15																8169.28	8162.18
6/27/15																	8162.58
6/28/15																	8162.91
6/29/15																8170.38	8163.26
6/30/15																	8163.54
7/1/15																	8163.83
7/2/15																	8164.13
7/3/15																8171.48	8164.36
7/4/15																	8164.67
7/5/15																	8164.91
7/6/15																	8165.13
7/7/15																8172.28	8165.29
7/8/15																	8165.42
7/9/15																	8165.55
7/10/15																8172.87	8165.75
7/11/15																	8165.92
7/12/15																	8166.06
7/13/15																	8166.17
7/14/15																	8166.26

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)¹	Baro. Pressure (ft water)¹	Water Temp. (°C)¹	Flow (gpm)¹	Flow (gpm)²	Water Temp. (°C)¹	Flow (gpm)¹	Flow (gpm)²	Water Temp. (°C)¹	Air Temp. (°C)¹	Baro. Pressure (ft water)¹	Flow (gpm)¹	Flow (gpm)²	Water Temp. (°C)¹	Flow (gpm)¹	Water Elev. (ft)¹	Water Elev. (ft)¹
7/15/15																	8166.34
7/16/15																	8166.44
7/17/15																	8166.45
7/18/15																	8166.50
7/19/15																	8166.51
7/20/15																	8166.55
7/21/15	15.3	25.4	5.4	79												8173.57	8166.56
7/22/15	12.4	25.4	5.4	77													8166.57
7/23/15	12.9	25.4	5.4	75													8166.56
7/24/15	13.4	25.5	5.4	71													8166.56
7/25/15	13.8	25.5	5.4	73				86									8166.53
7/26/15	14.5	25.4	5.4	74				86									8166.53
7/27/15	12.4	25.3	5.4	71				86									8166.48
7/28/15	9.6	25.5	5.4	66				84									8166.46
7/29/15	12.6	25.6	5.4	68				83								8173.37	8166.42
7/30/15	14.9	25.7	5.4	68				82									8166.38
7/31/15	16.4	25.6	5.4	67				81									8166.31
8/1/15	17.3	25.5	5.4	66				81									8166.22
8/2/15	17.6	25.4	5.5	69				81									8166.10
8/3/15	11.4	25.4	5.4	67				84									8166.01
8/4/15	13.9	25.5	5.5	63				83									8165.90
8/5/15	14.1	25.4	5.4	67				82									8165.74
8/6/15	12.7	25.5	5.5	62				81									8165.60
8/7/15	13.5	25.4	5.4	63				80									8165.43
8/8/15	10.7	25.4	5.4	59				80									8165.38
8/9/15	12.6	25.5	5.5	60				79									8165.33
8/10/15	14.7	25.5	5.5	60				78									8165.18
8/11/15	15.5	25.5	5.5	61				77									8165.01
8/12/15	15.8	25.6	5.5	59				77									8164.90
8/13/15	17.3	25.6	5.5	59				76									8164.79
8/14/15	18.8	25.6	5.5	60				75									8164.60
8/15/15	16.9	25.6	5.5	62				74									8164.36
8/16/15	16.8	25.5	5.5	60				73									8164.20
8/17/15	15.2	25.4	5.5	59				73									8164.06
8/18/15	12.6	25.4	5.5	57				72									8163.88
8/19/15	13.3	25.4	5.5	57				72									8163.69
8/20/15	14.3	25.4	5.5	58				72									8163.46
8/21/15	16.1	25.3	5.5	59				71									8163.37
8/22/15	14.9	25.4	5.5	58				71									8163.23
8/23/15	15.2	25.5	5.5	54				71									8163.01
8/24/15	18.3	25.6	5.5	54				72									8162.83
8/25/15	18.8	25.6	5.5	55				72								8169.97	8162.69
8/26/15	14.2	25.6	5.5	56				72									8162.51
8/27/15	15.0	25.6	5.5	53				72									8162.37
8/28/15	16.7	25.6	5.5	54				72									8162.14
8/29/15	18.7	25.5	5.5	55				72									8161.99
8/30/15	18.6	25.4	5.5	55				72									8161.68
8/31/15	16.0	25.4	5.5	53				72									8161.48
9/1/15	15.8	25.4	5.5	53				72									8161.21
9/2/15	17.0	25.4	5.5	51				73									8161.06
9/3/15	17.6	25.3	5.5	51				73									8160.87
9/4/15	16.9	25.2	5.6	53				73									8160.54
9/5/15	12.5	25.3	5.5	52				72									8160.34
9/6/15	8.0	25.5	5.6	44				72									8160.13
9/7/15	11.8	25.5	5.6	44				72									8159.86
9/8/15	12.2	25.5	5.6	44				72									8159.77
9/9/15	14.4	25.5	5.6	46				72									8159.52
9/10/15	15.5	25.5	5.6	45				72									8159.32
9/11/15	16.5	25.6	5.6	45				71									8159.09
9/12/15	16.6	25.5	5.6	47				71									8158.89
9/13/15	15.9	25.4	5.5	47				72									8158.60
9/14/15	13.4	25.3	5.5	47				71									8158.40
9/15/15	8.5	25.2	5.5	47				71									8158.17
9/16/15	4.3	25.3	5.5	44				70									8157.87
9/17/15	4.3	25.4	5.5	38				70									8157.74
9/18/15	5.6	25.5	5.5	39				69								8164.97	8157.50
9/19/15	7.7	25.5	5.5	39				69									8157.32
9/20/15	10.7	25.5	5.5	40				68									8157.14
9/21/15	13.6	25.4	5.5	43				64									8156.86
9/22/15	15.1	25.4	5.5	43				65									8156.60
9/23/15	15.4	25.5	5.5	43				64									8156.47
9/24/15	16.1	25.6	5.5	44				63									8156.29
9/25/15	17.0	25.6	5.5	44				63								8163.47	8156.09
9/26/15	16.8	25.5	5.5	43				62									8155.81
9/27/15	15.9	25.4	5.5	44				62									8155.58

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
9/28/15	15.3	25.4	5.5	45				62									8155.31
9/29/15	14.7	25.5	5.5	44				61									8155.07
9/30/15	15.5	25.5	5.5	44				61									8154.84
10/1/15	16.7	25.4	5.5	42				61									8154.61
10/2/15	8.2	25.3	5.5	42				61									8154.42
10/3/15	7.5	25.2	5.5	39				60									8154.07
10/4/15	9.5	25.2	5.5	39				59									8153.85
10/5/15	9.9	25.3	5.5	38													8153.58
10/6/15	10.1	25.5	5.5	38													8153.38
10/7/15	10.8	25.5	5.5	35													8153.19
10/8/15	12.1	25.6	5.5	35													8153.02
10/9/15	11.4	25.6	5.5	36													8152.76
10/10/15	14.5	25.5	5.5	37													8152.57
10/11/15	14.1	25.5	5.5	37													8152.32
10/12/15	11.3	25.6	5.5	36													8152.16
10/13/15	13.8	25.6	5.5	35													8151.98
10/14/15	14.4	25.6	5.5	34													8151.72
10/15/15	14.6	25.6	5.5	34													8151.48
10/16/15	14.5	25.5	5.5	35													8151.14
10/17/15	10.3	25.4	5.5	35													8150.97
10/18/15	10.4	25.4	5.5	36													8150.74
10/19/15	5.0	25.3	5.5	35													8150.35
10/20/15	4.4	25.4	5.5	34													8150.13
10/21/15	5.5	25.4	5.5	36													8149.91
10/22/15	4.9	25.3	5.5	38													8149.67
10/23/15	5.0	25.4	5.5	39													8149.51
10/24/15	6.7	25.5	5.5	39													8149.27
10/25/15	6.3	25.4	5.5	40													8149.00
10/26/15	7.3	25.3	5.5	40													8148.72
10/27/15	3.4	25.3	5.5	37												8156.06	8148.51
10/28/15	1.6	25.3	5.5	31													8148.28
10/29/15	0.4	25.2	5.5	31													8148.12
10/30/15	-0.2	25.3	5.5	32													8147.76
10/31/15	4.4	25.4	5.5	31													8147.50
11/1/15	6.2	25.4	5.5	32													8147.29
11/2/15	5.6	25.1	5.5	31													8147.01
11/3/15	1.4	24.9	5.5	33													8146.72
11/4/15	-4.1	25.1	5.5	32													8146.20
11/5/15	-6.1	25.3	5.5	34													8146.12
11/6/15	-6.3	25.4	5.5	34													8145.93
11/7/15	-2.8	25.5	5.5	35													8145.75
11/8/15	1.4	25.3	5.5	27													8145.55
11/9/15	0.4	25.1	5.5	26													8145.28
11/10/15	-5.6	25.1	5.5	31													8144.94
11/11/15	-6.3	25.4	5.5	31													8144.73
11/12/15	-3.4	25.5	5.5	29													8144.57
11/13/15	-0.7	25.5	5.5	29													8144.42
11/14/15	3.1	25.4	5.5	28													8144.20
11/15/15	2.9	25.1	5.5	28													8143.89
11/16/15	-5.4	24.9	5.5	34													8143.54
11/17/15	-9.0	25.3	5.5	34													8143.29
11/18/15	-4.5	25.2	5.5	24													8143.12
11/19/15	-2.4	25.3	5.5	24													8142.90
11/20/15	-4.1	25.4	5.5	28													8142.74
11/21/15	-7.9	25.5	5.4	39													8142.53
11/22/15	-1.9	25.5	5.5	28													8142.27
11/23/15	2.2	25.3	5.5	23													8142.04
11/24/15	-0.2	25.1	5.5	24													8141.84
11/25/15	-1.5	24.9	5.4	25													8141.56
11/26/15	-10.3	25.1	5.4	37													8141.23
11/27/15	-13.1	25.2	5.2	46													8140.97
11/28/15	-12.9	25.2	5.3	41													8140.79
11/29/15	-12.8	25.2	5.5	42													8140.51
11/30/15	-11.0	25.2	5.5	33													8140.34
12/1/15	-9.3	25.3	5.5	34													8140.18
12/2/15	-6.2	25.5	5.5	25													8139.91
12/3/15	-0.1	25.4	5.5	20													8139.73
12/4/15	-1.4	25.3	5.5	19													8139.47
12/5/15	-4.3	25.6	5.5	21													8139.26
12/6/15	-0.7	25.6	5.5	18													8139.04
12/7/15	-0.1	25.5	5.5	16													8138.89
12/8/15	2.0	25.5	5.5	16													8138.67
12/9/15	2.4	25.3	5.5	16													8138.37
12/10/15	-0.4	25.0	5.5	17													8138.07
12/11/15	-4.7	24.9	5.5	19													8137.78

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
12/12/15	-6.7	25.1	5.4	19													8137.56
12/13/15	-4.5	25.0	5.4	18													8137.31
12/14/15	-3.7	24.8	5.3	17													8137.04
12/15/15	-2.9	25.0	5.3	16													8136.77
12/16/15	-3.0	25.1	5.4	16													8136.55
12/17/15	-2.4	25.3	5.4	16													8136.40
12/18/15	-1.2	25.3	5.5	15													8136.26
12/19/15	-0.5	25.2	5.5	14													8135.98
12/20/15	-1.2	25.1	5.5	14													8135.73
12/21/15	-1.5	25.0	5.5	14													8135.53
12/22/15	-1.5	24.7	5.4	14													8135.26
12/23/15	-1.3	24.8	5.4	13													8134.97
12/24/15	-1.2	24.9	5.4	13													8134.73
12/25/15	-1.1	25.0	5.4	13													8134.47
12/26/15	-1.0	25.4	5.3	12													8134.34
12/27/15	-1.2	25.4	5.3	12													8134.22
12/28/15	-1.4	25.0	5.3	12													8133.97
12/29/15	-1.4	25.0	5.3	11													8133.79
12/30/15	-1.5	25.2	5.3	11													8133.56
12/31/15	-1.6	25.4	5.2	12													8133.39
1/1/16	-1.9	25.4	5.3	11													8133.19
1/2/16	-2.1	25.4	5.2	12													8133.03
1/3/16	-1.7	25.4	5.5	11													8132.81
1/4/16	-1.1	25.2	5.5	9													8132.58
1/5/16	-0.7	25.1	5.3	10													8132.40
1/6/16	-0.6	25.0	5.3	9													8132.10
1/7/16	-0.6	25.0	5.4	9													8131.78
1/8/16	-0.5	25.1	5.5	8													8131.58
1/9/16	-0.6	25.2	5.4	9													8131.44
1/10/16	-0.8	25.3	5.4	10													8131.23
1/11/16	-0.6	25.4	5.4	10												8138.77	8131.17
1/12/16	-3.4	25.5	5.4	12													8131.08
1/13/16	-3.2	25.3	5.4	11													8130.88
1/14/16	-2.3	25.1	5.3	10													8130.60
1/15/16	-1.8	25.1	5.4	9													8130.33
1/16/16	-1.5	25.2	5.4	9													8130.07
1/17/16	-1.2	25.3	5.4	8													8129.98
1/18/16	-0.8	25.3	5.5	8													8129.85
1/19/16	-0.6	25.3	5.4	8													8129.65
1/20/16	-0.6	25.3	5.4	7													8129.39
1/21/16	-0.5	25.6	5.5	7													8129.23
1/22/16	-0.5	25.4	5.6	7													8129.00
1/23/16	-0.5	25.2	5.5	7													8128.82
1/24/16	-0.4	25.1	5.4	7													8128.63
1/25/16	-0.4	25.3	5.4	7													8128.39
1/26/16	-0.3	25.5	5.4	7													8128.15
1/27/16	-0.3	25.6	5.4	7													8128.12
1/28/16	-0.2	25.5	5.4	7													8127.92
1/29/16	-0.1	25.3	5.4	6													8127.64
1/30/16	-0.1	25.0	5.2	6													8127.41
1/31/16	-0.1	25.0	5.4	6													8127.13
2/1/16	-0.1	24.9	5.3	5													8126.84
2/2/16	-0.1	25.1	5.4	5													8126.55
2/3/16	-0.1	25.4	5.3	5													8126.47
2/4/16	-0.2	25.5	5.4	5													8126.33
2/5/16	-0.2	25.6	5.5	5													8126.23
2/6/16	-0.2	25.6	5.5	5													8126.11
2/7/16	-0.2	25.7	5.5	5													8126.03
2/8/16	-0.2	25.8	5.5	5													8125.95
2/9/16	-0.1	25.7	5.6	4													8125.74
2/10/16	-0.1	25.6	5.6	4													8125.60
2/11/16	0.0	25.6	5.5	4													8125.09
2/12/16	0.0	25.6	5.6	4												8137.76	8125.12
2/13/16	0.0	25.5	5.6	4													8124.91
2/14/16	0.0	25.4	5.5	4													8124.71
2/15/16	0.0	25.4	5.5	3													8124.54
2/16/16	0.0	25.4	5.6	4													8124.29
2/17/16	0.0	25.2	5.5	3													8124.04
2/18/16	0.0	25.0	5.5	4													8123.80
2/19/16	0.0	25.3	5.5	4													8123.59
2/20/16	0.0	25.4	5.5	4													8123.47
2/21/16	0.0	25.5	5.5	4													8123.38
2/22/16	0.0	25.3	5.5	4													8123.18
2/23/16	0.0	25.4	5.5	4													8123.00
2/24/16	0.0	25.5	5.5	3													8122.83

	Lefty's Spring								Hidden Lake					North Boundary		Hidden Lake well	Exploration well 2
	Upper Lefty's					Lower Lefty's											
Date	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Air Temp. (°C)[1]	Baro. Pressure (ft water)[1]	Flow (gpm)[1]	Flow (gpm)[2]	Water Temp. (°C)[1]	Flow (gpm)[1]	Water Elev. (ft)[1]	Water Elev. (ft)[1]
2/25/16	0.0	25.5	5.5	3													8122.68
2/26/16	0.0	25.5	5.6	3													8122.55
2/27/16	0.0	25.4	5.6	3													8122.34
2/28/16	0.0	25.4	5.6	3													8122.09
2/29/16	0.0	25.4	5.5	2													8121.96
3/1/16	0.0	25.4	5.5	2													8121.77
3/2/16	0.0	25.4	5.6	2													8121.54
3/3/16	0.0	25.4	5.6	2													8121.40
3/4/16	0.0	25.4	5.6	2													8121.23
3/5/16	0.0	25.3	5.6	3													8121.08
3/6/16	0.0	25.0	5.4	3													8120.78
3/7/16	0.0	25.0	5.5	2													8120.50
3/8/16	0.0	25.1	5.4	2													8120.24
3/9/16	0.0	25.3	5.5	2													8120.08
3/10/16	0.0	25.4	5.6	2													8120.02
3/11/16	0.0	25.3	5.6	2													8119.87
3/12/16	0.0	25.2	5.6	2													8119.62
3/13/16	0.0	25.2	5.5	2													8119.46
3/14/16	0.0	25.1	5.4	3													8119.34
3/15/16	0.0	25.3	5.4	3													8119.21
3/16/16	0.0	25.4	5.5	3													8119.07
3/17/16	0.0	25.3	5.5	3													8118.99